RESEARCH ARTICLE

Volumetric Calculation of Hydrocarbon Generated from the Sargelu Formation in the Kurdistan Region, Iraq

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ABSTRACT

In an attempt to determine the amount of hydrocarbon generated from the Sargelu Formation, outcrop and borehole samples were collected. The areal distribution, density, and weight of the Sargelu Formation were determined by using traditional methods and a geographic information system. The amount of hydrocarbon generated was determined to be 3.4199×10^{12} kg.

Keywords: Sargelu Formation, Source rock, Hydrocarbon, Volumetric calculation, Iraq

1. INTRODUCTION

The Sargelu Formation was first recognized and described by Wetzel in 1948 (in Bellen et al., 1959) in the Surdash anticline in the Sulaimani Province of the Zagros High Folded Zone in the northeastern part of Iraq The lower part of the Surmeh Formation in Iran and the Dhruma Formation in Saudi Arabia are the age equivalents of the Sargelu Formation (Jassim and Buday, 2006a). The common source rock for hydrocarbon generation in the Folded Belt and Zagros Thrust zone is the carbonate and shale rock units of the Jurassic mainly found as part of the Sargelu Formation (Pitman et al., 2004). The organic matter (OM) of the Sargelu Formation is classified as type II and III kerogens (Odisho and Othman, 1992; Abdula, 2010, 2015). The OM is thermally in the post mature stage and within the gas-generation zone in the Miran Oil Field (Fatah and Mohialdeen, 2016). This formation entered into the oil-generation stage in the Late Eocene and entered into the condensate and gas-generation stage during the present age (Beydoun, 1993). The stratigraphic succession at the Emam Hasan and Masjid-e Suleiman oil fields of the western part of Iran was correlated by James and Wynd (1965) together with the Adaiyah, Mus, Sargelu, Najmah, and Gotnia formations of Iraq, which were described and defined in the Lexique Stratigraphique International for Iraq by Bellen et al. (1959). Qaddouri (1972) studied the Sargelu Formation in the Benavi area of the Duhok Governorate in the Iraqi Kurdistan Region. Al-Omari and Sadiq (1977) placed the Sargelu Formation within the Middle Jurassic succession. In a general review of the formation, Buday (1980) adopted the original description given by Wetzel (1948, in Bellen et al., 1959) and classified the depositional environment as a euxinic marine environment. Al-Barzanji (1989) studied the Muhaiwir Formation in the Iraqi Western Desert, pointing out that this formation was deposited within the same sedimentary cycle as the Sargelu Formation.

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The aim of this study was to calculate the amount of hydrocarbon generated from the Sargelu Formation in the Iraqi Kurdistan Region.

2. METHODS

The sample base for this study consisted of surface outcrops of the Sargelu Formation. The thicknesses of the Sargelu Formation in different locations in the Iraqi Kurdistan Region were provided by the Ministry of Natural Resources, Erbil. Geographic Information System (GIS) software was used to prepare an isopach map. The thickness of the Sargelu Formation was calculated by using 2 different methods. The first method was by using Excel to determine the average thickness. In the second method, the GIS software was utilized to find the average thickness. In addition, mathematical equations were applied to determine the volume, density, and weight of the Sargelu Formation throughout the area.

3. GEOLOGIC SETTING

The Late Triassic-Early Jurassic was the time during which the Neo-Tethys ocean opened (Dercourt et al., 1986) (Figure 1). The Iraqi Unstable Shelf was changed to a deep-sea environment because of the opening of the Neo-Tethys and the subsidence of the Unstable Arabian Shield (Numan, 1997). Marouf (1999) believes that because of the cooling of the adjacent oceanic crust that affected crustal under loading, there was an increase in the deepening and subsidence of the basin toward the east. The major change in the depositional setting and climate pattern occurred during the Middle Jurassic. Deposition of evaporates was rare because of the more humid climate (Murris, 1980). Liassic sedimentary basins changed to euxinic basins and the sedimentation setting became more uniform (Buday, 1980). In Iraq, the Sargelu and Muhaiwir Formations represent the Middle Jurassic (Figure 2). The Sargelu Formation has a broad geological distribution in Iraq and the depositional basin has a NW–SE trend (Abdula et al., 2015). The shoreline on the western edge of the basin was represented by the Rutba-Jazeera zone and the eastern shoreline with the zone of west Iran, the Sanandaj-Sirjan block (Jassim and Karim, 1984). The Sargelu Formation's geographic distribution (Fig. 3) extends toward the southeastern part of Iraq, Kuwait, and the southwestern part of Iran in the Lurestan zone and partly in the Khuzestan region (Darvishzadeh, 1991).

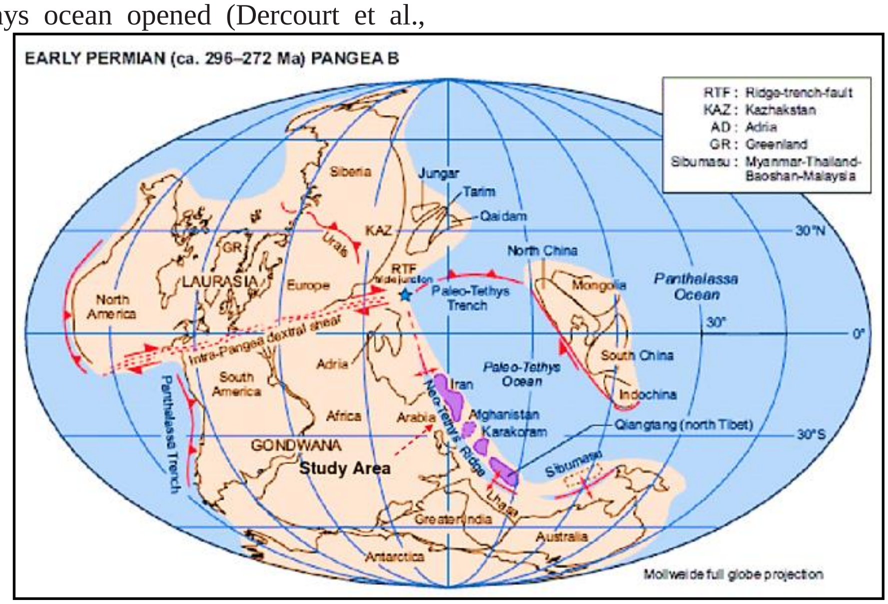

Figure 1. Opening of Neo-Tethys ocean during the Permian Period

(according to Muttoni et al., 2009).

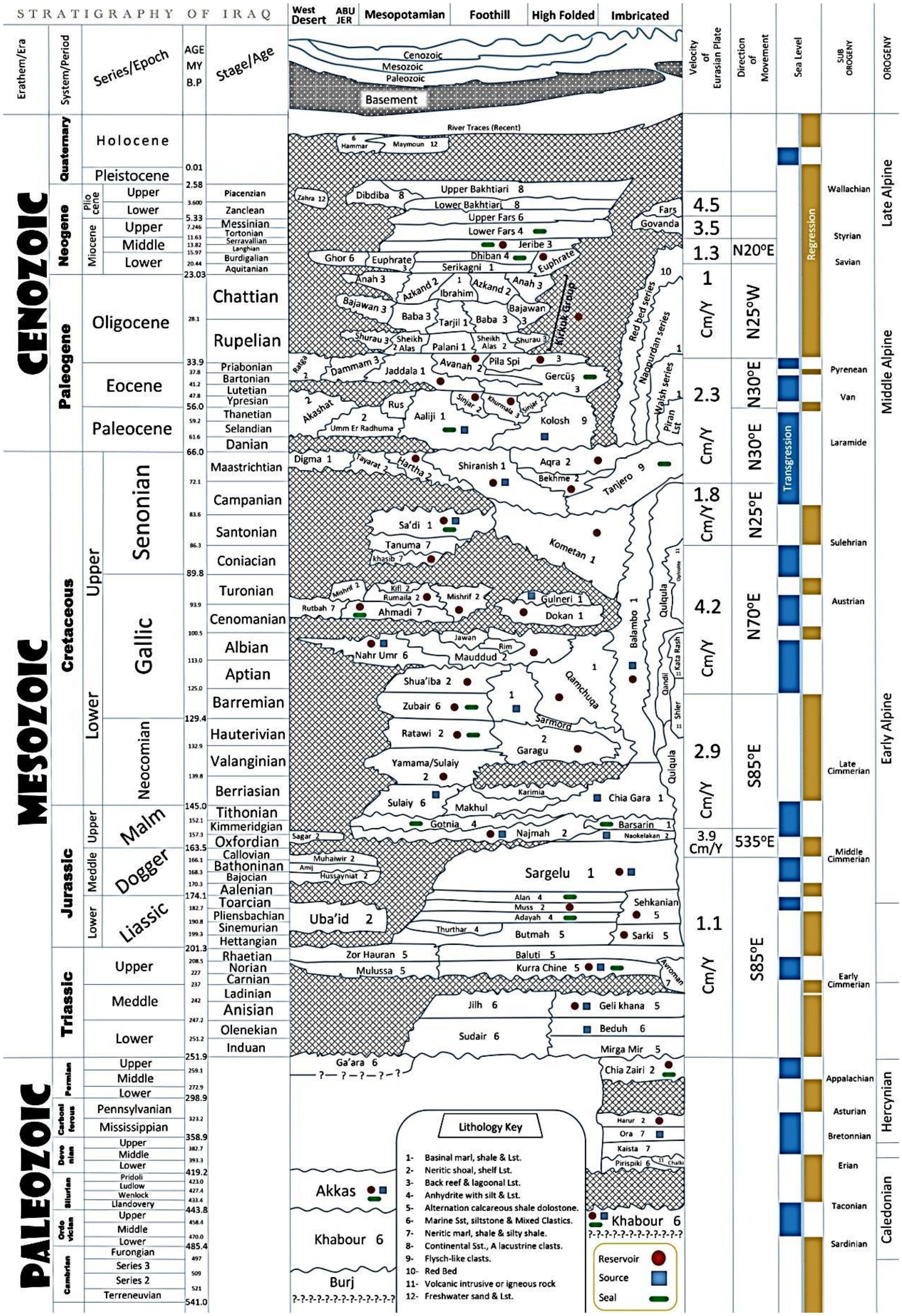

Figure 2. The stratigraphic correlation of the Jurassic formations in Iraq (redrawn from Bellen et al., 1959, and Al-Omari and Sadiq, 1977).

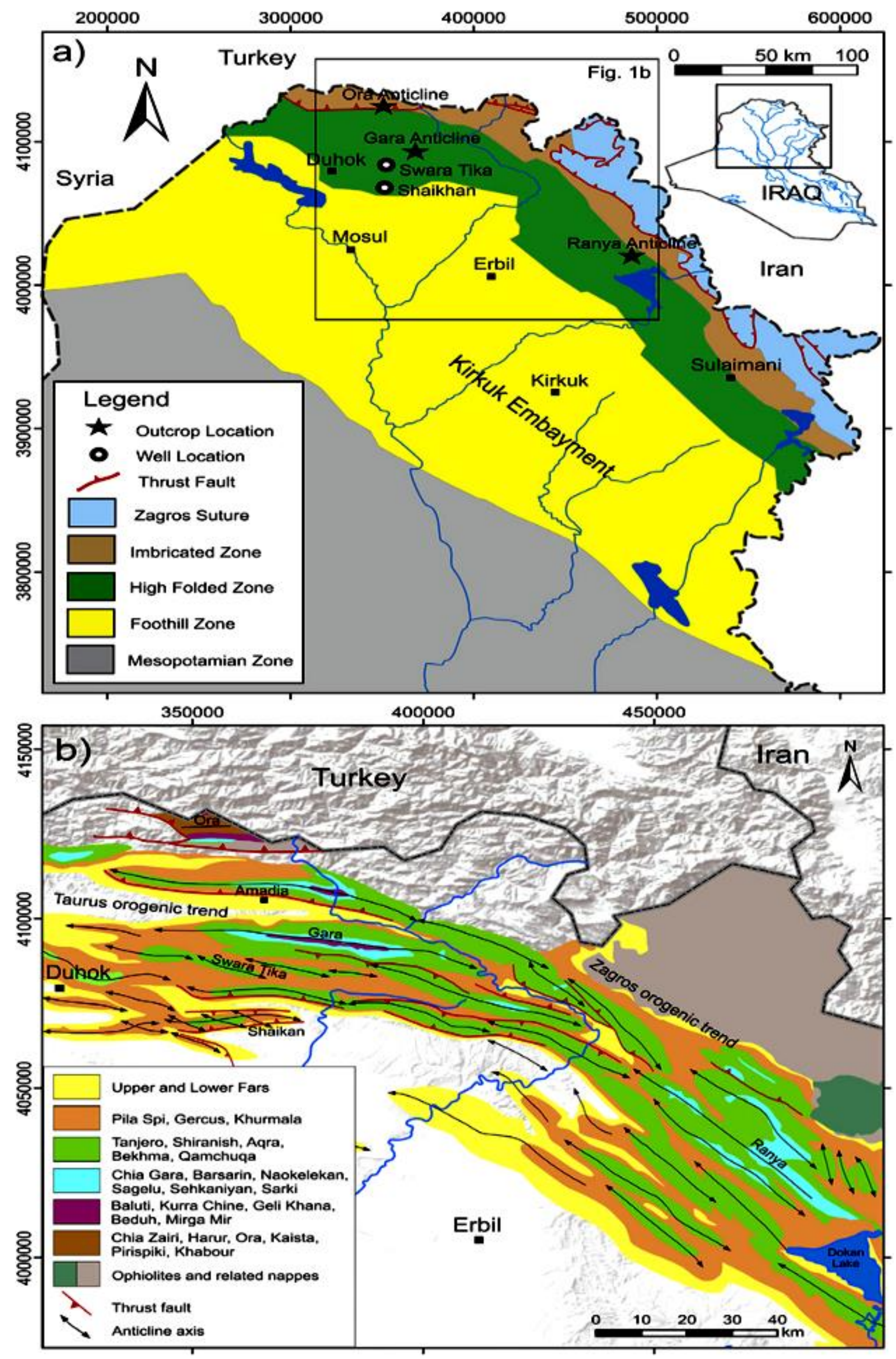

Figure 3. (a) A tectonic map of the Iraqi Kurdistan. The study area is indicated by the black rectangular box (according to Jassim and Buday, 2006a); (b) A simplified geological map of Kurdistan showing the anticlinal axes and the related thrust faults. The studied anticlines are labelled (according to Sissakian et al., 1995; Sissakian, 1997; and Csontos et al., 2012).

The Jurassic Period is currently determined to have lasted around 55.6 Ma (201.3–145.7 Ma) (Ogg et al., 2016). In the Early Jurassic, the sea level was low with the exception of the Early Toarcian, which is thought to have had a relative high sea level, a variant overall low level during the Middle Jurassic, and a scalar rise thereafter that lasted through much of the Late Jurassic. The climates serve as collateral evidence for these trends.

Faunal and isotopic data show relatively warm climates for most of the Jurassic Period, with some exceptions, and unconfirmed evidence of widespread glaciations during much of this period. However, the relative warmth of the Hettangian Epoch through to the Toarcian Epoch seems to have been interrupted by a cooler Late Pliensbachian Epoch through to the Early Toarcian Epoch (Hinnov and Park, 1999; Dera et al., 2009; Korte and Hesselbo, 2011; Suan et al., 2015; Korte et al., 2015). Korte and Hesselbo (2011) believe that the Early Jurassic may have vacillated between greenhouse and icehouse conditions.

In Iraq's Kurdistan Region, the Sargelu Formation crops out along the length of the High Folded, Imbricated, and Zagros Suture zones. Lithologically, the formation consists of dark gray limestones and dark papery shales. The lower part of the Sargelu Formation is usually represented by bituminous marly limestone (often dolomitized) and thin papery shale, whereas the middle part is composed of limestone, and the upper part is an intercalation of shale and bituminous limestone (Ahmed, 1997). In the uppermost part of the formation, the lithology becomes black laminated shale, and black chert bands can be seen with a continuous transition to the Naokelekan Formation, conformably (Fig. 2).

Within the Sargelu Formation, the following 3 main types of microfacies have been recognized: wackestone, packstone, and lime mudstone (Abdula et al., 2015). On the basis of these 3 microfacies and the lithofacies, the Sargelu Formation is interpreted to represent a ramp model deposition (Fig. 4). The organic-rich sediments of the Sargelu Formation revealed an euxinic (anoxic) depositional environment (Abdula et al., 2015).

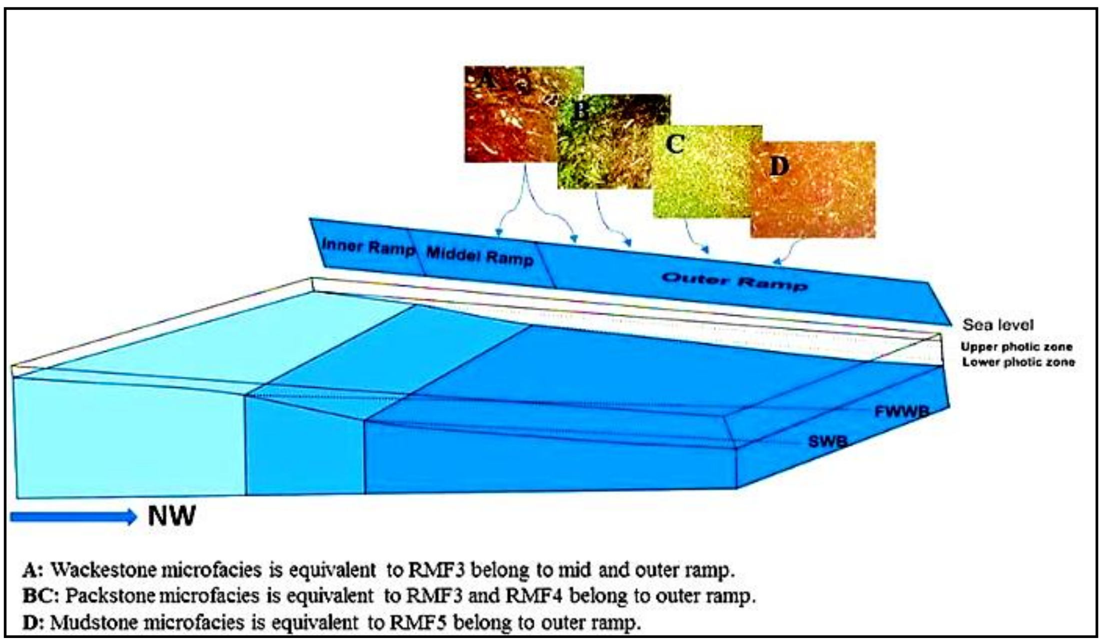

Figure 4. Depositional environment of the Sargelu Formation corresponds to ramp depositional model (according to Abdula et al., 2015

The thickness of the Sargelu Formation is diverse. The thickness of the formation (Fig. 5) in the Northern Thrust, Imbricated, and High Folded zones has a range from 20 m in the northwestern part of Iraq in the Ora and Chalki regions to 125 m in the northeastern part of Iraq in the Sirwan Valley near Halabja. It is 115 m thick at the type locality (Bellen et al., 1959; Buday, 1980; Jassim and Buday, 2006b; Abdula et al., 2015).

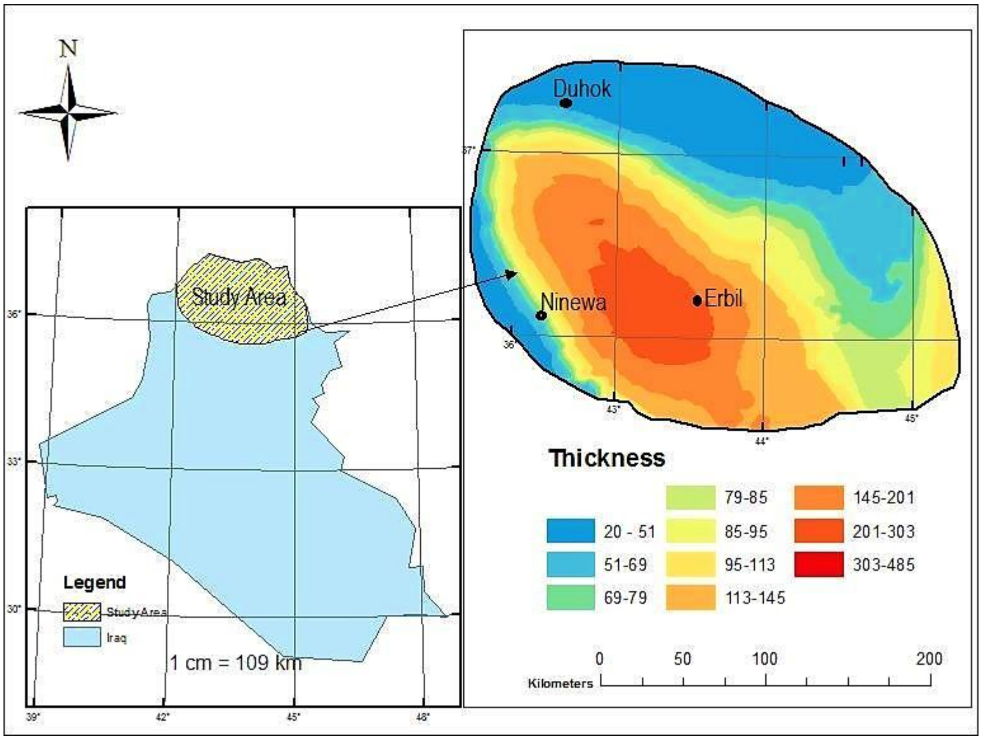

Figure 5. Isopach map of the Sargelu Formation in Iraqi Kurdistan

4. CALCULATIONS AND RESULTS

Inefficiencies associated with the expulsion, migration, and trapping of hydrocarbons are often large. Thus, the amount of hydrocarbon generated can be an enormous number when compared with the amount in place.

4.1. Area of the Sargelu Formation Expansion

For area determination, the GIS software was utilized according to the following steps:

GIS→ Study area→ Open attribute table→ Add field→ Area→ Calculate geometry→ Square kilometer (km^2)→ and Ok.

The area of the studied region in which the Sargelu Formation exists was determined to be 46,353.679 km^2.

4.2. Average Thickness of the Sargelu Formation

The generated thickness was calculated using 2 different methods. The first method was by using Excel to determine the average thickness. In the second method, GIS software was used to get more accurate results for the average thickness.

The following steps were used in the GIS software package:

Study area of the Iraqi Kurdistan Region (Fig. 5)→ Georeferencing→ Digitizing & creating shapefile for the study area→ Geostatistical wizard: Inverse Distance Weighting (IDW) (Data Field: Thickness) → Convert IDW to Raster→ Using Extract by Mask for Shapefile→ Right Click above the Raster Isopach (Properties: Histogram).

The average thickness of the Sargelu Formation was calculated to be 107.283 m.

4.3. Average Weight of the Sargelu Formation Samples

During the fieldwork, 7 rock samples from outcrops were collected. The dry weight for each sample was determined by using a sensitive balance. The average weight of the samples from the Sargelu Formation was determined to be 196.998 g.

4.4. Volume of the Sargelu Formation Samples

In the laboratory, the volume of the collected samples was determined by applying the following steps:

Choosing standard (stable) water volume for all samples (700 ml) → placing each dry sample into a beaker and measuring the increase in the water volume→ increase in water volume = volume of sample. The average volume of the samples of the Sargelu Formation is 75 ml.

4.5. Density of the Sargelu Formation

After determining the volume and weight of the samples, the density of the samples was calculated by using the following formula:

$$\text{Density} = \text{weight/volume}$$

$$= 196.998\ \text{g}/75\ \text{ml}$$

$$= 2627\ \text{kg/m}^3$$

4.6. Weight of the Sargelu Formation

To determine the weight of the Sargelu Formation, the following 2 equations were used:

$$\text{Volume} = \text{average thickness} \times \text{area} \quad (1)$$

$$= 107.288\ \text{m} \div 1000\ \text{km/m} \times 46{,}353.679\ \text{km}^2$$

$$= 4973.193\ \text{km}^3$$

By using the volume and density, the weight of the Sargelu Formation was determined by applying the following formula:

$$\text{Weight} = \text{density} \times \text{volume} \quad (2)$$

$$= 2627\ \text{kg/m}^3 \times 4973.193\ \text{km}^3$$

$$= 2627\ \text{kg/m}^3 \times 10^6\ \text{m}^3/\text{km}^3 \times 4973.193\ \text{km}^3$$

$$= 1.307 \times 10^{13}\ \text{kg}$$

$$= 1.307 \times 10^{13}\ \text{kg} \div 10^3\ \text{ton/kg}$$

$$= 1.307 \times 10^{10}\ \text{ton}$$

4.7. Average Total Organic Carbon of the Sargelu Formation Samples

The quantity of organic carbon in a source rock that contains kerogen and bitumen is called the total organic carbon (TOC), which is reported as the weight percentage (wt%) (Peters and Cassa, 1994). To determine the TOC (wt%), the data presented in Table 1 were utilized. The average TOC for each location was calculated individually, followed by calculating the total average TOC for all the locations in the Sargelu Formation. The average TOC (wt%) was determined to be 3.58 wt%.

Table 1: Total organic carbon and rock-eval pyrolysis data of the samples collected from the Sargelu Formation at different locations in the Kurdistan Region. The data are from Abdula (2015).

Well or location	Formation	Depth (m)	TOC (wt%)	S2 (mg HC/ g rock)	T_{max} (°C)	HI (mg HC/g rock)	Calculated Ro%
Qara Chugh-2	Sargelu	1560–1566	1.18	5.43	434	460	0.65
Qara Chugh-2	Sargelu	1582–1591	0.88	3.66	430	416	0.58
Qara Chugh-2	Sargelu	1608–1617	0.98	4.54	434	463	0.65
Qara Chugh-2	Sargelu	1629–1642	0.88	4.27	434	485	0.65
Qara Chugh-2	Sargelu	1650–1652	0.80	3.93	433	491	0.63
Guwair-2	Sargelu	2158–2165	0.18	0.38	439	211	
Guwair-2	Sargelu	2241–2250	0.31	0.82	440	265	0.76
Guwair-2	Sargelu	2267–2281	0.27	0.17	430	63	
Guwair-2	Sargelu	2321–2330	1.73	8.56	441	495	0.78
Guwair-2	Sargelu	2451–2476	0.34	0.93	438	274	0.72
Guwair-2	Sargelu	2559–2573	1.77	11.18	441	632	0.78
Guwair-2	Sargelu	2602–2612	2.40	13.30	441	554	0.78
Guwair-2	Sargelu	2615–2620	3.43	19.26	442	562	0.80
Tawke-15	Sargelu	2860–2870	11.80	67.45	440	572	0.76
Tawke-15	Sargelu	2880–2890	1.61	8.02	436	498	0.69
Tawke-15	Sargelu	2890–2900	0.21	0.52	435	248	0.67
Tawke-15	Sargelu	2900–2910	42.50	21.59	392	51	
Tawke-15	Sargelu	2910–2920	41.20	108.79	477	264	
Hanjeera	Sargelu	surface	0.67	0.01	338	1	
Hanjeera	Sargelu	surface	0.08	0.04	388	50	
Hanjeera	Sargelu	surface	0.17	0.04	409	24	
Sargelu	Sargelu	surface	2.54	0.52	496	20	1.77
Sargelu	Sargelu	surface	2.15	1.50	460	70	1.12
Sargelu	Sargelu	surface	0.39	0.28	459	72	1.10
Sargelu	Sargelu	surface	0.67	0.25	492	37	1.70
Barsarin	Sargelu	surface	3.37	1.31	489	39	1.64
Barsarin	Sargelu	surface	2.87	0.37	509	13	
Barsarin	Sargelu	surface	1.60	0.28	496	18	
Barsarin	Sargelu	surface	0.42	0.18	355	43	
Hawler-1	Sargelu	3140–3150	0.70	2.12	429	303	0.56
Hawler-1	Sargelu	3160–3170	1.06	3.45	432	325	0.62
Hawler-1	Sargelu	3190–3200	2.04	8.04	431	394	0.60
Hawler-1	Sargelu	3210–3220	1.80	6.06	428	337	0.54
Hawler-1	Sargelu	3250–3260	3.09	10.94	432	354	0.62
Gara	Sargelu	surface	4.04	29.38	435	727	0.67
Gara	Sargelu	surface	2.71	17.66	436	652	0.69

HI, hydrogen index.

4.8. Weight of TOC of the Sargelu Formation

TOC (wt%) of the Sargelu Formation was determined using the following equation:

TOC = (Weight of the Sargelu Formation) × (Average TOC of the Sargelu Formation)

$$= 1.307 \times 10^{10} \text{ ton} \times 3.58 \div 10^{2}$$

$$= 4.679 \times 10^{8} \text{ ton}$$

4.9. Average HI of the Sargelu Formation

The potential of a rock to generate oil can be determined by its HI. It was observed that the OM in the Sargelu Formation at Gara Mountain has the highest HI, whereas the lowest HI is at Hanjeera Village, which is located 2 km west of Raniya Town (Table 1). For this study, the HI for each location was obtained separately (Table 1). The average HI of the Sargelu Formation was determined to be 288.338 mg HC/g rock.

4.10. Type of Kerogen of the Sargelu Formation

Kerogen is OM that is disseminated in sediments and made of high-molecular-weight compounds (Whelan and Thompson-Rizer, 1993).

When the HI values of samples are greater than 600 mg HC/g $C_{org.}$ it implies that the samples are type I kerogen; if greater than 300 mg HC/g $C_{org.}$ it implies that the samples are type II kerogen; if greater than 200 mg HC/g $C_{org.}$ it implies that they are a mixture of types II and III kerogens; if greater than 50 mg HC/g C_{org} they represent type III kerogen; and if less than 50 mg HC/g C_{org} they indicate type IV kerogen (Tissot and Welte 1984; Peters and Cassa, 1994). Therefore, the studied samples are type II and III kerogens.

The T_{max} vs. HI plot (Fig. 6) showed that the collected samples from the Sargelu Formation represent type II and III kerogens.

4.11. Hydrocarbon Generated Amount

To determine the amount of generated hydrocarbon, the Shmoker (1994) flow diagram of the method for approximate calculation of the mass of hydrocarbons generated was applied.

First step: calculate the mass of organic carbon in the source rocks.

$$\mathrm{TOC/100\,(wt.\%)} \times \text{formation density } (\rho, \mathrm{g/cm}) \times \text{Volume of unit } (\mathrm{V, cm^3}) = \text{Mass of organic carbon } (\mathrm{M, g\ TOC}) \quad \text{Equation 1}$$

The weight of the Sargelu Formation was determined to be 1.307×10^{13} kg

Mass of Sargelu's TOC = 1.307×10^{13} kg × 10^3 kg/g

= 1.307×10^{16} g

Second step: estimate the mass of hydrocarbons generated per gram of organic carbon.

$$\text{Hydrocarbons generated per gram organic carbon } (\mathrm{R, mg\ HC/g\ TOC}) = \text{Hydrogen index prior to hydrocarbon generation } (\mathrm{HI_0, mg\ HC/g\ TOC}) \quad \text{Equation 2}$$

= 550 mg HC/g TOC – 288.338 mg HC/g TOC

= 261.662 (R, mg HC/g TOC)

Third step: multiply these data to determine the total mass of hydrocarbon that was generated as follows:

$$\text{Hydrocarbons generated by unit } (\mathrm{HCG, kg\ HC}) = \mathrm{R\ (mg\ HC/g\ TOC)} \times \mathrm{M\ (g\ TOC)}\ 10^{-6}\ \mathrm{kg/mg} \ldots\ldots\ldots\ldots\ldots \text{Equation 3}$$

= 261.662 (mg HC/g TOC) ×1.307×10^{16} (g TOC) × 10^{-6} (g/mg)

= 3.4199×10^{12} (HCG, Kg HC)

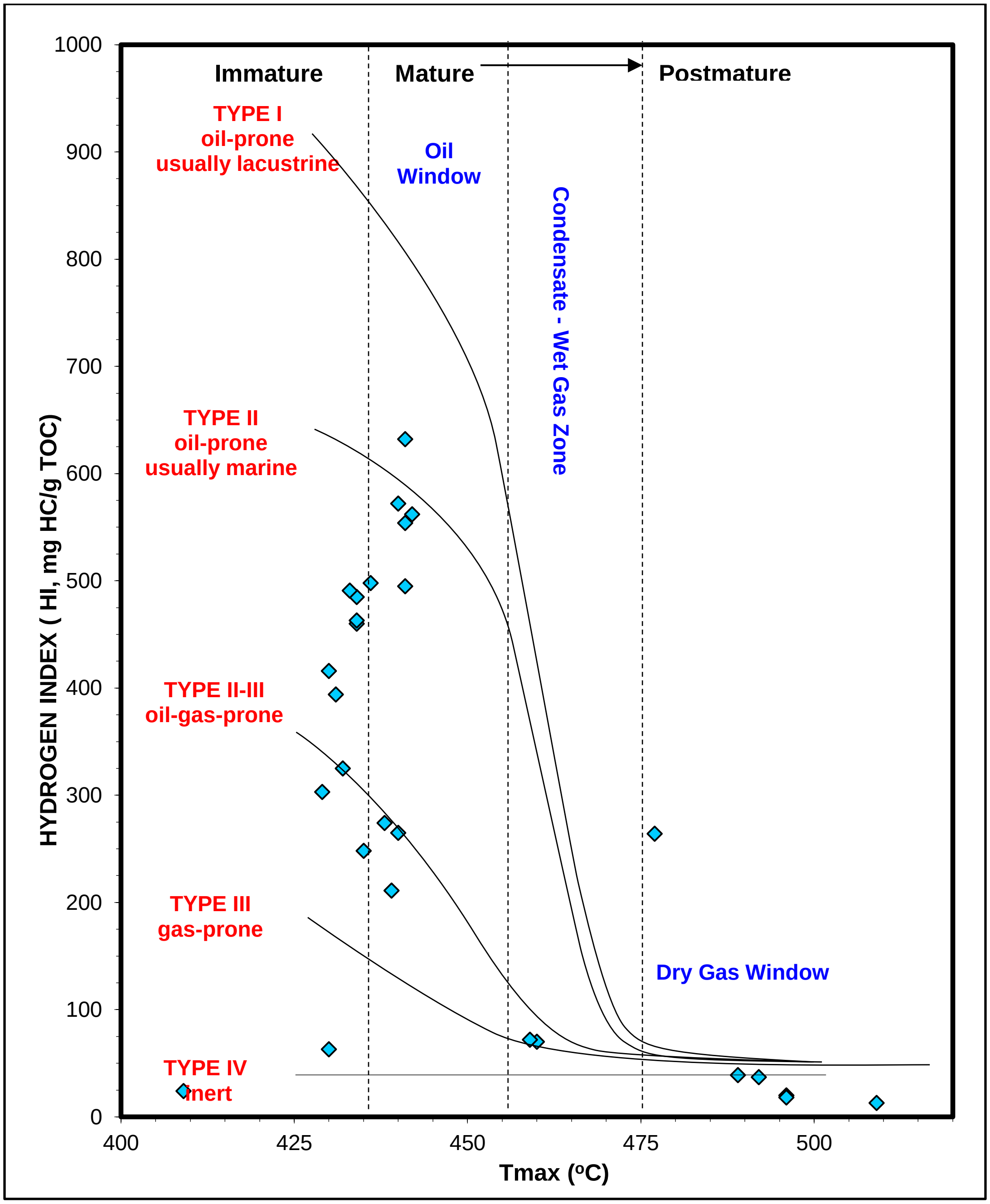

Figure 6. The HI vs. T_{max} plot for the collected samples of the Sargelu Formation from different location in the Iraqi Kurdistan (adapted from Espitalié et al., 1985)

5. CONCLUSIONS

The main conclusions from this study are that the average thickness of the Sargelu Formation is 107.283 m, the density is 2677 kg/m^3, the weight in the studied area is 1.307 × 10^{10} ton, the weight of TOC is 4.679 × 10^8 ton, and that the generated hydrocarbon amount is 3.4199 × 10^{12} kg.

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