

CHEMICAL COMPOSITION OF THE MINERAL MATTER OF THE ATTARAT UM GHUDRAN OIL SHALE, CENTRAL JORDAN

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Abstract. *The concession area of the Jordan Oil Shale Energy Co (JOSE) is located in the southern border zone of the Attarat Um Ghudran deposit, next to the Wadi Maghara deposit, both consisting of marinite type oil shale (OS). These deposits of the Upper Cretaceous to Lower Paleogene Muwaqqar Chalk-Marl Formation form a huge north-southward elongated oil shale basin in Central Jordan, with resources over 55 billion tons. JOSE has drilled a regular grid of boreholes with a full coring of the up to 90 m thick OS seam and its lower and upper contact layers. Visually, the OS unit is a rather homogenous dark-colored (grey, black, brownish grey) succession of finely bedded (laminated) kerogen-bearing carbonate rocks that has been in earlier papers described as a uniform lithological unit. The aim of the geological and lithological studies of the JOSE exploration area was (i) to investigate the vertical variation of OS composition and, if present, to define layers within the OS unit, and (ii) to identify lithological varieties and chemical composition of OS present in different layers.*

On the basis of field evidence, downhole gamma-logging, chemical analyses and other criteria, an original detailed scheme of the layered structure of oil shale and barren rocks was introduced. A total of eight OS layers (indexed as A, B1, B2, C, D, E1, E2, E3) and at least four barren dolomitic limestone interlayers were distinguished. The present publication is dedicated to the chemical study of the layers and the total OS seam. A representative gapless collection of 632 conventional core samples from 12 cores serves as the base for the comparative study of the layers. Two main (SiO_2 , CaO) and two subordinate chemical (Al_2O_3 and P_2O_5) components of the mineral matter (MM), and loss on ignition (LOI 500 °C) approximately reflecting the content of organic matter (OM), are the basic variables discussed. Contents of SiO_2 and CaO always show negative correlation,

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whereas local enrichment with Al_2O_3 and P_2O_5 occurs in certain interbeds. OM content in samples has no strong correlation with mineral matter abundances. The eight distinguished OS layers comprise both those strongly enriched in CaO, or oppositely in SiO_2 . The layers differ in rate of internal heterogeneity reflected in variation of standard deviation values. With rare exceptions, the barren limestone interlayers are dolomitized, strongly enriched with MgO and depleted of CaO. The database on the distribution of mineral compounds and trace elements serves for the 3-D block modelling of the deposit composition. However, further data analysis is required for the understanding of lateral changes of the layers' mineral composition, and geological and geochemical structure.

Keywords: oil shale, mineral matter, chemical composition, Maastrichtian, Attarat Um Ghudran deposit, Central Jordan.

1. Introduction

Cretaceous to Paleogene sedimentary sequences of the Afro-Arabian shelf sea contain vast volumes of organic matter [1, 2]. Abed and Amireh [3] have summarized the early (1959–1980) publications on the occurrence of oil shale (OS) in Jordan. The authors admitted that at this time oil shale was considered as a major future energy resource in Jordan devoid of oil. During the following more than 30 years a number of geological explorations resulted in the discovery of many new deposits (Fig. 1), and development of oil shale utilization technologies has continued since then [4–6]. A significant recent practical achievement is that after the geological survey, mining studies and engineering design efforts by the Jordanian Oil Shale Energy Co (JOSE), construction of an electric power plant is presently in an active preparation stage. It will be fueled with oil shale from the Attarat Um Ghudran deposit. The geological survey materials on the chemical composition of oil shale layers of the area have been used for the present publication.

Jordan has huge resources of oil shale [5–7], especially if calculated per unit of territory. When compared to many other thick oil shale suites [7], it is impressive that the whole thickness of the main OS unit, belonging to the Muwaqqar Chalk-Marl Formation (MCM), is often of considerably high organic matter (OM) content. In Central Jordan, OS lies near the surface with a thin overburden and shows a higher percentage of OM compared to other localities [8]. The richest oil shale-grade deposits are of the Late Cretaceous Maastrichtian age, in which OM is present as kerogen [3]. It originates from fossilized phytoplankton and zooplankton that flourished and deposited on the southern continental shelf of the Tethys Ocean [8]. Kerogen is the minor component in OS (from 0 to 36 wt%). According to the classification by Hutton [10], the largest Jordanian oil shale deposits belong to the family of marinite oil shales [5, 11]. The dominant minerals of

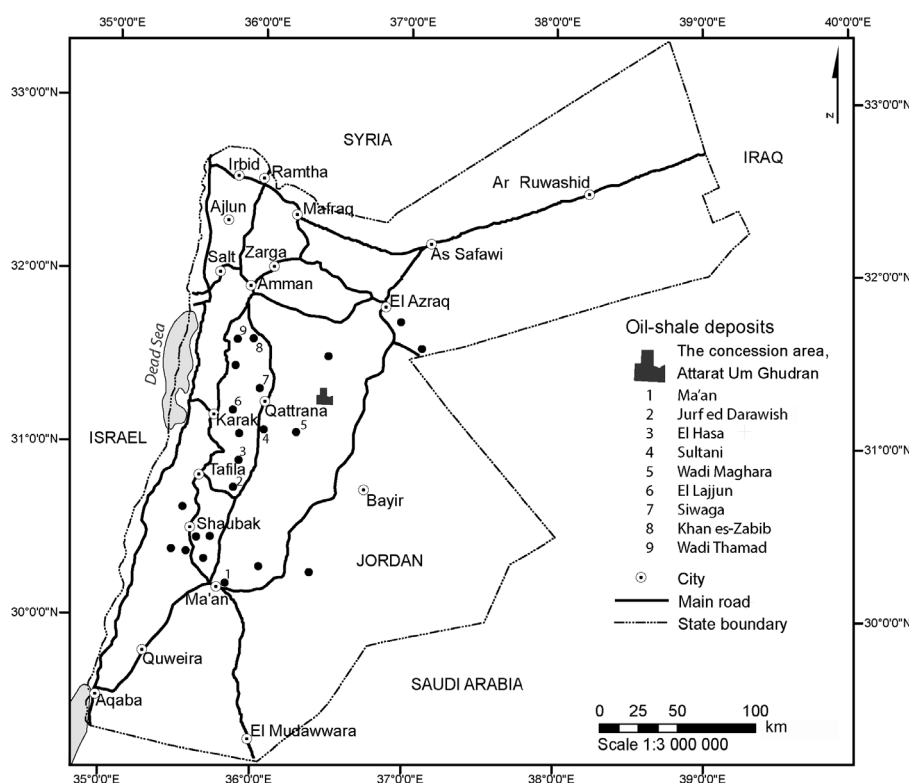


Fig. 1. Location of the Attarat Um Ghudran deposit comprising the concession area and other deposits in Jordan. Modified after [7].

Jordanian OS are calcite (calcium carbonate, from 31% to a maximum of 90%) and quartz (free silica, 0–37%), and occasionally minor mineral components, such as clay minerals, apatite (carbonate-flour apatite ($\text{Ca}_3(\text{PO}_4)_2$ $\text{Ca}_2\text{PO}_4(\text{CO}_3, \text{F})$) and pyrite (FeS_2) [8, 9].

The Attarat Um Ghudran (AUG) and Wadi Maghara (WM) oil shale deposits (Fig. 1) form a uniform, north-south striking elongated Attarat Um Ghudran-Wadi Maghara basin that covers an area over 1000 km² in Central Jordan with total geological resources over 55 billion tons of OS [5, 6].

Previous studies [3–6, 8, 11, 13] have shown certain differences in the average composition of mineral matter within and between different deposits of Jordan. Also the Maastrichtian OS of Southern Syria is of similar variable composition [12]. In more detail, variation in average mineral contents between different core intervals with different oil contents in the El Lajjun deposit have been demonstrated [13, 5, 6]. Compared with compositions of many other oil shales of the world [7], including the Estonian Paleozoic kukersite [14], and graptolite argillite [15–18], the Near East oil shales have specifically high contents of carbonate (calcite), silica (quartz, in places with

admixture of tridymite and cristobalite – unpublished data by the authors) and sulfur [8]. During 2007–2013, JOSE explored a concession area of about 73 km² situated in the southern border zone of AUG, next to WM. It is located about 40 km east of the town of Qattrana.

When starting the exploration, analysis of the historical research and exploration data demonstrated that, first, the Maastrichtian oil shale of Jordan and of its surroundings belongs to a principally uniform highly carbonaceous type of marinite, and second, a certain variability of its mineral composition occurs. However, the internal changeable mineral and chemical composition of the OS suite in Jordan including the exploration area has remained poorly understood as yet.

JOSE started geological exploration in Central Jordan in 2006. Through the previous geological exploration, the organic-rich rocks of the OS seam were usually described just as bituminous (or kerogen-bearing or OM-bearing) chalky marls or marls with limestone interlayers. In practice, it overshadowed the variability of OS mineral and chemical composition. Herein the study is focused on mineral components while the content of organic matter is determined using loss on ignition (LOI 500 °C) data only. Planning technologies for OS use requires a more precise definition and classification of raw material composition, structure and texture. Oil shales with different mineral/chemical composition exhibit different properties in the thermal processing. This is especially revealed when the ENEFIT technologies that are focused on the ample use of OM potential in OS are applied [19]. Herein, in particular XRD and XRF data on concentrations of mineral components are used. Evidence on the OM content is restricted to LOI 500 °C data.

The aim of the geological and lithological studies carried out in the JOSE exploration area was (i) to investigate the vertical variation of OS composition and, if present, to define layers within the OS unit, and (ii) to identify lithological varieties and chemical composition of OS present in different layers. Layered structure is characteristic of many oil shale deposits and basins. As an example, the layering-focused model of the Baltic Kukersite basin well serves for the demonstration of the spread of the oil shale lateral distribution and variation of quantitative and qualitative parameters [20, 21].

During the field campaign in 2008–2013, JOSE drilled a regular grid of boreholes with a full coring of the up to 90 m thick OS seam and of its lower and upper contact layers that were neither targeted nor reached in previous studies. From the beginning of exploration, a practical task was to create an easily applicable stratification scheme of the OS suite that would serve for the process of borehole logging and sampling. Using a variety of field and laboratory techniques, in the total succession of the oil shale unit eight OS layers (indexed as A, B1, B2, C, D, E1, E2, E3) with four dolomitic limestone interlayers were distinguished. Step by step, the validity of it within the entire exploration area was verified.

In order to understand the nature of both vertical and lateral compositional changes of individual layers as well as of natural typical and specific varieties of oil shale for their classification, further integrated petrographic, mineralogical and geochemical (including trace elements) studies are underway. The dataset obtained on the downhole gamma-logging, as well as micropaleontological and other studies enable further confirmation of the credibility of the detailed stratification scheme of the Attarat Um Ghudran deposit. The introductory interpretation of the large massif of analytical data in order to outline geochemical patterns of the OS seam and its individual layers in the JOSE concession area is the subject of the present writing.

2. Materials and methods

The paper presents results of the study of original drill core material carried out in the JOSE concession area. Drill cores obtained from owners of the previous oil shale projects conducted in the concession area were also examined and analyzed. JOSE is the owner of drill cores and detailed field and laboratory study data. A drilling grid of over 150 core and percussion boreholes was created. In order to establish and study the chemical layered structure of the OS seam and certain lithologies, chemical analyses of 1284 gapless core samples from 39 boreholes were completed. A most representative collection of 632 conventional core samples from 12 gapless sampled cores (with usual full core recovery) was chosen for the following comparative chemical study of separate layers. In the process of sampling and sample preparation, half of the bisected core material was subjected to coarse crushing into a fraction below 2 mm, and then split by separating a 1 kg homogenized portion to be forwarded to laboratories. Part of this 1 kg homogenized sample was fine-crushed and pulverized for the laboratory study of MM using mineralogical and geochemical analyses. Throughout the study, exploration quality control procedures were followed.

A database for the systematic studies of vertical and lateral variations of the composition of separate OS layers and the entire OS seam was created. It equally characterizes every defined OS layer of the OS seam from bottom to top and takes into account the internal variability of subunits thicker than 0.5 m within each layer. Barren interlayers have been omitted here. For the study of petrographic and chemical differences between the layers and spatial chemical variability within layers lithology-dependent sampling techniques were adopted. Visually, the OS unit of the Muwaqqar Chalk-Marl Formation is dominantly a rather unvaried dark-colored (dark grey to brownish grey) succession of finely bedded (laminated) very finely grained kerogen-bearing, highly carbonate rocks. Detailed visual observations as well as XRD and SEM-EDS studies revealed that the richest OS is actually composed of the dominating groundmass of about $< 5 \mu\text{m}$ carbonate and siliceous mud particles mixed with the unstructured OM – kerogen, and a

small amount of usually < 0.1 mm grains of carbonate and rare phosphate skeletal debris and random microfossils. Depending on the share and distribution of groundmass and grains, two main types of OS structure and texture dominate: (i) the most common thinly bedded (laminated) to almost massive mudstone composed of variably calcareous to siliceous shale and kerogen+/-clay minerals, with small or no admixture of grain-rich films (Fig. 2a), (ii) occasionally at certain levels, a dense alternation of thin beds of the above mudstone and < 2 mm thick microbeds, lenses or laminae of dominantly carbonate grain-bearing wackestone or packstone (visual volume share $> 10\%$ (rarely up to 50–70%)) appear (Fig. 2b). Intervals of mudstone and packstone+mudstone rich OS, each > 0.5 m thick, have been sampled separately, enabling us to follow the reflection of the main lithological changes in chemical composition and quality parameters in OS successions. In the succession of thinly bedded OS layers, more often in the lower part of the OS seam, rarely from mm- to many cm-size allochems (diagenetic concretions and/or lenses) occur. They are composed of either carbonate (calcite and/or dolomite sparite concretions; Fig. 2c) or silicified or phosphatized lenses or interbeds of barren rock varieties. However, they are of limited volume and therefore sampled together with the surrounding OS. Their texture and composition are studied using SEM-EDS techniques. X-ray Fluorescence (XRF) analysis was conducted at the Institute of Geology, Tallinn University of Technology (TUT), with an S4 Pioneer Spectrometer (Bruker AXS GmbH, Germany), using an X-ray tube with a rhodium anode, which operated with the power of 3 kW. The samples were measured with a manufacturer's standard as MultiRes modification (pre-

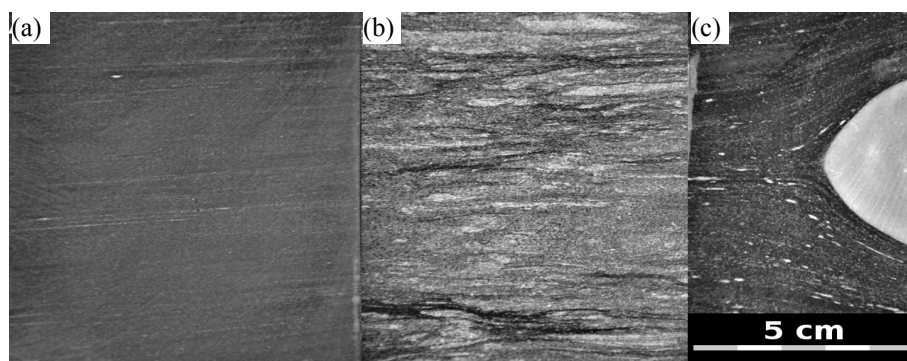


Fig. 2. Sedimentary (depositional and diagenetic) structures and textures of the Attarat oil shale, (a) and (b) representing the two main varieties of OS in the JOSE concession area of the Attarat Um Ghudran deposit: (a) – finely bedded mudstone with very thin parallel films of packstone and wackestone, both mostly composed of grains (carbonate shell debris) inclosed in mudstone; (b) up to 2–3 mm thick packstone and wackestone laminae and lenses (carbonate shell debris dominating) intercalated with mudstone; (c) a rounded diagenetic concretion of silicified limestone deforming the laminated mudstone OS with few grain-bearing lenses (the lower-middle part of the OS seam). The scale is the same for all the photos.

calibrated standardless method). The in-house standard ES-2 (“Dictyonema Shale”) was used as reference material [22]. Loss on ignition was determined from 1 g of sample material at 500 °C and 920 °C. As background information for the present paper, also the data of ICP-MS analysis of OS, mineralogical studies by X-ray diffraction and SEM-EDS methods of a selection of OS and its insoluble residue samples (completed at the Institute of Geology) were taken into consideration. These data, however, need additional publication. For understanding the distribution of components in the OS layers, descriptive statistical analysis was performed. Inter-relationship between concentrations of major and trace elements and contents of mineral carriers was studied using correlation analysis.

3. Chemical composition of oil shale layers

According to the existing exploration data, the OM in the sequence of the Attarat OS unit is represented by kerogen, usually forming 5 to 30 wt% of the total OS. Volumetrically, it corresponds to approximately 12 to 53 volume% of OM (with the density of around 1 g/cm³) among the, accordingly, 88 to 47 volume% of MM (with an average density of about 2.6 g/cm³). In the most common OS, with 16 mass% of OM, its calculated volumetric content is about 33%. Consequently, the visual share of OM in oil shale is much higher than expressed in its wt% values. It is significant to consider when integrating visual and analytical weighted data.

Table 1 summarizes the average contents of macrocompounds and trace elements detected in the representative collection of conventional core samples. Table 2 characterizes variations of two main (SiO₂, CaO), and two subordinate (Al₂O₃, P₂O₅) chemical components of the mineral matter in the Attarat OS layered sequence, and of LOI 500 °C, in most cases approximately reflecting the content of OM. However, in intervals with higher contents of clay minerals (especially in layer D – see Al₂O₃ in Table 2) the LOI 500 °C value may tend to slightly overestimate the OM content. Systematized analytical data only on the productive OS layers and the total of OS layers are used here, whereas the considerably thick (> 0.5 m) barren dolomite and limestone interlayers also present within the OS seam have been omitted.

Comparing the average compositions of separate layers (Table 2) and the total average composition of the sum of all samples (Table 1), a certain specialization of layers concerning the contents of the three main components CaO, SiO₂ and LOI 500 °C is obvious (Table 3).

In the frames of minimal to maximal average concentrations of the compounds, three of them show extraordinarily high values in certain but different layers: compositions of layers E1 and E3 are strongly dominated by CaO; layer D is extraordinarily rich in SiO₂ but remarkably poor in CaO; and in samples from layer E2 the LOI 500 °C value is extraordinarily high,

Table 1. Average chemical composition and standard deviations of OS layers A to E3 (see also Fig. 3) in the JOSE concession area, AUG deposit, based on the results of XRF and LOI analyses of dominantly gapless sampling of the shale seam from 39 drill cores

Mass%	Content	SD	ppm	Content	SD
SiO ₂	20.63	11.65	Sr	657	116
TiO ₂	0.08	0.04	V	430	267
Al ₂ O ₃	2.06	1.05	Zr	38	11
Fe ₂ O ₃	0.65	0.23	Y	16	6
MnO	0.002	0.00	Mo	167	100
MgO	0.71	0.20	Cu	60	18
CaO	33.57	7.84	Zn	891	378
Na ₂ O	0.19	0.05	Ni	180	66
K ₂ O	0.26	0.09	Cr	289	81
P ₂ O ₅	2.99	1.36	As	18	10
Cl	0.07	0.01	Cd	95	48
S	2.70	0.72	F	2633	1482
LOI 500 °C	15.93	4.48	Se	36	45
LOI 920 °C	35.65	6.41			

SD = standard deviation.

Table 2. Variation of the oil shale composition by layers. Average contents and standard deviations of the five main macrocomponents in 8 OS layers and average of the total collection (the representative collection of 395 samples with a total length of 672.1 m from selected 12 representative drill cores)

Layer	E3	E2	E1	D	C	B2	B1	A	Total OS of layers E-A
Boreholes No	5	6	6	12	12	12	12	12	12
Samples No	30	14	25	33	57	109	49	78	395
Analyzed total thickness, m	48.40	22.30	42.30	54.40	99.10	193.40	84.90	127.30	672.10
SiO ₂ , wt%	7.21	8.12	8.02	43.33	24.20	21.85	21.56	27.91	20.63
SD	0.65	1.21	0.60	4.67	2.22	1.36	1.50	3.30	11.65
Al ₂ O ₃ , wt%	1.78	1.53	1.95	4.89	2.57	2.35	1.15	1.40	2.06
SD	0.49	0.12	0.12	0.46	0.20	0.12	0.08	1.40	2.06
CaO, wt%	43.58	34.96	42.48	17.12	29.71	31.67	35.15	31.18	33.57
SD	1.69	1.81	0.90	3.68	1.86	1.00	1.02	2.00	7.84
P ₂ O ₅ , wt%	1.25	0.95	1.89	1.91	3.06	2.94	3.91	5.30	2.99
SD	0.16	0.12	0.16	0.18	0.41	0.14	0.24	0.81	1.36
LOI 500 °C, wt%	13.18	28.26	13.87	15.70	18.56	17.36	14.53	13.18	15.93
SD	2.20	2.10	0.75	4.90	2.44	0.62	1.18	1.18	4.48

SD = standard deviation.

Table 3. Average ranking of chemical components in OS layers (data from Table 2)

	CaO, wt%	SiO ₂ , wt%	LOI 500 °C, wt%	Al ₂ O ₃ , wt%	P ₂ O ₅ , wt%
E3	40–45	7–9	13–15	1–2	0.9–2
E2	29–36	7–9	26–30	1–2	0.9–2
E1	40–45	7–9	13–15	1–2	0.9–2
D	15–20	40–45	15–19	4.5–5	0.9–2
C	29–36	20–28	15–19	2–2.6	2.5–5
B2	29–36	20–28	15–19	2–2.6	2.5–5
B1	29–36	20–28	13–15	1–2	2.5–5
A	29–36	20–28	13–15	1–2	5–5.5
A–E3	29–36	20–28	15–19	2–2.6	2.5–5

Legend: Notional concentration ranks	Very high	Considerably high	Ordinary	Low
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suggesting its high energetic potential. In the distribution of the three compounds certain specific patterns are observed. The contents of CaO are considerably high in the lower layers (A–C) and very high in the dominant part of layer E, with the extremely low content in layer D. Contrarily, in the lower layers A–C the SiO₂ contents are ordinary, in the upper layers E1–E3 very low and in layer D extremely high. The LOI 500 °C values reflecting the OM content are not dependent on the CaO versus SiO₂ ratio in the sequence. OM-lean samples with low LOI (< 13%) have been occasionally found within the layers. Average Al₂O₃ contents are considerably high in the SiO₂-rich layer D but low or ordinary in the other layers. In fact, usually only certain thin sublayers are enriched with Al₂O₃ (Fig. 3). Concentrations of P₂O₅ decrease from the bottom of the OS seam upwards, being considerably high in layer A (overlying the phosphate-bearing Al-Hisa Formation e.g. [2]), ordinary in layers B1–C, and low in D–E3. The most homogeneous mudstone intervals may show maximal LOI 500 °C values, whereas the grain-rich intervals tend to show lower OM content.

Regularities found in the distribution of key components are manifested in all analyzed cores. Similarly, regularities in the spread of almost all the remaining macrocomponents and also of all trace elements in the OS sequence are quasi stable across the entire JOSE study area. Individual OS layers substantially differ in concentrations of all analyzed components. The produced dataset on the average concentrations by layers is reliable. However, it has to be noted that the nature of Na₂O and Cl concentrations differs from that of all other compounds. Namely, in many localities it is affected by infiltration of NaCl from surface continental waterbodies during recent continental epochs. It requires explanation in a special paper. Detailed visual, microscopic and SEM observations of thin beds, lenses and laminae show that on the detailed scale (mm-s and cm-s) the concentrations of all

compounds are even more variable, and the concentration maxima and minima of thin interlayers may significantly differ from the averages of OS layers.

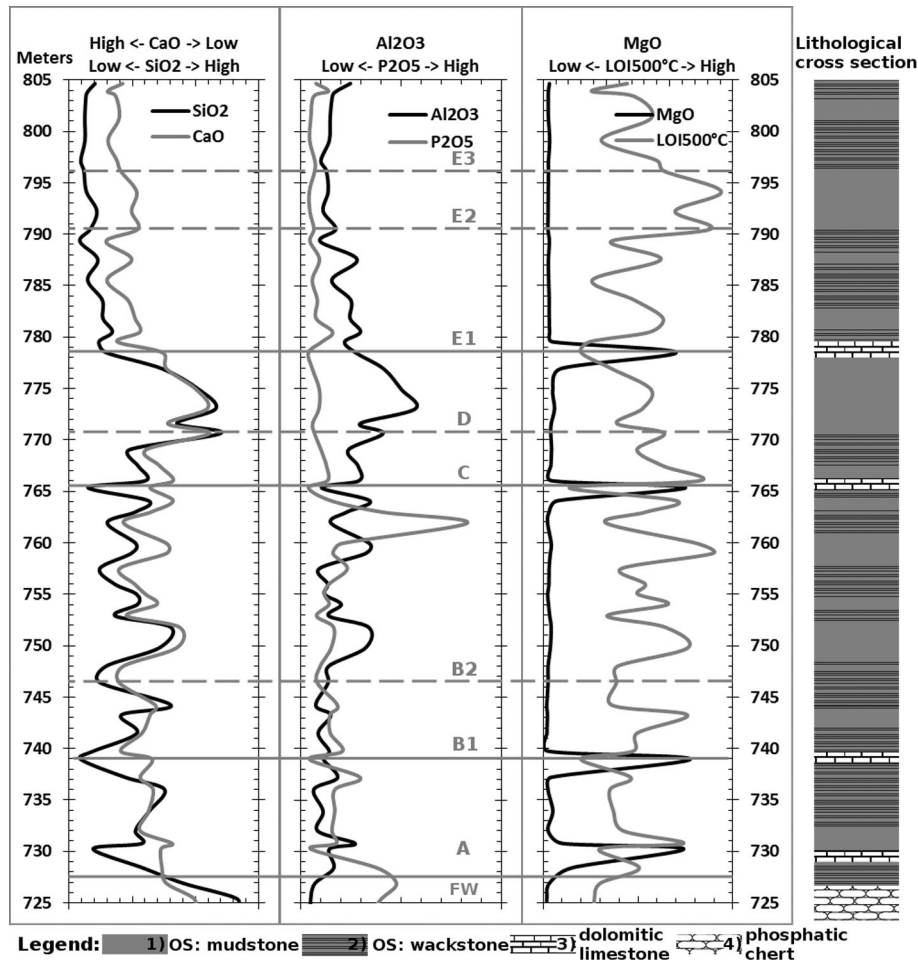


Fig. 3. Selected major element composition of MM and LOI 500 °C (reflecting the OM content) variation in a core section from the JOSE concession area. Average content values of individual 0.5–2 m long sample intervals are visualized. Note that the scales of CaO and SiO₂ contents are reverse. The OS layers are defined using complex data of visual lithological description, downhole natural gamma-logging and chemical data on the distribution of macrocompounds and trace elements.

On a 0.5–2 meter long sample scale, the internal compositional variance of each OS layer is reflected in the variation of standard deviation values (Tables 1 and 2). Comparing different components of the total sample collection from layers A–E3, the concentrations of CaO and LOI 500 °C

show considerably low variation, whereas concentrations of SiO_2 , Al_2O_3 and P_2O_5 are highly variable (Table 1). Comparing standard deviations of components' concentrations for separate layers from A to E3, the differences in the variability of components within a layer become evident (Table 2). The relatively low variability of SiO_2 as well as the lowest variability of CaO concentrations for layers B1, B2, E1 and E3 suggests a more homogeneous composition. The considerably high standard deviation values of SiO_2 and CaO for layers A, D and E2 are indicative of a more heterogeneous composition. A short analysis demonstrates that the changes of mineral composition most influence the chemical heterogeneity. Increase of the standard deviation of the five main chemical components depends on compositional changes: calcite versus silica in mudstone, a variable share of mudstone versus wackestone+packstone, and content variations of apatite, clay minerals and OM. As an example, the relative homogeneity of some layers and heterogeneity of others is visualized in Figure 3. The vertical distribution of compounds concentrations in layers from A to E3 in all 12 studied core sections is principally similar, suggesting a considerable lateral stability of the defined layers compositions.

In the succession of layers A–E3 (Fig. 3) the peaks of the MgO curve mark well the interlayers of barren dolomitic limestones. In some sequences, few minor barren limestone interbeds occur that are not separately depicted in Figure 3. In OS layers, the contents of CaO and SiO_2 usually show up negative correlation, the most remarkable are the SiO_2 peak and CaO low corresponding to layer D. The Al_2O_3 curve is well congruent to the SiO_2 curve, with a significant peak corresponding to layer D (Fig. 3). The LOI 500 °C curve is occasionally congruent to SiO_2 - Al_2O_3 peaks, but is usually poorly connected to mineral components.

Table 1 also presents the average contents and standard deviations of additional 10 major and 13 trace elements of the studied samples. The contents of usual major elements in a sedimentary rock (Fe_2O_3 , MgO, Na_2O , K_2O) remain below 1 wt%, whereas TiO_2 , MnO, and Cl are below 0.1 wt%. The average contents of P_2O_5 (2.99 wt%) and S (2.7 wt%) are considerably high. Standard deviation values of the average concentrations of certain major and trace elements are variable, mostly depending on the content variance of carrier minerals such as calcite, quartz, phosphate, clay minerals and OM. Many trace elements are present in concentrations higher than normal for carbonate rocks. Carrier minerals and macro- and trace-element content details are worthy of a separate approach to statistical methods.

4. Conclusions

The new analytical data on the representative sample collection of the entire OS sequence in the JOSE concession area enabled the authors to describe the stable layered internal chemical structure of the whole OS seam and to

discover its spatial variation of composition and energetic potential in a 73 km² portion of the Attarat Um Ghudran-Wadi Maghara oil shale basin. The data principally confirmed the concentration ranges of components reported by Abed and Amireh [3], Hufnagel [13], Hamarneh et al. [4, 5], Abed and Arouri [8] and Alali [6]. However, the regularities in the vertical distribution of chemical components and their variation patterns are new original information. The vertical distribution of the studied chemical element concentrations in all studied core successions, i.e. the layered structure, is principally similar but still remarkably changeable in details over the whole study area. It is revealed from the analytical dataset on the 37 core sections and additional data of visual and photo documentation and gamma-logging of over 150 core and percussion boreholes. The structure and composition of the OS seam suggest that its primary depositional nature has principally survived. In places, the identified layers show minor local tendencies of synsedimentary thickening or thinning. The OS layers have only locally slightly changed in the diagenetic processes, whereas the barren limestone interlayers are strongly enriched with MgO and depleted of CaO that is caused by diagenetic dolomitization.

The data obtained on the variation of the average chemical composition are probably applicable for the comparison of OS layers' compositions across the large Attarat Um Ghudran-Wadi Maghara OS basin of Central Jordan and possibly with the other OS basins and deposits in Jordan and farther. The chemical patterns firmly support the introduced original detailed stratification scheme of the studied oil shale unit that is deduced from the complex database. However, comprehensive comparative analysis of the chemical composition might be more fertile with the results of mineralogical studies, which is, however, the next separate research task.

The data on the layered chemical structure serve as geological and chemical base information for the OS quality and compositional modelling of the deposit, and for the design of mining and OS processing technologies.

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