Oil Shale, 2011, Vol. 28, No. 3, pp. 380–397
doi: 10.3176/oil.2011.3.03
ISSN 0208-189X

GEOLOGICAL CHARACTERISTICS AND SOME PROBLEMS IN DEVELOPMENT FOR OIL SHALE IN NORTHWEST CHINA

BAI YUNLAI[(a)*], TANG HUA[(b)], YAN KAI[(c)]

[(a)] Northwest Geological Research Institute(NWGI), PetroChina, Lanzhou 730020, China
[(b)] Xi'an Institute of Geology and Mineral Resources, 710054 Xi'an, China
[(c)] School of the Earth Sciences and Resources, China University of Geosciences (Beijing), 100086 Beijing , China

With the amount of oil resources becoming increasingly scarce, non-conventional resources such as oil shale, oil sands, and heavy oil, have caught our attention. There are abundant oil shale resources in Northwest China. Our analysis of field geological section surveys, standard mining investigations, and the laboratory analysis of important samples indicate that the oil shale in Northwest China is characterized by the following features: oil shale strata is 1–36 m thick, the color of slightly greasy, shiny and flaky oil shale is mostly brown-black, black with light brown streaks, but some oil shale outcrops appear maroon. Oil shale is of layered structure, irregular shape, conchoidal fracture, and low hardness, composed mainly of clay and silt-sized detrital minerals (feldspar and quartz). SiO_2 *and* Al_2O_3 *comprise a total of 52.54% of the rock, this indicates that oil shale is of the medium ash type. Organic carbon content of oil shale is 14% and that of total carbon 16.28%. Oil yield is generally 1.5–13.7%, overall caloric value 1.66–20.98 MJ/kg. Density of oil shale is 1.55–2.46 g/cc. Younger oil shale strata are characterized by progressively higher REE abundances. There are mainly three types of oil shale deposits: the littoral-neritic facies sedimentary deposits of the Middle and Upper Carboniferous – the Lower Permian, remnant lake bay-lacustrine facies sedimentary deposits of the Upper Permian, and shale which formed in inland deep water – half deep water lacustrine facies of the Mesozoic, the latter being of the major industrial type, and its origin is similar to "the Black Sea model." Oil shale layers are also the main oil source rock in the Ordos Basin. Oil shale layers which formed in deltaic environments in the Middle and Late Carboniferous and the Jurassic are mostly paragenetically related to coal beds. In the area, the total amount of predicted resources of oil shale is at least* $31{,}000\times10^8$ *t which is equivalent to about* 2000×10^8 *t of shale oil. Oil shale resources in the Ordos Basin account for 99% of the total and can be compared to oil shale resources in the Green River area of western North America. In Northwest China, the identified oil shale deposits are located in*

* Corresponding autor: e-mail *baiy16666@sina.com*

the vicinity of large and medium-sized cities, with good development prospects. If the problems of environmental pollution are solved and the appropriate techniques are used, the immense economic benefits can be obtained.

Introduction

As one of non-conventional energy resources, oil shale resources have attracted widespread attention. It is generally thought that oil shale is a fine-grained sedimentary rock containing significant amounts of kerogen, from which a significant quantity of oil can be fractionated. In oil shale, organic matter content is high (greater than 15%) and ash content is high (greater than 40%) as well. Oil shale can burn. The oil yield of oil shale is usually more than 3.5%, and caloric value 4.18–16.7 MJ/kg, which approximately amounts to half of the coal. Both oil yield and caloric value are two important indicators for the evaluation of oil shale [1-9].

The authors studied oil shale in NW China according to the Strategic Planning of Western China Development (SPWCD) and the need of China National Petroleum Corporation (CNPC). The locations of oil shale in the area mainly comprise Tongchuan City-Binxian County in Shaanxi province, Huatingxian County – Tanshanling of Tianzhu county – YaoJie of Lanzhou City in Gansu province, Tanshan of Guyuan City- Shangxiaheyan of Zhongwei County in Ningxia Hui Autonomous Region, Xiaoxia of Xining City in Qinghai province,Yaomoshan and Shuimogou of Urumqi City – Loucaogou of Changji City-Sangonghe of Fukang County in Xinjiang Uygur Autonomous Region, and Bagemaode of Wulatehouqi County in Inner Mongolia Autonomous Region. The total number of oil shale occurrences is 13 (Fig. 1). Oil shale resources in Northwest China are abundant, and the total amount of predicted resources of oil shale is at least $31{,}000\times10^8$ t which is equivalent to about 2000×10^8 t of shale oil.

These areas are mostly highland, the Gobi-desert areas and drought. In comparison to the eastern region, the economy is underdeveloped. While with the pace of development in West China, except the Bagemaode oil shale deposit in Wulatehouqi County (Inner Mongolia), other oil shale deposits and mineral occurrences are located near the railway and highway, transportation is convenient. Moreover, some oil shale deposits mentioned above are located near large and medium cities in the area, therefore, the development and utilization conditions would be better, and the benefits to be acquired would also be better.

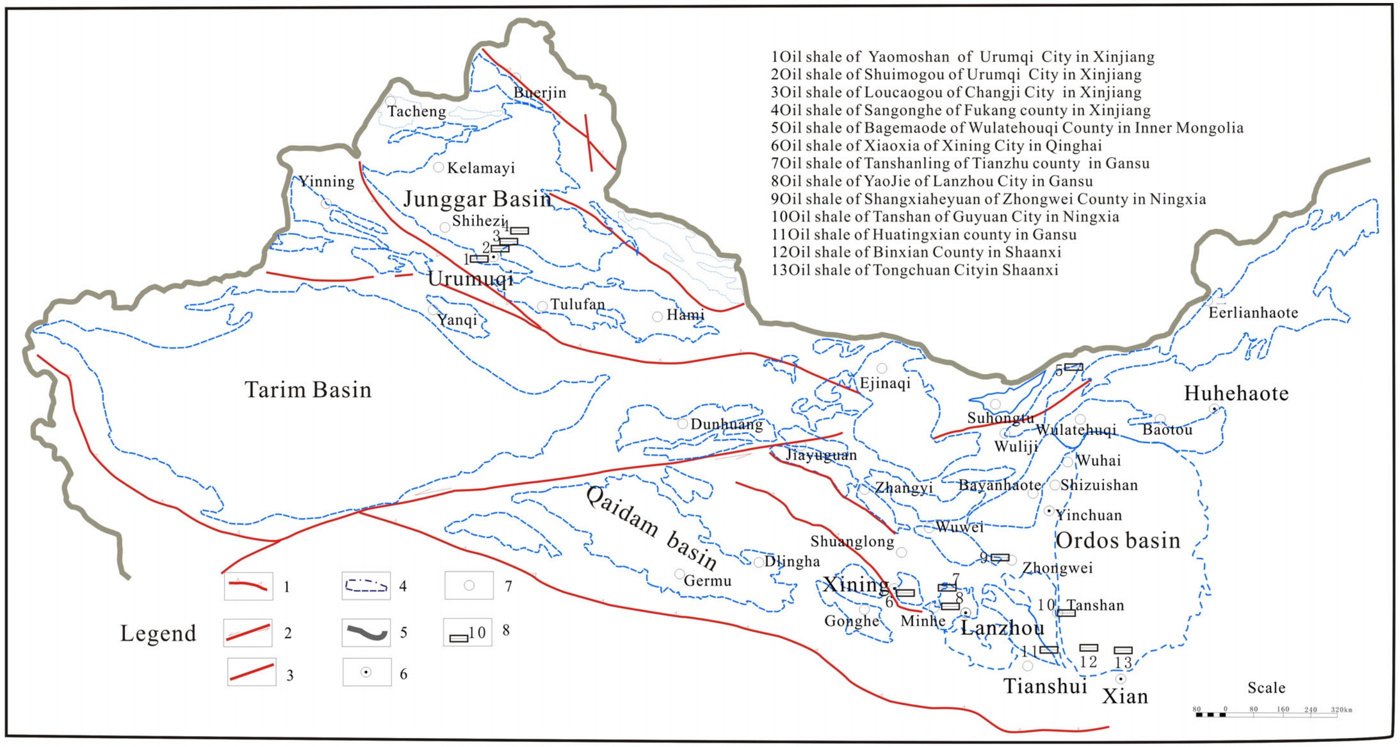

Fig. 1. Outcrop distribution map of oil shale deposits in Northwest China.

Key directions (legend):1 – nappe structure, 2 – strike-slip fault, 3 – fault, 4 – basin boundary line, 5 – national boundaries, 6 – big city, 7 – small city and small town, 8 – occurrences and numbers of oil shale deposit.

Methods and results

Investigations were made for the above 13 oil shale deposits in NW China, and some information was obtained from literature [2, 6, 8–15]. Therefore, Table 1 includes also the data on oil shale resources studied by others. The data on oil shale resources in the Ordos Basin are given by the authors basing on field survey, geological mapping and analysis for samples and logging data of oil fields [14, 15].

For identified distribution, quality, size, reserve and utilization conditions of oil shale deposits in the area, the research has been completed to survey field geological sections in a relatively detailed way, by geological mapping in some standard areas and trenching exposure in the cover area. Researches were also conducted to observe the attitude, size, distribution and geological characteristics of oil shale in field. For the results see Table 2. Some important specimens were collected and sent to the Gansu Coal Quality Supervision Examine Station for oil yield analysis and to the Test Center of Geophysical and Chemical Exploration Research Institute, Ministry of Land and Resources, for determination of macro, micro and rare-earth elements. Oil yield of oil shale was determined by Engineer Liu Bingyuan using the method of Gray-King low-temperature distillation according to the standard GB-T1341-2007.

The results of analysis are given in Tables 3–5 and in Fig. 2

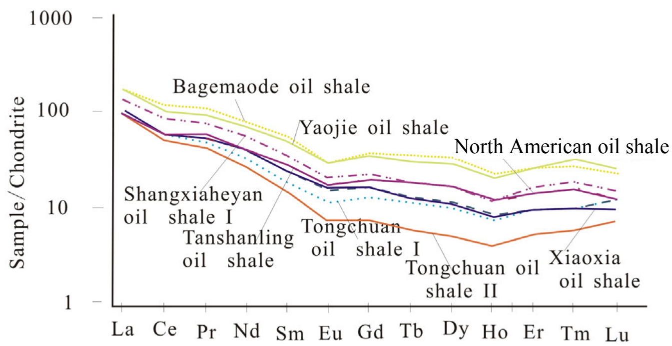

Fig. 2. Chondrite-normalized REE abundances in whole-rock samples of oil shale in Northwest China.

Table 1. **Statistics of total resources of each occurrence area of oil shale in Northwest China (unit ×10^8 t)**

Basin and age	Site	Potential mineral resources	Detected mineral resources				
		Resource extent	Detected or controlled basic reserve				Resources
		Predicted intrinsic economic resources (334)	Detected economic resources (121b)	Controlled economic resources (122b)	Controlled sub-economic resources (2m22)	Total	Inferred or controlled intrinsic economic resources (333)
Minhe basin-Xining Basin (J-K)	YaoJie in Lanzhou, Gansu [2, 6, 9–11]	10	1.8			1.8	
	Tanshanling in Tianzhu, Gansu [2, 6, 9–11]	15	2.68			2.68	
	Xiaoxia in Xining, Qinghai [2, 6, 9–11]	5	0.45			0.45	
	Whole basin	30					
Liupanshan Basin (C_2)	Shangxiaheyan in Zhongwei, Ningxia [2, 6, 9, 10]	10		0.04		0.04	4
	Whole basin [2, 6, 9, 10, 13]	10					
Junggar Basin (P)	Yaomoshan in Urumuqi, Xinjiang [2, 6, 9, 10, 12]	30		1.2	0.97	2.17	
	Shuimogou in Urumuqi, Xinjiang [2, 6, 9, 10, 12]	20			0.97	0.97	8.8 (Controlled)
	Lucaogou in Miquan, Xinjiang [2, 6, 9, 10, 12]	30			0.89	0.89	
	Jiucaiyuanzi in Jimushaer, Xinjiang [2, 6, 9, 10, 12]	20					37.26
	Sangonghe in Fukang, Xinjiang [2,6,9,10,12]	14					44
	Whole basin	114					
Suhongtu Basin (K_1)	Bagemaode in Inner Mongolia [2, 6, 9, 10]	300		0.8		0.8	26.5 (Inferred)
	Whole basin	300					
Ordos Basin (T_{2-3})	Tanshan in Guyuan, Ningxia [2, 6, 9, 10, 14, 15]	102		4		4	11
	Tongchuan in Shannxi [2, 6, 9, 10, 14, 15]	30000.92		9		9	
	Bin county in Shaanxi [6, 9]	280			0.06	0.06	
	Whole basin	30382.92					
	Total	30836.92	4.93	15.04	2.89	22.86	131.56
Total Resources		30991.34 (Equivalent to 2045.43 t of shale oil, 6.6% of oil yield)					

Table 2. **Main geological characteristics of oil shale deposits in Northwest China (supplemental literature [2, 10])**

Era	Typical deposits	Basin type	Sedimentary environment	Paleoclimatic conditions	Ancient plant combination	Character of oil shale bed					
						Total number of layers	Thickness, m	Oil yield, %	Area, km^2	Burial depth, m	Rank of co-existing coal
Early Cretaceous	Bagemode in Inner Mongolia	Rift-depressed	Inland lake	Warm zone-subtropical dry and humid alternating transition	Coniferophyte Classopollis Granodiscus Granulatus	6	49.4	6	520 predicted 42 identified	0–200	
Middle Jurassic	Xiaoxia in Xining Qinghai	Rift-depressed	Intermontane lake	Warm zone, humid	Pteris Ginkgo, Coniopteris	2	4.28–6.18 5.06 average	7.85	5.015	0–50	Long-flame coal
	Yaojie in Lanzhou Gansu	Fault-depressed, depressed	Intermontane lake	Warm zone, humid	Pteris Ginkgo, Equisetites, Coniopteris, Neocalamites	4	8.35–11.36 30.73 total	4.6–9	19	10–300	Long-flame coal Non-caking coal
	Tanshanling in Tianzhu Gansu	Fault-depressed, depressed	Intermontane lake	Warm zone, humid	Equisetites, Coniopteris, Neocalamites	2	11.6	5.98–7.98	10.375	10–250	Long-flame coal
	Tanshan in Guyuan Ningxia	Foreland basin	Piedmont lake	Warm zone, humid	Ginkgo, Ferns	4	4.22	11.2	300 predicted	100–300	Long-flame coal
Middle-Late Triassic	Ordos	Depression basin	Inland lake	Humid and hot	Ginkgo, Ferns, Cycads, Pine, Conchostracan, Ostracods, Bivalves,Fish	3	4–36	1.5–13.7	29000	0–1800	

Table 2. Continued

Era	Typical deposits	Basin type	Sedimentary environment	Paleoclimatic conditions	Ancient plant combination	Character of oil shale bed					
						Total number of layers	Thickness, m	Oil yield, %	Area, km^2	Burial depth, m	Rank of co-existing coal
Late Permian	Yaomoshan in Urumqi Xinjiang	Foreland basin	Lake-bay	Warm zone, semi-humid	Angara flora, Ostracods, Bivalves, Conchostracan Freshwater lamellibranch	10	71 (Single layer 2–5)	5.79–8.14	3.3	0–500	
	Lucaogou in Miquan, Xinjiang	Foreland basin	Lake-bay	Warm zone, semi-humid		23	66.18 (Single layer 2–10)	7.08	11.49	0–500	
	Shuimogou in Changji Xinjian	Foreland basin	Lake-bay	Warm zone, semi-humid		23	47 (Single layer 2–10)	5.4–10.3	4.34	0–500	
Late Carboniferous	Shangxiaheyan in Zhongwei Ningxia	Littoral-neritic sea basin	Coastal	Tropical and subtropical, humid	Cathaysia Lepidodendropsis	6	2.1 (Single layer 1)	8.9	4.68	Anthracite coal	

Table 3. **Analysis of macro, micro and rare-earth elements in oil shale (made by Xu Shanfa in 2009)**

Analysis technique	Element	Qualification rate	Laboratory
Flameless atomic absorption spectrometry (AAN)	Au	100%	The Test Center of Geophysical and Chemical Exploration Research Institute, Ministry of Land and Resources
Emission spectroscopy(ES)	Ag, B, Sn		
Atomic fluorescence spectrometry (AFS)	As, Ge, Hg, Sb, Se		
Pressed disc method–X-ray fluorescence spectra (XRF)	Ba, Br, Cl, Cr, Ga, Mn, Nb, Ni, P, Pb, Rb, Sr, Ti, CaO, K_2O, SiO_2, Al_2O_3, Fe_2O_3, TS (total sulfur)		
Inductively coupled plasma optical spectrographic method (ICP-OES)	Be, Bi, Cd, Co, Cs, Cu, Li, Mo, Sc, Na_2O, MgO		
Inductively coupled plasma-mass spectrography (ICP-MS)	Hf, Ta, Te, Th, Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sm, Tb, Tm, Y, Yb, In		
Catalytic spectrophotometry (COL)	I		
Oxidative-thermolysis–gas chromatography	N, total C		
Electrometric method	Organic C		

Discussion

Large resource potentials and low verification levels

Table 1 shows that the total amount of predicted resources of oil shale in NW China is about $31,000\times10^8$ t, which is equivalent to about 2000×10^8 t of shale oil. Oil shale resources in the Ordos Basin account for 99% of this amount and can be compared to oil shale resources in the Green River area of western North America. The latter also reach about 2000×10^8 t shale oil [9, 10]. However, the amount of proved and controlled economic reserves (121b + 122b + 2m22) is about 22.86×10^8 t, which is equivalent to about 1.5×10^8 t shale oil (burial depth is less than 300 m). The amount of identified resources is near to 131.56×10^8 t. The ratio of proved reserves of oil shale is significantly lower, and accounts only for about 6% of the proved oil shale reserves across the country (374×10^8 t) [2, 6, 9].

In the Ordos Basin, the predicted, intrinsic economic resources (334) are mainly distributed in more than 300 m under the ground [14].

The data above show that the exploration level of oil shale deposits in the regions is low. Furthermore, oil shale is distributed unevenly and buried deep, but demonstrates big potential of exploration and development in these regions.

Table 4. **Chemical composition of oil shale in Northwest China (%)**

Serial number	Sampling site	Sample number	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	LOI*	TFe_2O_3	CO_2	TS	Total
1	Xiaoxia, Qinghai	XX-1	41.75	14.00	3.22	1.01	0.32	0.34	0.46	1.09	0.01	0.15	0.96	36.15	4.13	1.49	0.45	99.46
2	Xiaoxia, Qinghai	XX-2	34.19	10.27	3.40	1.69	0.26	1.62	0.78	0.73	0.03	0.11	0.71	46.31	5.18	1.99	0.20	100.10
3	Tanshanling, Gansu	TSL-1	54.68	15.85	5.88	0.17	2.24	2.07	1.15	2.68	0.04	0.40	0.81	14.15	5.78	1.00	0.39	100.12
4	Tanshanling, Gansu	TSL-4	52.13	15.07	4.56	0.26	2.11	4.20	1.13	2.37	0.06	0.18	0.72	16.62	4.71	1.39	0.30	99.41
5	Yaojie, Gansu	YJ-1	48.15	21.43	5.87	0.25	0.62	0.14	0.55	2.39	0.05	0.19	0.76	18.94	5.97	0.09	0.48	99.34
6	Yaojie, Gansu	YJ-3	35.51	12.09	0.16	0.57	0.24	0.09	0.08	0.98	0.00	0.00	1.16	48.77	0.80	3.80	0.72	99.65
7	Bagemode, Inner Mongolia	BGMD-1	41.01	15.44	8.35	2.40	1.54	5.99	0.41	1.90	0.17	0.21	0.92	21.14	11.02	6.13	1.43	99.48
8	Bagemode, Inner Mongolia	BGM-2	33.06	8.51	0.94	2.25	0.37	0.58	0.46	0.40	0.03	0.28	0.75	52.03	3.44	0.89	0.09	99.66
9	Tanshan, Ningxia	Tanshan-1	20.44	7.12	6.36	1.50	0.83	0.27	0.27	1.12	0.013	0.05	0.32	61.73	8.01		0.43	100.02
10	Tuangchuan, Shaaxi	Tongchuan-1	52.02	13.42	5.01	2.02	1.12	0.78	1.66	2.96							1.16	

* Loss on ignition

Table 5. **Trace elements and rare-earth elements in oil shale in Northwest China (most ×10^{-6}, Au, Ag ×10^{-9})**

		Trace elements															
Sampling site	Sample number	Au	Ag	As	Ba	Co	Cu	Cs	Mo	Ni	Pb	Se	U	V	Zn	Mn	Ti	Sr
Xiaoxia mining area	XX-1	1.8	87	38.3	466	6.9	39.4	9	2.66	25	31.4	1.0	5.6	43.5	65.6			
	XX-2	2.5	92	23.4	304	9.4	31.8	5	3.11	49.9	168	1.01	5	30.8	85.7			
Tanshanling mining area	TSL-1	10.6	160	21.5	1018	13.1	42.3	17.5	2.29	33.5	26.5	0.81	6.3	76	89.9			
	TSL-4	5.2	178	23.4	286	10.9	37.4	15.1	1.45	26.8	22.7	1.04	4.6	67.4	106			
Yao jie mining area	YJ-1	4	127	17.6	267	12.5	29.8	6.9	1.29	31.1	28.6	2.94	12.9	61.3	102			
	YJ-3	2.1	299	4.8	432	3.8	39.9	16.9	1.24	8.2	29.7	0.12	5.3	22.6	24.3			
Shuimogou	Shuimogou -1	1.06	74	20.5	370	13.8	56.3	6.83	2.7	62.9	15.4	0.48	2.13	109.2	103.2			
Bagemaode mining area	BGMD-1	2.8	79	18	526	16.8	36.7	7	1.68	39.1	27.7	0.46	6.3	64.2	83			
	BGM-2	2.4	49	7.7	386	19.6	27.4	1.8	0.91	46.2	10.6	0.07	1.9	60	59.7			
Shangxiaheyan mining area	SXHY-1	4.8	107	40	630	21.3	49.8	10.6	1.05	61.2	28.2	0.73	4.5	82.7	95.2			
Southern of Ordos Basin (Tongchuan deposit)	Tongchuan II-2	3.95	171	66.0	1010	1.3	71.3	7.94	79.0	6.9	29 32	1.38	36.20	183	13.1	50 73	2970	146.5
	Tongchuan IV-2	1.19	177	38.0	655	4.6	55.7	8.68	73.0	17.3		0.42	26.66	228	29.0		2855	146.8
Continental crust		4	70	1.8	390	25	55	3	1.5	75	12.5	0.05	2.7	135	70	100	4500	340

Table 5. Continued

		Lanthanide series														
Sampling site	Sample number	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Lu	Sc	Y
Xiaoxia mining area	XX-1	31.4	50	6.5	25.6	5.1	1.16	4.12	0.66	3.43	0.63	1.86	0.3	0.28		
Tanshanling mining area	TSL-1	26.8	56	6.9	27	5.7	1.2	5.28	0.93	4.85	0.94	2.74	0.45	0.39		
Yao jie mining area	YJ-1	54	101	12.4	49.6	10.6	2.33	9.86	1.65	9.07	1.77	5.44	0.96	0.8		
Bagemaode mining area	BGMD-1	54.4	108	13.4	52.2	10.7	1.99	9.99	1.73	9.54	1.81	5.27	0.82	0.69		
Shangxiahe yan mining area	SXHY-1	42	78	9.7	35.9	6.8	1.45	5.74	0.96	5.08	1.02	3.1	0.54	0.46		
Southern of Ordos Basin (Tongchuan deposit)	Tongchuan II-2	26.31	45.05	5.14	17.28	2.72	0.50	1.94	0.29	1.58	0.32	1.06	0.18	0.21	8.63	9.8
	Tongchuan IV-2	29.60	50.54	5.88	21.27	3.80	0.78	3.30	0.53	2.91	0.59	1.96	0.30	0.36	7.99	19.8
North American shale		32	73	7.9	33	5.7	1.24	5.2	0.85	6	1.04	3.4	0.5	0.48		
Chondrite		0.3	0.91	0.12	0.64	0.2	0.07	0.26	0.05	0.3	0.08	0.2	0.03	0.03		

Note: The sample collected by Bai YunLai, Wu Wu-Jun (2005). Analysis by The Test Center of Geophysical and Chemical Exploration Research Institute, Ministry of Lands and Resources(2005); the earth element abundances is Taylor value [16], except Au, Ag in units of 10×10^{-9}, other elements in unit 10×10^{-6}

Temporal and spatial distribution of oil shale in the area

The oil shale in NW China mainly occurrs in different types of basins from the Late Paleozoic to Mesozoic (littoral-neritic basins and inland lakes), and generally in a shallow depth. But the oil shale in the Ordos Basin, which formed in the Middle-Late Triassic in a half-deep – deep lake, is buried deep, the maximum depth being nearly 2000 m.

In the Late Palaeozoic, oil shale formed mainly in the coastal basins on the passive continental margin southwest of the palae North China Plate and in the environment of inland lakes in the suturing zone between the palae Tarim Plate and palae Junggar Plate (Fig. 1). The former takes Shangxiaheyuan oil shale deposit in Zhongwei County, Ningxia, formed in the Late Carboniferous for an example, and the later takes Yaomoshan oil shale deposit in near Urumqi city Xinjiang, formed in the Late Permian for an example. The environment under which they formed was significantly different. The former formed mainly in a marine environment and the latter in a terrestrial environment. Though the Shangxiaheyan oil shale deposit in Zhongwei County is located in the North Liupanshan Basin, the environment when oil shale was forming was a coastal basin on the passive continental margin in the Late Paleozoic [17–20]. At first, the paleo environment in which the oil shale near Urumqi city (Jimusaer country) formed was considered to be marine, but because later the freshwater lamellibranch was found in the oil shale strata, then paleo environment was considered to have been terrestrial.

In the Mesozoic, oil shale mainly occurred in inland lakes after the collision of the palae North China Plate with the palae South China Plate. As for inland lake basins, the Ordos Basin formed mainly owing to pushing and shoving by Indosinian movement in south. Oil shale occurring in the Ordos Basin is also the main source rock of the superlarge Ordos oil field [17]. But in the Jurassic and Cretaceous, the development of inland lakes was mainly affected by subduction of the ancient Izanagi Plate in the east side or the Tethyan oceanic Plate in the south side [18, 19]. Tanshan oil shale formed in the Yan'an Formation in the early stage of the Middle Jurassic, and Tongchuan oil shale (including the oil shale which occurs in the Tongchuan oil shale peripheral region) formed in the Yanchang Formation in the Middle-Late Triassic. Yaojie oil shale, Tanshanling oil shale and Xiaoxia oil shale formed in the Minhe Basin and the Xining Basin, respectively, in the early stage of the Middle Jurassic [10, 11], and the two basins are genetically related belonging to the same basin in the early stage of the Middle Jurassic in essence. Bagemaode oil shale formed in Bayingobi Formation in the north-east edge of the Suhongtu Basin, which formed in the late period of the Early Cretaceous (Table 2).

Types of oil shale deposits and ancient environment

There are mainly three types of oil shale deposits in NW China: (i) littoral-neritic facies sedimentary deposits in the Late Carboniferous; (ii) residual lake bay–lake phase sedimentary deposits of the Late Permian; (iii) inland lake system sedimentary deposits (including lake facies and delta phase).

In the Late Carboniferous, paleoclimate in the region was interchanging between mild – wet and dry – wet, and ancient organisms belonged to Cathaysia Lepidodendropsis flora. In the late Permian, paleoclimate was semi-humid, and ancient organisms included Angara flora, ostracods, bivalves, conchostracan and freshwater lamellibranch. In the Middle-Late Triassic, paleoclimate was hot – humid, and ancient organisms were ginkgo, ferns, cycads, pine, conchostracan, ostracods, bivalves, fish, and, etc. In the Middle Jurassic, paleoclimate in the region was humid, and ancient plants were pteris, ginkgo, equisetites, coniopteris, neocalamites and, etc. In the Early Cretaceous, paleoclimate was alternating between dry – wet pertaining to temperate zone to subtropical zone, and ancient plants were Coniferophyta, Classopollis, Granodiscus, Granulatus and, etc (Table 2).

Area and thickness of oil shale beds

The areas of different oil shale deposits differ significantly. For example, the area of oil shale deposits in the Ordos Basin was about 29,400 km^2 [14] in the Middle-Late Triassic, and exceeded 100,000 km^2 in the Middle Jurassic [5, 18], but less than 35 km^2 in the Minhe Basin (Table 2). The area of proved oil shale reserves is generally between 3.3 and 520 km^2 (Table 2). Oil shale monolayer is generally thin – 1–5 m, though, in the Middle-Late Triassic, in the Ordos Basin, the main layers of oil shale were 3–36 m thick [5, 6]. Thickness of different oil shale deposits varies largely (Table 2), for example Yaomoshan oil shale deposit in Urumqi, Xinjiang, is 71 m thick, but only 4 m thick is the Tanshan oil shale in Ningxia.

Characteristics of oil shale samples and material composition

Oil shale is of light gray yellow, or light brown color in Eastern China [9], but mostly brown-black or black in NW China. Oil shale in NW China is characterized by slightly grease shiny and flaky, layered structure with irregular-conchoidal fractures and low hardness. If carving the surface of oil shale with a nail, you can see obvious brown bright streaks and plant debris. Oil shale looks like a brown paper with developed foliation and low hardness after it has been weathered, and some brown paper-thin sheets can directly burn. The surface of oil shale in the Tongchuan region looks maroon due to iron oxidation and is slightly rough due to the presence of sandy minerals. Fresh oil shale surfaces are black. In contrast to the oil shales of the other areas, both maroon color and roughness give the oil shale in the Tongchuan regions a certain appearance [14, 15]. The feature of layers and red surface prove that the oil shale in the Ordos Basin formed in the Middle-Late Triassic in inland deep water – half-deep water lake facies. Because it contains some clastic material, the oil shale should have been formed in a proximal material supply at setting. In microscope, clear angular fragments of feldspar can be seen. The oil shale is characterized by blastopelitic texture and tabular structure. It consists mainly of clay, silt, debris and iron. Both silt and debris contain quartz and plagioclase. Mineral part of oil shale consists of 92% clay, 3% silt and debris, and 5% iron. Mineral is lineated and of formed tabular structure. Microstructure of aphanitic clay is less sericitizated and is obviously orientational. Iron and aphanite fill in the clay. Silt and debris are angular, sub-angular or rounded, with a diameter of 0.03–0.06 mm, some are about 0.15 mm, up to sand grade level. Clay and arene gathered differently, so different composition of layers formed and, therefore, platy cleavage in the rock developed [14, 15]. Also, one of the signs of the Black Sea model is obviously characteristic of stratification [15].

Major and trace elements present in oil shale in the area

Abundance of macro elements, rare-earth elements and trace elements in oil shale in NW China are shown in Tables 4, 5, and distribution patterns of rare-earth elements are shown in Fig. 2.

From Table 4 it is clear that the main materials in oil shale composition are SiO_2 (20.44–54.68% of the rock) and Al_2O_3 (8.51–21.43% of the rock), both the total about 52.54% of the rock, indicating that the shale belongs to the medium ash type [3, 7]. The share of other components is small. Ash is mostly composed of silica and oil shale is of silica type (the standard of silica type is 40–70% SiO_2, 8–30% Al_2O_3, $Fe_2O_3 < 20\%$, $CaO < 20\%$) [3, 7]. If comparing the Fushun oil shale (61.59% SiO_2, 23.36% Al_2O_3 [3]) with the oil shale in NW China, excluding the oil shale in the Shuimogou district in the Junggar Basin which contains more SiO_2, the others in NW China contain less SiO_2, Al_2O_3. The above indicates that the ash yield of the oil shale in NW China is relatively low, generally less than 83%, which is the limit value of oil shale ash content (if it exceeds the limit value, oil shale would become “oil-bearing shale” [3]).

Study of trace elements in oil shale conduces comprehensive use of useful elements and treatment of harmful ones, so improving the level of oil shale utilization. It also can provide a basis for protecting the environment. The trace element content of oil shale is given in Table 5. The oil shale in the area contains significantly more As, Pb, and Se, while the content of Cu, Co, Ni is equivalent or lower than abundance in Continental crust (Taylor value) [3].

It is noteworthy that a significantly higher content of Mo, U, V of the oil shale in the Ordos Basin indicates that there may be a certain connection between the oil shale and large uranium deposits in the Ordos Basin. It is suggested that as the next step there should also be a search for molybdenum and vanadium minerals in the basin. In addition, oil shale in Ordos Basin has a ratio of Mn/Ti equivalent to 0.01, far less than 0.1, indicating that oil shale was deposited in a proximal deposit environment; whereas the ratio of Sr/Ba

0.17 indicates that the oil shale deposited in a lower-salinity lake; and the ratio of V/Ni 16 is not only related to the redox potential of water but also to the content of organic matter, indicating that the water was rich in organic matter and the environment was strongly reducing. In summary, the oil shale in the Ordos Basin deposited in an strongly reducing environment of freshwater and coastal water rich organic matter.

The distribution patterns of REE in oil shale in the areas are consistent with the distribution patterns of REE in sedimentary rocks formed in Post-Late Archean. Both distribution curves are parallel, and the value of La_N/Yb_N is 13.6 ± 2, with Eu anomaly, δEu value is 0.67±0.05. Figure 2 shows that younger oil shale strata contain progressively more REE, and distribution patterns of rare-earth elements are similar to those of the North-American shale.

Compared with the North-American shale, the oil shale in the Ordos Basin lacks rare-earth elements, and, compared with chondrite, it is enriched with a significant amount of Ce (Fig. 2).

Like oil shales formed at different times and in another parts of China, the oil shale in the Ordos Basin is characterized by high H/C and low O/C values [10].

Some problems in the development for oil shale in Northwest China

Analysis of development conditions of oil shale paragenesis with coal

The oil shales in Xiaoxia, Yaojie, Tanshanling, and Tanshan and Shang-xiaheyan are paragenetically related to coal beds. There are 5 m thick good-quality oil shale layers, with 7.8-% oil yield and complete preservation in Xiaoxia. In Yaojie, there are 31 m thick oil shale layers in which the 4^{th} oil layer is 4.73 m thick. In Tanshan, there are 12 m thick oil shale layers, with 200 million tonnes of industrial reserves (121b, detected economic resources) (Tables 1 and 2). The favorable factors of development and utilization are that oil shale can be mined simultaneously with coal. Doing so can reduce costs and improve mining efficiency. However, new techniques are needed because in Tanshan and Yaojie mining has caused some damage. In the newly-mined coal area, oil shale can be mined simultaneously with coal, and the mining depth may be increased considerably.

Mining of oil shale deposits in environmentally protected areas

Near Urumqi city, including Shuimogou, Yaomoshan, Lucaogou, Sangonghe, Jiucaiyuanzi, and other deposits, oil shale reserves amount to 4×10^8 t, and forecasting resources to 114×10^8 t. Thickness of oil shale layers is 47 m in Shuimogou, 71 m in Yaomoshan, 66 m in Lucaogou, and 281 m in Sangonghe with 3.69–13.7% oil yield on average. In Tongchuan, the southern Ordos Basin, there are 9×10^8 t of oil shale industrial reserves (121b, detected economic resources) with an average 6.6-% oil yield (Tables 1 and 2). Although there are certain guaranteed reserves, many of them are located in the area overlaid by a meadow or forest, or even in a park zone, such as Shuimogou. Open-pit mining is unlikely, as it considers using vertical *in-situ* recovery (MISR), a process jointly developed by the Occidental Oil Shale Company and Ralph M, Parson Corporation, used in commercial scale by Occidental companies in Colorado.

Opencast mining

In 1958, Bagemaode oil shale in Inner Mongolia was generally investigated by Geological survey of Inner Mongolia. Afterwards, partial drilling was done. It was shown that the Bagemaode oil shale deposit consists of 6 single layers, altogether 50 m thick, with 8119×10^4 t proven reserves, 300×10^8 t forecast resources, with 10–15% oil yield, maximum 25% oil yield, 14.63–16.72 MJ/kg caloric value, 49.85% volatile content (Tables 1 and 2), physical properties are good with a high mining and utilization value. Geological structure of the mine area is simple, thick deposit is well exposed, mine beds are stable, with small inclination (6–8°), hydrogeological conditions are simple, stripping ratio of 0.53 m^3/t within 0–300 m, and therefore, opencast mining would be suitable.

Conclusions

Oil shale in NW China consists of 1–36-m single layers with stratum distribution. Oil shale is mostly dark brown, black, at some places having a brown-red surface and slightly greasy luster. It contains clay minerals and silt-sized detrital minerals (feldspars and quartz) and is characterized by medium ash, average 1.5% to 13.7% oil yield, 1.66–20.98 MJ/kg calorific value, 1.55 to 2.46 apparent gravity. Younger oil shale strata have progressively higher REE abundances. Oil shale deposits can be classified into mainly three types: the littoral-neritic facies sedimentary deposits of the Middle and Late Carboniferous, remnant lake bay-lacustrine facies sedimentary deposits of the Late Permian, and inland lacustrine-delta facies sedimentary deposits of the Mesozoic. Oil shale which formed in inland deep water – half deep water lacustrine facies in the Mesozoic belongs to the major industrial type and its origin is similar to “the Black Sea model.” The oil shale layers are also the main oil source rocks in the Ordos Basin. Oil shale which formed in deltaic environments in the Middle and Late Carboniferous and Jurassic are mostly paragenetically related to coal. In the area, the total amount of predicted resources of oil shale are at least $31,000\times10^8$ t, equivalent to about 2000×10^8 t of shale oil, oil shale resources in the Ordos Basin account for 99% of the total and can be compared to oil shale resources in the Green River area of western North America. In Northwest China, identified oil shale deposits are located in the vicinity of large and medium-sized cities, with good development prospects. If the problems of environmental pollution will be solved and appropriate techniques are used, immense economic benefits can be obtained.

Acknowledgements

In this paper, the author has quoted the oil shale data from the Land and Resources Department of Shaanxi Province, Gansu Province, Qinghai Province, as well of Inner Mongolia Autonomous Region, Ningxia Hui Autonomous Region and Xinjiang Uygur Autonomous Region. During working in Xinjiang, Senior engineers Zhuxia and Feng Jing have offered various help. Moreover, Ph.D. Kurt Friehauf, Professor of Geology, Department of Physical Sciences, Kutztown University, US, has revised the abstract and Ph.D. Jenna Merrill the whole paper.

REFERENCES

1. The Office of the National Committee of Mineral Reserves Chief Editor. Reference manual of mineral industrial. – Beijing: Geological Publish House, 1987 [in Chinese].
2. *Guan, D., Niu, J., Guo, L. et al.* Unconventionality Oil and Gas Geology in China. – Beijing: Petroleum Industry Press, 1995. P. 228–287 [in Chinese].
3. *Yuan, J. Q., Zhou, S. Q., Zhai, Y. S.* Mineral Deposits. – Beijing: Geological Publishing House, 1979. P. 327–329 [in Chinese].
4. *Smith, J. W.* Oil shale resources of the United States // Mineral and Energy Resources. 1980. Vol. 23, No. 6. P. 15–23.
5. *Zhao, Y. T., Liu, W. B.* Advance in synthesized usage of oil shale in foreign countries // Advance in Earth Science. 1992. Vol. 7, No. 2. P. 49–50 [in Chinese with English abstract].
6. *Liu, Z. J., Liu, R.* Oil shale character and exploitation & utilization prospect // Earth Science Frontiers. 2005. Vol. 12, No. 3. P. 315–323 [in Chinese with English abstract].
7. *Zhao, L. Y., Chen, J. N., Wang, T. S.* Grade dividing and composition of shale in China // Geoscience. 1995. Vol. 5, No. 4. P. 423–429 [in Chinese with English abstract].
8. *Wang, S. Y., Xu, J. M., Wang, Z. H.* Present state of China′s oil shale development and utilization // Geological Economy of China. 1992. No. 5. P. 16–19 [in Chinese with English abstract].
9. *Liu, Z. J., Yang, H. L., Dong, Q. S. et al.* Oil shale in China. – Beijing: Petroleum Industry Press, 2009 [in Chinese].
10. *Bai, Y. L., Ma, L., Wu, W. J.* Geological characteristics and resources/reserves of oil shale in northwestern China and its exploitation and utilization conditions // Geology in China (Bimonthly). 2007. Vol. 34, No. 6 (Serial No. 334). P. 1109–1114 [in Chinese with English abstract].

11. *Bai, Y. L., Wu, W. J.* The resource characteristics of oil shale and analysis of condition of prospecting and using in Minhe Basin, west China // Natural Gas Geoscience. 2006. Vol. 17, No. 5. P. 627–633 [in Chinese with English abstract].
12. *Bai, Y. L.* Prospects for development of oil shale deposits in southeastern margin of Junggar basin // Xinjiang Petroleum Geology. 2008. No. 4. P. 462–465 [in Chinese with English abstract].
13. *Bai, Y. L.,Yang, Y. J., Ma, Y. H.* Main characteristics of oil shale deposits and analysis for foreground of prospecting and using in Tanshan, Guyuan, Ningxia, West-China // Gansu Geology. 2008. Vol. 17, No. 1. P. 65–71 [in Chinese with English abstract].
14. *Bai, Y. L., Wu, W. J., Ma, Y. H.* Geological characteristics and resource potential of oil shale in Ordos basin // Geology in China (Bimonthly). 2009. Vol. 36, No. 5 (Serial No. 334). P. 1123–1137 [in Chinese with English abstract].
15. *Bai, Y. L., Zhao, Y. C., Xu, D.* Geological characteristics and developing-prospecting of oil shale in Tongchuan-Huangling district, Shaanxi Province, China // Geoscience. 2010. Vol. 24, No. 1. P. 158–165 [in Chinese with English abstract].
16. *Zhao, L. S., Zhang, B. R.* Geochemistry. – Beijing: Geological Publishing House, 1979 [in Chinese].
17. *Bai, Y. L., Wang, X. M., Liu, H. Q., Li, T. S.* Determination of the borderline of the western Ordos basin and its geodynamics background // Acta Geologica Sinica. 2006. Vol. 80, No. 6. P.702–813 [in Chinese with English abstract].
18. *Tang, H., Bai, Y. L.* Formation and evolution of ancient land rise in the Western Ordos basin // Gansu Geology. 2006. Vol. 15, No. 1. P. 2–9 [in Chinese with English abstract].
19. *Zhang, H., Bai, Q. Z., Zhang, X. W.* Formation and Evolution of the Ordos Coal-Forming Basin. – Xian: Shaanxi Science and Technology Press, 1995 [in Chinese].
20. *Zou, G. C., Liu, Y. K., Li, X. B.* Jurassic basin-range tectonic pattern and depositional features of prototype basins in the Inner Mongolia-Gansu-Qinghai-Ningxia region // Geological Bulletin of China. 2004. Vol. 23, No. 3. P. 909–918 [in Chinese with English abstract].

Presented by E. Reinsalu
Received January 5, 2011