Main Geological Characteristics and Resource of Oil shale and its Development in Northwest China*

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Abstract

With the amount of oil resources becoming increasingly scarce, non-conventional resources such as oil shale, oil sands, and heavy oil, have caught redoubled attention. There are abundant oil shale resources in Northwest China, which have been preliminary researched in this study. My analysis of field geological section surveys, standard mining investigations, and the laboratory analysis of the important samples indicate that the oil shale in northwest China has the following features: 1) 1- 36m thick oil shale strata existed in the area. 2) The color of oil shale is mostly the brown-black, black, but the color of some oil shale outcrops is maroon. Oil shale has slightly grease shiny and flaky, layered structure, irregular shape-conchoidal fracture, small hardness and light brown streak. 3) In hand specimen, oil shale is mainly composed of clay mineral and silt-sized detrital minerals (quartz). 4) The main chemical components of oil shale are SiO2 and Al2O3which total 65.44% of the rock; indicate that the shale is the medium ash type. The organic carbon of oil shale is 14% and total carbon 16.28%, oil yield generally 1.5%-13.7%, for an overall caloric value of 1.66-20.98MJ/kg. The density of the shale is 1.55-2.46 g/cc. Younger oil shale strata have progressively higher REE abundances. 5) Oil shale deposits are mainly 3 types: the littoral-neritic facies sedimentary deposits in the middle and late Carboniferous - the early Permian, lake bay-lacustrine facies sedimentary deposits in the late Permian, and inland lacustrine–delta facies sedimentary deposits in Mesozoic. Oil shales which were formed in inland deep water - half deep water lacustrine facies in Mesozoic are the major industry type and its origin is similar to "the Black Sea model." Oil shales which were formed in deltaic environments in the middle and late Carboniferous and Jurassic are mostly paragenetically related to coal beds. 6) In the area, the total amount of predicted resources of oil shale at least 30000× 108 t which equivalents to about 2100× 108 t of shale oil and in which oil shale resources in Ordos basin

accounts for 99% and can be compared to oil shale resources in Green River area of western North American. 7) In northwest China, identified oil shale deposits are located in the vicinity of large and medium-sized cities, with good development prospects.

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, and from which a significant quantity of oil can be fractionated out. In oil shale, the organic matter content is higher (greater than 15%) and ash is higher (greater than 40%) also. Oil shale can burn. The oil yield of oil shale is usually more than 3.5%, and has a caloric value of 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].

According to the Strategic Planning of Western China Development (SPWCD) and the need of CNPC, oil shale in NW China had been studied by the authors. 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. Total count is 13 (Figure 1). The study of the authors indicated that there are abundant oil shale resources in northwest China and the total amount of predicted resources of oil shale at least 30,000× 108 t which is equivalent to about 2,100× 108 t of shale oil in northwest China .

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 Bagemaode oil shale deposit in Wulatehouqi County, Inner Mongolia, the other oil shale deposits and mineral occurrences are near the railway and highway, transportation is convenient. Some oil shale deposits mentioned above are, more importantly, located nearby large - medium cities in the area, therefore, the development and utilization conditions were better and the benefits acquired will also have been better.

Methods and Results

Part of the investigations had been done for the above 13 oil shale deposits in NW China and some information had been obtained by predecessors [2, 6, 8～15]. Therefore, except for the oil shale in Ordos basin, the oil shale resources which were accounted for by predecessors were used by authors in this study (Table1). The resources of oil shale in Ordos basin were accounted according to field survey, geological mapping, and analysis for samples and logging data of oil fields. (Table1) [14,15] For identified distribution, quality, size, reserve and utilization conditions of oil shale deposits in the area, research has been completed to survey field geological sections in a relatively detailed way, geological mapping in some standard area and trenching expose in the cover area. Research had also been conducted to observe the attitude, size, distribution and geological characteristics of oil shale in field. For results see Table 2. Some important specimens have been collected, and then sent to Gansu Coal Quality Supervision Examine Station for analysis oil yield of oil shale and the Test Center of Geophysical and Chemical Exploration Research Institute, Lands and Resources Ministry for analysis of macro, micro and rare-earth elements. For oil yield of oil shale, the method of analysis was Gray-King low temperature distillation, the test criterion is GB-T1341-2007, and analysis was done by Liu Bingyuan (2008). And for the analysis methods of macro, micro and rare-earth elements of oil shale see Table 3. For analysis results see Table 4, Table 5, and Figure 2.

Discussion

Large resources potentials and low verification levels

Table 1 shows that the total amount of predicted resources of oil shale in NW China was about 31,000 × 108 t, which is equivalent to about 2,026 × 108 t of shale oil, and in which oil shale resources in Ordos basin accounts for 99% and can be compared to the oil shale resources in Green River area of western North America. The latter also reaches about 2,000 × 108 t shale oil resources. [9,10] But the amount of proved and controlled economic reserves (121b +122b +2m22) is about 22.86 × 108 t, which is equivalent to about 1.5 × 108 t shale oil (burial depth is less than 300 m).The amount of identified resources is near 131.56 × 108 t. The ratio of proved reserves of oil shale was significantly low, which accounts for about 6% of the proved oil shale reserves across the country (374 × 108 t). [2,6,9]

In the Ordos basin, the predicted, intrinsic economic resource (334) mainly distributed in more than 300 m under the ground. [14] The above showed that the exploration level of oil shale deposits is lower in the regions. Furthermore it is maldistribution and deeply buried. But it demonstrated that big potentials of exploration and development exist in these regions in the same time.

Temporal and spatial distribution of oil shale in the area

Currently, the oil shale in northwest China mainly occurred in different types of basins from the late Paleozoic to Mesozoic (the littoral-neritic basins and inland lakes), and generally had a shallow depth. But the oil shale in Ordos Basin, which formed in the middle- late Triassic in half-deep lake - deep lake, had a big buried depth; the maximum depth is nearly 2,000 m. Specific features as follow:

In the late Paleozoic, oil shale mainly occurred in the coastal basins on passive continental margin of the southwest of palae North China plate and the inland lakes environment on the suturing zone between the palae Tarim plate and palae Junggar plate respectively (Figure 1). The former Shangxiaheyuan oil shale deposit in Zhongwei County, Ningxia is an example, formed in the late Carboniferous, and the latter Yaomoshan oil shale deposit of Urumqi city, Xinjiang is also an example, formed in the late Permian. They have significant differences in the environment under which they were formed. The former essentially formed in a marine environment and the latter essentially formed in a terrestrial environment. Though Shangxiaheyan oil shale deposit in Zhongwei county are distributed 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-environmental formed the oil shale in Urumqi city − Jimusaer country was treated as marine. Then because the freshwater lamellibranch found in the strata contained oil shale layers later, the paleo-environmental was treated as a the terrestrial environment.

In Mesozoic, oil shale mainly occurred in inland lakes after the collision of palae North China plate with palae South China Plate. Among inland lake basins, the generation of Ordos basin was mainly owing to pushing and shoving by Indosinian movement in the south. The oil shale occurred in Ordos basin is also the main source rocks of the super large Ordos oil field. [17] But in Jurassic and Cretaceous, the development of inland lakes was mainly affected by subduction of ancient Izanagi plate in the east side or Tethyan oceanic plate in the south side. [18,19] Tanshan oil shale was formed in Yan'an Formation in the early stage of the middle Jurassic, and Tongchuan oil shale (included the oil shale which distributed in Tongchuan oil shale peripheral region) was formed in Yanchang Formation in the middle-Late Triassic. Yaojie oil shale, Tanshanling oil shale and Xiaoxia oil shale were respectively formed in the Minhe basin and the Xining basin in the early stage of the middle Jurassic [10,11] and the two basins had genetic relationship and belong to the same basin in the early stage of the middle Jurassic in essence. Bagemaode oil shale was formed in Bayingobi Formation in north-east edge of Suhongtu basin, which formed in the late period of the early Cretaceous (Table 2).

Types and ancient environment of oil shale deposits in the area

There are mainly three types of oil shale deposits in northwestern China: (i) littoral- neritic facies sedimentary deposits in the late carboniferous; (ii) residual lake bay – lake phase sedimentary deposits in the late Permian; (iii) inland lake system sedimentary deposits (including lake facies and delta phase). In the late Carboniferous, paleoclimate in the region was interchange between mild – wet and dry - wet and ancient organisms were Cathaysia Lepidodendropsis flora. In the late Permian, paleoclimate in the region was semi-humid and ancient organisms were Angara flora, Ostracods, Bivalves, Conchostracan and the freshwater lamellibranch. In the middle - late Triassic, paleoclimate in the region was hot - humid environment 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 early Cretaceous, paleoclimate in the region was dry - wet alternating pertaining to temperate zone to subtropical zone and ancient plants were Coniferophyte, Classopollis, Granodiscus, Granulatus and etc. (Table 2)

Area and thickness of oil shale in the regions

The area among different oil shale deposits is significantly different. For example, the area of oil shale deposits is about 29, [14] in the middle-late Triassic, and exceeded 100,000 in the middle Jurassic [5,18] in Ordos Basin, but less than 35 in Minhe basin (Table 2). The area of proved oil shale reserves is generally 3.3 ~ 520 (Table 2). Oil shale had a thinner monolayer which is generally 1 ~ 5m thick, though, in the middle-late Triassic, in the Ordos Basin, the main layers of oil shale were 3-36 m thick. [5,6] A large thickness difference among different oil shale deposits also exists (Table 2), for example Yaomoshan oil shale deposit in Urumqi, Xinjiang is 71 m thick, but only 4 m thick in Tanshan oil shale, Ningxia.

Oil shale characteristics in hand specimen and material composition in the area

Oil shale appears light gray yellow, light brown in eastern China [9], but mostly brown- black or black in NW China. Oil shale in NW China has slightly grease shiny and flaky, layered structure, irregular -conchoidal fracture, small hardness. If carving the surface of oil shale with a nail, you can see obvious brown bright streaks. It is obvious the oil shale is greasy and shiny. Plant debris can be seen on it. It has a small hardness, developed foliation, and appears as a brown paper- thin sheet after it has been weathered, and some brown paper- thin sheets can directly burn. The surface of oil shale of Tongchuan regions appears maroon due to iron oxidation, with a slightly rough feeling due to oil shale contains sandy minerals. But it is black on fresh oil shale surfaces. In contrast to the oil shales of different areas, both maroon and rough feelings of oil shale in Tongchuan regions are marks of the significance. [14,15] According to the feature of layers and red surfaces, it has been shown that the oil shale in Ordos basin in the middle-late Triassic was formed in inland deep water - half deep water lake facies. Because it contained some clastic material, the oil shale should have formed in a proximal material supply setting. Microscopically, clear angular fragments of feldspar can be seen. The oil shale had blastopelitic texture and tabular structure. It mainly consists of clay, silt, debris and iron, etc. Both silt and debris composed quartz and plagioclase. In oil shale, mineral composition is 92% of clay, 3% of silt and debris, 5% of iron. Mineral is lineation and formed tabular structure. Microstructure aphanitic clay had minor sericitization phenomenon and is obviously orientational. Iron and aphanitic fill in the clay.

Silt and debris is angular, sub-angular or rounded, with a diameter of 0.03 ~ 0.06 mm, individual ones are about 0.15 mm, up to sand grade level. Clay and arene was relatively gathered, and different composition was distributed in layers, therefore, platy cleavage in the rock was developed. [14,15] Also, one of the signs of the Black Sea Model is obviously characteristic of stratification. [15]

Characteristics of major elements and trace elements of oil shale in the area

Abundance of macro elements, rare-earth elements and trace elements of oil shale in northwest China are shown in Table 4 and Table 5, and rare earth distribution patterns are shown in Figure 2.

From Table 4, it is clear to see that the main material composition of the oil shale is SiO2 (33% ~ 72% of the rock) and (8.51% ~ 21.43% of the rock), both total around 67.64% of the rock, and indicates that the main components of the oil shale is SiO2 and , belonging to the medium ash type. [3,7] The other components are less. Ash is mostly composed of silica. Oil shale falls into silica type（the standard of silica type is 40% ~ 70% of , 8% ~ 30% of , <20%, CaO < 20% [3,7]. If comparing the oil shale in Fushun (of 61.59%, of 23.36% [3]) with the oil shale in NW China, excluding the oil shale in Shuimogou district in Junggar basin, which had higher , the others have lower , in NW China. The above indicates that the ash of the oil shale in NW China is relatively low, generally less than 83% which is the limit value of ash content of oil shale (if it exceeds the limit value, oil shale should become “oil-bearing shale”). [3]

Study of trace elements in oil shale is conducive to comprehensive use of useful elements and to treatment of those harmful elements, and to improving of the value of oil shale utilization. It also can provide a basis for protecting the environment. The trace element content of oil shale refers to Table 5. From Table 5, the oil shale in the areas is significantly higher as, higher Pb, Se, while Cu, Co, Ni equivalent or lower than Continental crust abundance (Taylor value, 1992). [3]

It is noteworthy that the oil shale in Ordos basin with significantly higher Mo, U, V, which indicates that there may be a certain connection between the oil shale and the large uranium deposits in the Ordos basin. It suggested that in 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 near-source environment; whereas the ratio of Sr/Ba is 0.17 indicating that the oil shale was deposited in a lower salinity lake; and the ratio of V/Ni is not only related to the redox potential of water but also the content of organic matter, and the ratio of V/Ni is 16, indicating that the water has a rich organic matter and a strong reduction environment. In summary, the oil shale in Ordos basin was deposited under an environment of freshwater, coastal, strong reducing, 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 which formed in post-the late Archean, and both the distribution curve is parallel each other, and the value of LaN/YbN is 13.6 ± 2, with Eu anomaly, δEu value is 0.67 ± 0.05. Figure 2 shows that younger oil shale strata have progressively higher REE abundances, and rare earth distribution patterns similar to the North American shale.

Compared with the North American shale, the oil shale in Ordos is lacks rare earth, and compared with chondrite, it enriched with a significant amount of Ce. (Figure 2)
Like the oil shale which formed in a different time and in another part of China, the oil shale in northwest China has high H/C and low O/C. (Table 5)

Some problems in the development for oil shale in northwest China

An analysis for development conditions of oil shale paragenesis with coal

The oil shale in Xiaoxia, Yaojie, Tanshanling, and Tanshan and Shangxiaheyan are paragenetically related to coal beds. There are 5 m thick good quality oil shale layers, with 7.8% of oil yield and complete preservation in Xiaoxia. In Yaojie, there are 31 m thick oil shale layers in which the 4th oil layer is 4.73m thick. In Tanshan, there are 12 m thick oil shale layers, part of 200 million tons of industry reserves (121b, Detected、 economic resources) existed in Tanshan (Table 1 and Table 2). The favorable factors of development and utilization are that oil shale can be mined at the same time that coal is mined. Doing such can reduce costs and improve efficiency. However, new techniques are needed because in Tanshan and Yaojie a certain degree of damage has resulted from mining. In the newly mined coal area, oil shale can be mined simultaneously with coal and its mining depth may be increased considerably.

Mining of oil shale deposits in environmentally protected areas

Near Urumqi city, including Shuimogou, Yaomoshan, Lucaogou, Sangonghe, Jiucaiyuanzi, etc, there were 4 × 108 t of oil shale reserves, and 114 × 108 t of oil shale forecasting resources. Forty-seven meter thick oil shale layers existed in Shuimogou and 71 m in Yaomoshan and 66 m in Lucaogou, and 281m in Sangonghe. There is 3.69% -13.7% oil yield average. In Tongchuan, southern Ordos Basin, there are 9 × 108 t of oil shale industry reserves (121b, Detected, economic resources) and 6.6% oil yield average (Table 1 and Table 2). Although there are a certain guaranteed reserves, many of these are located in the overlay area of a meadow or forest, or even in a Park zone, such as Shuimogou, An open pit is unlikely, for it consider using vertical in-situ recovery (MISR), a process jointly developed by the Occidental Oil Shale Company and Ralph M. Parson Corporation Jointly, had been used in commercial scale by Occidental companies in Colorado.

Opencast mining

In 1958, Bagemaode oil shale in Inner Mongolia had been generally investigated by Geological survey of Inner Mongolia. Afterwards, partial drilling had been done. It was shown that Bagemaode oil shale mine consists of 6 single-layers, altogether 50 m thick, with 8,119 × 104 t proven reserves, 300 × 108 t forecast resource, and 10% to 15% oil yield, maximum 25% oil yield, 14.63 ~ 16.72 MJ/kg caloric value, 49% to 85% volatile (Table 1 and Table 2), good physical property, with a high mining and utilization value. The mine area had a simple geological structure, was well exposed and had a large thickness, more stable mine beds, less inclination (6 ~ 8°), simple hydrogeological conditions, and a stripping ratio of 0.53 /t within 0 - 300 m, therefore, opencast should be suitable.

Conclusion

Oil shale in northwest China had a stratum distribution, from 1 ~ 36 m thick single-layers. Oil shale is mostly dark brown, black, some having a brown-red surface, and slightly greasy luster. It consists of clay minerals and silt -sized detrital minerals (feldspar and quartz), with medium ash, 1.5% to 13.7% oil yield average, 1.66 ~ 20.98 MJ/kg caloric 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 in the middle and late Carboniferous, remnant lake bay-lacustrine facies sedimentary deposits in the late Permian, and inland lacustrine–delta facies sedimentary deposits in Mesozoic. Oil shale which was formed in inland deep water - half deep water lacustrine facies in Mesozoic are the major industry type and its origin is similar to “the Black Sea model.” The oil shale layers are also the main oil source rocks in Ordos basin. Oil shale which was 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 at least 30,000× 108 t is equivalent to about 2,100× 108 t of shale oil and in which oil shale resources in Ordos basin accounts for 99% and can be compared to oil shale resources in 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 are solved and appropriate techniques are used, immense economic benefits can be obtained.

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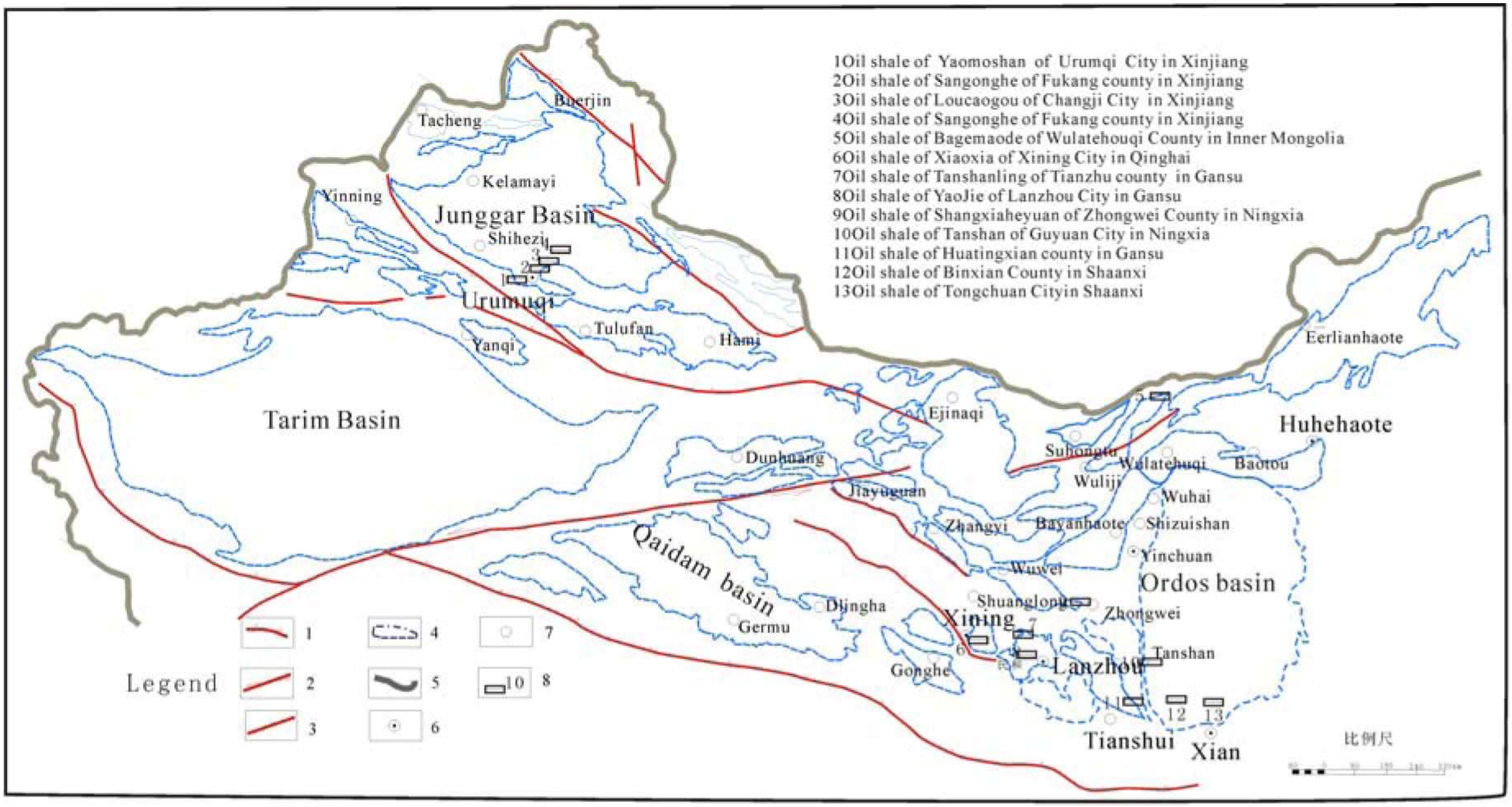

Figure 1. Outcrop distribution map of oil shale deposits in northwest China.

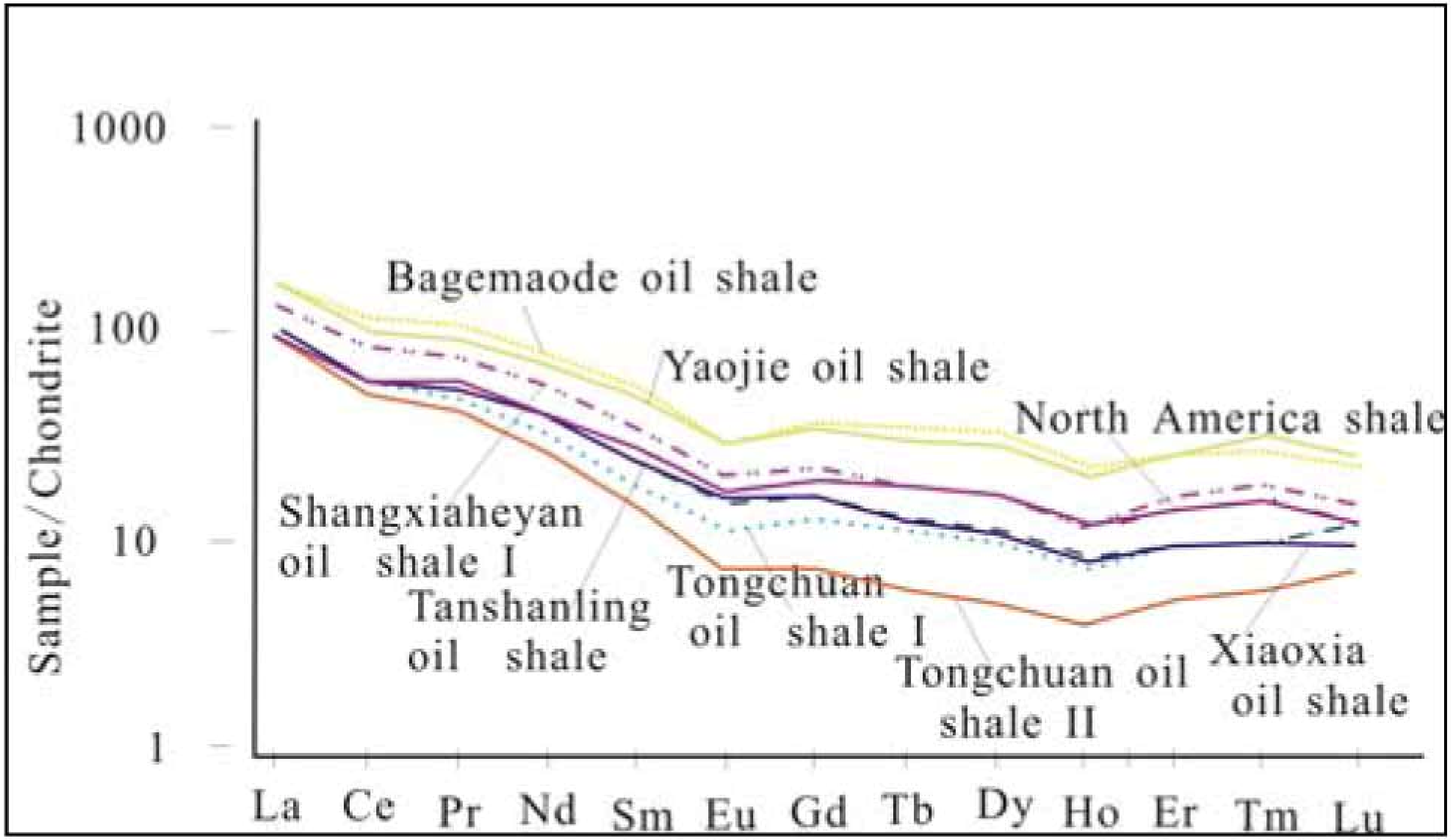

Figure 2. Chondrite-normalized REE abundances in whole-rock samples of oil shale in northwest-China.

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（×10^{8}t）	Detected or controlled basic reserve（×10^{8}t）				Resource（×10^{8}t）
		Prediction、intrinsic economy（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			
	Bin county in Shaanxi [6,9]	280			0.06	0.06	
	Whole basin	30382.92					
	Total	30847.92	4.93	15.04	2.89	22.86	131.56
Total Resources Reserves		31002.34×10^{8}t（Equivalent to 2036×10^{8}t of shale oil，6.6% of oil yield）					

Table 1. Statistics of total resources of each occurrence area of oil shale in northwest–China.

Era	Typical deposits	Basin types	Sedimentary environment	Paleoclimate condition	Ancient plant combination	Character of oil shale: Total NO .of Layer.	Thickness(m)	Oil yield (%)	Area (km^2)	burial depth(m)	Co-exist coal rank
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	
MiddleJurassic	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	Fore-land basin	Piedmont lake	Warm zone, humid	Ginkgo, Ferns	4	4.22	11.2	300 predicted	100-300	Long-flame coal
Middle-later 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	
Later Permian	Yaomoshan in Urumqi Xinjiang	Fore-land 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	Fore-land basin	Lake-bay	Warm zone, semi-humid		23	66.18 (Single layer 2 ~ 10)	7.08	11.49	0 ~ 500	
	Shuimogou in Changji Xinjian	Fore-land basin	Lake-bay	Warm zone, semi-humid		23	47 (Single layer 2 ~ 10)	5.4 ~ 10.3	4.34	0 ~ 500	
Later 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 2. Main geological characteristics of oil shale deposits in northwest China.

Analysis technique	Element	Qualification rate	Laboratory	Analyser	Time
Flameless atomic absorption spectrometry(AAN)	Au	100%	The Test Center of Geophysical and Chemical Exploration Research Institute, Ministry of Land and Resources	Xu Shanfa	2009
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				
Oxidate-Thermolysis –Gas Chromatography	N, total C				
Electrometric method	Organic C				

Table 3. Method of analysis for macro, micro and rare-earth elements of oil shale.

Serial number	Sampling sites	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	

Table 4. Chemical composition of oil shale in northwest China.

Sampling sites	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)	TongchuanII-2	3.95	171	66.0	1010	1.3	71.3	7.94	79.0	6.9	29	1.38	36.20	183	13.1	50	2970	146.5
	TongchuanIV-2	1.19	177	38.0	655	4.6	55.7	8.68	73.0	17.3	32	0.42	26.66	228	29.0	73	2855	146.8
Continental crust abundance		4	70	1.8	390	25	55	3	1.5	75	12.5	0.05	2.7	135	70	100	4500	340

Lanthanon aundance

Sampling sites	Sample numbers	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		
Bagaa mauder 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		
Shangxiaheyan 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	TongchuanII-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 deposit)	TongchuanIV-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, Lands and Resources Ministry (2005); the earth element abundances is Taylor value [16], except Au, Ag in units of 10×10^{-9}, the other element in unit 10×10^{-6}

Table 5. Abundance of trace element and rare-earth element of oil Shale in northwest China.