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K. UROV and A. SUMBERG

CHARACTERISTICS OF OIL SHALES AND SHALE-LIKE ROCKS OF KNOWN DEPOSITS AND OUTCROPS

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Editor of the Russian publication: Prof. **A. Aarna**,
Member of the Estonian Academy of Sciences, D.Sc. in engineering

Translated by Priit Kogerman, Ph.D.

This booklet has been first published in Russian in 1992. As it become evident, the material presented was of interest for a wide range of researchers working in the field of oil shales and related fossil fuels, but due to language barrier it was not always accessible. Therefore this time we publish the data in English and hope that they will be of use for any who is working or interested in this sphere of science.
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PREFACE

Oil shales are special among organogenous rocks not only in their genesis and composition but also in their role as power and chemical industry raw materials. They differ from humous caustobioliths by higher hydrogen content in their organic matter and consequently by higher yield of liquid organic products (shale oil) from their thermal decomposition. This is why oil shales are regarded as a potential source for producing artificial liquid fuels and raw materials for chemical industry. On the other hand, they are usually rich in mineral matter and for complex utilization of oil shales the problems connected with the utilisation of their mineral components must be solved.

The reserves of oil shales are as of yet insufficiently determined. But even the existing data presented at the 27th International Geological Congress (1984) put them at 11.5×10^{12} tonnes (the potential oil shale resources in the USSR are estimated at 2×10^{12} tonnes) or 550 billion tonnes of shale oil. Oil shale deposits are found on all continents; the reserves are more evenly distributed compared to oil and for many countries, oil shales represent practically the only type of fossil fuels. The actuality of the use of oil shales has always depended on the oil market; as the reserves of the latter are being depleted, the oil shales become more and more important as a source of energy and as alternative source of liquid fuels and chemical raw materials. Some rare and scattered elements are also concentrated in oil shales.

Despite the existence of relatively broad literature on oil shales, the data are dispersed in different sources and are difficult to collect for comparative analysis. The present edition attempts to fill this gap by collecting together the data on oil shales of known deposits and outcrops - the results of technical analysis, data on the composition of the organic and mineral components, the yield and composition of bitumoids and products of thermal decomposition. The data collected in this study may be useful for evaluating the quality of oil shales from specific deposits for use as industrial raw materials, for creating a classification for this class of caustobioliths or for determining, with the help of methods of mathematical statistics, interdependence of different indices that characterize the composition and properties of the oil shales.

INTRODUCTION

Before presenting the data on oil shales, it would be practical to discuss first some terminological questions. It is of course especially important to understand what is the content of the term 'oil shales'. Already Down and Himus [1] have noted that the term 'oil shales' is misleading and proposed to change it to the term 'kerogenic rocks'. The absence of a precise and generally accepted definition of oil shales has also been observed later [2-5]. Duncan [6] indicated that many deposits that are classified as oil shales are actually not shales, i.e. fine-grained, thin-layered sedimentary rocks. Finding the name 'oil shales' misleading, Vassoyevich [7] proposed to discard this failed term as soon as possible and replace it by 'semicaustoliths'.

At the UN symposium on development and use of oil shale reserves (Tallinn, 1968) Schlatter called the term 'oil shales' a misnomer, since these are not shales and they do not contain oil [9]. He noted, however, that this name is firmly in use, it is convenient, short and there is no necessity to change it.

At the present time 'oil shale' is still a term that is used quite freely: on the basis of existing definitions it is not possible to decide unequivocally whether a number of organic matter (OM)-containing rocks should be included into the oil shale class or excluded from them.

The diagnostic significance of different properties that are regarded as characteristic for oil shales is now discussed with the aim of finding a more acceptable definition for this class of caustobioliths [10]. For this purpose, oil shales are regarded first as a natural geological object, as a class of rocks that comprise the crust of earth and only then as a potential industrial raw material, i.e. mineral wealth.

As a defining characteristic of oil shales, almost all authors mention their capacity of generating significant quantities of liquid organic products (shale oil) upon their thermal decomposition [1-3, 5, 6, 9-29], although this property is rarely characterized quantitatively [3, 16, 21, 24, 25]. The following characteristics are also considered diagnostic (in the order of frequency that they are mentioned in the literature): high mineral content [1, 2, 4, 6, 8, 11, 15, 19-21, 23, 25, 26, 29, 30-35], insolubility of the major fraction of its OM in organic solvents [1-3, 5, 6, 11-16, 18-20, 26, 29, 35, 36], shale-like, thin-layered structure [2, 11, 13, 14, 16-21, 25, 37, 38], sapropelic origin [4, 8, 9, 13, 14, 16, 20, 22, 23, 25, 32, 39-42], specific elemental composition and especially enrichment in hydrogen (3, 16, 19, 20, 23, 27, 32, 40], the capacity of dry shale to ignite from a match [13, 14, 25, 32, 37, 38] (or a lighter [43]), relatively low degree of catagenetic transformation of their OM [9, 28, 35, 41, 44, 45] and autochthonousness [6].

The colour of the shale and composition of its mineral part are frequently mentioned in the descriptions but these cannot serve as defining features since colour of oil shales may vary from light gray, almost white (Novodmitrovo shale, the Ukraine) and dark yellow (kukersite) to dark brown, almost black (Scottish shale) and the mineral matrix may be with aluminosilicate, carbonate or silicate material prevailing.

Even though the capacity of oil shales to ignite and burn (or smoulder) with production of a strong odour is convenient to use for analysis under field conditions, this property should still be considered only a suggestive indicator since it is characteristic of all sediments that contain sufficient amounts of moderately transformed OM such as coals, rocks impregnated with oil, etc.

If one considers shaliness [13, 14, 16, 21, 37, 38] as defined in [23], this property is not observed in many caustobioliths that by a number of other significant features can be grouped with oil shales. The thin-layered structure, that is sometimes mentioned [2, 11, 17-20, 25], is characteristic for a number of rocks that have nothing in common with oil shales apart from this feature. Consequently, the diagnostic value of the above-mentioned features is not significant. It is inevitable to accept the fact that neither are all oil shales shales nor do all of them burn.

The *in situ* formation of the OM as a defining property of oil shales should be regarded with reservation since kukersite, for example, has allochthonic origin according to some authors [46] and it cannot at all be excluded that some others are not similar. From the geological viewpoint it is quite possible that the formation of allochthonic shales could take place not only *via* transport by water essentially simultaneously with its formation as it possibly happened during the formation of kukersite, but also as a result of a later alluvial deposition of the OM into the preformed deposits of shale.

On the other hand, the insignificant solubility of the OM of oil shales in low-boiling organic solvents (benzene, chloroform, etc.) appears to be an important distinguishing property as it allows to differentiate typical (pyrobituminous) oil shales from the rocks impregnated with organic compounds that are essentially soluble (natural asphalts, oil-sands, etc.).

It is the quantitative aspect that needs clarification here. Taking into account that in most rocks that are classified as oil shales, the yield of the bitumoid does not exceed 20 % of OM (and is usually significantly less than that), this amount can be accepted as an approximate upper limit. In addition to that the OM of oil shales, and not the OM of little transformed combustible rocks of the humous type, is characterized by low solubility in aqueous solutions of alkali (i.e. insignificant content of so-called humic acids).

The rest of the proposed characteristic features have to be examined in more detail.

High mineral content is, according to most authors, characteristic for oil shales; the opinions on the actual quantity of mineral substances, however, differ quite significantly. Thus, the lower limit for OM content has been proposed to be (%): traces [1, 19] (the upper limit of mineral content is not defined in [11, 15, 30] either), 5 [28], more than 5 (4 % shale oil in the rock) [6], 10 [4, 21, 23, 35], 10-15 [8, 25], 15 [5, 32, 47], 20 [33, 34, 48].

The situation is no better with the upper limit of OM content that has been proposed to be (%): 30 [23], 35 [47], 40 [4, 19, 32], 50 [33-35], more than 50 [1], 55 [21], appr. 60 (more than 30 [30] or 33 % [11, 15] of mineral material), 75 [31], 60-80 [25]. It has also been permitted not to establish any limits at all for the OM content in oil shale [9].

This position was earlier advocated by Dobryanski who argued that "classification of kerogen-containing rocks according to the property of kerogen amount per unit weight of the rock is not possible: it will always reflect either economic considerations or the situation of the technical culture, i.e., features that are not absolute" [16, p. 224]. In fact, OM content is first of all an industrial indicator (a simplified evaluation of fuels according to [49]) that cannot therefore serve as basis for a genetic classification.

In conclusion, it is hardly possible to reach universal agreement to the question of "obligatory" mineral content in oil shale by means of averaging the proposed numerical limits. If one establishes concrete limits for mineral content, some anomalously enriched or, on the contrary, containing less of OM layers of genetically and lithologically relatively uniform deposits should be excluded from this class of caustobioliths which seems to be artificial and unreasonable. For example, some parts of layers B and E of kukersite contain more than 65 % OM, whereas shale of layer IIa from the Lyuban deposit (Byelorussia), the kerogen of which is essentially identical to that of the neighbouring layers, contains less than 10 % OM.

While supporting the notion that oil shales represent an intermediate between dispersed OM and highly concentrated forms of fossil OM, we are still convinced that it is not appropriate to assign rigid numeric limits for the mineral content of oil shales. Neither researchers nor industrial workers will exclude from their sphere of interest specific types of rocks with dispersed OM, oil shales or sapropelitic coals, for the sole reason that the OM content of these samples falls into "the forbidden zone" for a given type of sedimentary rocks.

But this is not the main reason. For almost everybody working in the oil shale field, these caustobioliths are specific not so much in the quantity of their OM but rather in its composition. This aspect is characterized by several interdependent properties of shales such as significant yield of oil from its OM by semicoking, low level of its catagenetic transformation and enrichment in hydrogen.

High yield of semicoking oil from OM (even though usually without quantitative estimate) is recognized by the vast majority of investigators as one of the main distinctive features of oil shales. For shales of known deposits this value ranges from 20-70 %. Yield of oil from OM that is lower than 20 % is characteristic of combustible rocks of the humous type; from the OM of some brown coals, 20-25 % of oil is formed by semicoking. Apparently one can accept 20 % of oil from OM as an approximate minimal value for oil shales.

Apart from being an important industrial characteristic, the high yield of semicoking oil from OM is also an external reflection of the chemical composition and structure of the OM, of its specific internal peculiarities that are determined by the composition of the starting material and processes of its transformation. Therefore, this property is also a genetical characteristic of fossilized OM and can be regarded as an important diagnostic feature.

It is often indicated that the kerogen of oil shales has sapropelic origins. However, if 'sapropelic' is defined as organic material that has been formed under reducing, anaerobic conditions (according to the apparent contents of the term), a number of oil shales cannot be grouped with sapropelites (e.g. the Jurassic shales of Volga Basin and kukersite that were formed in the sea basin with normal oxygen levels, menilitic shales of the Carpathian region, the OM of which accumulated under semi-oxidative conditions).

Vassoyevich and co-authors note that the term 'sapropelic' has lost its meaning and recommend to base the classification on the predominant types of molecular structures, in this case aliphatic and nonaromatic cyclic; i.e., on specific chemical indicators. Unfortunately, the methods of quantitative determination of these structural elements in the OM have not been developed sufficiently; however, there is some evidence that the content of these groups in the OM correlates quite well with the yield of oil on semicoking [51, 52].

From these considerations it follows that before the term 'sapropelic' itself has been better specified, it is not appropriate to use it as a determining feature of oil shales. However, it is difficult to disagree with Kotlukov who wrote "carbonaceous argillites (shales) and liptobioliths of high mineral content should not be classified as true oil shales" [20]. In all cases, the main part of the kerogen of shales is a product of transformation of the OM synthesized by the aquatic organisms (aquagenic OM); this feature not only distinguishes it from the OM of humites that originate form the terrigenic OM, but in our opinion also basically determines the unique properties of the OM of oil shales. However, terrigenic OM is often present in oil shales as an additive; according to Dobryanski [16] the content of humous material in the OM of true oil shales should not exceed 25 %.

The peculiarities of the chemical composition of aquagenic OM are retained until a certain stage of catagenesis. The capacity of kerogen to produce significant quantities of liquid organic products under thermal decomposition is realized in mesocatagenesis under natural conditions and as a result, the OM of the shales loses one of its main differentiating features. (According to Gubkin, the oil shales are rocks that have not developed to the stage of production of petroleum [44].) During the late stages of catagenesis, the initial chemical differences in the organic starting materials are lost to a considerable degree [33]. The degree of catagenetic transformation of fossil coals has always been taken into account as a classifying parameter (such as the index of refraction of vitrinite, yield of volatiles, etc.).

It is practical to take this parameter into account in an analogous manner for oil shales as well, and to limit the range of use of the term 'oil shales' to the rocks that contain aquagenic OM the degree of transformation of which does not exceed early mesocatagenetic, i.e., that have not yet reached the phase of intensive generation of liquid hydrocarbons. With this definition, a group of "former" oil shales can be distinguished that to a significant extent have utilized their oil-producing potential. For example, shungites and other graphitoid shales belong to this group; the majority of investigators do not consider these to be oil shales.

It is quite apparent that the origin of the OM is reflected in its elemental composition. Because of the high hydrogen content in the starting, predominantly fatty material, the hydrogen content in the OM of oil shales is in the range of 7-10 % [20] and the atomic ratio of H/C is 1.2-2.0. According to Dobryanski [16], the atomic ratio of H/C of 1.4-1.5 is more typical for kerogens; Kein [27] proposes the ratio of 1.2-1.6. Karavayev [40] used this indicator as a classifying parameter and demonstrated that its value falls into the interval of 1.25-1.95 in all sapropelites and that the majority has H/C ratios of 1.5 or higher.

Thus, besides the yield of semicoking oil, the elemental composition of OM also represents an acceptable diagnostic indicator of oil shales. It must be noted that the yield of oil calculated for the OM correlates with the hydrogen content in the kerogen [53]; this is additional evidence justifying the use of high oil yield as a distinctive characteristic of oil shales.

Proceeding from the indices that the majority of specialists consider characteristic of oil shales and analyzing the diagnostic significance of each of these, this type of caustobioliths can be defined in a general manner as following: "Oil shale is a sedimentary rock containing organic matter of predominantly aquagenic origin, the degree of transformation of which does not exceed early mesocatagenetic, that has low solubility in low-boiling organic solvents but generates significant quantities of liquid organic products on thermal decomposition".

By defining oil shales as rocks containing OM that originates predominantly from aqueous organisms and has low degree of transformation (up to the long flame stage) in conjunction with low solubility and high yield of semicoking oil permits with sufficient certainty to differentiate oil shales and other combustible rocks*.

The above-mentioned definition is based on the properties of OM of oil shales as their more specific part. Oil shales are usually also characterized by their fine- or small-grained structure, the presence of some argillaceous material and other features which are, however, characteristic of not only shales and are therefore not diagnostic.

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* Since the definition of the term 'oil shale' is at the present time still under discussion, this book also contains data on some caustobioliths that according to the above-mentioned definition do not belong to oil shales by all their properties. However, from the actual data that characterize these combustible rocks, it is always possible to make a decision that corresponds to ones opinion.

When defining oil shales as an industrial raw material, it is necessary to introduce numerical indicators of quality that correspond to their manner of utilization, that change concurrently with technical progress but that are also dependent on the presence of resources of other raw materials. For example, if oil shales are used as fuel, their quality is determined foremost by their heat of combustion (at the present time not less than 1000-1500 kcal/kg or 4.2-6.3 MJ/kg); if used as raw materials for production of artificial liquid fuel - by the yield of semicoking oil (presently the minimum is 5-10 % of shale); as raw materials for the production of building materials, agrochemical products, etc. - by the requirements of the respective industries. These and similar characteristics of oil shales allow the estimation of their reserves for specific areas of utilization but cannot replace the general definition.

When defining the oil shales through the properties of their OM, it would seem to be appropriate to start from the term 'kerogen'. However, defining this type of caustobioliths as 'kerogenic (kerogen-containing) rocks' [1, 9, 54] is not sufficient, not as much because a number of authors define kerogen-containing rocks as the poorer varieties of oil shales (up to 10 % [47] or 15 % [5] OM), but rather because the term 'kerogen' itself is poorly defined and ambiguous. The vast majority of investigators working in the field of oil shales define kerogen as the lump OM of shales; however, for a number of scientists studying primarily dispersed OM, kerogen represents the nonsoluble in organic solvents part of fossil OM of any genetic type. Consequently, the use of this definition, that is attractive because of its brevity and closeness to traditional for mined rocks, in this particular case apparently leads to different interpretations of the contents of the term 'oil shales'.

To characterize the OM in shale we have used the content of so-called conditional organic mass [$100 - A^d - (CO_2)^d_M$] since the determination of the actual OM content in shales is difficult, especially because of the necessity of taking into account the water in crystal hydrates. For utilization of the general but also approximate formula of Krim [55] not sufficient data are available in most cases. Actually, for some oil shales (kukersite [56], Dictyonema shale of Estonia [57], Pripyat shale of Byelorussia [58], etc.) more accurate formulas for calculating the OM content have been developed; however, in the interests of comparability of the data, the content of conditional organic mass is presented for these as well. Since this indicator corresponds only approximately to the actual OM content, it is inevitable that some of the other indicators (that are determined by recalculation of the results of analysis per OM, such as elemental composition of OM, yield of semicoking products per OM, and others) are also approximate.

The part of the OM of shale that is soluble in low-boiling organic solvents is called bitumoid. This term was proposed by Vassoyevich in 1958 [59] and is preferred to the alternative 'bitumen' since it is unambiguous.

The designation of analytical indicators takes into account the corresponding standards wherever possible.

Chapter 1

COMPOSITION AND PROPERTIES OF OIL SHALES AND SHALE-LIKE ROCKS

Table 1. **General Characteristics of Oil Shales and Related Rocks**

No.	Oil shale (deposit, area)	Age	Analytical moisture, %	Per dry mass, wt.%			References
				Ash	CO_2 of carbonates	Conditional organic mass	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	Precambrian clayey (Estonia)	Vendic (Upper Precambrian)	1.5	92.7	0.7	6.6	60
2	Olenyek (Russia, Yakutia)	Cambrian	4.1	69.0	0.8	30.2	16
3	Kvarntorp (Sweden)	Upper Cambrian-Ordovician	1.4	79.0	1.0	20.0	22
4	Dictyonema (Estonia, Maardu)	Lower Ordovician	1.0	79.2	0.2	20.6	61, 62
5	Dictyonema (Estonia, Aseri)	Lower Ordovician	1.8	79.1	0.3	20.6	63
6	Dictyonema (Estonia, Toolse)	Lower Ordovician	1.3	80.5	0.1	19.4	61, 63
7	Kukersite (Estonia)	Middle Ordovician	0.5	46.5	18.0	35.5	64-66
8	Tetraspis (Estonia)	Upper Ordovician	3.4	79.0	5.8	15.2	67
9	Ashinsk (Russia, Bashkiria)	Middle Devonian	0.4	69.7	15.5	14.8	68
10	Turovo (Byelorussia)	Upper Devonian	2.3	70.1	12.7	17.2	69
11	Lyuban (Byelorussia)	Upper Devonian	1.0	71.1	17.2	11.7	70
12	Ukhta (Russia, Komyi)	Upper Devonian	1.0	76.4	13.0	10.6	71
13	Chernozatonsk (Kazakhstan)	Upper Devonian	6.1	36.2	9.8	54.0	72
14	Lemeza (Russia, Bashkiria)	Upper Devonian	4.9	72.1	0.2	27.7	73
15	Selenyakh (Russia, Yakutia)	Devonian	0.4	53.7	34.4	11.9	74
16	Antrim (USA)	Devonian	–	82.6	0.7	16.7	75
17	Westwood (Geat Britain, Scotland)	Lower Carboniferous	2.6	77.8	3.2	19.0	19, 76
18	New Glasgow (Canada)	Lower Carboniferous	–	76.9	4.3	18.8	19
19	Nova Scotia (Canada)	Lower Carboniferous	–	62.4	3.2	34.4	77
20	Ermelo (South Africa)	Lower Carboniferous	–	44.0	1.8	54.2	76, 78
21	Kenderlyk, the Kalyn-Kara seam (Kazakhstan)	Upper Carboniferous	3.4	51.6	Absent	48.4	79
22	Kenderlyk, the Karaungur seam (Kazakhstan)	Lower Permian	1.0	76.4	1.9	21.7	79

1	2	3	4	5	6	7	8
23	Kenderlyk, the Saikan seam (Kazakhstan)	Lower Permian	2.9	77.2	0.8	22.0	79
24	Ust-Kamenogorsk (Kazakhstan)	Carboniferous-Permian	0.8	74.0	3.2	22.8	80
25	Pashin (Russia, Perm District)	Carboniferous-Permian	2.8	73.4	0.1	26.5	16
26	Glen Davis (Australia)	Carboniferous-Permian	–	51.6	Absent	48.4	22, 78
27	Puertollano (Spain)	Carboniferous-Permian	–	63.0	2.0	35.0	78, 81
28	Irati (Brazil)	Carboniferous-Permian	5.4	64.2	1.8	34.0	19
29	Otain (France)	Permian	–	73.7	6.5	19.8	19
30	St.-Hilaire (France)	Permian	–	66.3	3.4	25.3	19
31	Cerro Largo (Uruguay)	Permian	–	78.4	Absent	21.6	19
32	Verkhnetutonchansk (Russia, Krasnoyarsk District)	Upper Permian	1.2	31.2	5.5	63.3	82
33	Omolon, Astronomicheskaya River region (Russia, Magadan District)	Lower Triassic	1.5	78.3	0.2	21.5	83
34	Omolon, Levyi Kedon River region (Russia, Magadan District)	Middle Triassic	1.4	82.2	0.2	17.6	83
35	Bogoslov, seam II (Russia, Yekaterinburg District)	Triassic-Jurassic	6.2	36.1	3.0	60.9	16
36	Alyouisk (Russia, Irkutsk District)	Jurassic	7.3	60.8	0.3	38.9	84, 85
37	Budagovo, the true sapropelite (Russia, Irkutsk District)	Jurassic	2.4	9.8	1.0	89.2	86-88
38	Budagovo, humic sapropelite (Russia, Irkutsk District)	Jurassic	9.5	28.5	2.9	68.6	87, 88
39	Budagovo, humic sapropelite (Russia, Irkutsk District)	Jurassic	10.1	52.0	5.2	42.8	86-88
40	Bouinsk (Russia, Tatarstan)	Jurassic	–	65.0	11.0	24.0	89
41	Voronye-Voloskovsk (Russia, Vyatka District)	Jurassic	–	75.3	4.6	20.1	89, 90
42	Würtenberg (Germany)	Jurassic	4.0	70.8	19.7	9.5	19
43	Sysol, Ibsk deposit (Russia, Komyi)	Jurassic	–	72.7	5.9	21.4	91, 92
44	Kashpir (Russia, the Volga oil shale basin)	Jurassic	6.9	58.2	11.3	30.5	93, 94
45	Kimmeridge (Great Britain, England)	Jurassic	3.0	37.7	2.5	59.8	19, 95
46	Levosviyazh (Russia, Tatarstan)	Jurassic	6.9	68.3	8.3	23.4	16
47	Manturovo (Russia, Nyzni Novgorod District)	Jurassic	–	57.3	3.5	39.2	16
48	Obshchiĭ Syrt, seam P_3A (Russia, the Volga oil shale basin)	Jurassic	–	56.2	10.0	33.8	96
49	Perelyub-Blagodatsk (Russia, the Volga oil shale basin)	Jurassic	2.7	47.2	7.2	45.6	97
50	Simbirsk (Russia, the Volga oil shale basin)	Jurassic	–	62.0	6.1	31.9	16
51	Kharanor (Russia, Chita District)	Jurassic	2.7	76.4	Absent	23.6	98
52	Khakhareisk, boghead (Russia, Irkutsk District)	Jurassic	4.8	17.3	–	82.7	99
53	Khakhareisk, oil shale (Russia, Irkutsk District)	Jurassic	8.2	43.9	–	56.1	99
54	Chagan (Russia, Orenburg District)	Jurassic	2.9	35.7	7.6	56.7	100, 101
55	Sysol, Poingsk region (Russia, Komyi)	Jurassic	9.4	66.8	5.3	27.9	102
56	Savelyev (Russia, the Volga oil shale basin)	Jurassic	–	61.4	10.8	27.8	103

Table 1. General Characteristics of Oil Shales and Related Rocks (end)

No.	Oil shale (deposit, area)	Age	Analytical moisture, %	Per dry mass, wt.%			References
				Ash	CO_2 of carbonates	Conditional organic mass	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
57	Yarenga (Russia, Komyi)	Jurassic	5.6	22.4	1.6	76.0	104
58	Nebi Musa (Jordan)	Cretaceous	1.5	63.1	14.9	22.0	53, 105
59	Olenyek, boghead (Russia, Jakutia)	Cretaceous	–	3.1	Absent	96.9	106
60	Timahdit (Morocco)	Cretaceous	6.0	68.8	8.1	23.1	53, 81, 107
61	Um-Barek (Israel)	Cretaceous	–	57.2	18.1	24.7	19
62	Efyie (Israel)	Cretaceous	–	56.1	20.0	23.9	19, 108, 109
63	Baisun (Uzbekistan)	Tertiary (Lower Eocene)	2.6	55.2	6.8	38.0	110
64	Eastern Chandyr (Uzbekistan)	Lower Eocene	2.7	66.1	15.1	18.8	111
65	Eastern Urtabulak (Uzbekistan)	Lower Eocene	3.2	53.9	6.3	39.8	111
66	Kapali (Uzbekistan)	Lower Eocene	2.5	60.1	10.2	29.7	112
67	Kultak-Zevardy (Uzbekistan)	Lower Eocene	2.8	62.6	14.6	22.8	111
68	Pamuk (Uzbekistan)	Lower Eocene	2.2	63.7	20.7	15.6	111
69	Sangruntau (Uzbekistan)	Lower Eocene	–	74.8	1.3	23.9	113
70	Todinsk (Uzbekistan)	Lower Eocene	2.5	65.7	6.5	27.8	114
71	Shurasan (Uzbekistan)	Lower Eocene	–	63.2	27.3	9.5	115
72	Bulgary (Tadjikistan)	Lower Eocene	–	62.8	8.1	29.1	53
73	Garibak (Tadjikistan)	Lower Eocene	5.8	51.2	0.2	48.6	116
74	Kulyiali (Tadjikistan)	Lower Eocene	8.0	77.3	0.1	22.6	116
75	Lyangar (Tadjikistan)	Lower Eocene	6.3	88.6	0.1	11.3	116
76	Tereklitau (Tadjikistan)	Lower Eocene	4.6	75.9	7.7	16.4	117
77	Yarmuk (Syria)	Lower Eocene	–	59.5	35.1	5.4	118
78	Boltysh (Ukraine)	Eocene	–	61.5	3.6	34.9	92, 119
79	Green River, Rifle, Colorado (USA)	Eocene	0.4	60.3	19.1	20.6	26, 75, 120
80	Green River, Utah (USA)	Eocene	–	61.6	19.0	19.4	75
81	Borov Dol (Bulgaria)	Upper Eocene	3.0	77.0	3.3	19.7	121

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
82	Pirin (Bulgaria)	Upper Eocene	2.8	60.9	4.6	34.5	121
83	Mandra (Bulgaria)	Eocene-Oligocene	0.8	58.7	13.6	27.7	121
84	Menilitic (Ukraine)	Paleogene	2.1	79.6	0.5	19.9	73, 122
85	Gurkovo (Bulgaria)	Paleogene	3.8	83.3	5.9	10.8	121, 123
86	Krasava (Bulgaria)	Paleogene	1.5	75.5	13.6	10.9	121
87	Koprinka (Bulgaria)	Paleogene	2.9	83.5	1.1	15.6	124
88	Novodmitrovo (Ukraine)	Paleogene-Neogene	4.5	74.1	4.8	21.1	125
89	Nevada (USA)	Paleogene-Neogene	–	46.2	0.6	53.2	18
90	Orepuki (New Zealand)	Paleogene-Neogene	–	32.7	1.7	65.6	19
91	Condor (Australia)	Paleogene-Neogene	–	64.5	2.5	33.0	126, 127
92	Aleksinac (Yugoslavia)	Paleogene-Neogene	3.0	79.0	2.8	18.2	77, 123, 128
93	Mae Sot (Thailand)	Neogene	–	68.0	11.0	21.0	19, 81, 129
94	Pula (Hungary)	Neogene	5.8	56.0	10.8	33.2	130
95	Tremembé-Taubaté paper shale (Brasil)	Neogene	–	60.3	0.2	39.5	77, 131
96	Tremembé-Taubaté lumpy shale (Brasil)	Neogene	–	82.3	0.3	17.4	77, 131
97	Guandun (China)	Neogene	–	72.1	2.0	25.9	132
98	Huadian (China)	Neogene	–	73.7	6.0	20.3	132
99	Fu Shun (China)	Neogene	5.0	75.4	3.4	21.2	22, 133
100	Maomin (China)	Neogene	–	73.4	1.4	25.2	133, 134

* By difference $(100 - A^d - (CO_2)^d_m)$.

Table 2. **Sulphur Content of Oil Shales, % on the Dry Mass**

Number of shale from Table 1	Total*	Pyritic	Sulphates	References
1	0.1	–	–	60
2	0.9	–	–	135
3	5.3	–	–	22
4	2.5	1.7	0.3	136
5	5.1	3.6	1.2	136
6	5.9	4.2	1.3	136
7	1.7	1.1	0.1	64, 65
9	2.2	–	–	68
10	2.6	–	–	69
11	1.2	0.8	–	70
12	0.4	–	–	71
13	5.1	1.2	1.2	92
14	1.9	–	–	73
16	3.2	–	–	75
17	0.7	–	–	76
18	0.7	–	–	76
20	1.0	–	–	78
21	0.9 (0.3)	0.1	0.4	79, 92
22	0.7 (0.3)	0.1	–	79
23	0.4 (0.1)	0.2	–	79
25	0.2	–	–	16
26	0.4	–	–	120
27	1.0	–	–	78, 81
28	2.0	–	–	22, 81
29	0.8	–	–	120
30	2.3	–	–	137
31	3.1	–	–	138
32	0.8	–	–	82
33	0.7	–	–	83
34	1.2	–	–	83
35	4.2	–	–	16
36	1.0	–	–	84
37	0.6	–	–	87, 88
38	0.5	–	–	87, 88
39	0.5	–	–	87, 88
40	8.0	–	–	89
41	1.7	–	–	90
42	2.7	1.7	0.1	139
43	3.2	0.8	0.3	92
44	5.0	0.8	0.6	92, 93
45	6.6	–	–	19
46	6.2	–	–	16
47	4.6	–	–	16
48	4.5	0.3	0.2	96
49	5.8	2.2	0.2	94, 140
50	3.8	1.9	0.1	16
51	0.4	–	–	98
52	0.4	–	–	99
53	0.8	–	–	99
54	8.3 (0.3)	1.9	0.1	101
55	2.5	–	–	102
56	3.9	–	–	103
57	7.9 (0.1)	2.8	0.8	104
58	3.7	–	–	53
60	0.5	–	–	106
61	6.2	–	–	131

Table 2. Sulphur Content of Oil Shales, % on the Dry Mass (end)

Number of shale from Table 1	Total*	Pyritic	Sulphates	References
63	5.1	3.1	0.1	16, 110
64	3.0	–	–	111
65	6.6	2.8	–	99
66	6.1	3.3	0.7	112
67	3.2	–	–	111
68	2.6	–	–	111
69	4.6	–	–	113
70	3.3	–	–	114
71	2.1	–	–	115
72	6.6	–	–	53
73	2.4	0.2	–	116
74	1.8	0.4	–	116
75	0.8	0.2	–	116
77	1.1	–	–	118
78	1.1	0.4	0.3	92
79	0.8	0.5	Traces	75, 120
80	1.1	0.4	0.1	16
81	1.9	1.0	–	121
82	2.2	1.0	–	121
83	2.6	1.8	–	121
84	2.1	0.9	–	122
85	0.6	0.3	–	121
86	0.8	0.6	–	121
87	0.9	0.7	–	124
88	4.6	–	–	125
89	4.9	3.6	0.4	16
90	0.6	–	–	131
92	2.8	–	–	123
93	0.9	–	–	81
95	0.2	–	–	77
96	0.3	–	–	77
99	0.5	–	–	22
100	1.1	–	–	141

* In brackets data on elemental sulphur are given.

Table 3. **Elemental Composition of Kerogen**

Number of shale from Table 1	Content, %					Atomic ratio H/C	References
	C	H	S	N	O (by difference)		
2	73.0	8.1	3.0	1.6	14.3	1.33	16, 131, 142
3	68.7	7.2	4.5	0.8	18.8	1.26	18, 22
4	70.5	7.4	4.2	2.5	15.4	1.26	61, 103
6	69.0	7.6	3.2	2.1	18.1	1.32	61
7	77.3	9.8	1.7	0.4	10.8	1.52	22, 143
8	64.5	8.7	26.8			1.62	144
9	72.7	8.8	7.4	2.1	9.0	1.45	68, 131
10	61.5	9.9	2.5	0.8	25.3	1.93	69, 89, 145
11	79.6	11.5	3.8	0.6	4.5	1.73	70
12	75.1	7.6	1.9	15.4		1.21	71
13	65.8	7.0	7.3	0.8	19.1	1.28	72, 92, 131
14	67.7	6.3	–	2.1	23.9	1.12	73
16	58.6	7.1	34.3			1.45	75
17	77.8	8.1	1.2	2.6	10.3	1.25	95
20	79.9	8.8	1.0	1.3	9.0	1.32	78, 131, 146
21	72.0	7.9	1.0	1.8	17.3	1.32	79, 92
22	75.6	10.7	1.4	2.2	10.1	1.70	79
23	70.6	9.8	0.5	3.5	15.6	1.67	79
24	77.6	7.5	1.0	2.5	11.4	1.16	80
25	58.0	9.4	0.5	0.6	31.5	1.94	16
26	83.0	10.3	1.0	0.7	5.0	1.49	146-148
28	68.1	10.3	3.7	1.6	16.3	1.81	22
29	72.4	9.8	3.4	2.4	12.0	1.62	19
30	85.6	8.0	1.1	1.3	4.0	1.12	149
31	61.9	7.1	–	1.0	30.0 (O + S)	1.38	19
32	71.5	8.5	–	1.9	18.1 (O + S)	1.43	82
33	60.8	6.7	–	2.9	29.6 (O + S)	1.32	83
34	57.8	6.6	–	3.5	32.1 (O + S)	1.37	83
35	57.2	8.1	–	1.4	33.3 (O + S)	1.70	16
36	69.1	10.9	0.8	1.7	17.5	1.89	85, 150
37	79.5	10.2	0.7	1.4	8.2	1.54	86-88
38	71.3	5.7	0.8	1.5	20.7	0.96	86-88
39	67.0	8.9	0.9	1.8	21.4	1.59	86-88
40	61.3	7.3	4.3	26.7		1.43	65
41	63.0	8.0	6.3	2.1	20.6	1.52	90, 131
42	81.8	8.9	0.6	1.5	7.2	1.31	131, 139
43	63.8	8.6	5.8	1.6	20.2	1.62	91, 92
44	67.1	8.0	10.2	1.2	13.5	1.43	93
45	72.4	7.9	–	2.0	17.7 (O + S)	1.31	19
46	61.8	7.0	31.2			1.36	16
47	60.6	7.9	5.6	1.9	24.0	1.56	16
48	61.1	7.6	10.4	0.8	20.1	1.49	96, 151
49	73.5	8.9	6.4	1.6	9.6	1.45	97
50	60.8	6.7	5.0	1.3	26.2	1.32	16, 131
52	74.6	8.9	16.5			1.43	99
53	69.2	6.2	24.6			1.08	99
54	68.6	8.0	8.3	1.1	14.0	1.40	92, 100, 152
55	57.5	7.0	2.8	2.0	30.7	1.46	153
56	62.2	7.0	5.7	25.1		1.35	103
57	70.4	7.9	5.5	1.5	14.7	1.35	104
58	75.4	10.0	7.0	7.6		1.59	105
59	81.6	11.1	0.5	0.8	6.0	1.63	154
60	68.9	8.5	7.0	3.0	12.6	1.48	75, 107
62	64.9	8.0	9.1	2.8	15.2	1.48	108

Table 3. Elemental Composition of Kerogen (end)

Number of shale from Table 1	Content, %					Atomic ratio H/C	References
	C	H	S	N	O (by difference)		
63	65.0	7.7	5.3	2.2	19.8	1.42	22, 131
64	66.2	6.5	–	2.5	24.8 (O + S)	1.18	111
65	68.9	7.7	–	3.1	20.3 (O + S)	1.34	99
66	58.2	6.0	4.1	2.6	29.1	1.24	112
67	68.9	6.9	–	2.8	21.4 (O + S)	1.20	111
68	67.5	6.4	–	3.5	22.6 (O + S)	1.14	111
70	62.3	7.6	–	2.8	27.3 (O + S)	1.46	114
72	77.0	7.4	4.3	2.4	8.9	1.15	155
73	61.2	5.7	2.3	1.1	29.7	1.12	116
76	66.5	7.8	–	2.6	23.1 (O + S)	1.41	117
78	71.8	9.9	1.3	1.6	15.4	1.65	92, 119, 156
79	80.2	10.1	1.5	2.6	5.6	1.51	157, 158
80	78.3	9.9	1.6	2.1	8.1	1.52	75, 148, 149
81	74.9	8.5	4.8	1.7	10.1	1.36	121
82	71.1	7.9	3.0	2.0	16.0	1.33	121
83	77.2	10.4	2.6	1.0	8.8	1.62	121
84	65.2	6.5	2.3	1.1	24.9	1.20	122, 131
85	72.1	8.2	3.5	1.9	14.3	1.36	121
86	71.4	8.5	3.2	1.7	15.2	1.43	121, 159
87	76.3	8.5	0.9	1.6	12.7	1.34	124
88	68.4	8.8	1.5	1.7	19.6	1.54	92, 125
89	82.4	8.2	4.3	1.6	3.5	1.19	149
92	75.7	9.3	–	2.1	12.9 (O + S)	1.47	128, 131
93	71.2	9.8	–	0.4	18.6 (O + S)	1.65	147, 160
94	71.8	10.1	1.9	0.8	15.4	1.69	130
95	67.9	10.4	3.7	1.6	16.4	1.84	77
96	53.9	9.0	5.2	2.8	29.1	2.00	77
97	59.8	8.5	4.6	2.3	24.8	1.71	132
98	60.1	9.9	3.9	1.5	24.6	1.98	132
99	73.7	9.9	2.4	3.0	11.0	1.61	131-133
100	67.0	9.6	2.8	1.6	19.0	1.72	133, 134, 141

Table 4. **Chemical Composition of the Mineral Part of Oil Shales, wt.%**

Number of shale from Table 1	SiO_2 (1)	Al_2O_3 (2)	Fe_2O_3 (3)	TiO_2 (4)	CaO (5)	MgO (6)	SO_3 (7)	K_2O (8)	Na_2O (9)	P_2O_5 (10)	Total of (1)-(10)	References
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
3	61.5	17.3	10.5	–	1.2	1.7	1.3	6.3	0.2	–	100.0	19, 131
4	61.1	15.4	0.6	0.7	0.9	1.6	1.1	8.8	0.7	0.2	91.1	137, 161
6	63.9	12.0	0.8	1.0	1.0	1.0	2.3	5.6	0.1	–	87.7	162
7	31.0	8.2	5.9	0.5	39.5	4.8	5.0	4.2	0.3	0.1	99.5	22, 65, 131
9	61.9	0.9	3.9	–	18.3	10.0	4.3	–	–	0.1	99.4	68
10	41.3	13.0	6.8	0.7	21.8	3.2	7.5	4.0	0.3	0.3	98.9	69, 89
11	36.8	16.0		–	29.4	2.0	5.0	–	–	–	89.2	163
12	66.4	4.5	1.5	–	22.8	1.3	1.6	1.0		0.4	99.5	16, 164
17	54.5	24.6	9.7	1.3	2.6	3.0	0.9	2.5	0.9	–	100.0	19, 95
18	59.5	23.6	8.5	–	3.1	1.8	0.7	2.3	0.5	–	100.0	19, 95
19	61.1	30.1	5.0	–	1.1	1.0	–	1.1	–	–	99.4	77, 131
20	61.2	30.5	2.9	–	1.6	1.7	–	2.1	–	–	100.0	77, 131
21	70.0	15.6 (+ TiO_2)	7.0	–	1.4	1.5	0.6	1.6	2.3	–	100.0	165
22	60.2	14.3 (+ TiO_2)	5.5	–	6.8	3.2	1.6	2.2	6.2	–	100.0	165
24	57.2	24.6		–	4.9	2.9	2.5	7.2		–	99.3	163
25	53.3	39.6	4.7	–	1.0	–	–	–	–	0.2	98.8	16
26	86.1	7.5	2.0	–	0.7	0.5	–	3.2	–	–	100.0	22, 78, 131
27	55.7	27.2	9.0	–	2.6	2.2	0.5	2.5	0.3	–	100.0	131
28	61.9	21.0	10.2	–	2.2	2.4	0.7	0.03	1.6	–	100.0	19, 22
29	54.1	20.1	6.9	–	9.3	3.7	1.3	2.2	2.4	–	100.0	19
30	47.0	18.3	7.6	–	17.8	3.5	0.4	1.7	0.5	–	96.8	19
31	66.8	14.5	10.7	–	0.6	1.5	1.5	3.0	0.6	–	99.2	138
38	67.2	9.9	6.1	–	9.5	2.4	–	–	0.2	–	95.3	88
40	36.2	12.7	9.5	–	26.0	2.1	11.3	–	–	0.8	98.6	89
41	58.8	19.4	6.2	–	6.3	2.4	4.5	–	–	–	97.6	89
42	36.2	12.2	5.9	–	32.8	2.2	4.0	1.8	0.7	0.2	96.0	131, 139
44	39.8	11.1	6.2	0.5	25.4	1.7	11.0	1.8	1.5	1.0	100.0	22, 131
45	54.1	18.2	9.5	0.9	6.6	1.3	3.4	–	–	–	94.0	95
47	56.5	9.1	11.8	–	3.9	2.8	5.7	–	–	1.8	91.6	16

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
48	38.3	14.5	5.3	0.7	25.0	1.7	8.2	2.6	3.1	0.6	100.0	96, 151
54	38.0	11.0	9.4	0.6	35.0	2.0	–	4.0		–	100.0	152
58	7.0	7.5	7.5	–	76.6	1.4	–	–	–	–	100.0	131, 138
60	46.2	10.3		–	11.8	1.2	–	–	–	–	69.5	138
61	10.4	2.5	3.6	–	27.6	10.0	1.0	–	–	2.5	57.6	19
62	10.0	2.0	0.9	0.2	47.6	0.8	1.2	0.4	0.3	4.6	68.0	108
63	40.2	15.5	11.1	–	16.6	2.4	9.5	–	–	1.5	96.8	22
65	34.7	19.6		–	23.6	3.1	11.8	7.1		–	99.9	163
66	–	–	–	0.3	–	–	3.4	1.5	–	1.2	–	112
69	54.8	21.9		–	12.3	3.2	6.2	1.6		–	100.0	163
70	–	–	–	–	–	–	–	1.4	–	2.5	–	114
71	19.2	12.4		–	57.3	2.3	5.1	1.1		–	97.4	115
76	47.3	11.5	12.9	0.5	9.6	2.4	9.6	4.6		1.2	99.6	117
77	5.9	0.6	0.3	–	46.2	1.0	–	0.03	0.01	2.9	56.9	166
78	57.5	19.4	6.6	0.1	7.1	2.1	2.9	1.2	0.9	–	97.8	22
79	43.0	12.0	4.6	0.8	21.7	9.1	2.2	2.9	3.3	0.4	100.0	120, 157
80	50.4	20.9		–	14.8	6.0	–	–	–	–	92.1	131
81	48.0	8.3	11.6	–	16.0	2.7	13.4	–	–	–	100.0	167
82	70.4	17.9	5.5	–	1.9	1.7	2.6	–	–	–	100.0	167
83	73.5				17.4	4.3	0.3	0.5	0.2	–	96.2	168
84	70.7	15.1	6.9	–	1.8	1.1	0.9	2.0	1.5	–	100.0	131, 161
85	54.5	22.4	7.1	–	8.8	1.4	5.8	–	–	–	100.0	167
86	58.5	14.6	4.7	0.8	8.6	2.6	7.4	1.9	0.9	–	100.0	167, 169
88	66.5	16.7	9.4	–	1.5	0.1	1.1	4.7	–	–	100.0	131
89	65.5	25.5		–	0.6	0.8	–	–	–	–	92.4	16
90	44.0	28.0	20.5	–	4.6	1.4	0.1	0.7	0.7	–	100.0	19, 131
91	68.8	17.3	8.9	0.9	0.8	1.4	–	1.0	0.5	0.3	99.9	170
92	41.6	13.3	11.2	–	22.6	3.6	5.7	1.6		–	99.6	128
93	60.8	19.9	4.8	–	3.3	3.8	–	–	–	–	92.6	131
94	49.0	13.5	–	–	24.5	–	–	–	–	–	87.0	171
95	58.0	24.4	8.5	–	2.6	3.3	1.4	–	–	–	98.2	19
96	55.6	24.8	9.5	–	3.1	3.8	0.5	–	–	–	97.3	19
97	56.2	26.5	10.8	–	0.9	1.7	–	3.9	–	–	100.0	131, 132
98	55.7	17.9	8.4	–	7.8	1.7	–	–	–	–	91.5	132
99	61.1	24.7	8.3	–	1.2	1.7	–	3.0	–	–	100.0	131, 132

Table 5. **The Content of Some Elements in Oil Shales, g/t**

Number of shale from Table 1	V	Mo	Ni	Cr	Co	Cu	Sr
4	470	84	–	65	12	–	–
6	800	434	245	–	23	145	87.0
7	28	3	21	38	3	17	151
10	5-500	1-10	5-50	5-500	5-50	5-50	10-500
28	40	3	68	90	19	45	300
36	10-30	Traces	10-30	–	–	10-30	–
38	20	1	60	400	20	–	300
41	100	10-100	–	–	–	–	–
42	100-515	4-30	30-219	42-118	7-35	–	–
44	7-200	50-300	100-300	1-30	10-100	10	Up to 1000
49	50	15	35	37	–	71	–
60	150	–	360	–	–	–	–
62	110	26	138	280	5	112	–
63	1000-3000	1000-10000	100-300	100-300	10-30	30-100	100-300
66	2350	1200	–	–	–	–	–
70	3750	1600	–	–	–	–	–
77	100-250	10-25	100-200	150-300	3-4	80-100	998-1104
78	12	6	10	10	–	8	150
79	80-110	27	24-70	170	–	44	580-760
84	100-1000	10-100	--	10-100	–	–	–
88	10-100	–	10-30	30-100	10-100	10-300	100-300

Table 5. The Content of Some Elements in Oil Shales, g/t (end)

Number of shale from Table 1	Zr	Pb	Ba	Others	Analyzed sample	References
4	–	–	330	Ti 5400, Rb 210	Oil shale	172
6	172	–	–	Rb 94, Y 11.4, Hg 0.8, Th traces	Oil shale	162, 173
7	49	24	140	Rb 39, Zn 49, As 8	Oil shale	174
10	5-50	5-100	5-500	Mn 100-5000	Ash	69
28	160	20	580	La 92, Y 26, Ca 19	Oil shale	175
36	100	–	–	B 30	Ash 450 °C	85
38	–	3000	300	Zn 400, Sn 200, La 200	Ash	88
41	–	–	–	Ti 1000-10000, Ga 10-100	Ash	89
42	–	–	–		Oil shale	139, 146
44	100-300	–	–	P 3000, Nb 10	Ash	131, 176
49	–	7	–		Oil shale	177
60	–	–	–	Ti 3300	Oil shale	178
62	38	10	250	Zn 310, Mn 41, Y 39, U 27	Oil shale	108
63	30-100	30	300-3000	Y 10-100, Be 30	Ash	89
66	–	–	233		Oil shale	112
70	–	–	–		Oil shale	114
77	60	67-174	200-300	Ti 800-1500, Zn 60-200	Oil shale	118
78	140	–	120	Ti 500, Mn 100, Zn 100	Oil shale	161
79	33	27-100	300	Ti 1200, Mn 420, Zn 70, U 5.4	Oil shale	120, 179, 180
84	10-100	100	–	Be 10-100, Ga 10-100	Ash	89
88	10-100	10-30	300-3000	Be 10-100, Ga 30-100	Ash	89

Table 6. **Mineralogical Composition of Inorganic Part of Oil Shales, %**

Number of shale from Table 1	Argillaceous minerals	Amorphic SiO_2 and quartz	Feldspars	Carbonates	Sulphates	Pyrite	Others	References
3	–	42-46	–	–	–	–	–	18
6	49	20	30	–	–	1	–	181
7	5.0	8.5	8.5	65.9	0.8	3.1	–	143
17	54.7	26.5	–	7.9	0.3	0.6	–	76
20	29.5	50.1	5.1	3.5	0.2	2.0	–	182
29	17.4	32.4	–	37.3	1.1	0.7	–	18
32	27.4	19.2	–	49.5	–	3.9	–	82
42	31.0	16.5	–	46.5	0.5	5.0	Kaolin 12.8	18, 139
44	60.0		–	35.4	4.0	5.0	Phosphates 1.3	176, 183
45	20.7	39.0	5.7	3.5	8.6	4.6	–	76
48	66.0		–	27.6	4.8	–	Phosphates 1.7	176
55	58.6	10.8	5.7	21.1	–	3.8	–	102
62	20.3	3.9	–	81.6	–	–	Kaolin 1.0	109
77	3	5	Traces	83	–	0.3	Francolite 9	166
79	13	13	21	48	–	1	Analcime 4	26, 184, 185
81	–	34.8		31.7	2.7	–	Kaolin 13.1	167
82	–	54.6		0.3	1.2	–	Kaolin 25.4	167
85	–	50.9		12.4	0.2	–	Kaolin 33.4	167
86	–	48.4		18.4	0.6	–	Kaolin 21.6	167
96	60-70		–	10	–	–	–	22

Chapter 2

BITUMOIDS OF OIL SHALES

Table 7. **Yield of Bitumoids from Oil Shales**

Number of shale from Table 1	Solvent*[1]	Yield, %		Refeences
		per dry oil shale	per conditional organic mass	
1*[2]	B : M (3 : 1); E	0.045	0.68	60
2	B : M (3 : 1); E	0.58; 0.05	1.92; 0.17	135
4	B : M (3 : 1); E	0.60; 0.03	3.36; 0.17	63
5	B : M (3 : 1); E	1.32; 0.10	6.41; 0.49	63
6	B : M (3 : 1); E	0.59; 0.08	3.24; 0.44	63
7*[2]	B : M (1 : 1)	0.27	0.71	186
8*[2]	Cl; B : M (3 : 1)	0.34; 0.36	1.75; 1.85	67
10*[2]	Cl; B : C_2H_5OH (2 : 1)	0.26; 0.38	1.60; 2.35	187
11	B : M (3 : 1); E	0.44	3.56	70
12	B : M (3 : 1); E	2.27; 0.08	21.42; 0.78	71
15	Cl	0.48	4.1	188
21*[2]	Cl; B : M (3 : 1)	1.40; 1.94	2.9; 4.0	79
22*[2]	Cl; B : M (3 : 1)	0.52; 0.11	2.4; 0.5	79
23*[2]	Cl; B : M (3 : 1)	0.18; 0.13	0.8; 0.6	79
24	B : M (3 : 1); E	0.52	2.3	80
26	B	1.2	2.48	148
29	B	0.53	2.68	148
32*[2]	Cl; B : M (3 : 1)	1.84; 1.01	2.9; 1.6	82
33	B : M (3 : 1); E	1.35; 0.01	6.28; 0.05	83
34	B : M (3 : 1); E	1.10; 0.02	6.25; 0.11	83
37	B : M (3 : 1); E	3.4	3.9	80
39	B : M (3 : 1); E	2.7	6.3	80
44	B : M (3 : 1)	0.78	2.76	93
54*[2]	Cl; B : M (3 : 1)	0.62; 0.46	1.1; 0.8	101
55*[2]	Cl; B : M (3 : 1)	0.39; 0.20	1.4; 0.7	153
57*[2]	Cl; B : M (3 : 1)	0.35; 1.64	0.46; 2.17	104
59	B : M (3 : 1); E	1.93; 0.27	1.98; 0.28	154
60	Cl	1.0	4.33	178

Table 7. Yield of Bitumoids from Oil Shales (end)

Number of shale from Table 1	Solvent[*1]	Yield, %		Refeences
		per dry oil shale	per conditional organic mass	
63	B : M (3 : 1); E	3.68; 0.17	9.68; 0.45	110
64	B : M (3 : 1); E	2.36; 0.25	12.55; 1.33	111
65	B : M (3 : 1); E	3.66; 0.17	9.20; 0.42	111
66	B : M (3 : 1); E	1.57	5.29	112
67	B : M (3 : 1); E	2.74; 0.10	12.01; 0.44	111
68	B : M (3 : 1); E	1.67; 0.06	10.71; 0.39	111
70	B : M (3 : 1); E	2.42	8.71	114
72	B : M (3 : 2)	2.65	9.1	155
73	B : M (3 : 1); E	6.13; 0.18	12.67; 0.37	116
74	B : M (3 : 1); E	1.61; 0.02	7.12; 0.09	116
75	B : M (3 : 1); E	0.71; 0.01	6.28; 0.09	116
78	B : M (1 : 1)	1.33	3.81	119
79[*3]	B; Cl; CS_2; CCl_4	2.23; 2.41; 2.76; 2.04	10.8; 11.7; 13.4; 9.9	16, 26
80[*3]	B; Cl; CS_2; CCl_4	0.94; 1.05; 0.76; 0.74	4.8; 5.4; 3.9; 3.8	16
81[*2]	Cl; B : M (3 : 1)	0.43; 1.05	2.1; 5.2	189
82	B : M (3 : 1)	1.0	2.9	190
83[*3]	Cl; *n*-hexane	0.54; 0.31	1.6; 1.12	191, 192
84[*2]	Cl; B : M (3 : 1)	0.38; 0.63	1.9; 3.2	122
85	B : M (3 : 1); acetone	0.22; 0.22	2.0; 2.0	192
86[*2]	Cl; B : M (3 : 1)	2.46; 0.58	5.5; 1.3	193
87	B : M (3 : 1); acetone	0.65; 0.13	4.15; 0.85	192
88	B : M (3 : 1); E	1.77; 0.02	8.39; 0.10	125
92[*3]	B; Cl; E; M	0.49; 0.57; 0.37; 0.66	2.32; 2.72; 1.78; 3.15	194
94	Cl; B : acetone : M	0.83; 0.32	2.51; 0.97	195

Notes: [*1] B - benzene, M - methanol, Cl - chloroform, E - diethyl ether.

[*2] Before separation of the bitumoid with the mixture of benzene : alcohol, the shale was treated with the 10 % hydrochloric acid.

[*3] A new sample of oil shale was used for extraction with every solvent. In all other cases the oil shale sample was sequentially treated with indicated solvents with indication of either total yield of bitumoid (in column 3 one value is shown) or the yield of bitumoid per each solvent separately.

Table 8. **Elemental Composition of Oil Shale Bitumoids**

Number of shale from Table 1	Solvent*	Content, wt.%					Atomic ratio H/C	References
		C	H	N	S	O (by difference)		
1	B : M (3 : 1); E	60.0	7.1	32.9			1.42	60
7	B : M (1 : 1)	71.8	10.5	0.5	17.2		1.75	186
8	Cl; B : M (3 : 1)	69.9	8.8	21.3			1.51	67
10	Cl; B : M (3 : 1)	76.9	10.3	0.5	12.3		1.61	145
11	B : M (3 : 1); E	74.9	10.3	1.0	13.8		1.65	70
12	B : M (3 : 1); E	81.6	10.7	1.1	1.8	4.8	1.58	71
15	Cl	78.6	7.0	0.6	13.8		1.07	196
21	Cl; B : M (3 : 1)	75.8	8.6	0.9	14.7		1.36	79
22	Cl; B : M (3 : 1)	80.7	11.0	0.6	7.7		1.64	79
23	Cl; B : M (3 : 1)	77.9	11.1	0.4	10.6		1.71	79
24	B : M (3 : 1)	78.6	10.8	0.8	0.4	9.4	1.65	80
32	Cl; B : M (3 : 1)	80.2	10.4	1.1	0.9	7.4	1.56	82
33	B : M (3 : 1); E	79.4	8.5	1.4	10.7		1.28	83
34	B : M (3 : 1); E	81.9	8.5	1.4	8.2		1.25	83
37	B : M (3 : 1)	78.7	12.0	0.6	1.1	7.6	1.83	80
39	B : M (3 : 1)	78.8	11.7	0.5	2.9	6.1	1.78	80
44	B : M (3 : 1)	72.2	9.3	1.2	5.2	12.1	1.54	93
54	Cl; B : M (3 : 1)	64.2	8.7	0.8	7.4	18.9	1.63	101
55	Cl; B : M (3 : 1)	74.8	10.4	1.1	3.0	10.7	1.67	153
57	Cl; B : M (3 : 1)	68.4	8.4	1.1	4.9	17.2	1.47	104
59	B : M (3 : 1); E	77.3	11.5	0.5	0.5	10.2	1.79	154
63	B : M (3 : 1); E	75.6	9.4	1.6	3.4	10.0	1.49	110
64	B : M (3 : 1); E	70.1	8.2	2.3	2.8	16.6	1.40	111
65	B : M (3 : 1); E	70.7	8.6	2.3	4.0	14.4	1.46	111
66	B : M (3 : 1); E	72.0	8.8	1.8	17.4		1.47	112
67	B : M (3 : 1); E	70.8	8.4	2.3	2.4	16.1	1.42	111
68	B : M (3 : 1); E	70.4	8.6	2.4	3.2	15.4	1.47	111
70	B : M (3 : 1); E	75.0	9.5	2.5	13.0		1.52	114
72	B : M (3 : 2)	81.8	9.5	1.6	3.5	3.6	1.39	155
73	B : M (3 : 1); E	69.6	8.0	1.2	6.3	14.9	1.38	116
74	B : M (3 : 1); E	72.6	8.7	1.4	5.3	12.0	1.44	116
75	B : M (3 : 1); E	75.6	9.2	0.9	2.3	12.0	1.46	116
78	B : M (1 : 1)	77.3	11.8	10.9			1.71	119
81	Cl; B : M (3 : 1)	78.8	11.9	0.6	0.7	8.0	1.81	189
82	B : M (3 : 1)	69.9	9.5	0.8	1.0	18.8	1.63	190
84	Cl; B : M (3 : 1)	72.2	8.0	0.6	19.2		1.33	122
86	Cl; B : M (3 : 1)	83.7	11.0	1.8	1.8	1.7	1.58	193
88	B : M (3 : 1); E	66.2	10.0	0.6	23.2		1.81	125

* B - benzene, M - methanol, Cl - chloroform, E - diethyl ether.

Table 9. **Chemical Group Composition of Bitumoids, %**

Number of oil shale from Table 1	Solvent[*1]	Group components						Notes	References
		Nonaromatic hydrocarbons	Aromatic hydrocarbons			Heteroatomic compounds			
			total	monocyclic	bi- and polycyclic	total	acidic		
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	B : M (3 : 1); E	9	4	–	–	87	64	2[*2]	60
2	B : M (3 : 1); E	15.5	8.9	7.3	1.6	75.6	–	–	135
4	B : M (3 : 1); E	18	19	11	8	63	–	–	63
5	B : M (3 : 1); E	8	17	10	7	75	–	–	63
6	B : M (3 : 1); E	46	38	24	14	16	–	–	63
7	M (1 : 1)	6.4	7.1	–	–	86.5	29.2	Asphaltenes 29.7	186
8	Cl; B : M (3 : 1)	10	22	11	11	68	–	–	67
10	Cl; B : M (3 : 1)	13.3	5.2	–	–	81.5	57.8	–	145
11	B : M (3 : 1); E	7.0	6.2	–	–	86.8	37.3	–	70
12	B : M (3 : 1); E	15	33	6	27	52	10	–	71
15	Cl	4.7	12.2	1.8	10.4	83.1	46.0	27.7[*2]	188, 196
21	Cl; B : M (3 : 1)	5.5	2.5	1.4	1.1	92.0	47.7	43.3[*2]	79
22	Cl; B : M (3 : 1)	12.9	8.2	3.9	4.3	78.9	46.6	43.4[*2]	79
23	Cl; B : M (3 : 1)	18.6	4.7	2.8	1.9	76.7	37.1	30.5[*2]	79
24	B : M (3 : 1)	13	17	9	8	70	–	–	80
32	Cl; B : M (3 : 1)	28.2	11.9	7.1	4.8	59.9	38.4	14.4[*2]	82
33	B : M (3 : 1); E	8	7	2	5	85	62	15[*2]	83
34	B : M (3 : 1); E	14	11	1	10	75	55	11[*2]	83
37	B : M (3 : 1); E	12		–	–	88	–	–	80
39	B : M (3 : 1); E	16		–	–	84	–	–	80
44	B : M (3 : 1)	8	11	5	6	81	–	–	93
54	Cl; B : M (3 : 1)	2.0	2.5	1.1	1.4	95.5	75.0	41.8[*2]	101
55	Cl; B : M (3 : 1)	10.6	–	–	–	61.1	26.3	Asphaltenes 28.3	153
57	Cl; B : M (3 : 1)	3.7	2.9	1.2	1.7	93.4	66.3	13.0[*2]	104
59	B : M (3 : 1); E	20.2	13.6	7.5	6.1	66.2	–	–	154

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
63	B : M (3 : 1); E	11	19	3	16	70	–	–	110
64	B : M (3 : 1); E	16	13	6	7	71	–	–	111
65	B : M (3 : 1); E	28	4	1	3	68	–	–	111
66	B : M (3 : 1); E	5.9	5.2	1.6	3.6	88.9	72.8	20.2*2	112
67	B : M (3 : 1); E	8	12	3	9	80	–	–	111
68	B : M (3 : 1); E	5	12	3	9	83	–	–	111
70	B : M (3 : 1); E	5	6	2	4	89	58	11*2	114
73	B : M (3 : 1); E	2	1	–	–	97	87	–	116
74	B : M (3 : 1); E	2	2	–	–	96	81	–	116
75	B : M (3 : 1); E	4	3	–	–	93	79	–	116
78	B : M (1 : 1)	8.7	–	–	–	–	–	–	119
79	B	15	2	–	–	–	–	Asphaltenes 10	146, 197
81	Cl; B : M (3 : 1)	6.7	4.1	2.0	2.1	89.2	80.0	54.9*2	189
82	B : M (3 : 1)	17	15	3	12	68	–	–	190
84	Cl; B : M (3 : 1)	3.7	3.2	1.6	1.6	93.1	78.5	46.1*2	122
86	Cl; B : M (3 : 1)	21.8	–	–	–	–	8.2	–	193
88	B : M (3 : 1); E	25	14	–	–	61	54	5*2	125

*1 B - benzene, M - methanol, Cl - chloroform, E - diethyl ether.

*2 Acids soluble in diethyl ether.

Chapter 3

PRODUCTS OF THERMAL DECOMPOSITION OF OIL SHALES

Table 10. **Yield of Oil Shale Retorting Products**

Number of shale from Table 1	Per dry shale, %				Per conditional organic mass of shale, %				References
	Oil	Pyrolytic water	Semicoke	Gases and losses (by difference)	Shale oil	Pyrolytic water	Semicoke	Gases and losses (by difference)	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.0028	–	–	–	0.58*1	–	–	–	60
2	6.9	1.1	87.7	4.3	22.8	3.6	59.3	14.3	16
3	6.7	2.0	86.4	4.9	24.2	7.2	50.9	17.7	19
4	2.7	2.2	92.6	2.5	16.7	13.6	54.3	15.4	62
5	1.0	3.2	93.5	2.3	6.0	19.3	61.3	13.4	136
6	1.8	2.7	92.0	3.5	9.3	13.9	58.8	18.0	61, 198
7	23.3	1.9	71.0	3.8	65.6	5.4	18.3	10.7	64, 66
8	6.4	–	89.9	3.7*2	42.1	–	33.6	24.3*2	67
9	6.3	0.4	90.2	3.1	43.2	2.7	32.8	21.3	68
10	8.6	2.0	87.1	2.3	47.3	11.0	29.1	12.6	69
11	6.3	1.4	90.2	2.1	52.5	11.7	18.3	17.5	199
12	4.3	0.8	94.6	0.3	40.6	7.5	49.0	2.9	71
13	22.8	7.5	57.4	12.3	42.2	13.9	21.1	22.8	72
15	1.3	0.1	96.4	2.2	11.0	0.8	72.9	15.3	74
16	3.7	1.7	90.4	4.2	22.2	10.2	42.5	25.1	75
17	8.2	2.2	86.6	3.0	43.2	11.6	29.5	15.7	19
18	5.3	2.2	88.7	3.8	28.2	11.7	39.9	20.2	19
19	18.8	0.8	77.7	2.7	60.0	2.6	28.8	8.6	77
20	17.6	3.0	75.6	3.8	34.0	5.8	52.9	7.3	77
21	9.7	3.2	70.0	17.1	21.6	6.6	38.0	33.9	200
22	13.6	1.7	76.7	8.0	45.9	5.8	20.7	27.6	73, 201
23	5.6	–	–	–	31.6	–	–	–	65
24	8.0	2.3	84.0	5.7	35.6	10.2	28.9	25.3	200
25	6.0	4.8	86.4	2.8	22.6	18.1	48.7	10.6	16
26	30.9	0.7	64.1	4.3	62.2	1.4	27.8	8.6	19, 22

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
27	17.8	1.8	78.4	2.0	50.9	5.1	38.3	5.7	19, 78
28	10.8	2.6	82.6	4.0	40.9	9.8	34.1	15.2	19, 22, 131
29	8.2	2.4	87.2	2.2	41.4	12.1	35.4	11.1	19
30	9.5	1.4	85.9	3.2	37.5	5.5	44.3	12.7	19
31	4.2	3.3	81.6	10.9	19.4	15.3	14.8	50.5	19
32	25.7	—	—	—	31.6	—	—	—	202
33	2.8	3.4	90.3	3.5	13.0	15.8	54.9	16.3	83
34	2.4	3.1	91.9	2.6	13.6	17.6	54.0	4.8	83
35	21.9	5.0	62.8	10.3	36.0	8.2	38.8	17.0	16
36	9.2	6.7	81.7	2.4	23.5	17.1	53.2	6.2	150
37	45.6	1.1	25.2	28.1	51.1	1.2	16.1	31.6	87, 203
38	5.2	10.4	72.0	12.4	7.6	15.2	59.2	18.0	87
39	18.9	9.0	72.1		44.2	21.0	34.8		87
40	8.5	4.2	76.9	10.4	35.4	17.5	—	—	89
41	5.7	3.3	87.5	3.5	27.6	16.0	37.8	18.3	90
42	4.5	1.5	94.0		47.2	15.7	37.1		139
43	7.7	5.7	76.8	9.8	23.2	16.8	31.6	28.4	91
44	12.0	4.8	79.8	3.4	39.3	15.7	33.8	11.2	65, 93
45	25.5	3.6	60.2	10.7	42.6	6.0	33.4	18.0	19
46	8.8	3.6	81.4	6.2	37.6	15.4	20.5	26.5	16
47	12.9	5.5	72.0	9.6	30.2	12.9	34.4	22.5	16
48	11.6	4.1	73.7	10.6	34.3	12.1	22.2	31.4	96
49	20.9	—	—	—	45.4	—	—	—	123
50	9.2	4.5	81.2	5.1	28.8	14.1	41.1	16.0	16
51	6.4	2.1	88.0	3.5	27.1	8.9	49.2	14.8	98
52	42.3	8.9	34.5	14.3	51.1	10.8	20.8	17.3	99
53	11.4	6.8	76.9	4.9	20.3	12.1	58.8	8.8	99
54	24.9	6.5	56.0	12.6	43.9	11.5	22.4	22.2	100
55	8.1	—	—	—	29.2	—	—	—	204
56	10.5	2.7	80.5	6.3	37.8	9.7	29.8	22.7	103
57	32.6	7.3	43.2	16.9	37.5	8.4	34.6	19.5	104
58	13.6	1.4	80.4	4.6	54.7	5.6	21.6	18.1	105, 191
59	76.0	2.7	8.8	12.5	80.2	2.8	3.7	13.3	154
60	5.6	1.5	92.9		43.6	11.6	44.8		123, 205
61	6.4	2.2	88.4	3.0	40.0	13.8	27.5	18.7	77

Table 10. Yield of Oil Shale Retorting Products (end)

Number of shale from Table 1	Per dry shale, %				Per conditional organic mass of shale, %				References
	Oil	Pyrolytic water	Semicoke	Gases and losses (by difference)	Shale oil	Pyrolytic water	Semicoke	Gases and losses (by difference)	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
62	7.6	2.7	87.9	1.8	31.8	11.3	49.4	7.5	109
63	13.5	5.3	73.3	7.9	35.5	13.9	29.7	20.9	110
64	5.0	5.6	85.0	4.4	26.6	29.8	20.2	23.4	110
65	10.6	7.3	72.3	9.8	26.6	18.3	30.4	24.7	110
66	7.6	1.4	83.8	7.2	25.6	4.7	45.5	24.2	206
67	6.2	3.0	83.0	7.8	27.2	13.2	25.4	34.2	110
68	3.7	5.1	87.3	3.9	27.0	23.0	15.6	34.4	110
69	6.1	4.4	84.9	4.6	25.5	18.4	36.8	19.3	163
71	3.5	–	93.5	3.0^{*2}	36.8	–	31.6	31.6^{*2}	115
72	12.8	–	–	–	44.0	–	–	–	155
73	16.5	2.5	78.4	2.6	34.0	5.1	55.6	5.3	116
74	3.1	4.2	91.6	1.1	13.7	18.6	62.8	4.9	116
75	0.3	2.6	96.5	0.6	2.7	23.0	69.0	5.3	116
76	6.6	5.0	85.8	2.6	27.4	20.7	41.1	10.8	117
78	17.5	3.9	72.9	5.7	41.5	9.2	35.8	13.5	163
79	13.7	1.5	80.3	4.5	66.5	7.3	26.2		75, 158
80	11.5	1.2	82.9	4.4	59.3	6.2	11.8	22.7	75
81	8.2	2.6	88.0	1.2	41.6	13.2	39.1	6.1	207
82	13.9	5.2	72.8	5.6	40.3	15.1	21.2	23.4	207
83	18.0	3.2	77.0	1.8	65.0	11.6	17.0	6.4	207
84	2.1	2.7	91.6	3.6	10.5	13.5	58.0	18.0	208
85	4.2	3.0	91.7	1.1	38.9	27.8	23.1	10.2	123, 207
86	5.3	2.9	91.2	0.6	48.6	26.6	19.3	5.5	207
87	6.0	1.4	88.3	4.3	38.5	9.0	25.0	27.5	207
88	5.1	4.6	86.3	4.0	24.2	21.8	35.1	18.9	125
89	29.5	–	–	–	54.8	–	–	–	18
90	24.8	8.3	57.6	9.3	37.8	12.7	35.4	14.1	19
91	6.2	6.9	83.6	3.3	18.8	20.9	50.3	10.0	127

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
92	10.3	5.8	79.9	4.0	49.0	27.6	23.4		77
93	26.1	3.8	66.3	3.8	65.6	9.5	15.3	9.6	19
64	11.9	86.0		2.1	35.8	57.9		6.3	130
95	21.1	4.2	71.7	3.0	53.4	10.6	28.4	7.6	77
96	4.0	3.9	89.4	2.7	23.0	22.4	39.1	15.5	77
97	8.3	87.3		4.4	32.0	51.0		17.0	132
98	9.5	3.8	82.9	3.8	46.8	18.7	15.8	18.7	132
99	7.8	3.4	84.7	4.1	36.8	16.0	27.8	19.4	22, 73, 133
100	8.8	3.7	84.1	3.4	33.0	13.9	34.8	18.3	133

*[1] Per organic carbon.

*[2] Together with pyrolytic water.

Table 11. **Elemental Composition of Semicoking Oils**

Number of shale from Table 1	Content, %					Atomic ratio H/C	References
	C	H	S	N	O (by difference)		
3	85.0	9.0	1.6	0.7	3.7	1.27	22, 77
4	83.3	9.3	2.6	1.0	3.8	1.34	61, 209
6	83.7	9.0	1.8	1.2	4.3	1.29	61
7	83.0	9.9	1.1	0.1	5.9	1.43	131, 140
8	83.9	10.1	6.0			1.44	67
10	82.4	11.5	0.8	0.4	4.9	1.67	69, 89
11	83.7	11.4	2.3	0.7	1.9	1.63	199
12	83.1	9.7	2.5	1.9	2.8	1.40	71
15	84.1	8.2	–	Traces	7.7 (+S)	1.17	74
16	83.8	10.6	1.8	0.7	3.1	1.52	75
17	85.8	12.6	0.5	0.7	0.4	1.76	22
19	–	–	8.5	–	–	–	53
20	86.4	11.7	0.8	0.6	0.5	1.63	77
21	85.9	10.5	0.7	0.5	2.4	1.47	200, 201
22	84.7	11.9	0.3	1.1	2.0	1.69	201
24	85.0	11.3	0.5	1.9	1.3	1.60	80
26	85.4	11.9	0.5	0.6	1.6	1.67	22, 131
27	85.6	12.1	0.5	0.8	1.0	1.70	77, 131
28	87.4	10.2	0.5	0.7	1.2	1.40	22
29	84.9	11.5	0.3	1.0	2.3	1.63	19
30	85.2	11.3	0.5	0.6	2.4	1.59	19
32	84.8	10.8	1.2	1.1	2.1	1.53	202
33	85.5	10.0	–	0.9	3.6 (+S)	1.40	83
34	85.1	10.4	–	0.9	3.6 (+S)	1.47	83
37	84.4	11.8	0.2	1.1	2.5	1.68	87
38	85.9	8.4	0.3	1.4	4.0	1.17	87
39	83.9	9.2	0.3	1.4	5.2	1.32	87
41	80.4	9.8	6.1	0.9	2.8	1.46	90
42	82.2	10.0	2.3	1.4	4.1	1.46	139
43	81.8	9.9	5.3	0.8	2.2	1.45	91
44	79.6	8.9	7.8	0.9	2.8	1.34	22, 210
45	80.9	8.6	6.5	1.4	2.6	1.28	211
47	80.7	8.3	6.1	1.0	3.9	1.23	16
48	77.2	9.0	8.1	5.7		1.40	96
49	79.1	9.0	7.5	4.4		1.37	123
54	78.3	8.6	9.3	0.9	2.9	1.32	100
55	78.9	8.8	5.8	1.1	5.4	1.33	204
57	76.9	8.4	8.1	0.9	5.7	1.31	104
58	78.6	9.7	8.5	3.2		1.48	105
59	83.7	11.4	–	0.8	4.1 (+S)	1.63	154
60	80.7	10.8	7.1	1.4		1.61	75
61	79.6	9.8	6.2	1.4	3.0	1.48	77
62	79.2	10.0	7.0	1.1	2.7	1.52	108, 109
63	82.0	10.3	3.7	1.6	2.4	1.51	22, 110
64	79.9	10.0	3.7	1.5	4.9	1.50	110
65	79.4	9.8	4.8	1.5	4.5	1.48	110
66	79.2	9.4	–	1.3	10.1 (+S)	1.42	206
67	81.6	9.8	4.3	1.6	2.7	1.44	110
68	80.8	9.9	4.4	1.5	3.4	1.47	110
69	80.7	10.0	7.8	1.5		1.49	115
72	82.3	9.8	2.0	1.0	4.9	1.43	155
73	82.0	9.7	–	1.2	7.1 (+S)	1.42	116
74	80.8	9.5	–	0.9	8.8 (+S)	1.41	116
75	83.1	9.1	–	1.1	6.7 (+S)	1.31	116

Table 11. Elemental Composition of Semicoking Oils (end)

Number of shale from Table 1	Content, %					Atomic ratio H/C	References
	C	H	S	N	O (by difference)		
78	83.6	11.5	1.3	0.9	2.7	1.65	212
79	84.4	11.5	0.7	1.8	1.6	1.64	75, 158
80	84.7	12.0	0.6	2.1	0.6	1.70	75
82	80.3	10.0	0.9	1.4	7.4	1.49	190
83	85.7	12.7	1.6			1.78	191
84	81.3	9.7	3.6	0.9	4.5	1.43	131, 208
85	86.8	12.2	0.5	0.5		1.69	123
86	85.8	10.7	–	1.8	2.7 (+S)	1.50	159
88	84.6	11.0	–	0.9	3.5 (+S)	1.56	125
90	83.4	11.8	0.6	0.6	3.6	1.70	77
91	84.7	12.1	0.4	1.0	1.9	1.71	127, 213
92	82.8	11.8	1.2	0.9	3.3	1.71	77, 123
93	84.4	12.4	0.4	1.1	1.7	1.76	77
94	84.6	11.6	2.0	1.8		1.65	130
95	85.1	12.4	0.4	2.1		1.75	19
96	85.7	11.5	0.6	2.2		1.61	19
97	84.8	11.4	0.5	1.1	2.2	1.61	132
99	85.4	12.2	0.6	1.3	0.5	1.71	22, 210

Table 12. **Characteristics of Semicoking Oil According to Boiling Ranges**

Number of sample from Table 1	% of distillation at temperature (°C)	Notes	References
1	*2*	*3*	*4*
3	25 (up to 200); 10 (200-250); 15 (250-300)	–	22
7*	8 (up to 200); 8 (200-250); 10 (250-300); 14 (300-350)	–	204
10	24.5 (up to 200); 36.0 (200-300); 5.5 (300-325)	–	89
11	13 (up to 200); 21 (200-250); 17 (250-300); 24 (300-350)	Pilot retort	163
14*	46.2 (up to 220); 7.9 (220-240); 21.0 (240-300)	–	68
16*	16 (up to 205); 30 (205-316); 30 (316-427); 22 (427-538)	–	75
17	10 (up to 200); 10 (200-250); 10 (250-300); 20 (300-350)	–	22
20*	3.7 (up to 230); 20.8 (230-300)	–	139
21*	11 (up to 200); 21 (200-300); 16 (300-350); 8 (350-400)	–	200
22	25 (up to 200); 13 (200-250); 17 (250-300); 13 (300-375)	–	73
24*	3 (up to 200); 9 (200-250); 25 (250-300); 10 (300-350)	–	200
28	19 (up to 200); 20 (200-250); 15 (250-300); 8 (300-350)	–	22
32*	66 (up to 400)	–	202
41*	10.7 (up to 200); 19.7 (200-300)	–	90
42	8 (up to 200); 34 (200-300); 24 (300-366)	–	139
44*	2.9 (up to 200); 9.8 (200-250); 15.1 (250-300); 13 (300-350)	Retort shale oil	93
45	61.1 (up to 360)	–	211
47	17.6 (up to 200); 11.2 (200-250); 17.6 (250-300); 17.6 (300-350)	–	16
48	24.8 (up to 200); 12.5 (200-250); 16.7 (250-300)	–	96
51*	2.4 (up to 180); 1.5 (180-230); 1.0 (230-300)	–	98
54*	19.5 (up to 200); 7.5 (200-250); 7.0 (250-300); 12.5 (300-350)	–	100
55*	12 (up to 200); 9 (200-250); 10 (250-300); 8 (300-350)	–	204
58*	16.1 (up to 200); 26.8 (200-300); 23.0 (300-391)	–	105
60*	13 (up to 200); 26 (200-316); 28 (316-427)	–	75
63	20 (up to 200); 10 (200-250); 14 (250-300); 9 (300-325)	–	22, 73
65	3 (up to 200); 16 (200-250); 21 (250-300); 23 (300-350)	Pilot retort	163

1	*2*	*3*	*4*
69	4 (up to 200); 13 (200-250); 19 (250-300); 10 (300-350); 8 (350-400)	Retort shale oil	113
78	19 (up to 200); 12 (200-250); 15 (250-300); 21 (300-350)	–	22
79	4.4 (up to 200); 10.2 (200-300); 16.7 (300-350)	–	22
80*	8 (up to 205); 18 (205-316); 25 (316-427); 33 (427-538)	–	75
84	19.0 (up to 200); 12.4 (200-250); 20.1 (250-300); 8.5 (300-325)	–	73
86*	11.5 (150-250); 15.3 (250-300); 4.4 (300-350)	Pilot retort	214
92*	6 (up to 250); 15 (250-300); 28 (300-350)	–	77
96	4 (up to 200); 11 (200-250); 16 (250-300); 34 (300-350)	Pilot retort	215
97	10 (up to 259); 20 (260-300); 20 (300-350)	–	132
99	10 (up to 250); 10 (250-300); 30 (300-350)	–	22

* wt.%, in all other cases vol.%.

Table 13. **Density of Semicoking Oils**

Number of shale from Table 1	Density ρ^{20}_4	References	Number of oil shale from Table 1	Density ρ^{20}_4	References
2	0.972	135	53	0.855	99
3	0.974*	18, 22	54	1.011	100
4	0.983	61	55	0.988	204
6	0.990	61	57	0.969	104
7	0.964*	66, 73, 216	58	0.936	105
10	0.894	89, 145	59	0.873	154
11	0.896	199	60	0.961	123
12	0.977	71	63	0.955*	22, 110
17	0.877	22	64	0.974	110
20	0.912	139	65	0.963	110
21	0.918*	200, 201	67	0.967	110
22	0.805	73	68	0.956	110
24	0.941	200	72	0.915	155
25	0.874	16	73	0.980	116
26	0.890	22	74	0.958	116
28	0.921	22	78	0.888*	22, 89
31	0.921	138	79	0.911	75
32	0.913	202	82	0.935	190
33	0.874	83	83	0.857	200
34	0.884	83	84	0.987*	73, 162
37	0.846	87	85	0.878	123
38	0.958	87	88	0.929	125
39	0.906	87	89	0.900	18
41	0.964	90	92	0.908	123
42	0.965	139	93	0.890	123
43	0.964	91	94	0.922	171
44	0.974	217	95	0.868	19
48	1.003	96	96	0.896	123
49	0.944	123	97	0.912	132
52	0.835	99	99	0.898	22

* Average value.

Table 14. **Chemical Group Composition of Semicoking Oils, %**

Number of shale from Table 1	Group components							Notes	References
	Nonaromatic hydrocarbons	Aromatic hydrocarbons			Heteroatomic compounds				
		total	monocyclic	bi- and polycyclic	total	acidic	basic		
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
2	12.3	49.7	19.5	30.2	38.0	5.5	9.3	–	135
4	8.0	46.0	7.0	39.0	46.0	–	–	–	61
6	10.0	46.0	9.0	37.0	44.0	–	–	–	61
7	18.0	25.0	8.0	17.0	57.0	23.0	–	Olefins 7.0	217
8	16.0	31.0	12.0	19.0	53.0	–	–	–	67
10	22.0	37.0	3.0	34.0	41.0	5.9	0.7	–	145, 218
11	32.0	31.0	3.0	28.0	37.0	2.7	–	–	199
12	17.0	37.0	7.0	30.0	46.0	2.0	–	–	71
14	–	–	–	–	–	7.9–9.9	–	–	68
15	11.7	34.5	3.2	31.3	53.8	6.6	–	–	74
16	65.0		–	–	35.0	–	–	Olefins 7.0	75
17	–	–	–	–	–	2.4	–	–	22
20	–	–	–	–	–	1.2	–	–	77
21	26.7	21.5	9.7	11.8	51.8	0.6	7.4	–	200, 218
24	21.8	28.6	13.6	15.0	49.6	4.0	1.2	–	208, 218
25	–	–	–	–	–	1.6	–	–	16
28	20.0	–	–	–	–	1.2	–	–	22
32	57.3	15.9	4.1	11.8	26.8	3.0	–	Olefins 22.8	202
33	11.0	22.0	6.0	16.0	67.0	58.0	–	EAC* 2.0	83
34	12.0	21.0	3.0	18.0	67.0	56.0	–	EAC* 3.0	83
36	34.0	28.0	–	–	38.0	4.0	–	–	150
37	40.0		–	–	60.0	2.5	0.7	Carboxylic acids 0.3	86, 87
38	47.0		–	–	53.0	7.6	–	–	87
39	46.0		–	–	54.0	4.3	1.5	–	86, 87
41	–	–	–	–	–	3.2	1.2	–	89
42	–	–	–	–	–	1.3	0.5	–	139

Table 14. Chemical Group Composition of Semicoking Oils, % (end)

Number of shale from Table 1	Group components							Notes	References
	Nonaromatic hydrocarbons	Aromatic hydrocarbons			Heteroatomic compounds				
		total	monocyclic	bi- and polycyclic	total	acidic	basic		
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
43	–	–	–	–	–	5.0	1.7	–	91
44	9.0	38.0	16.0	22.0	53.0	4.0	3.7	–	93, 218
47	–	–	–	–	–	2.9	1.9	–	16
48	3.3	39.1	–	–	57.6	3.4	1.7	Asphaltenes 5.6	96, 219
52	–	–	–	–	–	8.8	1.2	–	84
54	4.2	51.9	15.9	36.0	43.9	6.6	–	–	100
55	21.5	32.9	17.6	15.3	45.6	4.3	–	–	204
57	9.0	39.4	2.6	36.8	51.6	7.2	–	–	104
58	30.8	56.1	–	–	13.1	1.2	–	–	105
59	24.0	32.0	11.0	21.0	44.0	3.5	3.6	–	154
60	20.0	57.0	–	–	23.0	2.0	–	–	53
63	22.0	44.0	7.0	37.0	34.0	1.7	4.0	–	110, 218
64	16.0	33.0	7.0	26.0	51.0	1.3	–	–	110
65	26.0	43.0	6.0	37.0	31.0	1.1	–	–	110
66	12.4	42.4	2.9	39.5	45.2	4.4	–	–	206
67	12.0	38.0	4.0	34.0	50.0	1.0	–	–	110
68	21.0	27.0	7.0	20.0	52.0	1.4	–	–	110
72	27.0	44.0	10.0	34.0	29.0	1.7	2.1	–	155
73	13.0	45.0	3.0	42.0	42.0	4.5	–	–	116
74	35.0	32.0	5.0	27.0	33.0	3.3	–	–	116
75	30.0	46.0	10.0	36.0	24.0	5.5	–	–	116
78	54.0	18.0	–	–	28.0	1.8	–	–	143, 220
79	24.6	21.7	–	–	53.7	–	–	Olefins 11.7	22, 75 221
80	46.0		–	–	54.0	–	–	Olefins 10.0	75
81	64.0	13.3	–	–	22.7	2.2	2.9	Asphaltenes 4.4	121

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
82	27.0	26.0	15.0	11.0	47.0	3.0	2.1	Asphaltenes 10.5	121, 190
83	34.5	45.8	21.6	24.2	19.7	1.2	–	–	191
84	22.8	28.7	9.5	19.2	48.5	4.0	1.2	–	208, 218
85	53.9	15.4	–	–	30.7	8.8	3.6	Carboxylic acids 0.6	121
86	63.8	9.0	–	–	27.2	4.0	3.2	Carboxylic acids 0.8	121
87	57.4	19.2	–	–	23.4	4.2	6.5	Carboxylic acids 0.6	207
88	19.0	48.0	16.0	32.0	33.0	3.0	–	–	125
91	48.0	–	–	–	–	–	1.0	Olefins 20.0, Nitriles 11.0	213
94	–	–	–	–	–	6.0	–	–	171
97	–	–	–	–	–	2.8	–	–	132
99	55.0		–	–	45.0	4.9	–	Paraffins 18, Carboxylic acids 0.5	22, 132

* EAC – ether-soluble acidic compounds.

Table 15. **Composition of Gaseous Products of Semicoking, vol.%**

Number of shale from Table 1	Content													References
	CO_2 (1)	CO (2)	H_2S (3)	H_2 (4)	CH_4 (5)	C_2H_6 (6)	C_3H_8 (7)	C_4H_{10} (8)	C_2H_4 (9)	C_3H_6 (10)	C_4H_8 (11)	Others	Total of (1)-(11)	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
1	13	–	–	58	23	–	–	–	–	–	–	–	94	60
3	5.5	1.5	21.0	15.6	16.1	4.1	1.4	1.3 ($+C_4H_8$)	0.7	1.2	–	O_2 1.5, N_2 28.0, C_5 1.6	99.5	223
4	20.3	5.7	13.6	27.1	25.8				7.5			–	100.0	103
7	25.1	8.5	14.2	5.2	13.4	10.9	5.1	1.7	3.1	4.3	2.4	N_2 6.1	100.0	66, 216
8	12.5	–	–	20.0	23.0	–	–	–	–	–	–	–	55.0	67, 144
10	26.8	5.0	8.4	33.8	4.5	6.4	2.9	1.3	6.4	2.5	2.0	–	100.0	224
11	–	–	–	–	20.0	17.2	22.4	10.4	7.2	11.1	11.7	–	100.0	70, 199
12	22.5	4.7	4.7	32.8	16.2	6.0	2.1	0.7	1.4	1.7	0.9	N_2 6.1, C_5 0.2	100.0	164
15	24.3	5.0	2.1	19.6	36.3	5.7	1.8	0.6	2.3	1.4	0.9	–	100.0	74
16	9.7	14.3	29.1	22.4	13.4	3.3	2.5	–	1.1	1.5	–	–	97.3	75
21	29.3	14.1	2.8	7.6	29.7	5.1	3.1	0.9	3.2	2.6	1.6	–	100.0	200
24	17.8	6.3	0.8	41.9	9.2	6.1	2.7	1.4	2.3	2.8	2.0	N_2 5.2, C_5 1.5	100.0	164
30	11.7	1.6	6.8	18.4	32.0	16.5	–	–	8.5	–	–	N_2 4.5	100.0	15
32	6.7	7.7	–	2.0	47.0	17.1	4.8	2.5	3.8	6.5	1.9	–	100.0	202
33	31.0	13.4	–	9.4	28.6	7.6	2.7	1.3	2.1	2.8	1.1	–	100.0	83
34	38.4	7.3	–	6.4	26.9	8.6	3.2	1.2	2.6	4.2	1.2	–	100.0	83
37	–	–	–	–	45.6	14.7	6.6 ($+C_3H_6$)	1.4	28.0	–	3.1	–	99.4	203
39	–	–	–	–	56.1	10.8	5.6 ($+C_3H_6$)	2.0	19.8	–	4.6	–	98.9	203
41	39.2	5.9	–	27.1	21.0				6.8			–	100.0	90
44	40.5	6.1	9.4	17.1	11.7	6.0	2.3	0.8	1.7	2.0	1.9	N_2 0.5	100.0	164
45	25.0 ($+H_2S$)	2.4	–	19.2	38.5				8.0			N_2 6.6, O_2 0.3	100.0	211
48	47.5	10.2	–	13.7	21.1	–	–	–	–	–	–	C_2–C_4 7.7	100.0	96
54	7.8	3.2	56.5	7.4	18.5	2.6	1.2	0.3	0.7	1.0	0.5	O_2 0.1, N_2 0.2	100.0	100
55	36.6	1.9	14.7	30.4	3.9	5.1	1.5	0.7	0.3	1.5	1.1	N_2 2.3	100.0	204
56	23.1	6.7	26.9	16.1	22.7				4.5			–	100.0	103
57	15.6	10.6	34.0	6.2	26.0	4.5	0.3	0.7	0.6	1.0	0.5	–	100.0	104

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
58	14.5	1.0	25.2	21.6	–	–	–	–	–	–	–	Alkanes 28.4, Alkenes 9.3	100.0	225
60	15.4	5.0	19.9	31.1	18.5	4.3	1.8	–	1.2	1.1	–	–	98.3	75
63	28.9	3.8	1.6	32.2	13.7	7.4	2.3	1.1	1.6	2.0	1.5	N_2 3.2, C_5 0.7	100.0	164
64	–	–	–	–	43.6	21.8	11.9	4.1	5.3	7.4	5.9	–	100.0	110
65	–	–	–	–	59.2	15.7	9.7	3.2	5.3	4.5	2.4	–	100.0	110
66	16.5	16.6	20.5	22.7	15.8	4.1	1.0	0.5	0.9	1.0	0.4	–	100.0	206
67	–	–	–	–	41.7	24.2	12.1	4.0	4.1	8.5	5.4	–	100.0	110
68	–	–	–	–	43.4	26.1	12.3	3.2	3.8	6.9	4.3	–	100.0	110
69	30.8	4.8	16.5	18.0	12.6	5.6	1.8	0.7	1.3	1.6	1.4	N_2 4.5, C_5 0.4	100.0	164
71	25.3	4.3	9.9	29.8	13.5	4.4	1.6	0.8	1.1	1.3	1.1	N_2 6.4, C_5 0.5	100.0	164
73	35.6	3.1	13.8	14.4	19.5	5.4	2.1	0.6	2.6	1.7	1.2	–	100.0	116
74	41.9	3.2	7.5	19.7	16.9	4.2	1.2	0.4	2.7	1.4	0.9	–	100.7	116
75	60.5	1.0	Traces	6.7	22.0	3.2	0.6	0.4	4.1	0.9	0.6	–	100.0	116
78	26.2	7.5	4.6	24.7	12.0	8.9	3.0	1.3	2.9	3.1	2.1	N_2 2.8, C_5 0.9	100.0	226
79	24.4	3.1	3.6	26.0	19.5	9.2	3.6	2.0	3.3	2.2	3.1	–	100.0	120, 158
80	30.3	16.8	3.3	24.2	15.2	4.3	1.7	–	0.9	1.1	–	–	97.8	75
83	4.3	–	Traces	50.9	22.2	10.8	6.6	2.5	–	–	–	N_2 2.0, O_2 2.7	100.0	191
84	32.2	5.6	30.7	2.4	17.3	4.3	2.1	0.7	1.1	1.4	0.9	N_2 1.3	100.0	208
86	21.6	4.4	14.2	28.5	19.2	6.5	2.3	0.6	–	1.8	0.9	–	100.0	159
88	31.8	1.1	32.6	14.2	11.3	3.0	1.2	0.5	2.1	1.3	0.9	–	100.0	125
91	51.6	2.5	0.0	27.5	8.6	3.7	1.7	0.8	1.2	1.6	0.8	–	100.0	127
95	15.3	7.8	0.9	36.6	14.4	6.7	2.5	1.3	2.6	3.0	3.8	N_2 3.7, C_5 1.4	100.0	164
96	16.8	5.7	8.2	38.2	10.3	4.4	2.1	1.1	1.7	2.9	2.2	N_2 6.1, C_5 1.3	100.0	164

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INDEX

Index of oil shales and oil shale deposits (the number in brackets denotes the oil shale number in the tables)