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OIL YIELD AND BULK GEOCHEMICAL PARAMETERS OF OIL SHALES FROM THE SONGLIAO AND HUADIAN BASINS, CHINA: A GRADE CLASSIFICATION APPROACH

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Abstract. *Oil shale evaluation is based on oil yield by low-temperature carbonization, which is an extremely complex process. The TOC, semi-coke content, gas loss, bulk density,* S_2 *and HI correlate well with oil yield. The organic matter in the oil shale from the Songliao Basin, China, is of lacustrine origin, while that in the oil shale from the Huadian Basin, China, stems from different sources. Comparative studies show that the simple organic matter composition of the Songliao oil shale facilitates industrial oil shale grade classification on the basis of TOC content only. Complex mixtures of organic matter found in the Huadian oil shale require, in addition to the TOC content, also the* S_2 *and HI for grade classification. Knowing organic matter quality and the deduced oil yield conversion factor enables the industrial grade classification of oil shale on the basis of TOC content.*

Keywords: *oil shale, industrial grade classification, Songliao Basin, Huadian Basin.*

1. Introduction

With the shortage of conventional oil and gas unconventional energy sources such as oil shale, shale gas and shale oil receive more and more attention. China, Estonia, Brazil, Australia and other countries have derived a significant economic benefit from large-scale development and utilization of oil shale [1–6]. Generally, oil shale is defined as a solid combustible sedi-

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mentary rock containing organic matter and a high amount of mineral matter, and from which shale oil can be obtained by low-temperature carbonization. The oil shale with an oil yield higher than 3.5%, rich in organic matter, is mainly sapropelic and mixed type (humic-sapropelic and sapropel-humus type). Its calorific value is generally not lower than 4.18 MJ/Kg [1]. Based on the experience acquired from the handling of Chinese Fushun and Huadian oil shales, oil yield is a key factor to be taken into account in oil shale mining and utilization. Carried out in 2006, the third Chinese National Oil and Gas Resource Assessment titled "A New Round Evaluation of Oil and Gas Resources" takes the oil yield of 3.5% as a cut-off grade for resource estimation. The industrial grade classification of oil shale involves three categories: low-quality (oil yield 3.5–5.0%), medium-quality (oil yield 5.0–10.0%), and high-quality (oil yield > 10.0%) [7–10].

In China, oil shale is mainly distributed in large depression and small fault basins. However, the content and type of organic matter of oil shales vary in different basin types. Therefore, in order to carry out oil shale exploration and development projects, research on oil yield and other parameters should be carried out in depression and fault basins separately. Laboratory oil yield tests involve complex experimental processes, are time-consuming and require the use of chemical reagents, which may have a hazardous impact on human health. Oil shales from a typical large depression basin (Songliao Basin) and a small fault basin (Huadian Basin) serve as examples to prepare a new guideline for oil shale industrial grade classification.

2. Regional geological setting

2.1. Songliao Basin

The Songliao Basin is a lacustrine basin which was formed during the Cretaceous Qingshankou-Nenjiang period with an intense deposition of mudstones rich in organic matter [11]. According to regional geologic features the Songliao Basin is divided into the following six first-order structural units: the North Plunge, Northeastern Uplift, Southeast Uplift, Centre Depression, Western Slope and Southwestern Uplift (Fig. 1). According to Feng et al., the evolution of the Songliao Basin started in the syn-rift stage Late Jurassic to Early Cretaceous, and continued in the Early to Late Cretaceous post-rift stage, finally ending with a structural basin inversion in the Cenozoic [12].

In the lower part of the Qingshankou Formation and in the Nenjiang Formation several thick oil shale layers of medium quality are developed. Studies show that the formation of oil shale in the Songliao Basin is related to marine transgressions, tectonic subsidence and rapid rising lake level changes [13–16].

In this study, oil shale of relatively high quality from the Qingshankou Formation in the Southeast Uplift has been investigated.

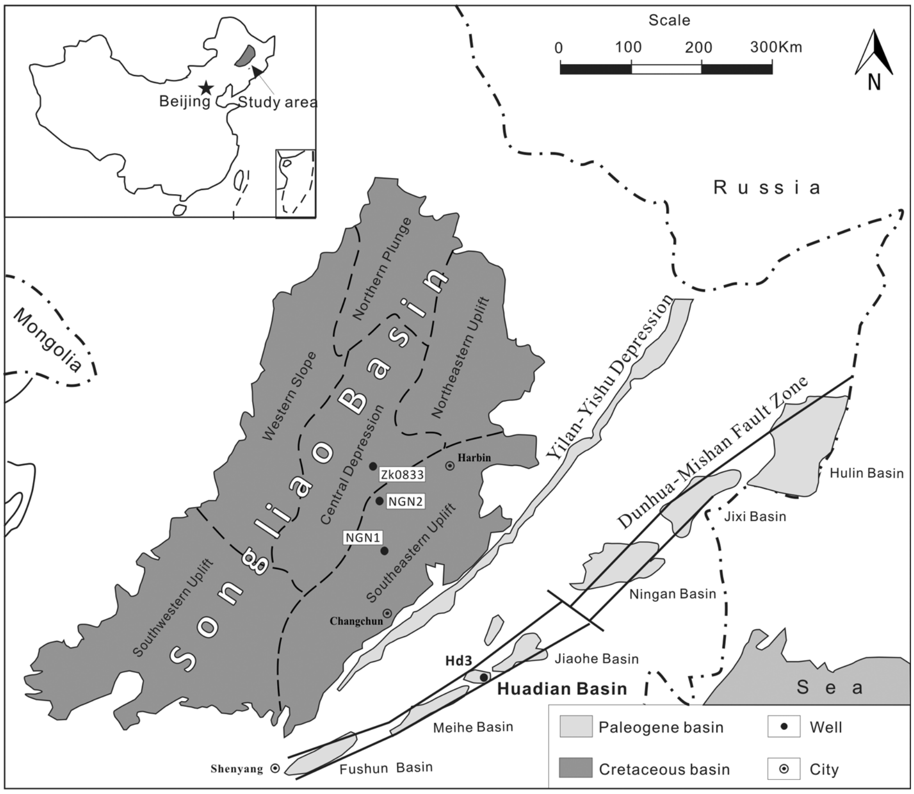

Fig. 1. Geological sketch of Songliao and Huadian basins.

2.2. Huadian Basin

The Huadian Basin is a famous oil shale- and coal-bearing fault basin in NE China. It is situated along the Dunhua-Mishan fault zone, which belongs to the northern branch of the Tancheng-Lujiang Fault Zone (Fig.1). The tectonic evolution of the northern segment of the Tancheng-Lujiang Fault Zone is divided into the left-lateral strike-slip tenacity shear stage, the left-lateral tenso-shear stage, the right-lateral compression shear stage, and the right-lateral strike-slip fault depression stage, followed by a structural inversion. The tectonic evolution of the Huadian Basin is mainly controlled by the right-lateral strike-slip fault depression and structural inversion [17]. Carboniferous and Permian metamorphic rocks formed the basement of the Huadian Basin; the basin fill consists of coal-bearing series in the Jurassic, followed by glutenite rocks in the Cretaceous. In the Paleogene Huadian Formation, oil shale- and coal-bearing series occur, covered on an unconformity by Quaternary series. The Paleogene Huadian Formation is the main filling stratum in this basin and can be subdivided into three members: (1) the Pyrite Member in the lower part, (2) the Oil Shale Member in the middle, and (3) the Carbonaceous Shale (coal-bearing) Member in the upper part (fast filling compressing stage). The Oil Shale Member is the key layer of this study. Several oil shale layers (dark grey mudstones) are developed in this member [18]. The sedimentary evolution of the Oil Shale Member is represented by a semi-deep to deep lake environment. Previous studies show that the quick tectonic settlement combined with favorable paleoclimate conditions supported high lake productivity and promoted oil shale formation [19–20].

3. Sampling and methods

In the Sangliao Basin, oil shale samples were collected from three core wells, which had been drilled by Shell in 2006. Well NGN1 (sampling depth 355 to 477 m) is located in the southeastern edge of the basin; well NGN2 (sampling depth 151 to 240 m) is in the southeastern slopes of the basin; and well ZK0833 (sampling depth 625 to 863 m) is located in the center of the basin (Fig. 1). Samples from the Upper Cretaceous Qingshankou Formation were taken every meter. Most samples were grey-brown or dark grey oil shale, and dark gray or grey mudstone.

In the Huadian Basin samples were collected within the Huadian Formation from well HD3 (Fig. 1), which was drilled entirely. In this well high-quality oil shale was deposited in 13 layers. The bulk geochemical analysis of the core was performed within the depth interval of 424 to 471 m. Samples from the Oil Shale Member were taken every meter and were mainly brown or taupe black oil shale, and dark grey or grey mudstone.

Based on the large number of systematic tests, data for samples with oil yield > 2.5% were selected for discussion. The oil yield of samples from well NGN1 is generally low, therefore the oil yield > 1.5% was used as a cut-off value in this paper.

The Mineral Resources Supervision and Inspection Center of the Ministry of Land, Changchun, China, tested the oil yield on 905 samples by the Fischer Assay Procedure (ASTM D3904). From this sample set 129 rock samples (oil yield > 2.5%, and from NGN1 oil yield > 1.5%) and 40 samples (oil yield < 2.5%, and from NGN1 oil yield < 1.5%) were picked out for TOC analysis, pyrolysis and density tests. The total organic carbon (TOC) of samples pre-treated with concentrated hydrochloric acid was measured using a Leco elemental analyzer. Pyrolysis was carried out employing a Delsi Rock-Eval RE II instrument. The Rock-Eval method estimates the amount of pyrolyzate (mg HC/g rock) that will be released from kerogen during gradual heating in a He stream, and normalized to the TOC content gives the hydrogen index (HI). An MDMDY-35 fully automatic machine was used to determine the bulk density of samples based on the criteria of GB/T 23561.2-2009.

4. Results and discussion

4.1. Characteristics of oil shale

Based on core observation and geochemical analysis, the oil shales of the Songliao and Huadian basins are mudstones. Oil shales of different industrial grades significantly differ in color and bedding structure.

4.1.1. Songliao Basin

The oil yield of the oil shale from the Songliao Basin is usually medium to low [21], ranging for most samples from 3.5 to 6.0%, with 10.2% being the highest. The color of the high-quality oil shale (F) is brown and the rhythmic bedding of clay and carbonate layers on an approx. 0.1 mm scale is well developed (Fig. 2). The cracks formed in high-quality oil shale during hydrocarbon expulsion are filled with sparry calcite. Testing results are presented in Table 1.

The medium-quality oil shale (C, D), with an oil yield of 5.1 and 6.1%, respectively, shows a light tan color and well-developed horizontal bedding (Fig. 2). The low-quality oil shale (A, E) is mainly greyish black or dark grey in color. The horizontal or massive bedding is well developed, with some intercalations of sand strips (Fig. 2). The characteristic parameters of the low-quality oil shale are given in Table 1.

According to the industrial grade classification (oil yield < 3.5%), the non-oil shale sample (B) from the Songliao Basin is represented by a grey mudstone (oil yield 1.9%). This rock type shows intense embedded sand

Fig. 2. Petrological characteristics of mudstone in the Qingshankou Formation, Songliao Basin: F – high-quality oil shale; C, D – medium-quality oil shale; A, E – low-quality oil shale; B – non-oil shale.

Table 1. Test results for oil shale samples from the Songliao Basin

Sample	Depth, m	Oil yield, %	TOC, %	Semi-coke, %	Gas loss, %	Density, g/cm^3	S_2, mg/g	HI, mg/g	Organic matter type
A	206	3.6	5.1	93.6	1.7	2.18	34.5	672	I
B	207	1.9	3.5	95.2	1.5	2.20	21.9	628	I
C	224	5.1	7.1	90.7	2.7	2.15	49.4	697	I
D	225	6.1	7.9	89.9	2.9	2.15	55.4	704	I
E	232	4.8	7.3	91.5	2.3	2.16	50.9	699	I
F	233	10.2	13.6	84.7	3.7	2.04	99.2	729	I

bands within clay, as well as a massive and horizontal bedding (Fig. 2). Typical testing results are given in Table 1.

In summary, with increasing oil yield, the color of oil shale changes from dark grey to brown, and the TOC content, pyrolysis value S_2, HI and content of volatile compounds gradually increase; in contrast, the density and semi-coke content gradually decrease. All samples plot in the modified HI-Tmax diagram in the outlined area of type I kerogen [22].

4.1.2. Huadian Basin

The oil shale samples from the Huadian Basin are partly of high quality. Through systematic testings, the oil yield of one sample amounted to 19.8%, while most samples afforded shale oil in the range of from 3.5 to 9.0%.

The high-quality oil shale (C) with an oil yield of 19.8% is of dark brown color and with a well-developed horizontal bedding. Notable in this sample are abundant unbroken shell fossils and well-preserved plant remains (Fig. 3). The typical chemical characteristics of this oil shale are given in Table 2.

The medium-quality oil shale (E) yielding 9.0 % shale oil (Fig. 3) is brown in color; the clayey layers are often rich in plant remains (coaly particles). Horizontal bedding and slumping like structures similar to bioturbation are developed in some layers. The chemical characteristics of the oil shale are presented in Table 2.

The low-grade oil shale (D, I), yielding, for example, 4.9 and 3.9% shale oil, respectively, is greyish black and with a massive bedding. This oil shale type contains small amounts of plant remains and shell fragments (Fig. 3). The characteristics of this oil shale type are given in Table 2.

The non-oil shale samples (oil yield < 3.5%) in the Huadian Basin (A, B, F, G, H) are represented by grey mudstones with a well-developed massive bedding and small amounts of sandy strips (Fig. 3).

With increasing oil yield, the color of the Huadian oil shale changes from gray-black to dark brown, and the TOC content, pyrolysis value S_2, HI and content of volatile compounds gradually increase; in contrast, the rock density and semi-coke content gradually decrease. According to the modified HI-T_{max}

diagram the investigated samples plot in the outlined area of kerogen types II_1, II_2 and III.

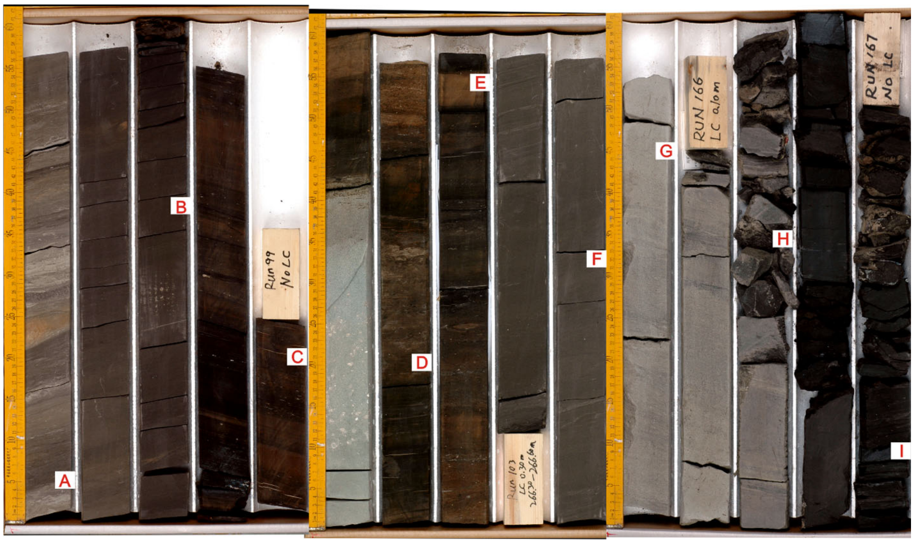

Fig. 3. Petrological characteristics of mudstone in the Huadian Basin. Letters correspond to the oil shale qualities and summarized chemical parameters presented in Table 2.

Table 2. Test results for oil shale samples from the Huadian Basin

Sample	Depth, m	Oil yield, %	TOC, %	Semi-coke, %	Gas loss, %	Density, g/cm^3	S_2, mg/g	HI, mg/g	Organic matter type
A	252	0.4	1.1	96.0	2.1	2.24	0.9	89	III
B	253	1.0	3.1	94.5	2.2	2.24	13.1	418	II_1
C	254	19.8	30.3	69.8	7.4	1.6	132.4	437	II_1
D	266	4.9	8.9	88.6	3.5	2.1	45.2	508	II_1
E	267	9.0	13.1	85.5	2.8	2.0	58.6	447	II_1
F	268	0.2	0.1	97.7	1.1	2.26	0.25	197	II_2
G	422	0.1	0.2	98.7	0.3	2.27	0.1	43	III
H	423	0.1	0.9	98.0	0.3	2.32	0.8	85	III
I	424	3.9	24.8	87.0	3.5	1.74	44.1	178	II_2

Comparison of oil shale samples from the Songliao and Huadian basins reveals significant differences in kerogen type. The organic matter of the Songliao oil shale is mainly composed of kerogen type I, while that of the Huadian oil shale is represented by a mixture of kerogen types II_1, II_2 and III. This is also demonstrated by comparing oil yields at a given TOC content. So, to get a similar oil yield, a nearly twice as high TOC content is required in Huadian oil shale samples as in Songliao oil shale samples. To draw up simple exploration guidelines it will, as the first step, be necessary to investigate the two basin types separately and, in the second stage, to cross-check the outlined guidelines. With positive results this research may contribute to the fast industrial grade classification of oil shales from similar-type basins.

4.2. Classification parameters of oil shale

Systematic analysis of oil shale and mudstone samples from the Songliao and Huadian basins shows a strong positive correlation to exist between oil yield and TOC content, Rock Eval pyrolysis peak S_2, calculated hydrogen index (HI) and gas loss rate. In contrast, the bulk density and semi-coke content show an opposite trend. Establishing the relationship between these parameters and oil yield may contribute to a more convenient and efficient evaluation of oil shale quality.

4.2.1. TOC content, pyrolysis value S_2 and HI versus oil yield

The industrial grade classification of oil shale is based on oil yield and this parameter is strongly related to TOC content and organic matter type. Therefore, the TOC content combined with organic matter classification is one of the most important parameters for oil shale quality control.

The Songliao Basin is a large depression basin covering an area of 26×10^4 km^2 (Fig. 1). Samples from three wells representing deep, intermediate and shallow water environmental conditions were analyzed in respect to various classification parameters. As seen in Figure 4, samples from different environments vary in TOC content. In the deep water environment, far from the shoreline, the organic matter is represented by lamalginite algae (kerogen type I) [13, 16] and the TOC content correlates well with oil yield. In the intermediate water area, closer to the coast line, this correlation slightly weakens. In shallow water conditions, near the coastline, this correlation is more weakly expressed (Table 3, Fig. 4). This decrease in the correlation coefficient is explained by the presence of an admixture of terrigenous organic matters of low oil yield.

The oil shale from a small elongated Huadian Basin, with an area of approximately 26 km^2, shows a distinct correlation between the selected parameters and oil yield, unlike that from the Songliao Basin. However, the TOC content of Huadian oil shale samples correlates with oil yield very weakly. Taking into account that the organic matter in the Huadian oil shale is composed of various kerogen types (II_1, II_2 and III), the respective correlation coefficient ($R^2 = 0.65$) is not surprising (Table 3, Fig. 5). With respect to oil yield, organic matter quality (kerogen type) is more important than TOC content as seen from the highest values for the marked (coal) sample in the graph (Fig. 5).

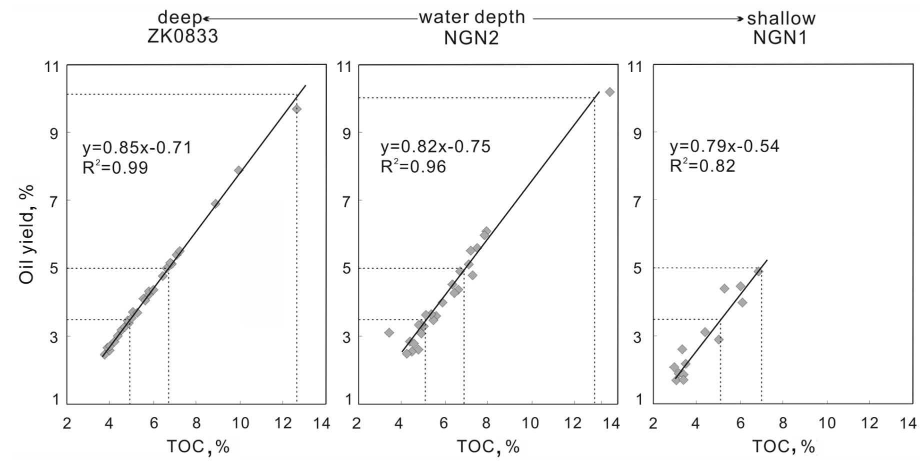

Fig. 4. The relationship between the oil yield and TOC content of oil shale samples from the Songliao Basin at different distances from the coastline.

Table 3. Summarized correlation coefficients against oil yield

	Songliao Basin			Huadian Basin
	deep water	intermediate water	shallow water	
TOC	$y = 0.85x-0.71$ $R^2 = 0.99$	$y = 0.82x-0.75$ $R^2 = 0.96$	$y = 0.79x-0.54$ $R^2 = 0.82$	$y = 0.76x-2.95$ $R^2 = 0.65$
Semi-coke	$y = 85.25-0.87x$ $R^2 = 0.98$	$y = 81.86-0.84x$ $R^2 = 0.88$	$y = 111.32-1.16x$ $R^2 = 0.43$	$y = 75.94-0.80x$ $R^2 = 0.95$
Gas loss	$y = 7.14x-7.07$ $R^2 = 0.53$	$y = 3.85x-3.08$ $R^2 = 0.40$	$y = 5.26x-5.63$ $R^2 = 0.21$	$y = 3.57x-6.57$ $R^2 = 0.69$
Density	$y = e^{(17.8-7.27x)}$ $R^2 = 0.72$	$y = e^{(17.7-7.52x)}$ $R^2 = 0.63$	$y = e^{(25.1-10.64x)}$ $R^2 = 0.45$	$y = 72.0-33.3x$ $R^2 = 0.62$
S_2	$y = 0.11x\ 0.37$ $R^2 = 0.99$	$y = 0.11x-0.25$ $R^2 = 0.96$	$y = 0.10x-0.27$ $R^2 = 0.92$	$y = 0.17x-3.32$ $R^2 = 0.64$
HI	$y = e^{(0.023x-14.9)}$ $R^2 = 0.98$	$y = e^{(0.017x-9.9)}$ $R^2 = 0.85$	$y = e^{(0.013x-8.2)}$ $R^2 = 0.38$	

The pyrolysis value S_2 reflects the potential of oil shale and mudstone for hydrocarbons formation and is strictly related to organic matter quality and content. The correlation coefficients agree well with TOC data (Table 3). The weak correlation of Huadian oil shale samples is explained by the same fact as mentioned above.

Hydrogen index (HI) depends on the ratio of S_2 to TOC and reflects the potential of oil shale and mudstone for hydrocarbons generation by pyrolysis. The expected positive correlation of HI with oil yield is well expressed in samples from the deep water environment of the Songliao Basin, becoming weaker in samples from intermediate and shallow water environments (Table 3). This is due to the presence of an admixture of terrestrial organic

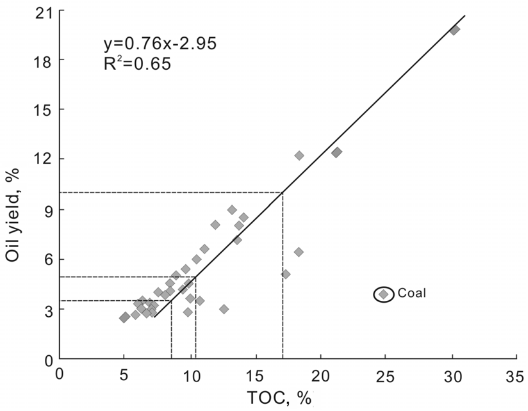

Fig. 5. The relationship between the oil yield and TOC content of oil shale samples from the Huadian Basin.

matters with lacustrine algal material. In the Huadian oil shale, no such correlation exists due to the presence of a mixture of different organic matter types.

Summarizing the results from the correlation graphs of TOC content, pyrolysis value S_2 and HI versus oil yield, a simple extrapolation resp. oil yield calculation is only possible with one dominant organic matter type, as seen from the data on the Songliao oil shale. In oil shale containing a mixture of different organic matter types, as in samples from the shallow water environment of the Songliao Basin and well founded in samples from the Huadian Basin, the calculation of the expected oil yield based on TOC, pyrolysis S_2 and HI data gives unsatisfactory results and cannot therefore be recommended for oil shale grade classification.

4.2.2. Semi-coke content, gas loss and bulk density versus oil yield

In this study, the semi-coke content represents the amount of residue from the low-temperature carbonization of oil shale. Analyses show that there is a clearly expressed negative correlation between the semi-coke content and oil yield (Fig. 6, Table 3). The correlation coefficient in the samples from the Songliao Basin decreases with decreasing water depth due to the presence of an admixture of terrestrial organic matters. This has also been observed in case of the correlation trends discussed above.

It has to be noted that the samples from the Huadian Basin display an excellent correlation between semi-coke content and oil yield. This astonishing correlation may result from the dominance of type III kerogen over kerogen types II_1 and II_2, and a high amount of type III organic matter still remained in the semi-coke. Comparing oil shales at equivalent oil yield, samples from the Huadian Basin have a significantly lower semi-coke content than the Songliao samples (Figs. 6, 7), indicating that the production rate of oil from the Huadian oil shale is relatively low.

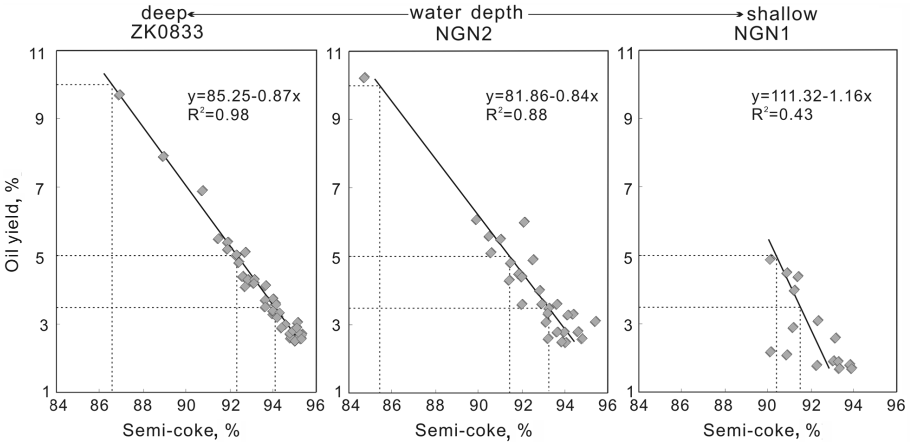

Fig. 6. The relationship between the semi-coke content and oil yield of oil shale samples from the Songliao Basin.

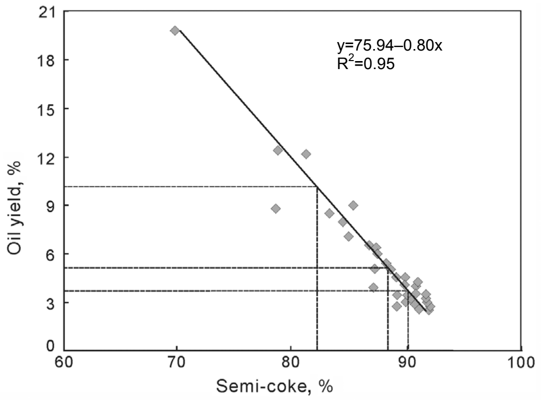

Fig. 7. The relationship between the semi-coke content and oil yield of oil shale samples from the Huadian Basin.

Gas loss is a sum of losses of all the volatile compounds (hydrocarbons and water vapor) released during the low-temperature carbonization. There is only a weak positive correlation between gas loss and oil yield (Table 3), indicating that in addition to the organic matter content, the mineral matrix, especially the amount of clay minerals, influences gas loss.

The bulk density of oil shale and mudstone in general decrease with increasing organic content. The correlation between the bulk density and oil yield is weak in both sample sets (Table 3). Therefore, an additional effect of mineralogical factors like compaction and diagenetic alterations must be considered when comparing oil shales from different basins.

Summarizing the results from the graphs of semi-coke content, gas loss and bulk density versus oil yield, only the semi-coke content data shows a correlation trend. The variation can also be explained by the presence of an admixture of terrestrial organic matters and lacustrine organisms. Although the excellent correlation between the selected parameters and oil yield of samples from the Huadian Basin is difficult to explain, this may be related to an admixture of different kerogen types.

4.2.3. Type of organic matter

A key factor in forecasting the oil generation potential of a particular rock is the estimation of its organic matter type. Traditionally this is done by the microscopic maceral analysis, but routine analysis in the oil industry uses mainly pyrolysis data to calculate hydrogen and oxygen indexes, and their position in the HI-T_{max} diagram will allocate the kerogen type. Problems in the interpretation of data may arise in case of mixtures of organic materials from different sources. For example, a mixture of kerogen types I and III plot in the Van Krevelen graph in the outlined area of kerogen type II.

The oil shale samples from the Songliao Basin show HI values in the range from 600 to 800 mg HC/g TOC and plot in the outlined area as kerogen type I with a slight tendency towards kerogen type II_1 in samples from the shallow water environment (Fig. 8).

The oil shale samples from the Huadian Basin show widely varying HI values, scattering from kerogen type I to kerogen type II_2 (Fig. 8). A simple mass balance calculation shows that kerogen type II (HI about 500 mg HC/g TOC) may be obtained by diluting three parts of kerogen type I (HI about 800 mg HC/g TOC) with four parts of kerogen type III (HI approximately 100 mg HC/g TOC). Such a mixing is supported by the great variation of HI data covering all industrial oil shale grades. Non-oil shale samples show at moderate TOC contents high HI values, but give only low oil yields. This may indicate small alterations of organic matter.

4.3. Alternative parameters for oil shale category classification

The classical industrial grade oil shale classification is based on oil yield by Fischer Assay. This method is costly and time-consuming and often results in environmental hazards. Therefore alternative parameters should be tested to get satisfactory results in forecasting oil yield from oil shales of different deposits. To respond to this challenge samples from the depression-related Songliao Basin and the fault-related Huadian Basin have been investigated. The results are summarized in Table 4. A general conclusion from the available data set is that oil yield is a function of TOC content and organic matter quality (kerogen type). Pure TOC measurements neglecting kerogen quality will result in the distorted industrial oil shale grade classification.

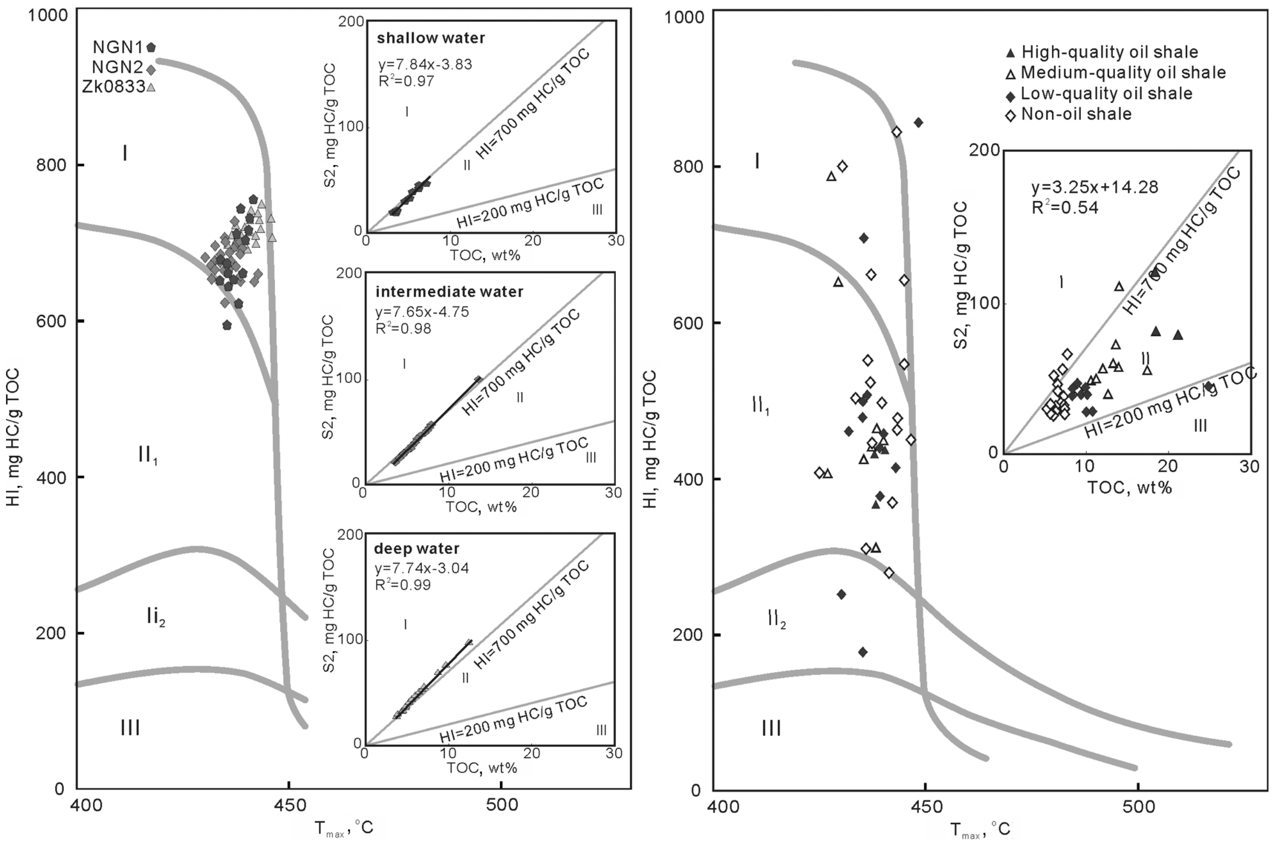

Fig. 8. Hi-T_{max} diagram of oil shale samples from the Songliao (left) and Huadian (right) basins (according to Espitalié et al., 1984; the oil and gas industry standards of the People's Republic of China (SY/T 5735─1995), 1995; Langford and Blanc-Valleron, 1990) [22–24].

Table 4. Parameters for evaluating grade classification of oil shale in the Songliao and Huadian basins

Basin		Industrial grade	Color	TOC, %	Semi-coke, %	Gas loss, %	Density, g/cm^3	S$_2$, mg/g	HI, mg/g	Kerogen type
Songliao Basin	depth	< 3.5	grey	< 4.9	> 94.2	< 1.5	> 2.29	< 35.2	< 711	I
		3.5–5.0	dark grey	4.9–6.7	94.2–92.3	1.5–1.7	2.29–2.24	35.2–48.8	711–727	I
		5.0–10.0	light brown	6.7–12.5	92.3–86.5	1.7–2.4	2.24–2.14	48.8–94.2	727–758	I
		> 10.0	brown	> 12.5	< 86.5	> 2.4	< 2.14	> 94.2	> 758	I
	shallow	< 3.5	grey	< 5.1	> 92.7	< 1.7	> 2.24	< 35.6	< 707	I–II$_1$
		3.5–5.0	dark grey	5.1–7.0	92.7–91.4	1.7–2.0	2.24–2.21	35.6–48.8	707–734	I
		5.0–10.0	light brown	7.0–12.8	< 91.4	> 2.0	< 2.21	> 48.8	> 734	I
Huadian Basin		< 3.5	grey	< 8.5	> 90.6	< 2.8	> 2.06	< 39.4	/	I–II–III
		3.5–5.0	grey-black	8.5–10.4	90.6–88.7	2.8–3.2	2.06–2.01	39.4–48.0	/	I–II$_2$
		5.0–10.0	brown	10.4–17.0	88.7–82.4	3.2–4.6	2.01–1.86	48.0–76.9	/	I–II$_1$
		> 10.0	dark brown	> 17.0	< 82.4	> 4.6	< 1.86	> 76.9	/	II$_1$

/ – data show no correlation

5. Conclusions

Based on tests with a large set of samples, oil yield, TOC content, semi-coke content, gas loss, bulk density, pyrolysis value S$_2$ and calculated hydrogen index (HI) have been analyzed to attempt establishing new evaluation parameters for determining the industrial grade of oil shale. Since the evaluation parameters should be applicable to oil shales from different basins, the depression-related Songliao Basin and the fault-related Huadian Basin have been selected to create these new parameters.

The industrial oil shale grade classification groups oil shales according to oil yield into four classes: < 3.5; 3.5–5.0; 5.0–10.0; and > 10%. Therefore the correlation coefficients of test parameters have been evaluated against oil yield. The TOC content, pyrolysis value S$_2$ and calculated hydrogen index (HI) show an excellent correlation with oil yield and variations are discussed in respect to kerogen quality. Samples with simple-composition organic matter, i.e. having only kerogen type I (Fig. 8), found in the central area of the Songliao Basin show the best correlation values. From the center of the basin (deep water) over an intermediate stage to the lakeside (shallow water) correlation values decrease as a result of the presence of an admixture of terrestrial organic materials (plant remains).

In case of the Huadian oil shale there is in general a weak correlation between the selected parameters and oil yield, except for semi-coke content.

The low correlation in the samples of this oil shale is associated with the presence of organic matter from various sources (Fig. 8). The elongated extension of the lacustrine fault-related Huadian Basin supports the fluvial and aeolian input of plant debris (kerogen type III). As a result, the lacustrine organic matter (algae) is diluted by type III kerogen to form an artificial kerogen type II (Fig. 8).

In summary, for oil shale with simple organic matter composition (kerogen type I) the TOC content alone may be used for industrial grade classification, and respectively the oil yield calculation. For their industrial grade classification oil shales composed of a mixture of various organic matters need also oil yield calculation, in addition to the TOC content, pyrolysis value S_2 and calculated hydrogen index (HI). Knowing the TOC content to oil yield conversion factor, TOC content alone may be used for industrial grade classification and deposit evaluation. Kerogen quality plays a key role in oil shale quality assessment.

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