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Original Research

Organic Matter Assessment of the Jurassic Bazeh-Howz Formation of the Binalud Basin, Iran: Insights from Organic Petrography and Geochemistry

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Abstract

The Bazeh-Howz Formation represents Jurassic siliciclastic strata in the Binalud Basin, northeastern Iran, composed of fluvio-deltaic deposits, that consist of three major types of facies, conglomerate (monomict and polymict orthoconglomerates), sandstone (quartzarenites, sublitharenites, feldspathic litharenites or phyllarenites), and shale. The formation has an underlying fault contact and is overlain by Cretaceous carbonates. Fine-grained deposits (shale) with organic material represent more than 65% of the strata (>1000 m), and commonly alternate rhythmically with siltstone and very fine-grained sandstone. Pyrolysis of 17 samples indicates 0.18 to 26.3 wt. % of total organic carbon (TOC), with an average of 3.09 wt. %. The amount of free hydrocarbon and the residual potential are generally low, which indicates a poor potential to generate hydrocarbon. The organic matter is residual carbon, with no indication of pyrolysis carbon (PC). Based on oxygen and hydrogen (OI, HI) indices, the organic matter is reworked and migratory, and the samples do not contain primary and free organic matter (kerogen). Petrological studies show that the organic material is solid bitumen and pyrobitumen, filling intergranular pores and fractures and following lamination in places. Reflectance of organic fragments varies from 1.12 to 1.77, indicative of the varied genesis and formation time of solid bitumen.

Keywords: Binalud Basin, Organic geochemistry, Bazeh-Howz Formation, Jurassic, Bitumen

1. Introduction

The Binalud mountain range of northern Iran follows a northwest-southeast trend between the Turan Plate and the continental shelf of Central Iran. Facies similarities and the tectonic features document that the Jurassic strata of the Binalud mountains are gradational between Central Iran and the Alborz mountain range to the west (Nabavi 1976), as part of a sedimentary basin on the Central Iran platform that formed during the Palaeozoic. Alavi (1991) suggested that the Binalud mountain range is a folded and faulted belt of thin crust that formed after the collision between the Iran and Turan lithospheric plates at the northeastern margin of the Iranian microcontinent, with Palaeozoic, Mesozoic and Cenozoic strata.

Jurassic strata are present in many sedimentary basins of Iran, including Kopet-Dagh, Zagros, Central Iran and Binalud (Poursoltani et al. 2007; Fürsich et al. 2009; Wilmsen et al. al. 2009a; Poursoltani and Pe-Piper 2015; Poursoltani 2017; Poursoltani et al. 2022). The Binalud Basin (Fig. 1) has been studied by many researchers from different perspectives (Eftekhar-Nejhad 1980; Alavi 1992; Sheikholeslami and Kouhpeyma 2012; Zeraatkar and Rahimi 2012; Rahimi and Ghaemi 2014), and Poursoltani et al. (2022) studied the coarse-grained sedimentary rocks west of Mashhad.

In the Jurassic succession of the eastern Binalud Basin, the Arefi, Aghounj, and Bazeh-Howz formations cover a wide area along the Palaeotethys suture northwest of Mashhad. The Bazeh-Howz Formation has been studied repeatedly (e.g., Wilmsen et al. 2009a, b, Vaez-Javadi and Allameh (2015) and Poursoltani and Fürsich 2020). It consists of shales, conglomerates and sandstones deposited in a fluvial-deltaic environment (Poursoltani et al. 2015). In the study area, the contact with the underlying strata is not known (Figs. 1–3), and the formation is capped by Cretaceous carbonates.

Jurassic siliciclastic sediments in the Binalud area are one of the most significant deposits for the interpretation of ancient conditions (Poursoltani and Fürsich 2020). The present study documents the organic geochemistry and hydrocarbon generation potential of the locally organic-rich strata. Conventional petroleum accumulations remain a major energy source worldwide, including in Iran where advances in exploration are contributing significantly to the increase in energy reserves.

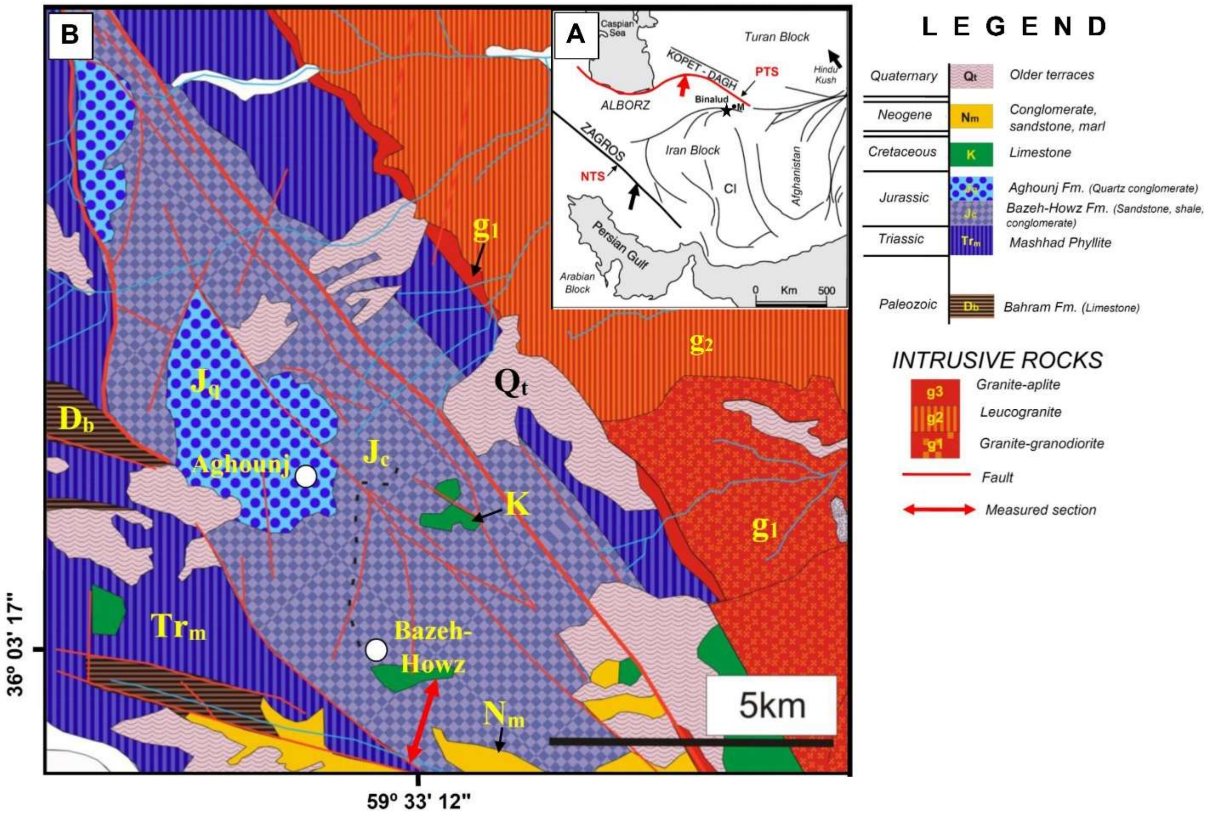

Figure 1. A) Tectonic setting of Iran and adjacent area (PTS: Palaeotethys Suture. NTS: Neotethys Suture. M: Mashhad). Capitalized names indicate major mountain belts. The arrows indicate present-day relative motions. Star showing study area. Modified from Lyberis and Manby (1999). B) Geological map of the studied section (arrowed), simplified from the geological map of Mashhad (1:250,000 scale).

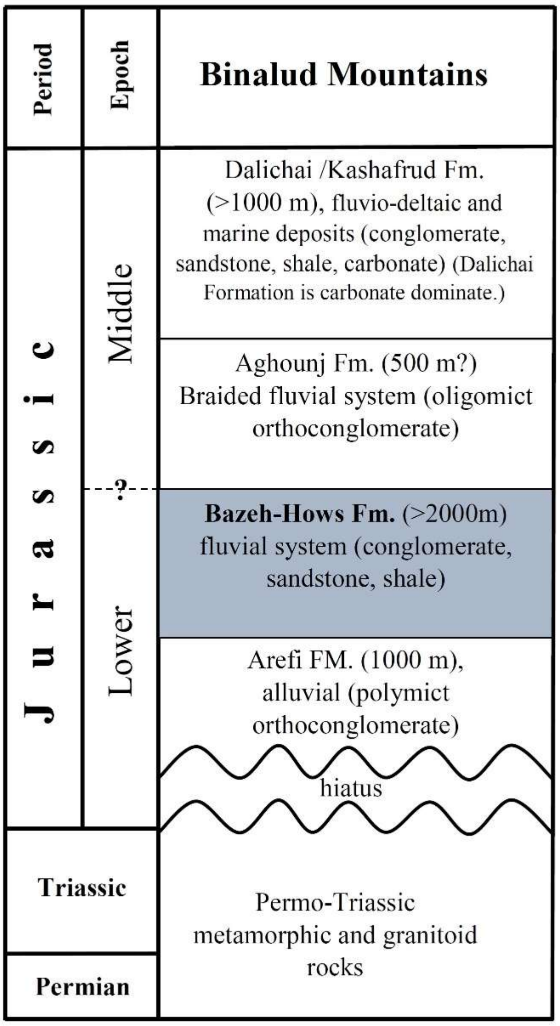

Figure 2. Generalized Triassic and Lower to Middle Jurassic stratigraphy of the Binalud Rregion (modified from Poursoltani and Fürsich 2020). Change: (>2000 m); Dalichai/Kashafrud Fm. (the Dalichai Fm. is carbonate dominated).

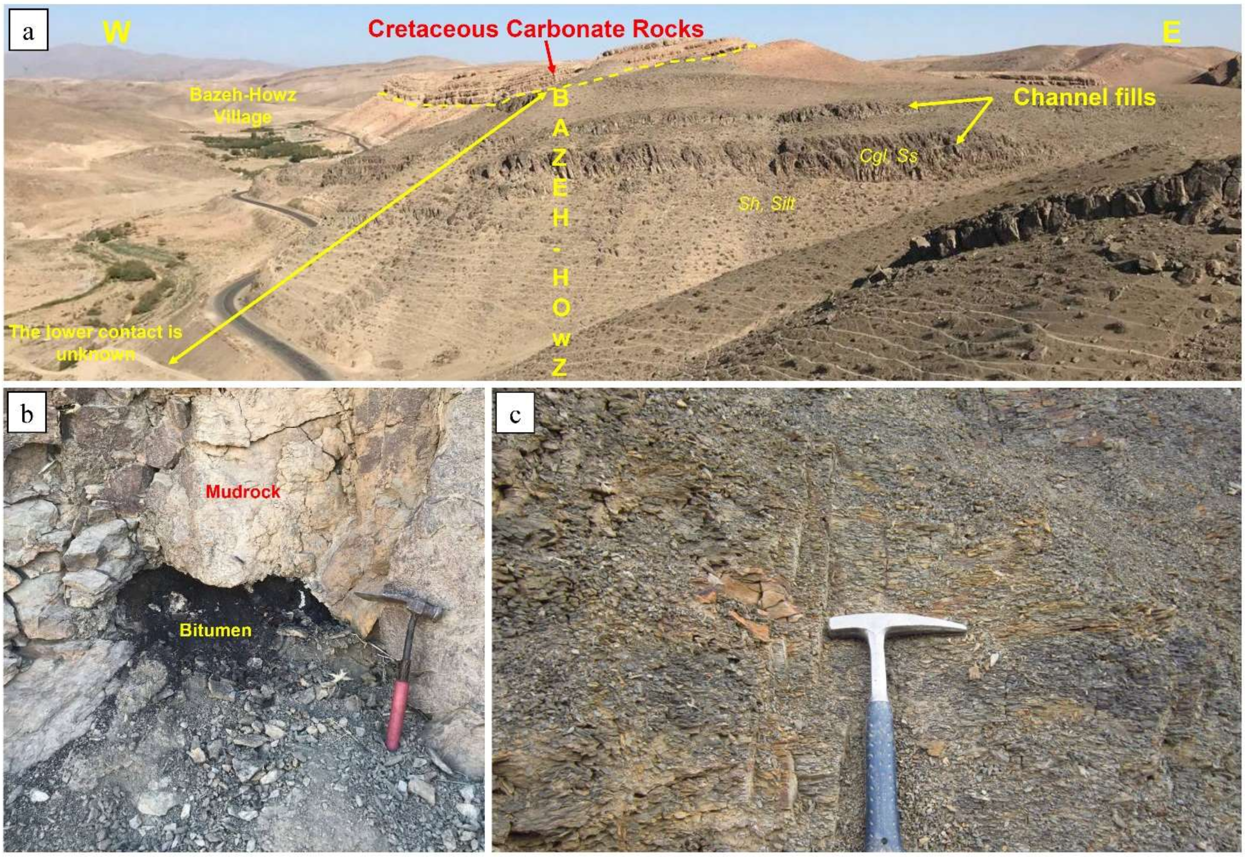

Figure 3. Outcrop photographs of the Jurassic Bazeh-Howz Formation. A) Panoramic view of the study area, with dashed line marking the upper contact with Cretaceous carbonates. The lower contact of the formation is unknown. B) Mudstone with a mass of bitumen. C) A thick shale bed (size of hammer: 60 cm).

2. Stratigraphy and sedimentology

The Bazeh-Howz Formation in the Binalud mountain range south of Mashhad is >1000 m thick. It consists predominantly of green, black and locally brown mudstone and laminated siltstone, characterised by abundant plant remains, forming extensive outcrops, and is interbedded with minor intercalations of conglomerate and sandstone (Fig. 4; Vaez-Javadi and Allameh 2015; Poursoltani et al. 2022).

Well-bedded units, several metres thick, comprise medium-grained sandstone, locally with very fine- to coarse-grained beds. The main sedimentary structures of these lithofacies include planar lamination and ripple cross-stratification. Conglomerate beds 0.5 to 2 m thick are present locally and consist mainly of monomict and polymict orthoconglomerate with well-rounded quartz fragments, associated with minor sandstone intercalations. According to Poursoltani and Fürsich (2020) the sandstones are quartzarenite, sublitharenite, feldspathic litharenite or litharenite (phyllarenite). Graded bedding is prominent in the coarse-grained packages, which rest on erosional surfaces and are interpreted as channel fills. The strata are interpreted as fluvio-deltaic deposits with a strong river influence (Poursoltani et al. 2015; Poursoltani and Fürsich 2020).

3. Material and methods

A total of 25 samples of fine-grained strata containing organic matter were collected in a well-exposed part of the outcrop belt (Fig. 4), and 17 samples relatively rich in organic matter were selected for geochemical and petrographic analysis. Photographs were taken of the section, sedimentary structures, and organic-rich layers.

The selected samples were geochemically analysed using the Rock-Eval 6 device, IFP France (IFP 160000), at the Geochemical Research Unit of the Tehran Oil Industry Research Institute (Table 1). Following the manufacturer's calibration instructions, an empty sample container was analyzed initially to ensure that the device was calibrated, after which 65 mg of each prepared sample was weighed and analysed using standard protocols, with a standard sample placed between every 10 to 15 samples. In the Rock-Eval 6 device, the TOC value was obtained from the sum of pyrolysis carbon (PC) and residual carbon (RC).

In addition, from each sample a thick-section was prepared to detect the organic components present using a Leitz-MPV-COMBI reflection microscope. Using an oil-immersion lens with a magnification of 125 (Taylor et al. 1998), vitrinite reflectance was determined as the percentage of light reflected from the surface of the sample, based on a standard calibrated method for microscopical determination (ASTM 2014), in comparison with a standard sample that reflects 100% of the light.

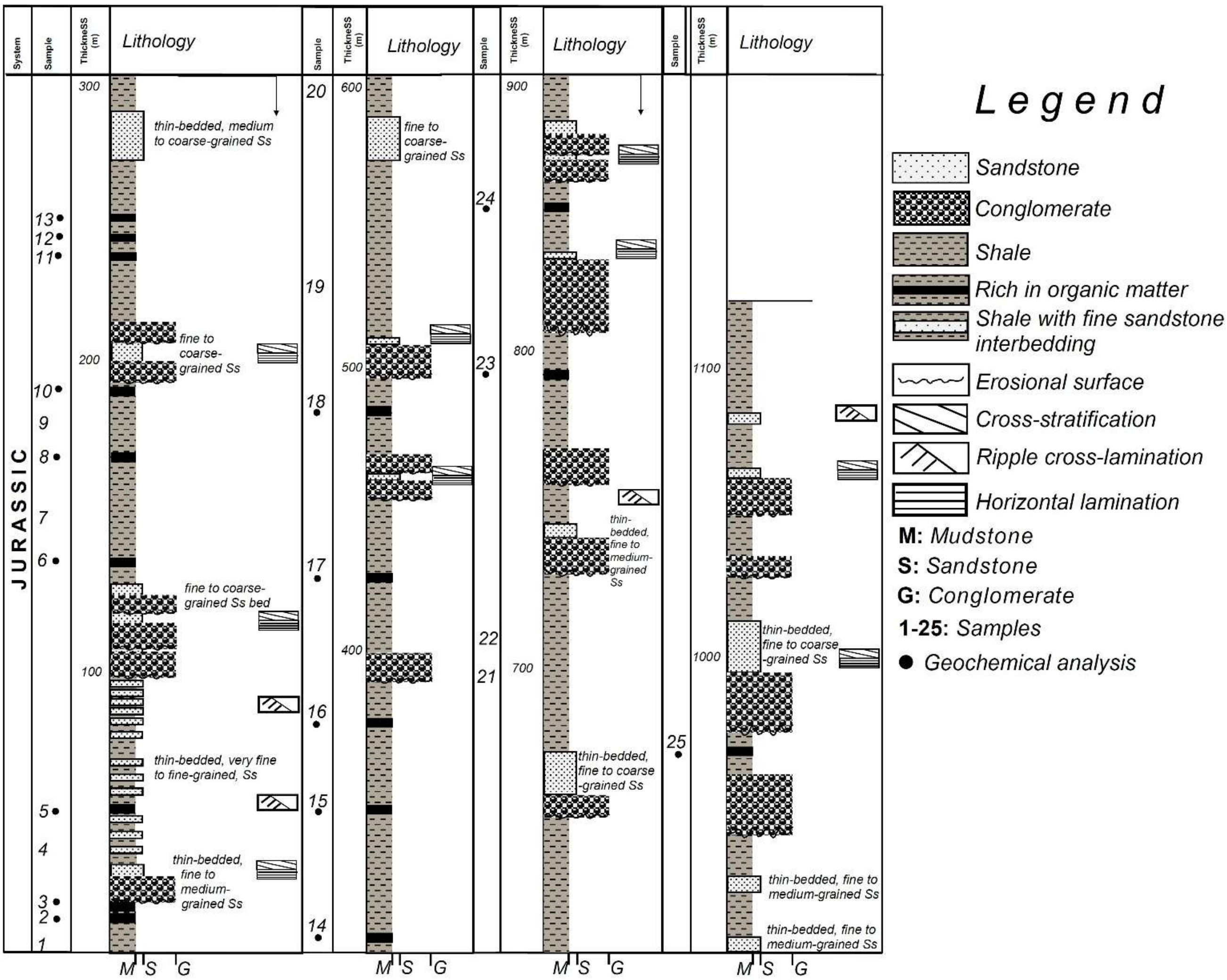

Figure 4. Stratigraphic log of the section studied, showing position of samples. For location of section see Fig. 1B. Black circles indicate position of samples used for geochemical analysis

Table 1. Results of the Rock-Eval analysis of the studied samples from the Bazeh-Howz Formation. (Tmax: maximum temperature ; PC: pyrolysis carbon; RC: Residual Carbon; TOC: Total Organic Carbon; HI: Hydrogen Index; OI: Oxygen) Index). You have to explain all terms (e.g., S1, S2, TPI etc) in the table caption

Sample	S1	S2	TPI	Tmax	Tpeak	S3CO	S3'CO	S3	S3'	PC	RC	TOC	HI	OI CO	OI
2	0.02	0.01	0.56	508	548	0.03	0.19	0.34	1.5	0.01	0.7	0.71	2	5	48
3	0.01	0.02	0.22	368	408	0.01	0.09	0.13	1.17	0.01	0.39	0.4	5	3	34
5	0.01	0.05	0.11	540	580	0.08	2.31	3.63	17.26	0.11	7.55	7.66	1	1	47
6	0	0	0	260	300	0.01	0	3.32	7.72	0.09	0.67	0.76	0	1	439
8	0	0	0	604	644	0.01	0	3.04	8.35	0.08	0.95	1.04	0	1	294
10	0	0.03	0.11	545	585	0.03	0.39	1.11	4.95	0.03	1.85	1.88	2	2	59
11	0	0.01	0.41	498	538	0.01	0.12	0.32	1.58	0.01	0.49	0.51	1	3	64
12	0	0.05	0	443	483	0.05	1.04	2.71	14.98	0.08	5.3	5.38	1	1	50
13	0	0.01	0	529	569	0.01	0.37	0.8	4.28	0.02	1.78	1.81	1	0	45
14	0.01	0.02	0.32	496	536	0.02	0.13	0.1	0.19	0.01	0.95	0.95	2	2	10
15	0.01	0.01	0.38	527	567	0.03	0.1	0.22	0.89	0.01	0.64	0.65	1	4	34
16	0.05	0.39	0.11	352	392	0.33	9.68	10.87	42.86	0.35	26	26.3	1	1	41
17	0.02	0.07	0.23	526	566	0.05	0.27	0.53	1.64	0.02	1.93	1.96	4	2	27
18	0.01	0.19	0.07	383	423	0.21	0.39	1.33	6.38	0.06	1.82	1.88	10	11	71
23	0.02	0.05	0.27	343	383	0.01	0	0	0.37	0.01	0.17	0.18	26	4	0
24	0.04	0.04	0.48	369	409	0.01	0.01	0.02	1.04	0.01	0.2	0.21	22	5	8
25	0.07	0.09	0.45	393	433	0.02	0.04	0.07	0.79	0.02	0.24	0.25	34	7	28

4. Results

The results of the Rock-Eval analysis of the mudrocks are given in Table 1. They show that total organic carbon (TOC) ranges from 0.18% (sample 23) to 26.3% (sample 16), with an average value of 3.09% (Fig. 5). TOC is compared with residual carbon (RC), and pyrolysis carbon is low (Table 1). The values of parameters S1 and S2 (value of free hydrocarbon and value of residual potential) are almost zero or very low. In addition, HI and OI show different results. The range of HI is 0 to 34, whereas OI ranges from 0 to 439.

The microscope study showed that the organic components are solid bitumen and pyrobitumen, with no evidence of standard macerals in the samples (Figs. 6-10). Microscope images lead to the inference that, in most samples, the migration of hydrocarbons and the distribution of solid bitumen and pyrobitumen are mainly a function of the lithology and rock texture. In samples with higher porosity, the volume of incoming hydrocarbon and the remaining solid bitumen is also higher. In other samples, organic materials are limited to seams and fractures, rather than being intimate components of the rock (e.g., Furmann et al. 2014). The presence of lamination in some samples has caused the solid bitumen to accumulate in bedding-parallel layers.

Due to the lack of maceral vitrinite in the samples, the reflectance of solid bitumen has been measured (Table 2). One of the most basic steps in geochemical studies is to determine the maturity of the source rock, which is measured by the vitrinite reflectance level of organic material (Mukhopadhyay 1992). In the Bazeh-Howz Formation, vitrinite reflectance varies from 1.12 (sample 5) to 1.77 (sample 14).

5. Discussion

The results show that almost all the TOC in the samples is residual carbon (RC), and pyrolysis carbon (PC) is not present (e.g., Mashhadi and Rabbani 2015). The low values of S1 and S2 indicate minimal free hydrocarbons and residual production potential in the samples. Thus, the samples have a low (near-zero) quantity of organic material and production potential, and they cannot be considered as viable source rocks. With a very low S2 value (<0.2), Tmax values are not reliable, and the thermal maturity cannot be interpreted for this formation (e.g., Katz 1983; Furmann et al. 2015).

Based on the oxygen index (OI), hydrogen index (HI), and the geochemical results, the bulk of the organic matter in the Bazeh-Howz Formation is inferred to have been reworked, and the high residual carbon content indicates the presence of migratory hydrocarbon residues. These entered the basin as detrital particles during sedimentation, many probably from erosion of unknown older strata. Thus, the Bazeh-Howz Formation is inferred to contain only a minor amount of primary organic matter. The existing primary organic matter indicates a source rock that is rich in organic matter and a probable source of petroleum. Its identification requires further investigations (e.g. Sarhan 2023).

Due to these constraints, it is not possible to use standard Rock-Eval diagrams, because most of the data are located outside the respective diagrams and cannot be interpreted from the point of view of organic geochemistry and source rock potential. The solid bitumen is of the non-perforated (reworked) and migratory type, and it typically fills interparticle pores and fractures (e.g. Sarhan and Selim, 2023). These results support the Rock-Eval analysis and the high percentage of residual carbon, implying that the organic materials originated in older strata either in the study area or outside the basin, something that needs to be investigated.

Based on Sanei's (2020) classification, the solid bitumen in the samples is mostly origin and pyrobitumen. Solid original bitumen indicates that the oil entered the shales as paraffinic hydrocarbons, which were converted into solid bitumen due to thermal cracking. The non-productive residues of this paraffin oil were retained as carbon (pyrobitumen) under elevated temperatures through time. Changes in vitrinite reflectance confirm the different genesis and formation time of solid bitumen in the studied sedimentary succession.

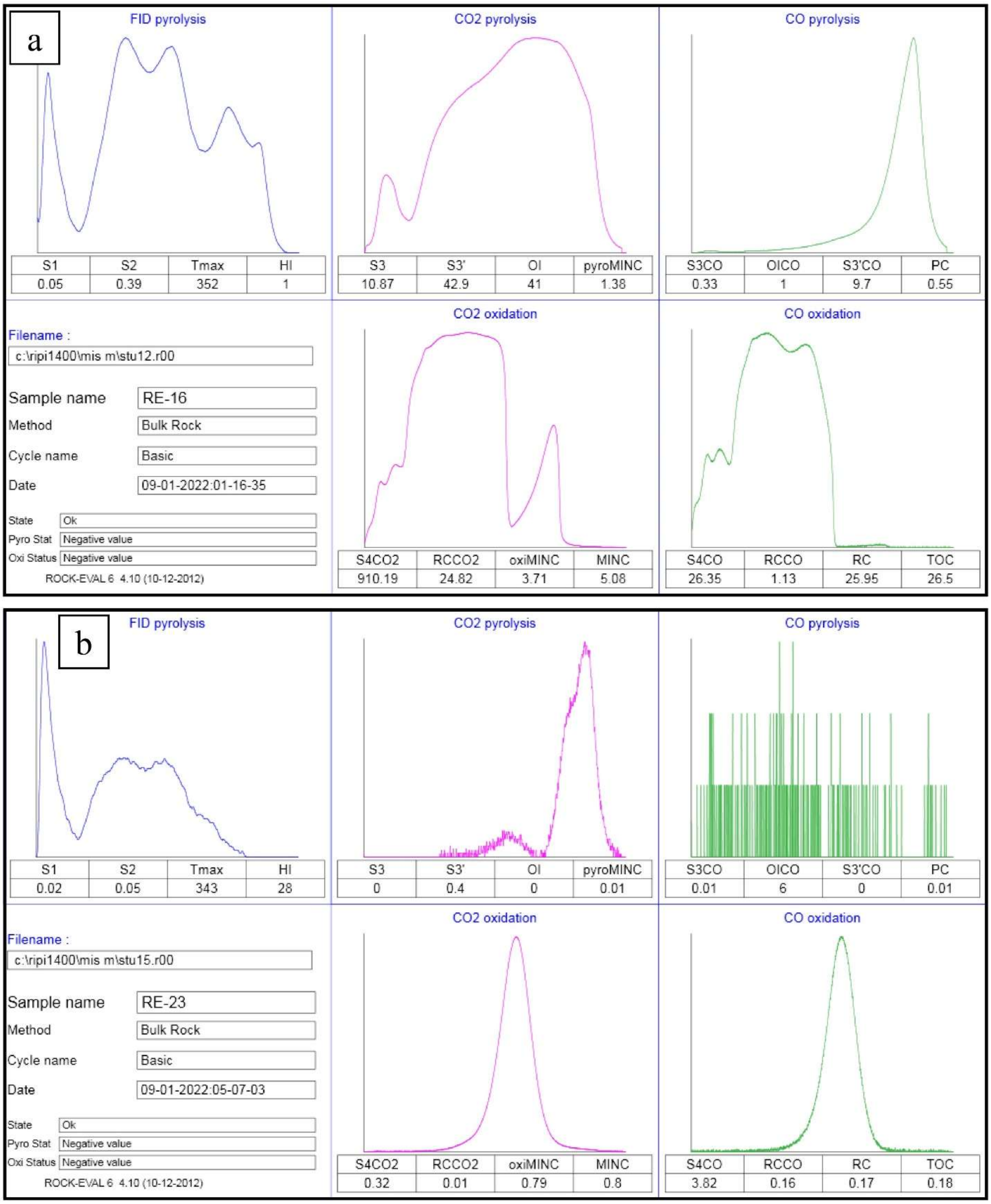

Figure 5. Pyrograms obtained from the pyrolysis analysis of two samples (16 (TOC Max) and 23 (TOC Min)) from the Bazeh-Howz Formation according to Table 1.

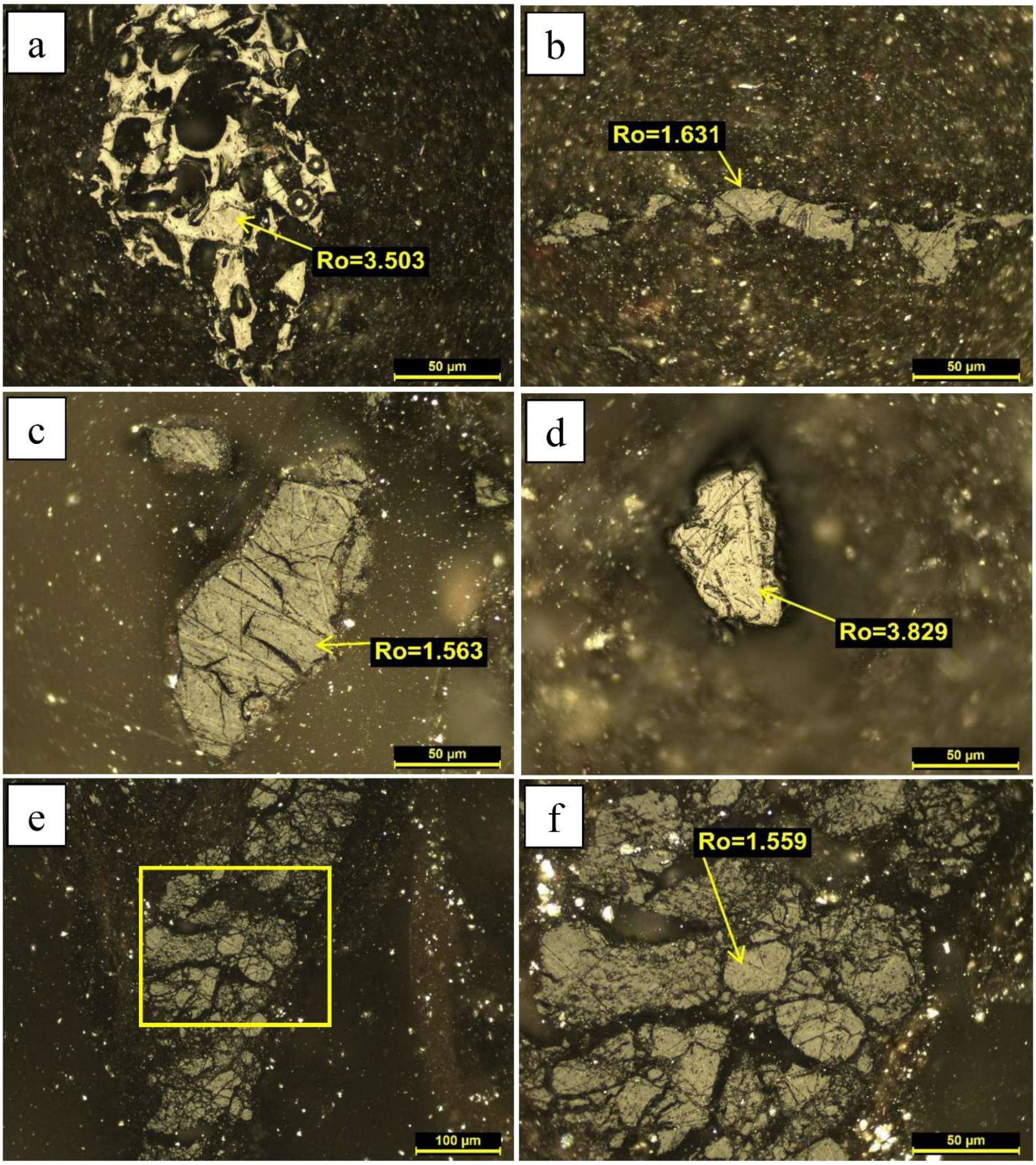

Figure 6. Microscope images (reflected light) of solid bitumen and pyrobitumen in the Bazeh-Howz Formation. A) Fully carbonised organic materials; high vitrinite reflectance indicates complete carbonisation (sample 2). B) Pyrobitumen as fracture fill, which indicates the migration of organic materials (sample 2). C) Solid bitumen (sample 3). D) Fully carbonised organic matter with high vitrinite reflectance (sample 3). E) Solid bitumen filling fractures (sample 10). F) Close-up of E.

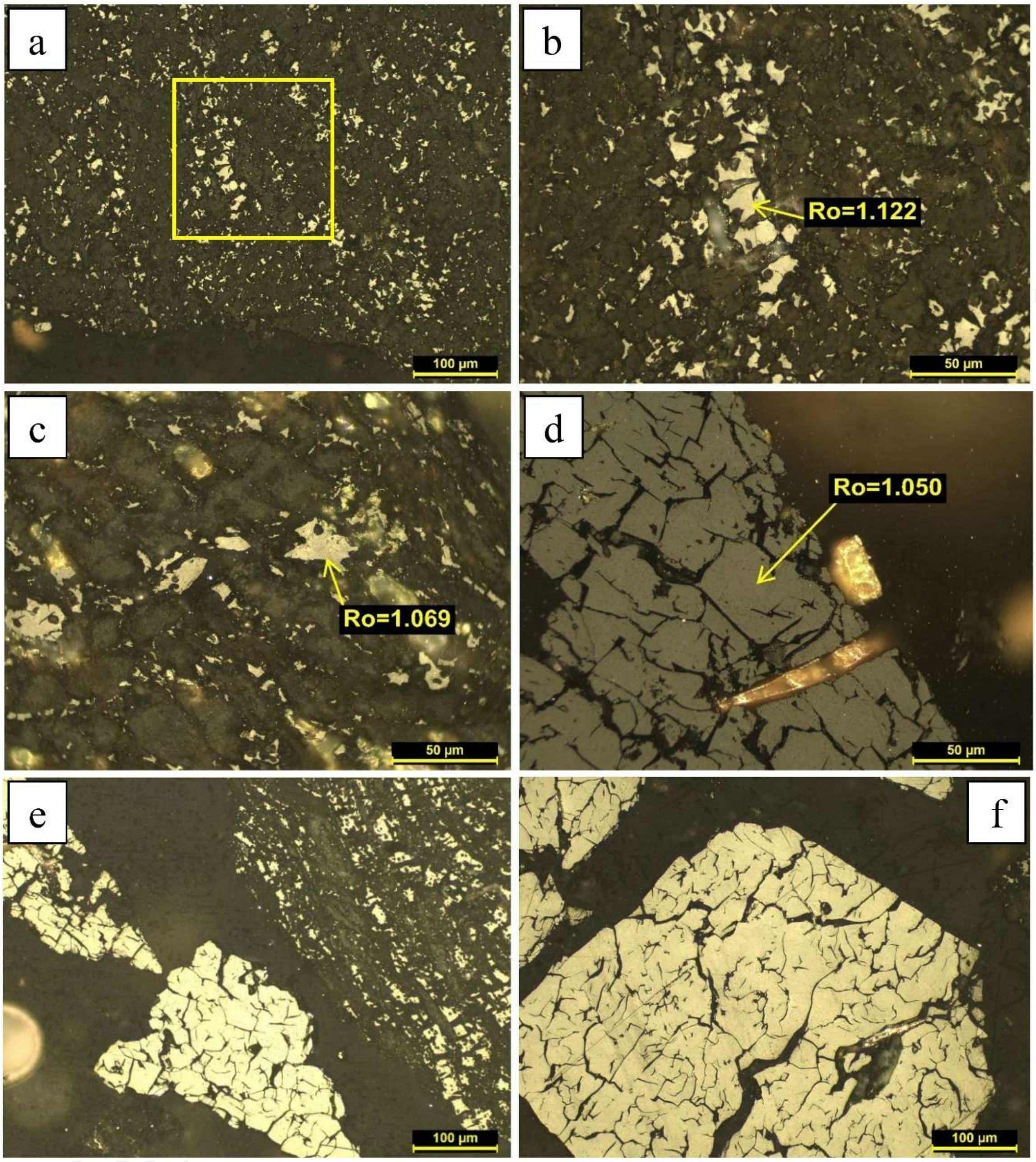

Figure 7. Microscopic images (reflected light) of solid bitumen in sample 5 of the Bazeh-Howz Formation: A) High content of scattered pyrobitumen showing the high porosity of the samples. B) Close up of A. C–F) Large pieces of pyro-bitumen that indicate the high porosity of the samples and a large volume of incoming hydrocarbon. In (E), the sample is laminated, and the pyrobitumen has adopted a layered state.

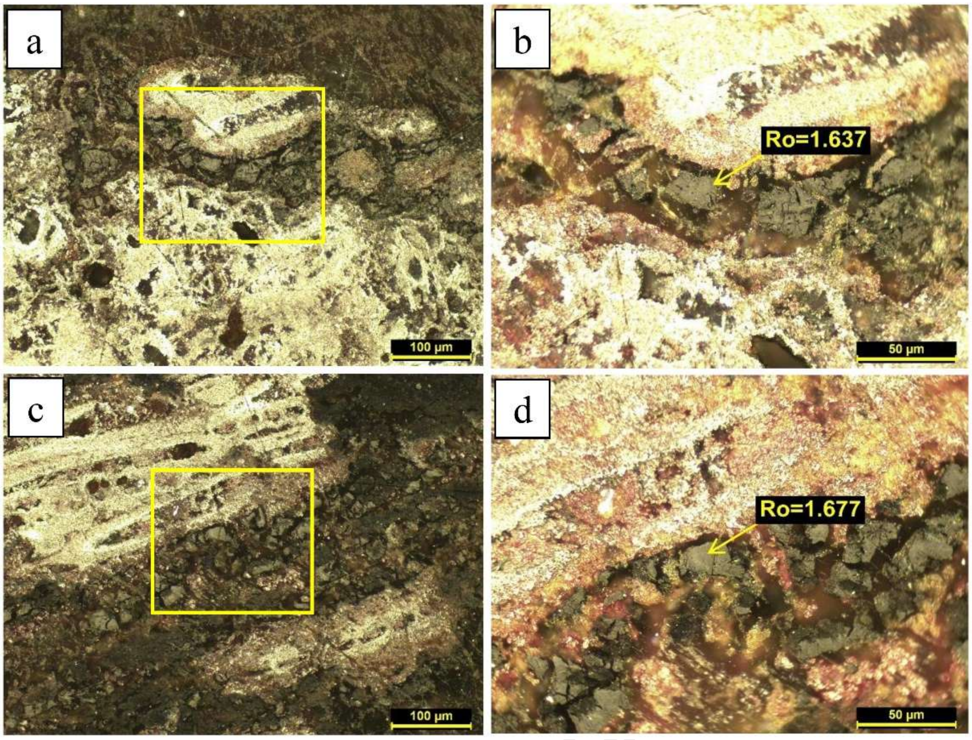

Figure 8. Microscopic images (reflected light) of solid bitumen in sample 8 of the Bazeh-Howz Formation. A, C) The bitumen appears as fracture fillings in the lithofacies . B, D) Close-up images of (A) and (C), respectively.

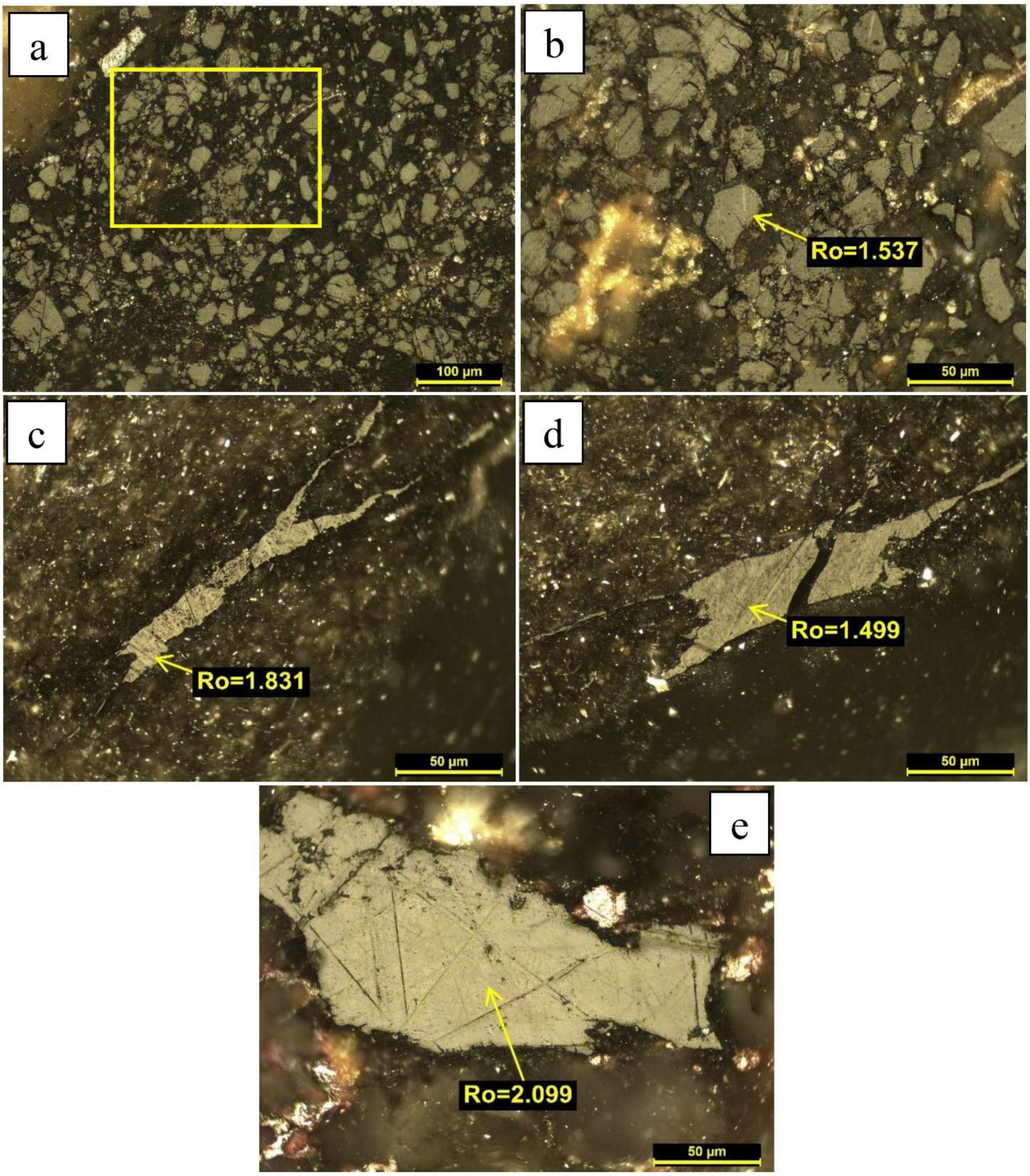

Figure 9. Microscope images (reflected light) of solid bitumen in samples of the Bazeh-Howz Formation. A) Pore filled with solid bitumen in a host rock with high porosity. B) Close up of (A) (sample 12). C, D) Fractures filled with solid bitumen (sample 14). E) Solid bitumen with high vitrinite reflectance, which indicates higher maturity than other samples. This bitumen fills the pores in the host rock (Sample 13).

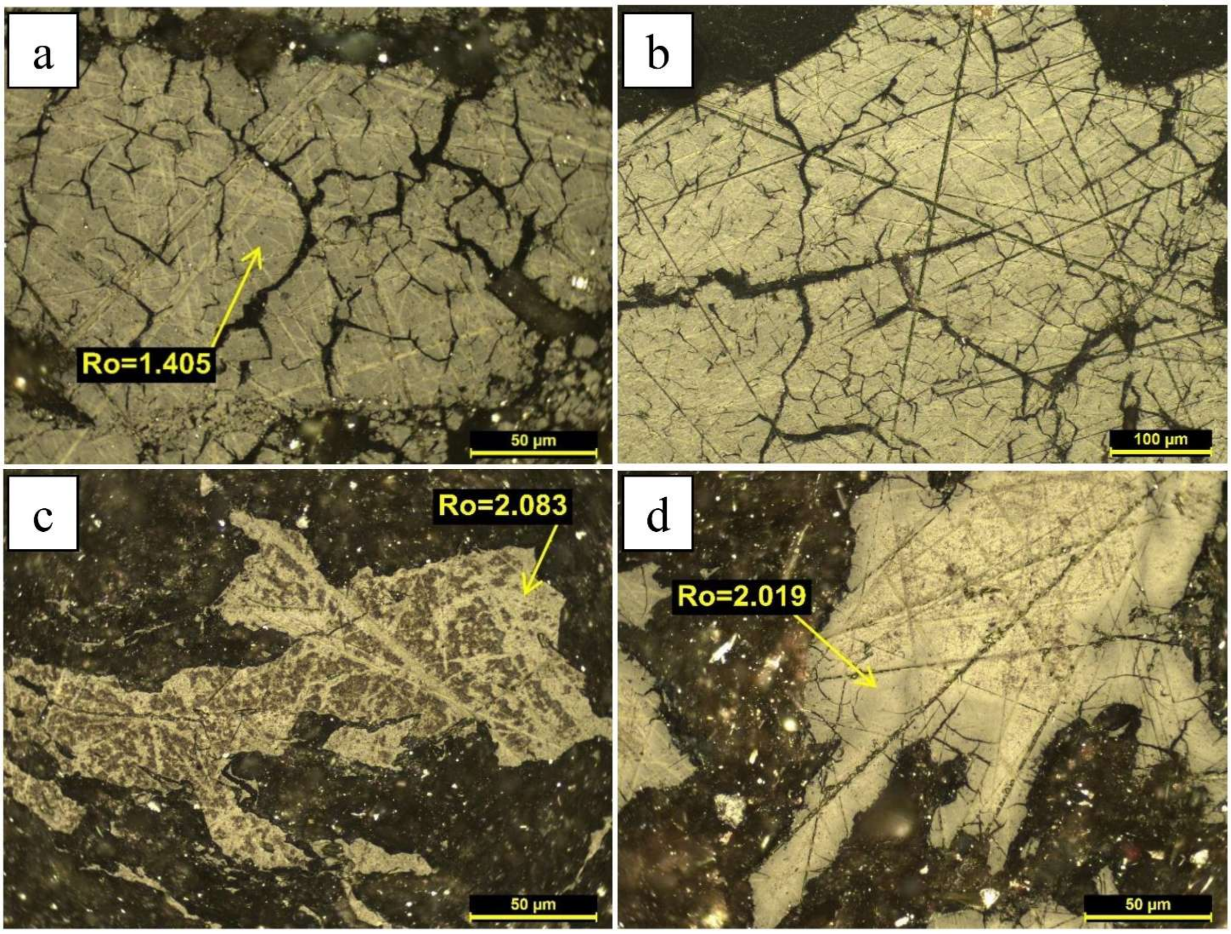

Figure 10. Microscope images (reflected light) of solid bitumen in the Bazeh-Howz Formation. A, B) Large pieces of solid bitumen, indicating the high volume of reworked organic material (sample 16). C, D) Solid bitumen with high vitrinite reflectance, indicating higher maturity (sample 17).

Table 2. Results of vitrinite reflection of solid bitumen in samples of the Bazeh-Howz Formation.

Sample	Solid Bitumen Reflectance%			
	Number of Reading	Min	Max	Mean
2	27	1.09	1.81	1.48
3	30	1.33	1.75	1.57
5	20	1.02	1.46	1.12
6	37	1.03	1.63	1.3
8	15	1.31	1.79	1.56
10	26	1.36	1.83	1.6
11	26	1.39	1.78	1.55
12	42	1.21	1.79	1.43
13	27	1.33	1.87	1.61

14	14	1.45	2.03	1.77
15	14	1.4	1.85	1.63
16	52	1.26	1.88	1.56
17	32	1.43	2.24	1.74
18	34	1.28	1.68	1.49
23	-	No Data		
24	-	No Data		
25	-	No Data		

6. Conclusions

- Rock-Eval analysis of 17 shale samples from the Bazeh-Howz Formation in the Binalud Mountains yielded total organic carbon (TOC) values of 0.18 to 26.3%, with an average value of 3.09%. which indicates a high TOC.
- Free hydrocarbons and residual potential are very low to zero, indicating minimal residual production potential in the formation.
- Due to the very low value of S2 (<0.2), it is not possible to interpret the maturity of the samples based on the maximum temperature (Tmax).
- Almost all the organic carbon in the samples is residual carbon (RC), and pyrolysis carbon (PC) is not present. Based on the parameters oxygen index and hydrogen index, the organic matter is unstable and migratory, with minimal primary organic matter generated at the time of deposition.
- Standard organic macerals were not observed during microscope analysis, and the organic matter is solid bitumen and pyrobitumen, commonly of late origin, as well as pyrobitumen type in intergranular space, in fractures, and along lamination planes. The organic material entered the rock as paraffinic hydrocarbons that were converted into solid bitumen due to thermal fracture, leaving non-productive residues that were eventually converted to pyrobitumen. This inference is supported by the results of the Rock-Eval analysis and the high percentage of residual carbon.

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