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YIELD APPRAISAL OF THE CRETACEOUS-PALEOGENE OIL SHALES OF THE QUSEIR-SAFAGA AREA, RED SEA, EGYPT

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ABSTRACT

Oil shales are source rocks of low to moderate maturity, which are considered as a potential deposit for future hydrocarbon generation. In Egypt, the epicontinental Cretaceous-Paleogene sequence is a part of a Middle East belt of oil shale deposits. The belt, in the Egyptian territories, is trending east-west and extending from the Quseir-Safaga district along the Red Sea to the Kharga-Dakhla oases in the Western Desert, passing through the Nile Valley between Idfu and Qena. These oil shales are constrained to the Duwi-Dakhla formations in ascending order. In this study, the Fischer assay technique is used to get oil yield for 37 selected oil shale core samples from seven localities along the Red Sea to come up with an evaluation. The average oil yield values of Abu Shegela, M. Rabah, Sodmine, and Um El-Huweitat areas are acceptable from the economic and processing points of view for the exploitation step. Raw-mix designs are necessary for high-yield and low-medium-yield strata for future exploitation of these shales. We propose the In-Capsule Retorting method to extract oil from the study oil shales, because of its inexpensive and environment-friendly characters.

Keywords: Oil shale; Cretaceous-Paleogene; Oil yield; Fischer Assay; Red Sea; Egypt

INTRODUCTION

Oil shales are source rocks of low to moderate maturity standing as potential deposits for hydrocarbon generation with the aid of retorting techniques (e.g., Ryan et al., 2010). The major part of the organic matter fraction in these sediments is the kerogen, which could be fractionated to yield oil, gas, and residual carbon through a pyrolysis process (e.g., Ellis, 2011).

In Egypt, as well as other countries in the Middle East, oil shale deposits of good quality have widespread occurrences (Dyni, 2003). The Cretaceous-Paleogene sequence of Egypt is a part of the oil shale belt in North Africa and the Dead Sea areas. This belt is trending east-west in Egypt from the Quseir-Safaga district along the Red Sea to the Kharga-Dakhla landscape in the Western Desert. They are excellent source rock, which produced laterally extensive oil fields in other countries (Robinson and Engel, 1993). However, these rocks in central Egypt have not undergone adequate catagenesis, and consequently massive immature to marginally mature oil shale sequence exists (El-Shafeiy et al., 2014; 2016).

Oil yield is a crucial parameter to determine the feasibility of an oil shale deposit to be exploited as a source of synthetic oil production via a retorting process (Jaber et al., 2011). Several sedimentological, bio-stratigraphic, organic geochemical, and mineralogical studies have been carried out on the Egyptian oil shale (e.g., Tröger, 1984; Ganz et al., 1987; Hendriks et al., 1987; Glenn and Arthur, 1990; El-Kammar 1993; Tantawy et al., 2001; Baioumy and Ismaeil, 2010; El-Shafeiy, 2012; and others). On the other hand, insufficient data are available on their oil yield potential (e.g., Darwish, 1984; Moustafa et al., 2014; Shaker et al., 2014; Al-Alla and Nassef, 2015). However, these studies were conducted based on some samples collected from the Duwi Formation that were dumped out of the phosphate mines several decades ago and subjected to subaerial exposure. Nevertheless, the present work investigates the oil yield from the Fischer assay technique for cored oil shale samples collected from both the Duwi and Dakhla formations at several localities along the Red Sea coast of Egypt. The results presented here are part of a project on the evaluation of Cretaceous-Paleogene oil shales in Egypt.

Geologic Setting

The late Cretaceous transgression developed a broad continental shelf in North Africa (Baioumy and Tada, 2005). Widespread phosphate-rich sediment sequences, favored by upwelling and high productivity, existed during the late Cretaceous along the south-eastern margins of the Tethys associated with the Syrian Arc system (Ashckenazi-Polivoda et al., 2011; Schneider-Mor et al., 2012). The Cretaceous-Paleogene black shale deposits of Egypt are belonging to the Duwi and Dakhla formations in ascending order. Their depositional environments were mainly inner (Duwi Formation) to middle and rarely outer (Dakhla Formation) shelf system (e.g., Tantawy et al., 2001; El-Azabi and Farouk, 2011). The Duwi Formation is composed mainly of phosphates, which is accompanied by organic-rich shales, glauconites, oyster limestone, cherts, and siltstones (e.g., Germann et al., 1985; Abed and Al-Agha, 1989; El-Kammar 1993; and references therein). The existence of organic-rich strata indicates a period of high primary productivity that favored the preservation of organic matter (Glenn and Arthur, 1990). On the other hand, the Dakhla Formation is composed mainly of foraminifera-rich dark shales and marl with limestone and rare mudstone intercalations (e.g., El-Azabi and Farouk, 2011).

The deposition of the Duwi Formation represents the initial stage of the late Cretaceous marine transgression in Egypt. Baioumy and Tada (2005) subdivided the Duwi Formation in the Red Sea area into lower, middle, upper, and uppermost members. The Dakhla Formation; however, is subdivided into Hamama and Beida members in an ascending order in the Red Sea area according to Abdel Razik (1972), Awad et al. (1992), and Zalat et al. (2008). These members are separated by an intraformational unconformity that represents the Cretaceous-Paleogene boundary. The Dakhla Formation is unconformably overlain by chalky limestone of the late Paleocene Tarawan Formation (Awad and Ghobrial, 1965).

As in other oil shale deposits occurring elsewhere, the Cretaceous-Paleocene oil shale of Egypt are consisting of a relatively small proportion of organic matter, whereas most of the rock constituents are inorganic materials. Based on their organic carbon content, these oil shales meet the accepted standards of source rock with good to excellent hydrocarbon generative potential, which are of low to moderate maturity with organic matter belong to kerogen Type I (algal) and II (mixed marine) (e.g., El-Kammar, 1993; Robinson and Engel, 1993; El-Shafeiy et al., 2012; El-Kammar, 2014; El-Shafeiy et al., 2014; El-Kammar, 2015; El-Shafeiy, 2017). The immaturity is constrained by a low T_{max} (mainly <435 ºC) and, therefore, these oil shales can be considered as a potential oil to oil-gas prone source rocks. The oil shales in the Red Sea area can be considered as marls to argillaceous limestone with a significant degree of pyritization, sulfurization, and a limited degree of dolomitization (El-Aref and Darwish, 1987; El-Kammar, 1993; El-Shafeiy et al., 2012; El-Shafeiy et al., 2016).

MATERIAL AND METHOD

Sampling

Thirty-seven organic-rich samples were collected at different depths from seven cores drilled by the Egyptian Mineral Resources Authority (EMRA) and sponsored by DanaGas© Egypt. The drilling sites are in the Eastern Desert of Egypt including; Abu Shegela, Yonous, Zog El-Bohar, Sodmine, Um El-Huweitat, Mohamed Rabah, and Wassief (Fig. 1). The selected oil shale samples are generally of high organic carbon contents but cover different organic carbon quality.

Fisher Assay analysis

About 100 grams of the ground oil shale samples were dried at 70 °C for 24 hours. After cooling to the room temperature in a desiccator, the pulverized sample is then transferred to the retorter. Within 60 minutes, the temperature rises to reach 520 °C. The organic gases resulted from the thermal destruction of the kerogen can be converted into a liquid by the aid of the cooling unit. The weight of the burnt spent sample is recorded after cooling down to room temperature. The water can be separated from the liquid organic matter after the addition of 100 ml of xylene. Water is then heated up the thereafter condensed and separated from the oil. Accordingly, the weight of oil and water can be then recorded. Additionally, the weight of volatile loss can be determined.

RESULTS AND DISCUSSION

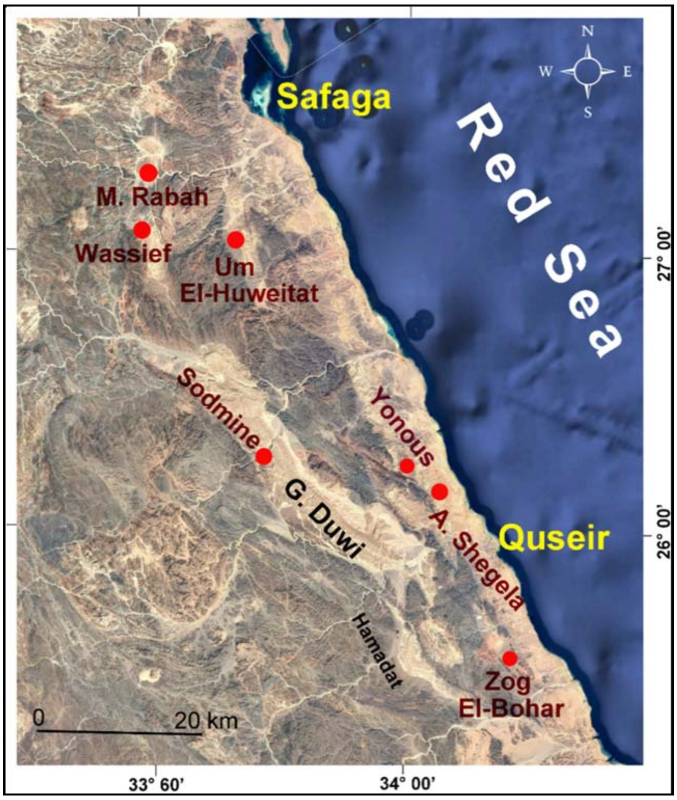

Fig. 1: A Google Earth image for the location of the studied boreholes (red circles) around the Quseir and Safaga cities and their location names (in brown).

Fischer Assay yield

The oil yield of the studied Quseir- Safaga oil shale samples (Table 1) is found to range from 0.2% (2.3 l/ton, Wassief) to 10.4% (109.5 l/ton, M. Rabah) with an average of 3.5 wt% (i.e., approximately 35 liters of shale oil/ton of raw oil shale). The density of the yielded oil indicates mainly a heavy oil could be generated; however, the results of Moustafa et al. (2014) referred to the shale oil as a medium to heavy crude oil. The samples of M. Rabah borehole have the highest oil yields (average 4.5% or ~ 45 l/ton), followed by Sodmine and Um El-Huweitat (average 3.8% or ~ 38 l/ton, for both) compared to the other areas. When gas loss with an average of about 2.6% is added, this will bring the potential total yield of useful energy products to become ~ 6% or ~ 60 l/ton. A worthy productive deposit could be expected to deliver at least 37.8 l/ton of shale oil (Dyni, 2003; Speight, 2012). Thus, the oil yield averages of the localities Sodmine, Abu Shegela, M. Rabah, and Um El-Huweitat are above the indicated cut-off value (Table 1). These values are close to that previously reported by Darwish (1984) on the Nakheil black shales.

The obtained data of the oil yield are significantly higher than those of Shaker et al. (2014), particularly for Abu Shegela and Um El-Huweitat areas. These differences can be attributed as either due to the effect of subaerial exposure on their samples, the difference in sampling strategies, and stratigraphic level, or less probably due to the difference in the experimental procedures used.

The gas loss % shows a direct relationship with the oil yield (Fig. 2) with a correlation coefficient of 0.9 (Table 2). It is worth to mention that the gas loss % in the Dakhla Formation of Quseir area shows slightly higher values than that for the Duwi Formation (Fig. 2), which is mostly linked to the quality of the organic material. Here, it can be revealed that the Fischer assay technique does not measure the total amount of energy of an oil shale sample because other gases can have significant energy content.

Therefore, this technique can be used as a reference to assess approximately the energy potential of an oil shale reserve (e.g., Speight, 2012).

Table 1: The studied oil shale samples, their stratigraphic position, and their Fisher assay.

Well	Depth (m)	Fm.	Age	Oil (L/ton)	Water (L/ton)	Oil density (g/cm^3)	Oil yield wt%	Gas-plus-loss wt%	Water yield wt%	Spent Shale wt%
Abu Shegela	46	Dakhla	Paleocene	19.06	36.24	0.95	1.81	2.20	3.62	91.87
	47			7.48	18.37	0.95	0.71	1.06	1.84	96.29
	48			18.99	21.92	0.96	1.82	1.87	2.19	93.82
	49			49.40	30.16	0.95	4.70	3.20	3.02	88.88
	50			81.07	36.54	0.95	7.73	4.23	3.65	84.18
	51			32.04	22.33	0.95	3.05	2.41	2.23	92.21
	67		Maastrichtian	21.57	26.52	0.95	2.04	1.99	2.65	92.82
	70			24.99	27.00	0.95	2.38	2.57	2.70	91.35
	98			9.66	52.16	0.95	0.92	1.83	5.21	91.94
Average (n=9)				29.36	30.14	0.95	2.80	2.37	3.01	91.48
Yonous	80	Duwi	Maastrichtian	61.49	42.58	0.91	5.58	3.22	4.26	86.94
Zog El-Bohar	59	Dakhla	Paleocene	31.75	59.63	0.95	3.01	2.99	5.96	87.84
	115			16.00	39.36	0.95	1.52	3.81	3.94	90.23
Average (n=2)				23.88	49.50	0.95	2.26	3.40	4.95	89.03
Sodmine	110	Dakhla	Paleocene	70.03	48.45	0.94	6.59	4.40	4.84	83.17
	111			36.83	70.20	0.93	3.42	3.02	7.02	86.43
	112			14.72	60.39	0.93	1.37	2.57	6.04	89.52
Average (n=3)				40.53	59.68	0.93	3.79	3.33	5.97	86.37
Um El-Huweitat	42	Dakhla	Paleocene	80.09	45.92	0.95	7.57	4.17	4.59	83.16
	94		Maastrichtian	52.73	25.75	0.95	5.01	2.95	2.57	88.97
	97	Duwi	Maastrichtian	40.71	24.20	0.95	3.87	2.49	2.42	90.72
	106			15.73	22.76	0.96	1.52	1.64	2.28	94.56
	110			23.76	12.35	0.96	2.27	1.62	1.24	93.87
	111			75.91	25.00	0.96	7.25	3.99	2.50	85.26
	112			29.50	31.88	0.95	2.81	2.33	3.19	91.18
	114			52.34	19.84	0.95	5.00	2.76	1.98	89.26
	115			41.08	15.03	0.96	3.93	2.81	1.50	90.76
	126			20.14	19.25	0.95	1.91	1.47	1.92	94.19
	127			21.00	25.46	0.95	1.99	1.85	2.55	93.61
	128			38.26	26.82	0.95	3.63	2.50	2.68	91.08
	129			31.16	93.80	0.92	2.87	2.63	9.38	85.11
Average (n=13)				40.19	29.85	0.95	3.82	2.55	2.98	90.13
M. Rabah	86	Duwi	Maastrichtian	109.56	23.15	0.95	10.40	4.51	2.31	81.77
	87			43.60	25.34	0.95	4.14	2.19	2.53	91.13
	88			43.64	32.04	0.96	4.17	2.81	3.20	89.72
	89			38.01	31.45	0.96	3.63	2.67	3.14	90.53
	90			38.31	35.49	0.95	3.65	2.74	3.55	89.57
	91			24.76	30.32	0.95	2.35	2.00	3.03	91.61
	92			33.30	33.95	0.95	3.16	2.17	3.39	90.77
Average (n=7)				47.31	30.25	0.95	4.50	2.73	3.02	89.30
Wassief	91	Dakhla	Paleocene	2.32	73.16	0.95	0.22	0.91	7.31	91.55
	163	Duwi	Maastrichtian	30.93	27.46	0.95	2.95	2.21	2.75	91.60
	166			37.73	30.95	0.95	3.59	2.33	3.09	89.98
Average (n=3)				23.66	43.86	0.95	2.25	1.82	4.38	91.05
MAXIMUM				109.56	93.80	0.96	10.40	4.51	9.38	96.29
MINIMUM				2.32	12.35	0.91	0.22	0.91	1.24	81.77
AVERAGE (n=37)				37.36	34.82	0.95	3.54	2.61	3.48	89.93

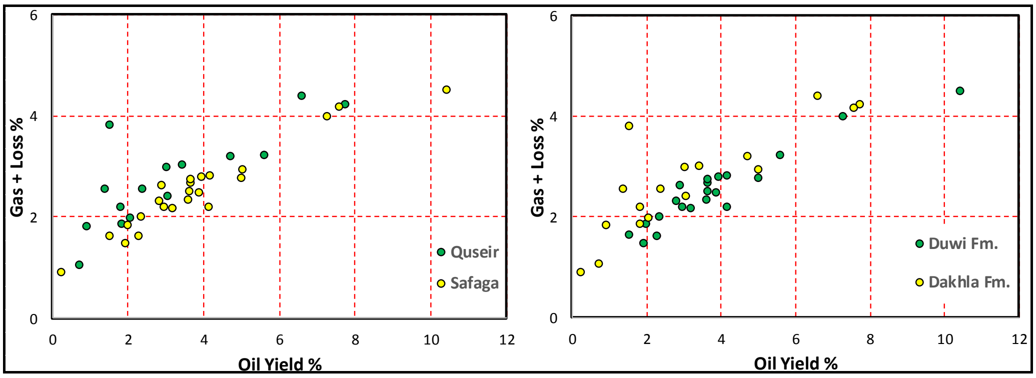

Fig. 2: A cross plot for the Oil Yield (%) versus the Gas+Loss (%) data from the Fischer Assay of the studied Quseir-Safaga samples.

Table 2: A correlation matrix for Fischer assay data of the studied oil shale samples. The bold numbers indicate significant correlations of the investigated variables.

	Oil density (g/cm^3)	Moisture %	Oil yield %	Gas-plus-loss %	Water yield %	Spent Shale %	Oil (L/ton)	Water (L/ton)
Oil density* g/cm3	1.00	-0.69	-0.02	-0.11	-0.68	0.36	-0.05	-0.68
Moisture %	-0.69	1.00	-0.09	0.13	0.98	-0.46	-0.08	0.98
oil yield wt.%	-0.02	-0.09	1.00	0.91	-0.11	-0.83	1.00	-0.11
Gas-plus-loss %	-0.11	0.13	**0.91**	1.00	0.13	-0.92	0.91	0.13
Water yield %	-0.68	0.98	-0.11	0.13	1.00	-0.45	-0.10	1.00
Spent Shale %	0.36	-0.46	**-0.83**	-0.92	-0.45	1.00	-0.83	-0.45
oil (L / ton)	-0.05	-0.08	1.00	0.91	-0.10	-0.83	1.00	-0.10
Water (L / ton)	-0.68	0.98	-0.11	0.13	1.00	-0.45	-0.10	1.00

The average content of spent shale in the analyzed samples ranges between 81.7% and 92.2% by weight with an average of 89.8%, as shown in Table 1. Spent shale is the residual ash of the pyrolysis process, which is considered here mainly as a high carbonate-base spent shale (e.g., Jaber et al., 2011). The spent shale content is inversely related to the oil (Fig. 3) and gas yields with R^2 of -0.8 and -0.9, respectively (Table 2). However, it does not show a special spatial or temporal distribution (Fig. 3). The final resulting ash may be further utilized as a supply for cement production, building materials, road establishment, enhancing the strength of civil-engineering structures, a filler in polymeric compounds (e.g., PVCs), and heavy metals extraction such as redox-sensitive metals (e.g., U, V, Mo, etc.). Since the mineral fraction of the oil shale in the Quseir-Safaga area is essentially carbonate, the retorting temperature should not exceed 700 °C, to avoid the major loss of energy due to the endothermic decarbonation reaction (El-Kammar, 2017).

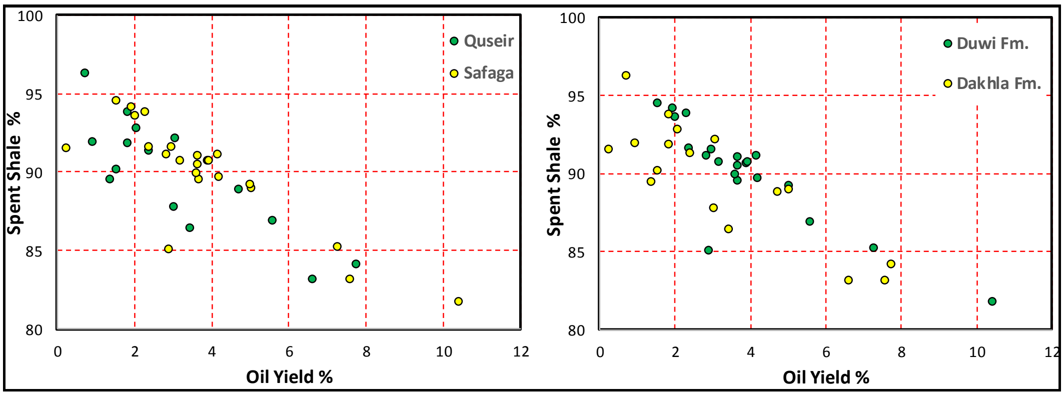

Fig. 3: A cross plot for the Oil Yield (%) versus the Spent Shale (%) data from the Fischer Assay of the studied Quseir-Safaga samples.

It is known that high-grade oil shale losses a big part of its energy upon extraction when the moisture content is high. The relatively low moisture content of the studied samples (about 3.4% on average; Table

1) is a very encouraging technical character. Consequently, the energy loss because of the endothermic dehydration reaction is expected to be very low. The lowest water yield was observed in the samples from M. Rabah, Um El-Huweitat, and Abu Shegela samples (Table 1); however, it is not as good as the oil shale from Jordan for example (1.4%; Alnawafleh and Fraige, 2015). The results of this study are comparable with those reported by Shaker et al. (2014), using different sampling strategies, stratigraphic horizons, and locations for these oil shale deposits. However, the study oil shale has a relatively lower-yield of shale oil and gas, compared to other deposits in Jordan and the Dead Sea area, US Green River, and the Estonia (up to 250 l/ton shale oil yield), (e.g., Shirav (Schwartz) and Ginzburg, 1983; Jaber et al., 2011; Speight, 2012; Alnawafleh and Fraige, 2015).

Future Prospect in Egypt

Most estimates of worldwide shale oil resources are based on data for Fischer assay. The present study recommends an accurate oil-in-place estimation for Quseir-Safaga oil shales, based on a very large database of Fischer Assay results. We provide optimistic data for some prolific stratigraphic intervals in the Quseir-Safaga area, whereas more investigations are in need. The expected high-grade oil shale is confined to the strata belonging to the uppermost Duwi and lowermost Dakhla formations (El-Kammar, 2014; El-Shafeiy et al., 2014; 2016). It is important to figure out the areas containing high grade, shallow, and accessible oil shale-bearing strata. However, the structure disturbance due to the Red Sea rifting and earlier tectonics works against cost-efficient exploitation (El-Kammar, 2017). This difficulty will not last for long because of the rapid enhancement of the unconventional mining operation technologies to exploit the oil shale from tilted blocks at a reasonable cost (e.g., El-Kammar, 2017).

The production of shale oil through the modern and cheap technology “capsule design” or EcoShale In-Capsule (e.g., Speight, 2012), which is less expensive than fracking and more environment-friendly, should be considered. It integrates surface mining with a relatively low-temperature cooking method in an impoundment that is designed in the space produced from the shale mining excavation (cf. Speight, 2012). The capsule is heated using pipes circulating hot gases derived from burning natural gas or can be its own produced gases (e.g., Patten, 2010; Bolonkin et al., 2014; Boak, 2014). The filled capsule with oil shale is capped with impermeable material and soils (e.g., Zendehboudi and Bahadori, 2017). The capsule can be heated up faster than the *in-situ* process (Boak, 2014), with the assumption that a capsule could be dimensioned 380 x 150 x 50 meters = 2850000 m^3. The assumed average density of oil shale is about 2.7 g/cm^3 (Fertl, 1976), therefore, the total mass of the needed oil shale to completely fill the capsule is about 7695 tons. A rough estimation of about 270 thousand liters (1698 bbl.) of shale oil and 200 thousand liters of gas would be produced as end products for one run of 12 months.

CONCLUSIONS

In Egypt, we should find out an environment-friendly utilization method of oil shale as a part of our future energy approach. In this study, the oil shale samples were analyzed to determine their hydrocarbon yield using the Fischer assay technique. The oil shale of the Quseir area has a better yield compared to that of Safaga. However, the overall average of shale oil yield is around 37.5 liters/ton, which is above the cut-off value for the shale oil production. The average oil yield values of some localities (e.g., Abu Shegela, M. Rabah, Sodmine, and Um El-Huweitat) are considered acceptable from the economic and processing point of view to satisfy a part of the local growing energy demands in Egypt. On the other hand, the relatively high S% could be a problem and a major source of pollution if not considered when designing the oil shale processing system. The present study does not give a complete picture of the shale oil yield results of the Cretaceous-Paleogene shales, which could not be easily achieved using such a limited amount of data. The study provides pilot data for those interested in aspects of the oil shales in Egypt.

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Yield appraisal of the Cretaceous–Paleogene oil shales

تقييم المحتوى الزيتى للطفلة الزيتية لصخور العصر الطباشيري العلوى–الباليوجين في منطقة البحر الأحمر في مصر

معتز الشافعي

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الخلاصة

ان صخور الطفلة الزيتية هي صخور مصدرية متوسطة الى منخفضة النضج ، والتي يمكن أن تكون مصدر محتمل من مصادر الطاقة فى المستقبل . فى مصر، تمثل صخور تتابع العصر الطباشيري العلوى–الباليوجين جزء من حزام الطفلة الزيتية فى منطقة الشرق الأوسط . يقع هذا الحزام فى الاراضى المصرية متجها من الشرق الى الغرب ، ويمتد من منطقة سفاجا–القصير على طول ساحل البحر الأحمر إلى الواحات الخارجة والداخلة في الصحراء الغربية، عبر وادي النيل بين منطقتى إدفو وقنا. هذه الصخور الزيتية منحصرة غالبا فى تتابع تصاعدى من مكونى الضوى والداخلة. في هذه الدراسة ، تم تقييم محتوى الزيت عن طريق تحليل فيشر Fischer assay لسبعة وثلاثون عينة اختيرت من العينات الاسطوانية اللبية من سبع أبار فى منطقتى سفاجا والقصير . إن متوسط محتوى الزيت في مناطق أبو شيجيلة ، محمد رباح ، صودمين ، وأم الحويطات مقبول من وجهتى النظر الاقتصادية وايضا المعالجة التعدينية وقابلة للاستغلال. ان تصميم مزيج نسب المواد الخام ضرورى وحيوى بين الطبقات ذات المحتوى العالى والطبقات ذات المحتوى المتوسط والمنخفض للتطوير والاستخدام الأمثل لصخور الطفلة الزيتية في المستقبل. وفي هذا الصدد، فإن الدراسة الحالية تقترح طريقة كبسولة التقطير In–Capsule Retorting لاستخراج الزيت من الطفلة الزيتية لانها غير مكلفة وصديقة للبيئة .

الكلمات الدالة: صخور الطفلة الزيتية؛ الطباشيرى العلوى–الباليوجين ؛ المحتوى الزيتى؛ تحليل فيشر؛ البحر الأحمر؛ مصر.