

# Source Rock Evaluation and 1-D Basin Modelling Approach for the Sargelu Formation, Atrush-2 Well, Kurdistan Region-Iraq

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## Abstract

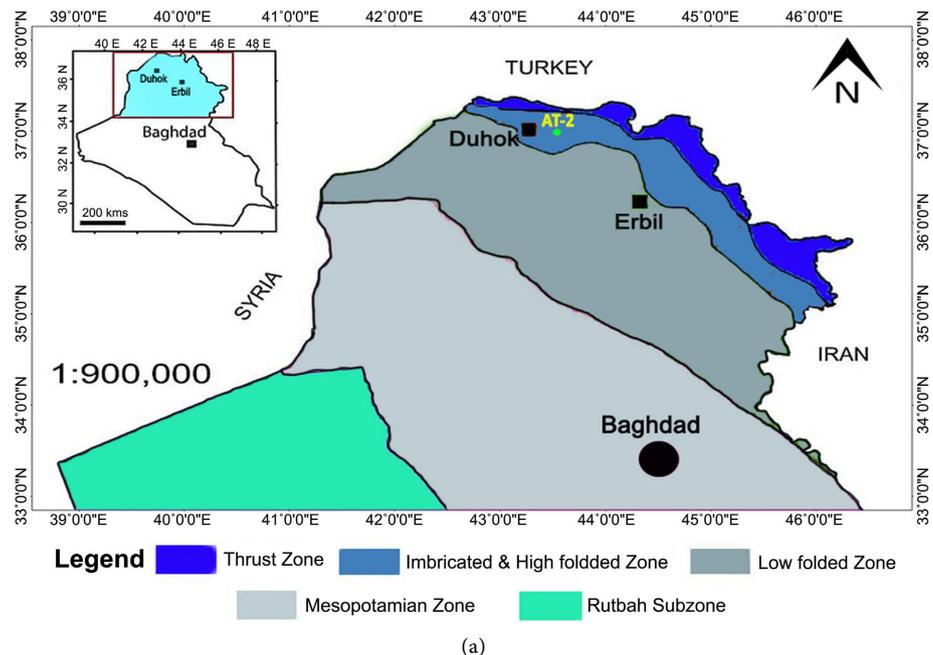
The present study focuses on source rock evaluation of the Sargelu Formation by using core chips of rocks collected from well Atrush-2, Duhok, Kurdistan Region-Iraq. The Rock-Eval pyrolysis and vitrinite reflectance were executed. Subsequently, the selected parameters were used for source rock evaluation and 1-D Basin Modelling calibration. The upper part of the formation mainly comprises argillaceous limestone with low content of organic matter (0.64% - 1% TOC). By contrast, the lower part is dominated with shale interval and contains high amounts of TOC values (>4% for 1272 - 1278 m) revealing good to very good quality source rock. Accordingly, good to very good hydrocarbon generation potential is suggested for this formation. Organic matter of the Sargelu Formation contains type II and mixed-type II-III kerogen. The values of Tmax and vitrinite reflectance (Ro%) demonstrate that the formation is thermally mature and in the oil zone. In order to construct a thermal history of the formation and determine the timing of hydrocarbon maturation and generation, the 1-D basin modelling PetroMod 2019.1 was used in this study. Based on the 1-D Basin modelling simulation and its outputs, about 3500 m of overburden have been eroded at the study area. The present-day heat flow was found to be 30 mW/m<sup>2</sup>. The organic matter of Sargelu Formation entered the early oil zone in 64 Ma and reached the main oil zone ca. 5 Ma. The formation is still in the main oil zone at present-day. In well Atrush-2, the highest rate of oil generation for the Sargelu Formation was in the 8.5 Ma, the onset of oil expulsion from Sargelu Formation was in 50 Ma and the expulsion mass has been reached 0.5 Mtons at present-day.

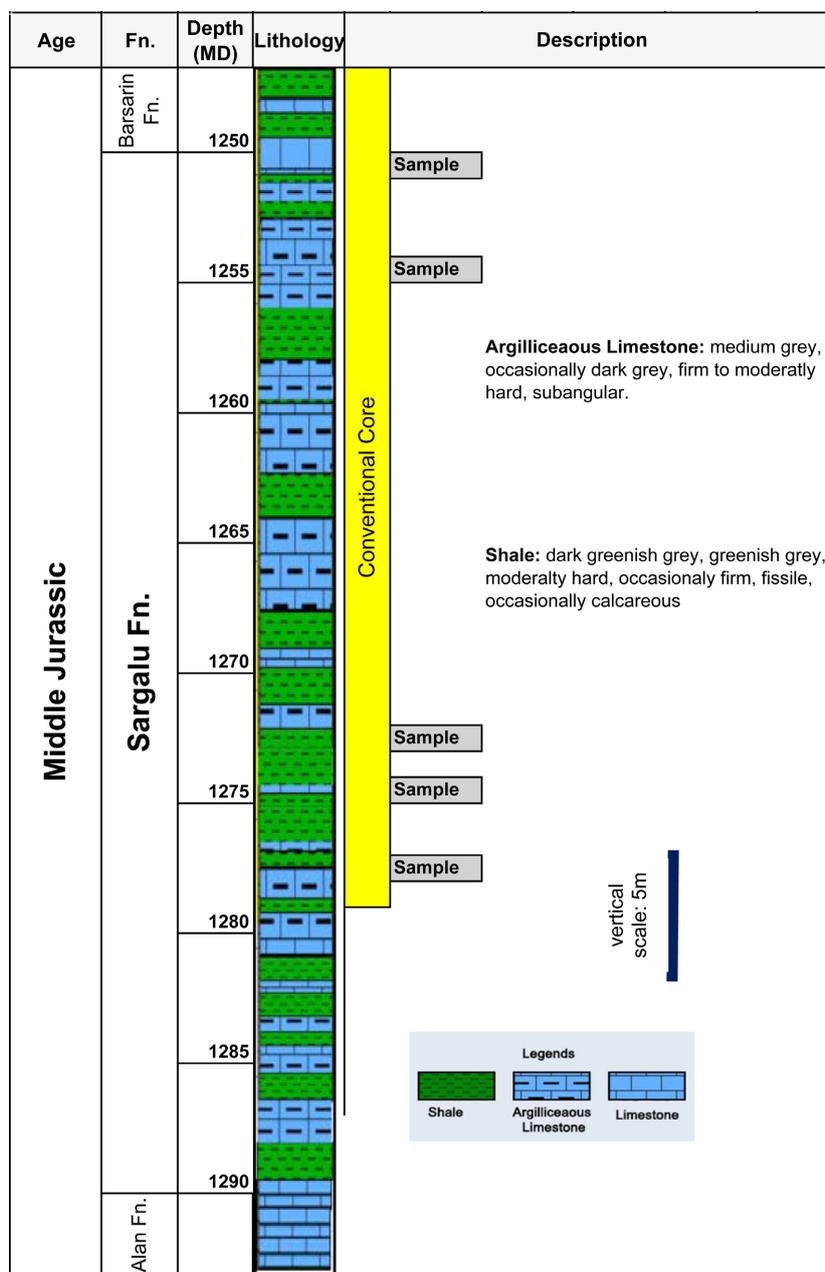
## Keywords

Sargelu Formation, Source Rock, Well Atrush-2, 1-D Basin Modelling, Iraq

## 1. Introduction

The Mid-Late Jurassic megasequence was deposited during a period of isolation of main intra-shelf basin of Mesopotamia, the base of this megasequence with deposition of the Sargelu and Muhawir formations in Rutbah subzone [1]. The oil fields of North Iraq are considered to be part of the Zagros Fold Belt [2]. The Atrush Oil Field is located northeast of Duhok City in Iraqi Kurdistan Region. Herein, this block is one of the biggest and challenging oil developments in the area. According to the Iraqi tectonic division, the study area (well Atrush-2) is located within the High Folded Zone (Figure 1). The Sargelu Formation was first recognized and described by Wetzel in 1948 [3] from Surdash Anticline of the High Folded Zone of NE Iraq. In its type section, this formation comprises 115 m of thin-bedded, black, bituminous and dolomitic limestone and black shale, and it was deposited in euxinic marine environment [4]. In well Atrush-2, the total thickness of the formation is 40 m (1250 - 1290 m), and it is mainly composed of dark grey argillaceous limestone interbedded with black shale in the lower part (Figure 1). Abdula *et al.* [5] defined three microfacies in this formation, namely; mudstone, wackestone and packstone. The first requirement of a play is a potential source rock, where a play is a model of how a petroleum charge system, reservoir, trap may contribute in producing petroleum. The Middle-Upper Jurassic succession contains some of the world's major hydrocarbon systems [6]. Moreover, Pitman *et al.* [7] and Sachsenhofer *et al.* [8] believe that





(b)

**Figure 1.** (a) Tectonic division of Iraq showing location of the study area (modified after [1]). (b) Lithological column of the Sargelu formation at well Atrush-2, based on well data.

the most common and important source rocks in the Zagros Fold Belt can be the Sargelu and Naokelekan formations. The Type II-S, and mixture of II-III kerogens were suggested for this formation by many authors [2] [9] [10] [11] [12] [13]. The goal of this study is new interpretations via geochemical screening method that leads to source rock evaluation and 1-D Basin modelling to estimate the time of onset of petroleum maturation, generation and expulsion in Atrush Oil Field.

## 2. Materials and Methods

### 2.1. Rock-Eval Pyrolysis

Rock-Eval Pyrolysis is considered as a reliable geochemical screening method which provides information on the quality, quantity, and thermal maturity of the organic matter in a sample [14]. In this study, five core plugs of argillaceous limestone and shale intervals from well Atrush-2 (depth 1251 - 1278 m) were analyzed through Rock-Eval 6 Pyrolysis at GH Geochem Laboratory, Birkenhead, United Kingdom. The sum of 100 mg from each sample was crushed and heated up to 850°C in the absence of oxygen to obtain the analytical parameters. The S1, S2, S3, Tmax parameters were directly measured during pyrolysis, while other parameters, such as TOC, HI, OI, and PI, were calculated from the measured parameters (Table 1).

### 2.2. Vitrinite Reflectance

Vitrinite reflectance stands as excellent method for characterization of the state of organic matter maturity [15]. The samples were taken from core chips and analyzed from depth 1251 - 1278 m, at GH Geochem Laboratory, Birkenhead, United Kingdom. The measurements of vitrinite are based on the amount of incident light reflected from the vitrinite group (Table 1). The whole-rock specimen is compressed and embedded in resin and then polished while processing samples for the study of vitrinite reflectance. In this case, numerous microlithotypes and their relationship to the organic matter deposited within the matrix are more readily seen. The reflectance measuring equipment connected to the microscope (Leica DFC 350FX digital camera at Brock University) during the study tests, the percentage of white light reflected from polished vitrinite particles, and the findings are recorded as Ro% for each sample over an average of around 50 measurements.

Results are plotted against other Rock-Eval parameters (e.g. HI), and were

**Table 1.** Results of Rock-Eval pyrolysis and Ro% of the Sargelu formation in well Atrush-2.

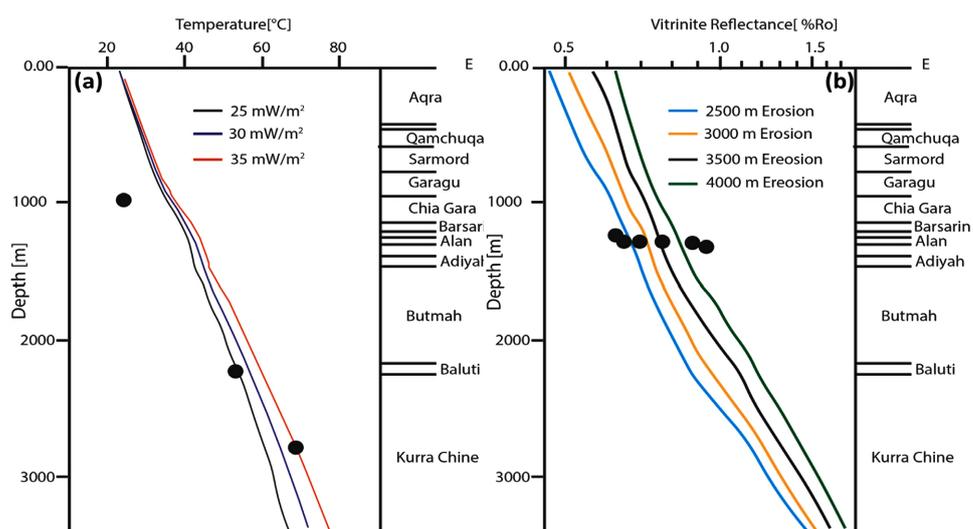
Sample ID	Depth (m)	TOC %	S1	S2	S3	T <sub>max</sub> (°C)	HI	OI	PI	PP	Ro (%)
S-1	1251	1.00	0.08	1.92	0.27	435	192	27	0.04	2.0	0.55
S-2	1256	0.64	0.13	2.41	0.3	431	377	47	0.05	2.5	0.65
S-3	1272	4.08	0.45	33.99	0.35	443	833	9	0.01	34	0.66
S-4	1275	5.00	0.9	26.48	0.14	443	530	3	0.03	27	0.68
S-5	1278	4.98	1.01	25.56	0.31	441	513	6	0.04	27	0.88
<b>Average</b>		<b>3.14</b>	<b>0.51</b>	<b>18.07</b>	<b>0.27</b>	<b>439</b>	<b>489</b>	<b>18</b>	<b>0.03</b>	<b>18</b>	<b>0.68</b>

**Abbreviations:** S1: Volatile hydrocarbon (HC) content, mg HC/g rock; TOC: Total Organic Carbon, %. S2: Remaining HC generative potential, mg HC/g rock; PI: Production Index = S1/(S1 + S2). Tmax: Temperature at maximum of S2 peak; P.P: Petroleum Potential Yield = S1 + S2 (mg HC/g rock). HI: Hydrogen Index = S2 × 100/TOC, mg HC/g TOC; Ro (%) = Vitrinite Reflectance.

used as maturity indicator for well AT-2. Besides, the values of vitrinite made a reliable calibration tool while constructing 1-D basin modelling.

### 2.3. 1-D Basin Modelling

The burial and thermal history of Sargelu Formation was reconstructed and modelled using PetroMod 1-D version 2019.1 of Schlumberger. The stratigraphic succession in the studied well starts with the outcropping Upper Cretaceous Aqra Formation, on top, and down to the Upper Triassic Kurra Chine Formation in the bottom. Moreover, fourteen depositional events, two unconformities and one erosional event were inserted in the field of main inputs. The age and event of each formation were taken from Bellen *et al.* [3], Jassim and Goff [1], English *et al.* [16] Edilbi [17]. To obtain reasonable results, the mixed lithologies of each rock unit were edited in tool of Lithology Editor. Palaeo-water depth (PWD), temperature at the sediment water interface (SWIT) and Palaeoheat flow (PHF) are the three important boundary conditions that were used in modelling. In this procedure, Palaeo-water depths were set based on the nature of the lithologies of each formation and literature reviews, for example Aqrabi and Badics [18], and Edilbi [17]. The temperature at the sediment-water interface (SWIT) was set as paleo-latitude of Middle East, and latitude 38, using the available information on global mean temperature at sea level of Wygrala [19]. The Palaeoheat flow (PHF) were set based on the tectonic history of the study area through geological time [1] [4] and heat flows associated with different tectonic styles of basin formation of Allen and Allen [20]. To determine the present-day heat flow, three models were tried and a present-day HF of 30 mW/m<sup>2</sup> (Figure 2(a)) was recognized as the best match to BHT. Due to erosion



**Figure 2.** (a) Model calibration by matching measured and modelled temperatures for Well Atrush-2. The best match is from present-day heat flow of 30 mW/m<sup>2</sup>. (b) Model calibration by comparing measured and modelled Vitrinite Reflectance in well Atrush-2. In these scenarios, different amounts of the eroded sediments were considered in which the best match was achieved by adding 3500 m sediments.

of huge overburden in the studied area, the eroded sediments should be restored before simulation the model. Thus, to estimate the amount of missing overburden, different amounts of eroded sediments were tested and modelled. Consequently, 3500 m of erosion were added to satisfy the best fit between calculated and measured values (**Figure 2(b)**). The conductivity of the rock units was obtained from lithological information available in PetroMod.

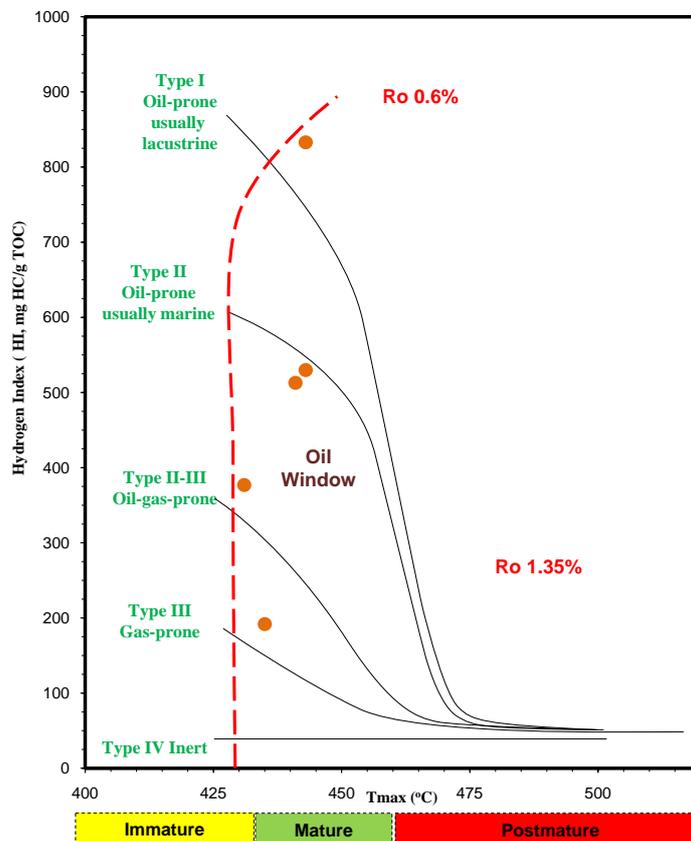
### 3. Results and Discussion

#### 3.1. Source Rock Assessment

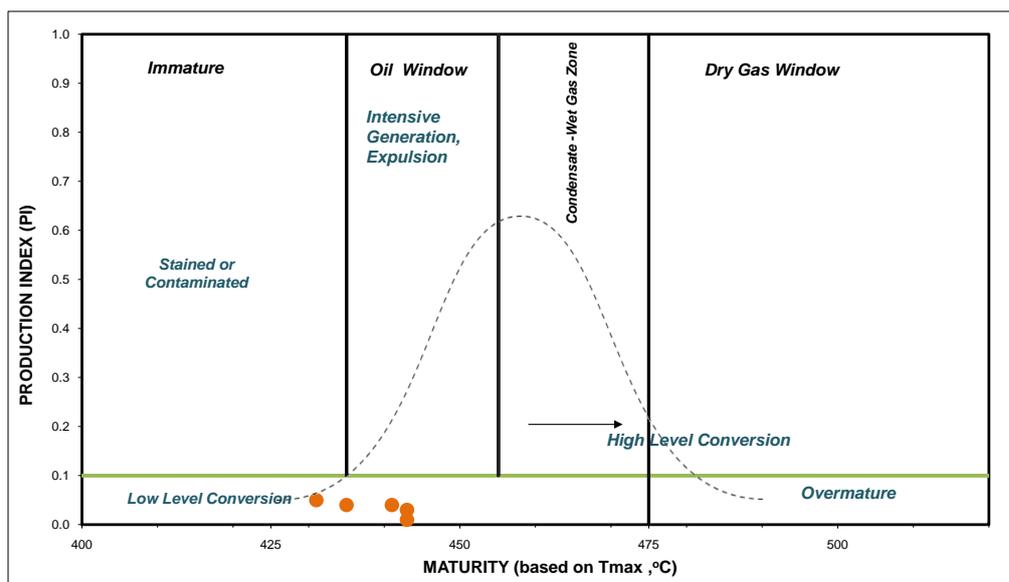
A potential petroleum source rock is referred as any rock that has the competency to generate and expel sufficient amounts of hydrocarbons to form an accumulation of oil and gas [21]. The source rock evaluation of sedimentary rocks is mainly based on the type and content of organic matter with its thermal maturity. The quantity of organic matter in sedimentary rocks can be defined as total organic carbon (TOC%) that is widely used to evaluate petroleum potential of a source rock especially when plotted against other parameters [22]. The minimally acceptable TOC for a potential source rock is 0.5% - 1% [15] [22] [23] [24]. The upper part of the Sargelu Formation which is mainly comprised of argillaceous limestone, contains less amount of organic carbon which ranges from 0.64% - 1%, while the lower part, which is shale dominant, comprises high TOC values (avg. > 4%). Based on the TOC (%) content, the formation has a good to very good organic matter richness. The plot of HI versus Tmax or Ro% can be used to determine the kerogen quality and maturity rather than Pseudo-Van Krevelen diagram (HI versus OI). This eliminates the effects of OI as an indicator of kerogen type [21]. The results of pyrolyzed samples and the plots of HI vs Tmax suggested a mixture of Type II and II-III kerogen except for the shale interval at 1272 m, which revealed Type I kerogen, as reflected by the high HI index and low OI (**Table 1**). The high values of HI show that the formation is more likely an oil prone. Almost, the same types of kerogen have been reported by several authors such as [2] [10] [13] [25] [26]. As shown in **Figure 3**, the organic matter of the formation is thermally mature and in the oil zone, except one sample which belongs to the early mature zone [23] [24]. The plot of Production Index and Tmax (**Figure 4**) also displays that almost all samples are in the oil zone. The Production Index shows the level of thermal maturation and the presence of migrated and contaminated hydrocarbons [15]. The values of PI less than 0.1, 0.1 to 0.15, 0.15 to 0.4 indicate immature, early mature and peak mature, respectively. The values greater than 0.4 indicate late stage of thermal maturity for oil [23]. The plot of Production Index versus Tmax can be used to determine levels of kerogen conversion and maturity. Accordingly, the analysed samples of the Sargelu Formation in Atrush-2 well are mainly in early mature with low level of conversion and are not contaminated (**Figure 4**).

#### 3.2. Basin Modelling

As mentioned in the methods and material section, the top of well Atrush-2 is



**Figure 3.** Cross-plots of HI vs  $T_{max}$  including vitrinite reflectance (R%), showing kerogen quality and thermal maturity stages of analysed samples.



**Figure 4.** Plot of PI vs  $T_{max}$  showing maturation and hydrocarbon production of the Sargelu formation [15].

the Aqra Formation (Upper Cretaceous) and the deepest formation encountered by drilling is the Upper Triassic Kurra Chine Formation. The total depth drilled

in this well is 3400 m. The total thickness of the overburden from ground surface to the top of the Sargelu Formation, in this well, is 1178 m. This amount of overburden is insufficient for thermal maturation of the underlying Middle Jurassic-aged Sargelu source rock. The study area was subjected to uplift in the Miocene [17] [27] [28] [29] [30] causing erosion of remarkable thickness of sediments. Subsequently, older formations became exposed. In order to obtain the present-day heat flow, few plausible scenarios were modelled and the best fit to bottom hole temperature (BHT) was achieved by a present-day heat flow of 30 mW/m<sup>2</sup>. Then, the amount of the eroded sediments, 2500 m, 3000 m, 3500 m, 4000 m of the missing overburden were added on top of the Aqra Formation. The best fit between the measured and calculated vitrinite reflectance of Sweeney and Burnham [31] was achieved from erosion of 3500 m of sediments in the studied well. The stage of source rock maturation and oil and gas generation can be deduced by vitrinite reflectance (Ro%). The simulation of the modelled vitrinite reflectance (Easy %R) versus time shows that the Sargelu Formation entered the early oil zone in the 64 Ma and reached the main oil zone around 5 Ma. The formation is still in main oil zone at present-day (Figure 5 and Figure 6(a)).

The generation mass for the studied formation began in the 158 Ma (0.01 Mtons), then increased almost in 49 Ma, followed by outstanding increase to 0.52 Mtons at present-day. The highest rate of oil generation for the Sargelu Formation in well Atrush-2 was in the 8.5 Ma (Figure 6(b)). Transformation ratio (TR) is defined as the ratio of converted mass fraction of source rock that has been thermally matured and generated hydrocarbons to the total generation potential of a source rock [32] [33]. Based on the modelling, the Sargelu Formation in Atrush-2 Well began to generate oil in 149 Ma prior to onset on oil generation. The transformation was nearly low at 50 Ma, then started to increase and 26% conversion was reached in the 5 Ma. Influenced by Zagros orogeny and consequent uplifting and erosion, the transformation ratio has been ceased since

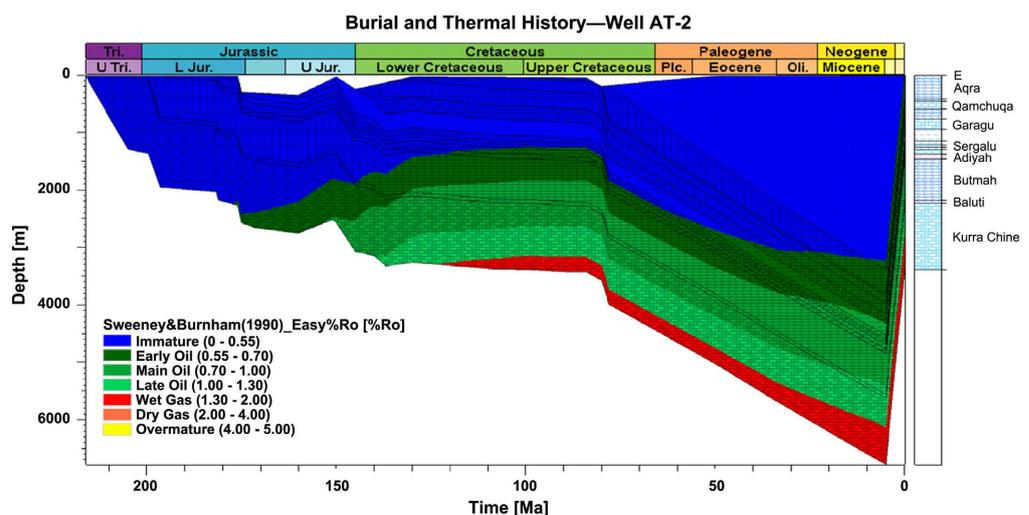
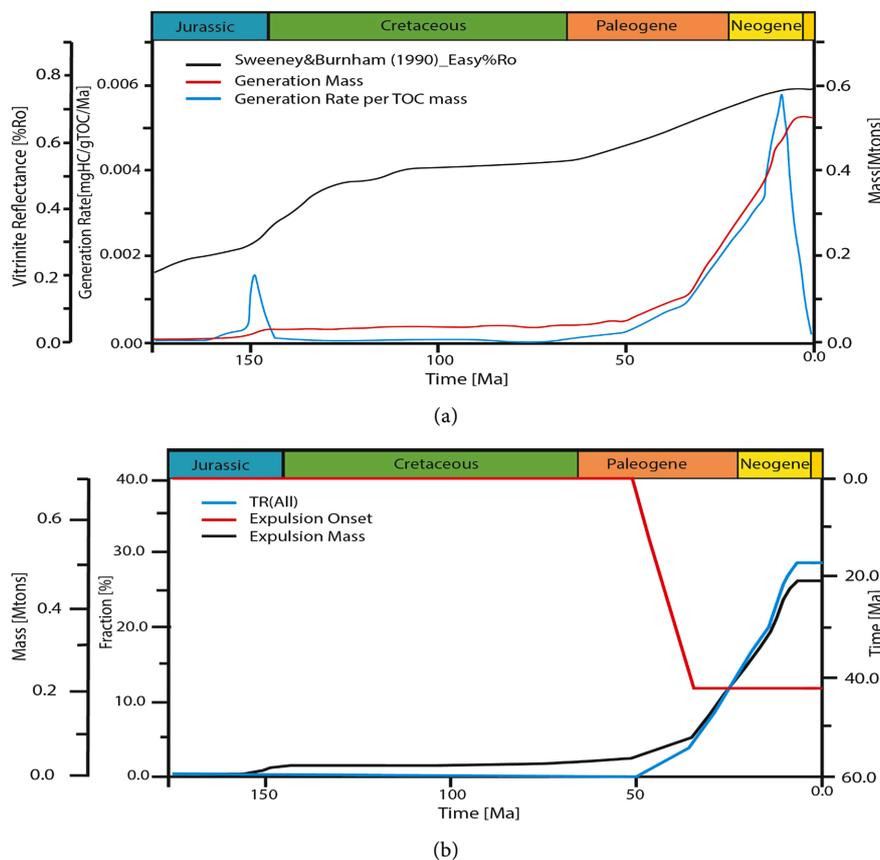


Figure 5. Thermal history modelled through geological time for whole stratigraphic succession in Well Atrush-2.



**Figure 6.** Time plot showing (a) vitrinite reflectance ( $R_o$ ), generation rate [mgHC/gTOC/Ma] and generation mass, and (b) trends of transformation ratio, expulsion onset and expulsion mass of the Sargelu formation through the geological time in well Atrush-2.

5 Ma. The petroleum expulsion is the ratio of the expelled petroleum to the amount of generated petroleum. The onset of oil expulsion from the Sargelu Formation was in 50 Ma, later the expulsion mass reached 0.5 Mtons at present-day. Several previous investigations related to the Sargelu Formation, has concluded different levels of thermal maturity at different tectonic zones in different locations in Iraqi Kurdistan [16] [17] [25] [34] [35]. These differences can also refer to variation of the overburden rocks, groundwater flow, and conductivity of the rock units. For instance, the study of Abdula [36] on the geothermal gradient in selected wells in the Iraqi Kurdistan, has displayed the different geothermal gradients values. The Geothermal gradient for the studied area is around 17.83 - 19.74 C/km [36], which is relatively low compared to that of the Low Folded Zone.

Abdula [34] modelled hydrocarbon generation of the Sargelu Formation in Jabal Kand Oil Field, and stated that the Sargelu Formation has not started generation oil and gas in that oil field. He argued that low maturity and oil generation are due to low thickness of the overburden in that area. Hakimi *et al.* [10], in their study on hydrocarbon generation from the Sargelu Formation from six wells in Kurdistan Region, Northern Iraq, concluded that the formation is in the

peak oil zone and more than 50% of oil has been generated and expelled since the Late Eocene to present-day, and the formation has reached higher level of thermal maturity in the wells Aj-8, Taq-1 and Zab-1. Moreover, based on the model of Sachsenhofer *et al.* [8], for well Shores-1, the oil generation rate of the Sargelu Formation attained its peak at 55 Ma and then again at 5 Ma.

#### 4. Conclusion

The results of Rock-Eval Pyrolysis showed that the Sargelu Formation in Well Atrush-2 can be characterized as fair source rock in the upper part, while considered as good to very good source rock, in the lower part, in terms of organic matter richness. The Type II and mixed Type II-III kerogens are suggested for the formation. The values of Vitrinite Reflectance (R%) and Tmax revealed that the formation is thermally mature and has entered the oil window. From the obtained results of 1-D basin modelling, it was confirmed that the formation entered early oil zone at 64 Ma, then reached the main oil zone around 5 Ma. The formation commenced oil generation in 146 Ma and about 26% conversion was reached at present-day. The onset of oil expulsion from the Sargelu Formation was in 50 Ma and the expulsion mass has scored 0.5 Mtons at present day.

#### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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