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# CHARACTERISTICS AND RESOURCE POTENTIAL OF OIL SHALE IN CHINA

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***Abstract.*** *Based on the results of the National Oil Shale Resource Evaluation in China conducted from 2003 to 2006, and combined with the new exploration progress in recent years, the characteristics and resource potential of oil shale in China have been systematically studied in this paper. Oil shale resources in China are abundant, with deposits mainly found in the continental environment and, secondarily, in marine-continental facies.*

*The color of oil shale is black to grayish black, black to gray brown or gray to dark gray. In general, the darker the color, the higher the quality of oil shale. The most common minerals in oil shale are clay minerals, quartz and feldspars. The concentration of organic carbon in Chinese oil shale is high, between 7.48 and 38.02%. By organic genetic type, oil shale can be divided into sapropelic, humosapropelic and saprohumic oil shale. Oil shale used for industrial purposes has a medium to high oil yield and high ash content. Oil shale resources in China are mainly concentrated in 20 provinces and autonomous regions, 50 basins and 83 petroliferous shale areas. Total oil shale resources are estimated at approximately 978 billion tons, i.e. about 61 billion tons of in-place shale oil, mainly distributed throughout eastern and central China and the Qinghai-Tibet Region in western China. This paper outlines the distribution of oil shale deposits in China with respect to depositional basin type, and oil shale age and grade. Oil shale in China was deposited mainly in extensional and intra-plate basins during the Mesozoic and the Cenozoic. The size of the basins diminishes from older to younger deposits. Oil shale resources that yield shale oil more than 5% by weight account for about 72% of the rock's total resources in the country.*

***Keywords:*** *Chinese oil shale, shale oil yield, resource evaluation, resource distribution, Cenozoic, Mesozoic.*

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## 1. Introduction

Due to fluctuating global oil prices, unconventional oil and gas resources, such as oil shale, shale gas, etc., have been receiving more and more attention lately. Because of its specific composition and structure, oil shale has good prospects for use in many fields, such as the chemical and building materials industries, medicine, agriculture, environmental protection, etc. [1–7]. Oil shale deposits are found in many parts of the world, but these are distributed unevenly and have not been developed and used very well. The basins are concentrated in the U.S., China, Russia, Jordan, Brazil, Morocco, Australia, Estonia, Canada, Zaire, Italy, France, etc. Total world resources of oil shale are equivalent to 411 billion tons of in-place shale oil, the United States with its approximately 340 billion tons being the leading country in the world, while China ranks second [8, 9]. At the same time, the geological exploration of oil shale in most countries has been insufficient and the amounts of discovered resources are very small.

Oil shale resources in China are abundant and are mainly distributed in the continental environment. Oil shale-bearing basins are both large depression and small fault basins. Oil shale deposits range widely in age from the Late Paleozoic to the Cenozoic, and were formed in a variety of depositional environments, including fresh-water, brackish and salt lakes, as well as limnic and coastal swamps, commonly in association with the deposits of coal and gypsum. The current geographical environment of oil shale deposits is mainly plain, loess tableland and plateau, partly distributed in the low-mountain hilly region. The current depth of oil shale resources is evaluated to be between 0 and 1000 m, but these are mainly buried in shallow layers, between 0 and 500 m, favorable for development and use [10].

There is not yet a widely accepted definition for "oil shale". For example, Zelenin and Ozerov [11] defined oil shale as a solid combustible organic rock which is rich in sapropelic, humosapropelic or saprohumic organic matter and was deposited in marine, lacustrine, deltaic and fluvial environments. Organic matter accounts for 10 to 60% of oil shale composition and is evenly distributed in silicate, aluminum silicate or carbonate minerals. When heated it will yield oil, combustible gas and ash (semicoke). Dyni [8] defined oil shale as a fine-grained sedimentary rock containing organic matter that will yield substantial amounts of oil and combustible gas upon destructive distillation. Zhao et al. [12] defined oil shale as a solid combustible rock with high ash content, of sapropelic, humic or mixed origin, with an oil yield more than 5% and a calorific value higher than 7.5 MJ/kg, which meet the requirements for industrial minerals. The main difference between oil shale and coal in China is in ash content, which is higher in oil shale (more than 40%). Oil shale and carbonaceous shale primarily differ in oil yield, which is higher from the former (over than 3.5%). It is internationally recognized that shale with an oil yield more than 0.25 barrel shale oil per ton (equal to oil yield more than 3.5%) is called oil shale [13]. The above definitions are all based upon a researcher`s perspective and consider certain features or properties of oil shale. However, the majority of researchers have not taken into account oil yield, and thus the boundary between oil shale and non-oil shale is vague. In this paper, oil shale in China is defined as a solid combustible organic rock with a high ash content (more than 40%) that upon low-temperature distillation yields generally more than 3.5% of oil. The content of organic matter (sapropel, humosapropel or sapropel-humus) of oil shale is very high, and the calorific value is higher than 4.18 kJ/g. The lower limit of industrial indices (oil yield and calorific value) may change as the economic and technical conditions for oil shale development advance [10].

Based on the results of the National Oil Shale Resource Evaluation conducted from 2003 to 2006, and combined with the progress of oil shale resource exploration in China in recent years, this paper thoroughly studies the mineral composition, organic geochemistry and quality characteristics of Chinese oil shale and analyzes its resource potential. In order to better reveal the resource status and distribution of oil shale in the country, we classified oil shale resources of different regions according to basin type, time and oil yield.

## 2. Characteristics of oil shale in China

### 2.1. Physical properties

Oil shale in China is mainly black to grayish black, black to gray brown or gray to dark gray, usually with a dull or pitchy luster, or greasy appearance. Within a single oil shale deposit, in most cases, the color of high quality oil shale is darker than that of poor quality rock, and its luster is relatively intense. For instance, in Fushun, the oil yield of dark brown oil shale reaches 12%, but the oil yield of gray oil shale is generally between 3.5 and 6%. Likewise, the color of Huadian oil shale changes greatly: oil shale with the highest oil yield (24%) is gray brown, but that with the lowest oil yield (generally less than 10%) is grayish black. The colour of oil shale in the southern deposits of China is lighter than in its northwestern, northeastern and central deposits. The density of oil shale is between 1.55 and 2.48 $t/m^3$ (Table 1), and, generally, the higher the density of oil shale is, the lower its oil yield is, due to the lower organic content in the sample.

**Table 1. Characteristics of oil shales in 50 oil shale basins of China**

| Region | Basin | Basin type | Age | ▲Burial depth, m | Density, t/m$^3$ | ▲Number of ore beds | ▲Total thickness of ore beds, m | ▲Area of ore beds, km$^2$ | ▲Average oil yield, % | Highest oil yield, % | Average ash content, % | Average calorific value, MJ/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Eastern China | Bohaiwan | Extensional | Cenozoic | 200–850 | 1.72 | 3 | 46.10 | 5.33 | 5.93 | – | 59.61 | 10.04 |
| | Chaoyang | Extensional | Mesozoic | 20–500 | 2.19 | 4 | 36.52 | 16.28 | 4.65 | 7.00 | 71.20 | 12.90 |
| | Dayangshu | Extensional | Mesozoic | 0–500 | 1.81 | 3 | 2.06–2.61 | 0.06–1397.46 | 7.61 | 14.06 | – | 6.01 |
| | Fengning | Extensional | Mesozoic | 0–350 | 2.11 | 6 | 10.95 | 1.31 | 6.06 | 13.38 | 84.18 | 4.94 |
| | Fengshan | Extensional | Mesozoic | 30–440 | 2.36 | 26 | 31.82 | 0.68 | 4.46 | – | 82.52 | 2.70 |
| | *Fushun | Strike-slip | Cenozoic | 0–750 | 2.12 | 2 | 49.20 | 35.00 | 5.86 | 12.00 | 76.10 | 4.75 |
| | Fuxin | Extensional | Mesozoic | 0–210 | 2.24 | 2 | 2.88 | 2.51 | 4.47 | – | – | – |
| | Heishan | Extensional | Mesozoic | 14–400 | 1.70 | 5 | 43.32 | 5.47 | 5.06 | 13.58 | 56.11 | 11.76 |
| | *Huadian | Strike-slip | Cenozoic | 0–1000 | 1.99 | 13 | 12.10 | 32.43 | 8.59 | 24.80 | 69.37 | 9.99 |
| | Jianchang | Extensional | Mesozoic | 10–960 | 2.15–2.48 | 6–15 | 18.40–22.08 | 12.22–93.23 | 4.52 | 12.13 | 78.02 | 3.69 |
| | *Jiaolai | Strike-slip | Cenozoic | 10–1000 | 1.55 | 1–6 | 6.17–16.18 | 2.51–75 | 10.95 | 18.49 | 58.45 | 11.66 |
| | Jiangjiaying | Extensional | Cenozoic | 45–300 | 1.38 | 1 | 1.43 | 0.08 | 7.87 | 10.05 | – | 4.09 |
| | Jining | Intra-plate | Upper Paleozoic | 360–710 | 1.59 | 1 | 1.82 | 21.40 | 16.51 | 14.53 | 46.51 | 20.93 |
| | Laoheishan | Extensional | Mesozoic | 0–1000 | 1.54 | 1 | 0.85 | 168.57 | 15.13 | 19.82 | 55.40 | 11.55 |
| | Linkou | Extensional | Cenozoic | 0–500 | 1.87 | 1 | 2.60 | 147.37 | 10.01 | 23.60 | 59.94 | 25.52 |
| | *Luozigou | Extensional | Mesozoic | 0–800 | 1.94 | 27 | 49.92 | 12.29 | 6.72 | 14.37 | 76.39 | 20.35 |
| | Meihe | Strike-slip | Cenozoic | 0–1000 | 2.00 | 1 | 12.73 | 11.48 | 4.83 | 9.16 | – | – |
| | Shulan | Strike-slip | Cenozoic | 450–1000 | 2.00 | 1 | 3.37 | 113.99 | 5.53 | 6.05 | – | – |
| | Sichakou | Extensional | Mesozoic | 40–530 | 2.08 | 21 | 32.70 | 6.13 | 5.29 | 5.88 | 88.90 | 1.69 |
| | *Songliao | Extensional | Mesozoic | 0–1000 | 2.04 | 1–25 | 2.60–38.94 | 60–19567 | 4.77 | 16.30 | 82.55 | 4.19 |
| | Tantou | Strike-slip | Cenozoic | 10–295 | 2.15 | 25 | 66.90 | 0.54 | 4.86 | 9.03 | 74.90 | 4.50 |

(Continuation of Table 1)

| Region | Basin | Basin type | Age | ▲Burial depth, m | Density, t/m³ | ▲Number of ore beds | ▲Total thickness of ore beds, m | ▲Area of ore beds, km² | ▲Average oil yield, % | Highest oil yield, % | Average ash content, % | Average calorific value, MJ/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tongbai | Strike-slip | Cenozoic | 20–300 | 2.14 | 32 | 33.03 | 5.56 | 6.20 | – | 74.90 | – |
| | Weichang | Extensional | Mesozoic | 30–315 | 2.17 | 10 | 13.80 | 2.21 | 4.62 | 8.67 | 84.01 | 1.09 |
| | Yangshugou | Extensional | Mesozoic | 0–800 | 1.88 | 1–19 | 19.13–74.00 | 1.25–6.99 | 5.54 | 10.29 | 69.50 | 4.82 |
| | Yanheying | Extensional | Mesozoic | 20–300 | 2.09 | 1 | 7.43 | 0.40 | 8.50 | 13.23 | 86.00 | 3.87 |
| | *Yilan | Strike-slip | Cenozoic | 0–1000 | 2.00 | 5 | 6.10 | 15.91 | 6.85 | 9.12 | 84.35 | 7.59 |
| | Yin'E | Strike-slip | Mesozoic | 0–187.4 | 1.88 | 4 | 1.12–7.09 | 48.43–152.59 | 4.50 | 15.30 | 77.38 | 3.82 |
| Central China | Hetao | Extensional | Mesozoic | 0–200 | 2.22 | 1 | 3.58 | 6.48 | 4.00 | 4.65 | – | – |
| | Liupanshan | Intra-plate | Upper Paleozoic | 0–500 | 2.02 | 1 | 2.17 | 3.94 | 4.45 | 9.09 | 58.32 | – |
| | *Ordos | Intra-plate | Mesozoic | 0–1000 | 1.90–2.21 | 1–3 | 0.79–13.9 | 1.68–6928.52 | 6.12 | 9.25 | 76.55 | – |
| | Sichuan | Intra-plate | Mesozoic | 0–500 | 2.30 | 1 | 0.80 | 2207.98 | 4.23 | 6.00 | – | – |
| Southern China | Banshi | Intra-plate | Mesozoic | 0–200 | 2.20 | 3 | 4.99 | 0.09 | 4.10 | – | 89.58 | 0.74 |
| | *Beibu Gulf | Strike-slip | Cenozoic | 0–500 | 1.60 | 3–7 | 19.1–52.89 | 3.47–30.95 | 4.85 | – | 72.74 | 5.68 |
| | Chuxiong | Intra-plate | Mesozoic | 200–1000 | 2.18 | 1 | 0.72 | 1.02 | 5.16 | 6.50 | – | – |
| | Ji'An | Intra-plate | Mesozoic | 0–75 | 2.00 | 1 | 2.78 | 0.32 | 4.93 | 6.89 | 64.50 | 34.6 |
| | Jurong | Strike-slip | Cenozoic | 26–190 | 2.20 | 1 | 2.65 | 6.94 | 4.82 | – | 80.80 | 2.20 |
| | Lanping-simao | Strike-slip | Cenozoic | 0–600 | 2.26 | 2 | 16.50 | 0.74 | 4.90 | 9.38 | 85.17 | 31.30 |
| | *Maoming | Extensional | Cenozoic | 0–1000 | 1.80 | 1-6 | 16.28–24.67 | 37.35–426.97 | 6.14 | 13.00 | 72.74 | 5.68 |
| | Napeng | Extensional | Cenozoic | 0–150 | 1.63 | 4 | 4.74 | 0.29 | 6.34 | – | 55.19 | 7.60 |
| | Pingxiang | Intra-plate | Mesozoic | 0–600 | 1.4–-2.00 | 1–3 | 1.21–5.49 | 1.44–8.61 | 5.31 | 8.70 | 72.12 | – |

(Continuation of Table 1)

| Region | Basin | Basin type | Age | ▲Burial depth, m | Density, t/m$^3$ | ▲Number of ore beds | ▲Total thickness of ore beds, m | ▲Area of ore beds, km$^2$ | ▲Average oil yield, % | Highest oil yield, % | Average ash content, % | Average calorific value, MJ/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Qinzhou | Extensional | Cenozoic | 0–330 | 1.71 | 7 | 2.33 | 4.55 | 6.45 | 11.05 | 64.16 | 11.07 |
| | Xiangxian | Extensional | Cenozoic | 0–600 | 1.80 | 3 | 2.91 | 8.19 | 3.61 | 3.73 | – | – |
| | Xinning | Intra-plate basin | Mesozoic | 86–218 | 1.94 | 1 | 1.84 | 8.66 | 7.80 | 13.22 | 66.46 | 31.59 |
| Western China | A'Ba | Flexural basin | Cenozoic | 0–500 | 1.48 | 1 | 6.28 | 86.46 | 6.16 | 9.72 | – | – |
| | *Junggar | Flexural | Upper Paleozoic | 0–1000 | 2.17 | 1–23 | 44.73–160 | 1.09–151.88 | 7.73 | 14.92 | 77.35 | 7.85 |
| | *Minhe | Strike-slip | Mesozoic | 0–1000 | 2.07 | 2–3 | 18.6–39.03 | 10.51-62.63 | 5.44 | 17.72 | 69.87 | 6.93 |
| | Qaidam | Extensional | Mesozoic | 0–1000 | 2.00 | 1–2 | 20.31–20.9 | 3.50–399.56 | 9.14 | 13.90 | 68.00 | – |
| | Xining | Extensional | Mesozoic | 0–800 | 1.86 | 1 | 4.32 | 6.36 | 10.32 | 10.54 | 62.21 | 9.86 |
| Qinghai-Tibet Region | Lunpola | Strike-slip | Cenozoic | 0–550 | 2.00 | 2 | 57.14 | 726.70 | 11.28 | 11.28 | – | – |
| | Qiangtang | Flexural | Mesozoic | 0–500 | 2.00 | 1 | 12.32–13.37 | 3.68–1624 | 9.18 | 9.18 | 53.27 | 10.78 |

Note: ▲ Data based on [10]; * typical oil shale basin; – data not available.

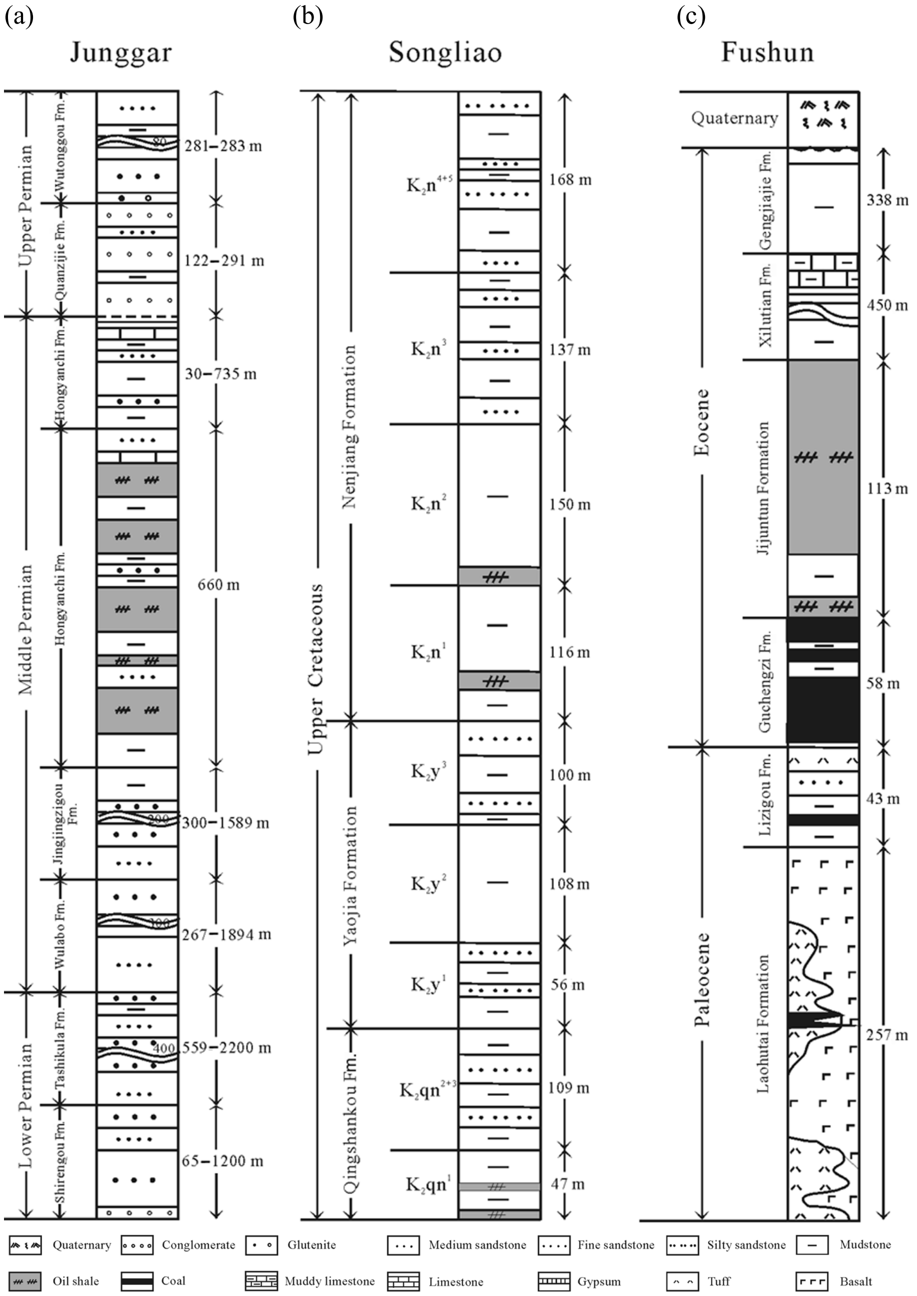
### 2.2. Rock association characteristics of oil shale-bearing series

Oil shale in China deposited primarily in the continental environment and, secondarily, in marine-continental facies. In continental oil shale-bearing series, as the Junggar Basin in northwestern China, the Upper Paleozoic oil shale mostly occurs with shale, silty shale, dolomitic limestone and muddy limestone (Fig. 1a). The Mesozoic oil shale in the Songliao and Ordos basins, for example, occurs together with mudstone, carbonaceous shale and siltstone (Fig. 1b). The Cenozoic oil shale is chiefly found together with coal, sometimes developing above the coal seam as in the Fushun Basin (Fig. 1c), sometimes below it as in the Huadian Basin (Fig. 1d), and sometimes interbedded with the coal seam as in the Dalianhe (Fig. 1e), Huangxian, Changpo and Yaojie basins. The oil shale-bearing series of marine-continental facies mainly consists of lagoon mudstone intercalated with muddy limestone, oil shale and gypsum as in the Biluocuo oil shale deposit in Tibet (Fig. 1f).

### 2.3. Mineral assemblage characteristics

Minerals of oil shale mainly originate from synsedimentary terrigenous clastics and sediments formed by biochemical action. The most common minerals in continental oil shale in China are clay minerals, quartz, feldspars, calcite, siderite and pyrite, of which quartz and feldspars account for 47.6% on average, and clay and carbonate minerals respectively 46.1 and 14.1%. Of clay minerals, kaolinite shows a relatively high content, followed by illite and illite/smectite mixed-layer minerals, while Dalianhe oil shale surpasses Maoming, Yaojie and Dongsheng oil shales in kaolinite content (57%). Montmorillonite is the most abundant clay mineral in Huadian oil shale. At the same time, the Junggar Basin oil shale is devoid of clay minerals, but instead, dolomite is present in remarkable amounts (Table 2).

By contrast, there is a good linear relationship between the contents of clay minerals and organic matter of oil shale, that is, the higher the content of clay minerals, the higher the abundance of organic matter. Figure 2 shows the relationship of the total organic carbon (TOC) content with the contents of clay minerals as well as terrigenous detrital minerals of oil shale of the Songliao Basin in northeast China. From the figure it can be seen that TOC is poorly correlated with the content of terrigenous detrital minerals (Fig. 2a), but correlates well with that of clay minerals (Fig. 2b). The respective correlation coefficients are 0.72 ($K_2qn^1$ + $K_2n^1$) and 0.73 ($K_2n^2$) (Fig. 2b), indicating that clay minerals play a decisive role in organic matter enrichment.

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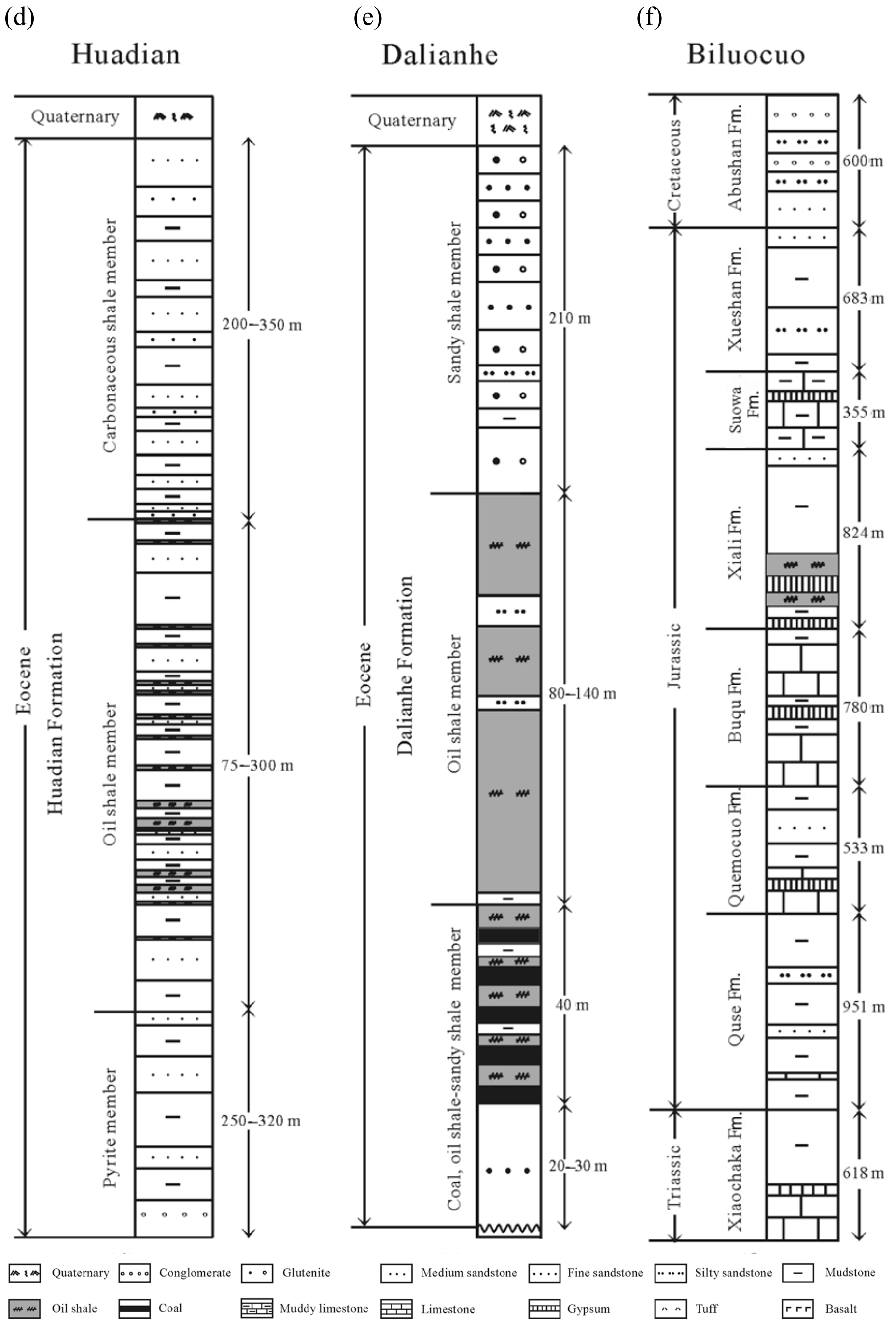


Fig. 1. Rock association characteristics of oil shale-bearing series in typical oil shale basins of China. (Abbreviation: Fm. – Formation.)

**Table 2. Mineral composition of oil shales in typical oil shale-bearing areas of China established by the X-Ray method (some data revised from [14])**

| Sample number | Location | Relative content of minerals, ω(B)/$10^{-2}$ | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Clay minerals | | | | | | Terrigenous detrital minerals | | | | Carbonate minerals | | | Other minerals | | | | |
| | | K | S | I/S | I | Chl | Total | Q | Fs | Pl | Total | Cc | Dol | Total | Sid | Py | Zeo | Gy | Total |
| YYY-3 | Dalianhe | 57 | | 3 | 4 | – | 64 | 33 | 2 | 1 | 36 | – | – | – | – | – | | | |
| YYY-4 | Dalianhe | 33 | | 2 | 6 | | 41 | 38 | 4 | 3 | 45 | | | | 14 | | | | 14 |
| HD3-327B | Huadian | | 31 | | | | 31 | 33 | 4 | | 37 | 28 | | 28 | | 4 | | | 4 |
| HD3-339 1/2 | Huadian | 14 | 28 | | 14 | | 56 | 36 | | 4 | 40 | 3 | | 3 | | 1 | | | 1 |
| YYY-6 | Huadian | 2 | 57 | | | | 59 | 14 | 1 | 1 | 16 | 22 | | 22 | | 3 | | | 3 |
| S29 | Nong'an | 5 | | 34 | 32 | | 71 | 16 | 5 | 6 | 27 | | | | | 2 | | | 2 |
| S27 | Nong'an | 6 | | 31 | 33 | | 70 | 15 | 3 | 6 | 24 | 4 | | 4 | | 2 | | | 2 |
| X30 | Qingshankou | 5 | | 12 | 29 | | 46 | 40 | 5 | 7 | 52 | | | | | 2 | | | 2 |
| YYY-8 | Luozigou | 6 | | 4 | 5 | | 15 | 51 | 19 | 15 | 85 | | | | | | | | |
| ZAJ04 | Meihe | 17 | | 17 | 19 | | 53 | 20 | 9 | | 29 | | | | 18 | | | | 18 |
| X-26 | Meihe | 27 | | 13 | 21 | | 61 | 31 | 6 | | 37 | | | | 2 | | | | 2 |
| YYY-12 | Fushun | 13 | | 8 | 8 | | 29 | 55 | 7 | 6 | 68 | | | | 3 | | | | 3 |
| YYY-13 | Fushun | 19 | | 3 | 8 | | 30 | 54 | | | 54 | | | | 16 | | | | 16 |
| YYY-14 | Maoming | 46 | | 3 | 9 | | 58 | 31 | 5 | 2 | 38 | | | | | 4 | | | 4 |
| YYY-15 | Maoming | 45 | | 3 | 12 | | 60 | 32 | 2 | 1 | 35 | | | | | 5 | | | 5 |
| YYY-16 | Maoming | 44 | | 5 | 12 | | 61 | 28 | 4 | 3 | 35 | | | | | 4 | | | 4 |
| YYY-17 | Maoming | 38 | | 3 | 10 | | 51 | 35 | 5 | 4 | 44 | | | | 3 | 2 | | | 5 |
| YYY-34 | Tongchuan | 3 | | 8 | 24 | | 35 | 46 | 10 | 9 | 65 | | | | | | | | |
| YYY-37 | Dongsheng | 37 | | | 9 | | 46 | 53 | | | 53 | | | | | | | 1 | 1 |
| YYY-39 | Changling | 5 | | 5 | 23 | | 33 | 37 | 7 | 11 | 55 | 8 | | 8 | | 4 | | | 4 |
| YYY-42 | Yaojie | 41 | | 3 | 14 | | 58 | 35 | | | 35 | | | | 7 | | | | 7 |

(Continuation of Table 2)

| Sample number | Location | Relative content of minerals, ω(B)/$10^{-2}$ | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Clay minerals | | | | | | Terrigenous detrital minerals | | | | Carbonate minerals | | | Other minerals | | | | |
| | | K | S | I/S | I | Chl | Total | Q | Fs | Pl | Total | Cc | Dol | Total | Sid | Py | Zeo | Gy | Total |
| YYY-48 | Fushun | 20 | | 2 | 5 | | 27 | 46 | 5 | 5 | 56 | | | | 17 | | | | 17 |
| YYY-49 | Huangxian | 2 | | 15 | 5 | | 22 | 38 | 3 | 3 | 44 | 13 | | 13 | 7 | | 14 | | 21 |
| YYY-51 | Weichang | 5 | | 7 | 9 | | 21 | 56 | 14 | 9 | 79 | | | | | | | | |
| YYY-55 | Yima | 13 | | | 33 | 9 | 55 | 30 | 3 | 2 | 35 | | | | 10 | | | | 10 |
| YYY-57 | Yima | 15 | | | 23 | 8 | 46 | 38 | 4 | 3 | 45 | | | | 9 | | | | 9 |
| J1-5 | Junggar | | | | | | | 36.3 | 14.5 | 28.7 | 79.5 | | 20.5 | 20.5 | | | | | |
| J1-8 | Junggar | – | – | – | – | – | – | 38.7 | 9.9 | 36.6 | 85.2 | – | 14.8 | 14.8 | – | – | – | – | – |

Note: ω(B) – mass fraction. Abbreviations: K – kaolinite; S – smectite; I/S – illite/smectite mixed-layer mineral; I – illite; Chl – chlorite; Q – quartz; Fs – alkali feldspars; Pl – plagioclase; Cc – calcite; Dol – dolomite; Sid – siderite; Py – pyrite; Zeo – zeolite; Gy – gypsum.

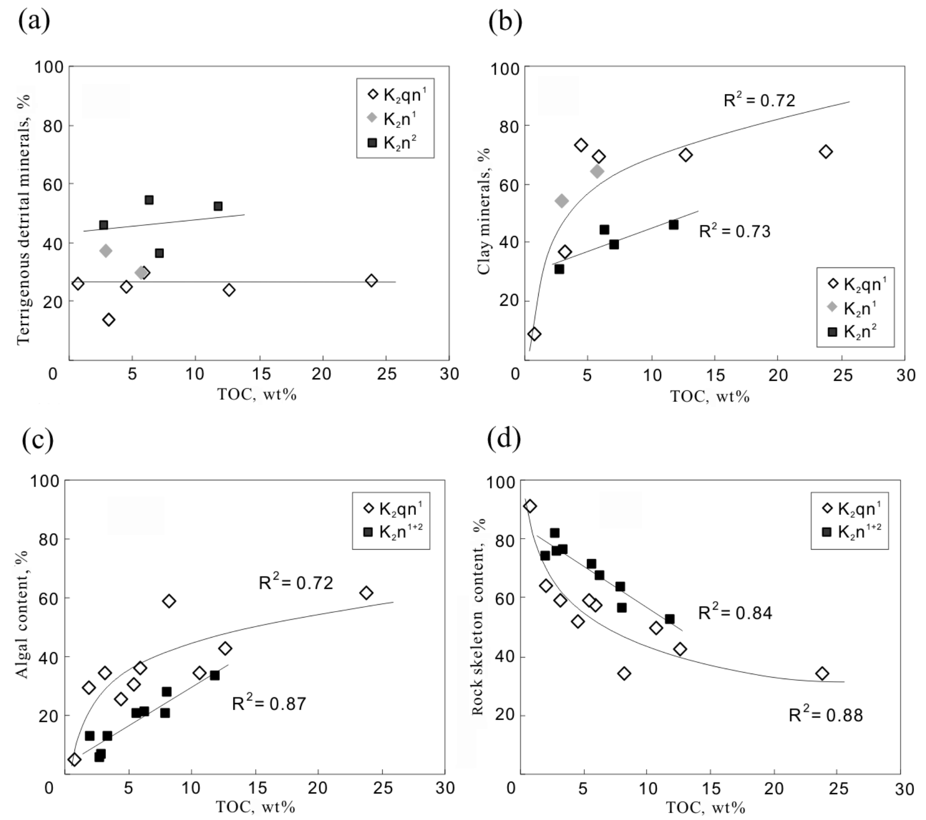


Fig. 2. Correlation between TOC and mineral contents of oil shale in the Songliao Basin, NE China (data about $K_2n^{1+2}$ in (c) and (d) are from [15]). $K_2qn^1$ – oil shale samples from the first member of the Upper Cretaceous Qingshankou Formation; $K_2n^1$ – oil shale samples from the first member of the Upper Cretaceous Nenjiang Formation; $K_2n^2$ – oil shale samples from the second member of the Upper Cretaceous Nenjiang Formation; $K_2n^{1+2}$ – oil shale samples from the first and second members of the Upper Cretaceous Nenjiang Formation.

## 2.4. Organic geochemical characteristics

Oil shale is a fine-grained sedimentary rock which is rich in organic matter and is mainly composed of such elements as C, H, O, N and S. The concentration of organic carbon in Chinese oil shale is high, between 7.5 and 38%, but mostly from 10 to 30%, the average TOC is 21.5% (Fig. 3a). Oil shale with an organic carbon content of 7–20% is mainly distributed in the Dalianhe, Yaomoshan, Fushun, Maoming, Luozigou and Sangonghe basins, and oil shale with an organic carbon content of 20–40% is predominantly deposited in the Yaomoshan, Maoming, Tongchun, Dalianhe, Fushun, Huadian and Dongsheng basins. The vitrinite reflectance (*Ro*) of oil shale is generally between 0.41 and 0.6%, and the maximum pyrolysis temperature ($T_{max}$) is from 423 to 446 °C [10], showing that most oil shale is immature or at the low-maturity stage of thermal evolution.

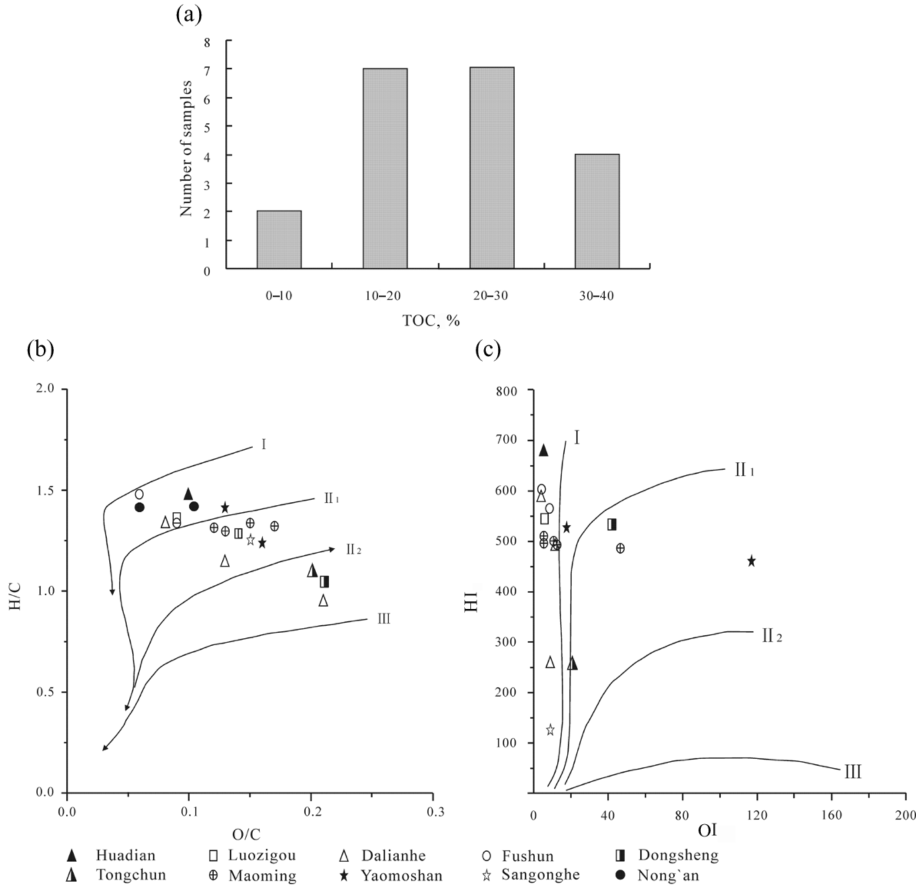


Fig. 3. Distribution of contents and types of organic matter of oil shale in the main oil shale basins of China (element ratio and Rock-Eval data revised from [10] are plotted on van Krevelen diagrams).

The organic matter of continental oil shale mainly consists of lamalginite and telaginite (Figs. 4 a–b, d–e, h–i), followed by a small amount of vitrinite, sporinite and intertinite (Figs. 4c–g and j) [15, 16]. Lamalginite may originate from assemblages of algae and bacteria, and telaginite stems from solitary and colonial algae [15]. Statistical analysis shows that the content of organic matter is mostly positively correlated with the algal content (Fig. 2c) but negatively with the rock skeleton content (Fig. 2d), showing that the organic matter of oil shale is mainly contributed by high palaeo-lacustrine productivity. Meanwhile, the results of chemical element and rock pyrolysis analysis of 18 continental oil shale samples from 11 deposits of China indicate that the H/C atomic ratio is between 0.95 and 1.55, the O/C atomic ratio is from 0.04 to 0.21, the hydrogen index (HI) between 128 and 753, and the oxygen index (OI) from 2.19 to 117.28 (Figs. 3b–c). The kerogen types

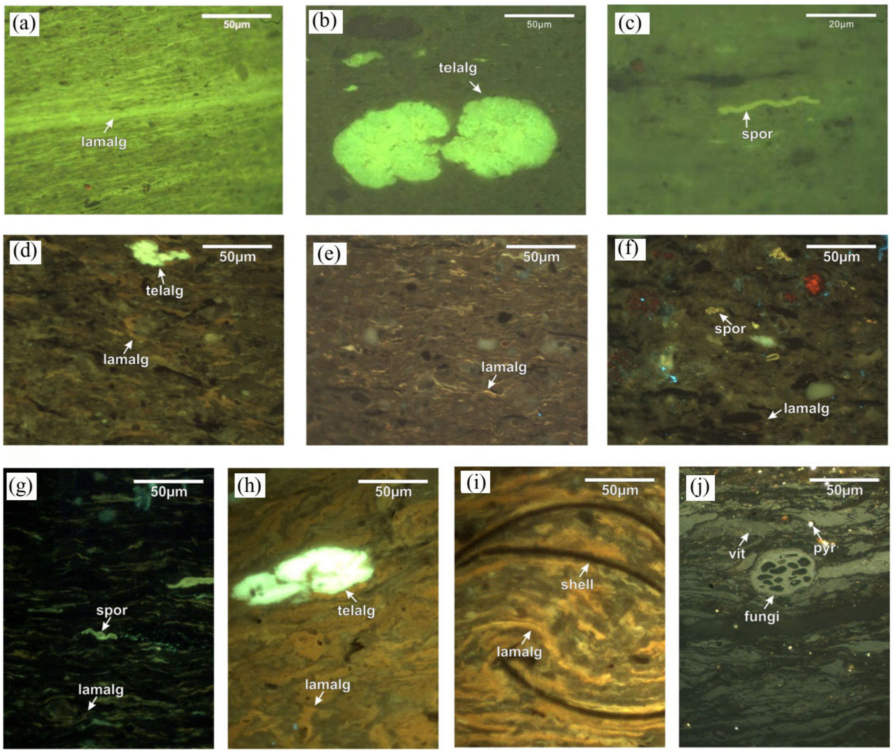


Fig. 4. Photomicrographs of typical Chinese oil shale samples: (a)–(c) polished sections of Songliao oil shale samples under oil immersion, photos are from [15], (a) sample S29 under UV light, (b) sample X38 under UV light, (c) sample X17 under UV light; (d)–(f) polished sections of Fushun oil shale samples under oil immersion, photos are from [16], (d)–(f) field samples under UV light; (g)–(j) polished sections of Huadian oil shale samples, photos are from [17], (g) sample HD20 under UV light, (h) sample HD25 under UV light, (i) sample HD65 under UV light, (j) sample HD85 under white light. (Abbreviations used: lamalg – lamalginite; telalg – telaginite; spor – sporinite; shell – Ostracod shell; vit – vitrinite; pyr – pyrite; fungi – funginite.)

are predominantly sapropelic (I) and humosapropelic ($II_1$), followed by saprohumic ($II_2$) (Figs. 3b–c). Thus, from the organic origin point of view, oil shale in China can be divided into three types: sapropelic, humosapropelic and saprohumic oil shale.

### 2.5. Industrial oil shale characteristics

Oil yield, ash content and calorific value are the three key parameters for evaluating the quality of industrial oil shale.

### 2.5.1. Oil yield

Oil yield is the mass fraction of shale oil in oil shale. This index is used for defining the oil shale mineral resource quality, for evaluating the suitability of oil shale refining, and for identifying the oil shale properties for the needs of the low-temperature industry. Based on most national and international scalars and the current and future exploitation rates of oil shale, the cut-off grade of oil yield (ω) is defined in the National Oil Shale Resource Evaluation in China to be more than 3.5 %, and three oil yield categories are distinguished: low, medium and high, i.e. 3.5% < ω ≤ 5%, 5% < ω ≤ 10% and ω > 10%, respectively [10]. Statistical analysis shows the oil yield has an obvious linear correlation with the content of organic carbon. When oil yield is higher than 3.5%, the content of organic carbon is usually higher than 6% (Fig. 5). Thus, organic carbon content can be used as one of the indicators for judging oil shale quality, being especially suitable for evaluating oil shale in oil- and gas-bearing basins.

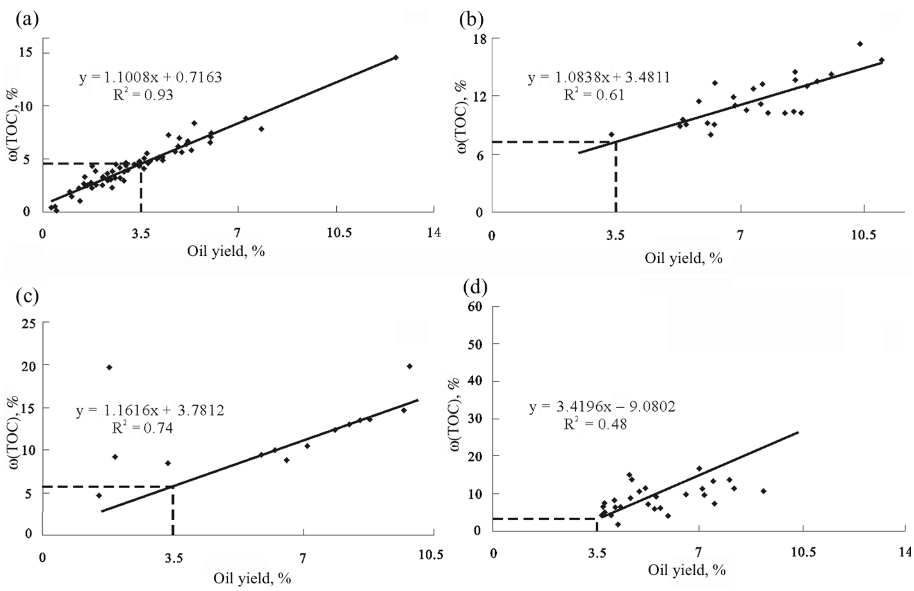


Fig. 5. Correlation between oil yield and organic matter content of oil shale samples from major oil shale basins of China: (a) Songliao, (b) Luozigou, (c) Fushun, (d) Qaidam. (Data in (b) and (c) are from [14]).

### 2.5.2. Ash content

Ash content is a key index for distinguishing between high-carbon oil shale and coal in China and can measure the quality of oil shale. The lower this parameter for oil shale, the higher its content of organic carbon and the better its quality. Usually, the ash content of oil shale is more than 40%, while the ash content of coal is less than 40%. According to the statistical oil yield and ash content data of 54 oil shale-bearing deposits in China, ash content is mainly between 53.3 and 84.4% (Table 1), and by ash content there may be distinguished two types of oil shale: high-ash and low-ash oil shale. The ash content of low-ash oil shale is in general less than 65% and oil yield more than 10%, while the ash content of high-ash oil shale is between 65 and 90%, and oil yield from 3.5 to 10% [10]. Chinese oil shale is mostly high-ash oil shale.

2.5.3. Calorific value

Calorific value is an important parameter for assessing the worth of oil shale as industrial fuel. The calorific values of oil shale in different deposits in China are very different. Even within the same area, the calorific value of oil shale in different layers may vary. The calorific value is the lowest, 4.2 kJ/g, in Nong'an oil shale, and the highest, 34.6 kJ/g, in Ji'An oil shale. Generally, oil shale with a high calorific value is mainly distributed in the Huangxin, Luozigou, Huadian and Aocheng basins, oil shale with a medium calorific value is deposited in the Dalianhe, Maoming, Yaomoshan and Yaojie basins, and oil shale with a low calorific value is found in the Fushun, Nong'an and Changpo basins (Table 1).

## 3. Oil shale resource potential in China

From 2003 to 2006, China evaluated its oil shale resources for the first time ever. The working area for evaluation was divided into five regions: eastern, central, southern and western China and the Qinghai-Tibet Region in western China. The total evaluation area was 1.62 million $km^2$, of which the oil shale distribution area made up approximately 0.18 million $km^2$. The evaluation was based on a new Chinese standard of solid mineral resources/ reserves classification (GB/T17766-1999) and followed the evaluation standards of coal resources, as well as international practice [17, 18]. In practice, the system of evaluation and basic terminology of national oil shale resources were established, with due consideration of geological, economic and feasibility factors, as well as three-dimensional resources classification concepts in line with international standards were adopted [10]. The resource evaluation methods used were mainly the traditional volumetric method (Fig. 6) and geological analogy [19, 20], and the boundary evaluation parameters were oil yield more than 3.5%, buried depth less than 1000 m and thickness of signal-layer oil shale more than 0.7 m.

With the improvement of oil shale exploration after 2006, the size of China's oil shale resources has changed greatly, especially in Northeast China. The Geological Survey Institute of Jilin Province conducted a detailed survey on oil shale in the southeastern uplift of the Songliao Basin from 2006 to 2010, and discovered four large-scale oil shale deposits in the

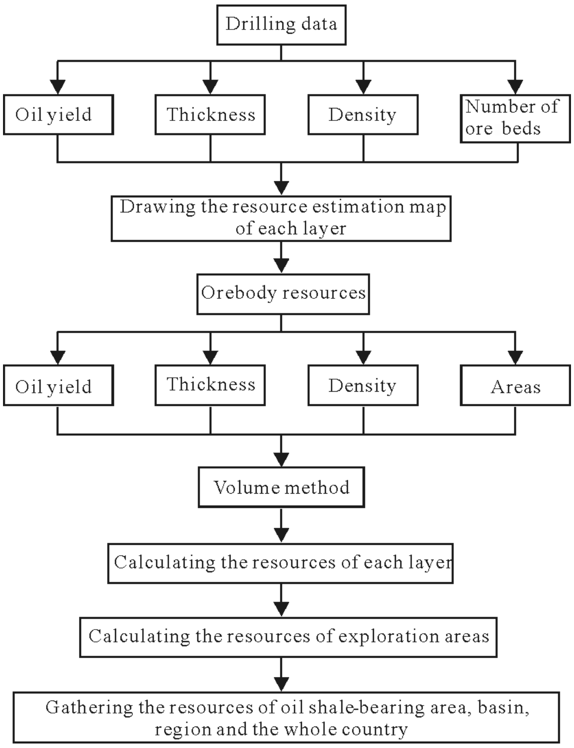


Fig. 6. Flow chart of oil shale resources estimation by using the volumetric method, based on [10].

region: Fuyu-Changchunling, Qianguo-Nong'an, Sanjingzi-Dalinzi and Shenjingzi. The data originate from the Geological Archives of Jilin Province. The Tuha Oil Field of PetroChina Company Limited discovered a new, Bagemaode oil shale-bearing area in Bayinnaoer City of the Inner Mongolia Autonomous Region in 2007. The Daqing Oil Field of PetroChina Company Limited carried out a thorough investigation of the Linkou Basin in Heilongjiang Province in 2006, and found that oil shale resources had increased. From 2006 to 2008, Royal Dutch Shell performed a series of hole drillings in the Huadian, Meihe and other basins. As a result, the resource prediction accuracy in these oil shale-bearing areas increased significantly.

Combined with the new exploration progress, the evaluation results showed that China's oil shale resources are abundant and are widely distributed across the country.

### 3.1. Results of oil shale resources evaluation

China's oil shale resources are concentrated in 50 basins in 20 provinces and autonomous regions. There are 83 petroliferous shale areas in total throughout the country (Fig. 7). The oil shale resources of China are estimated at

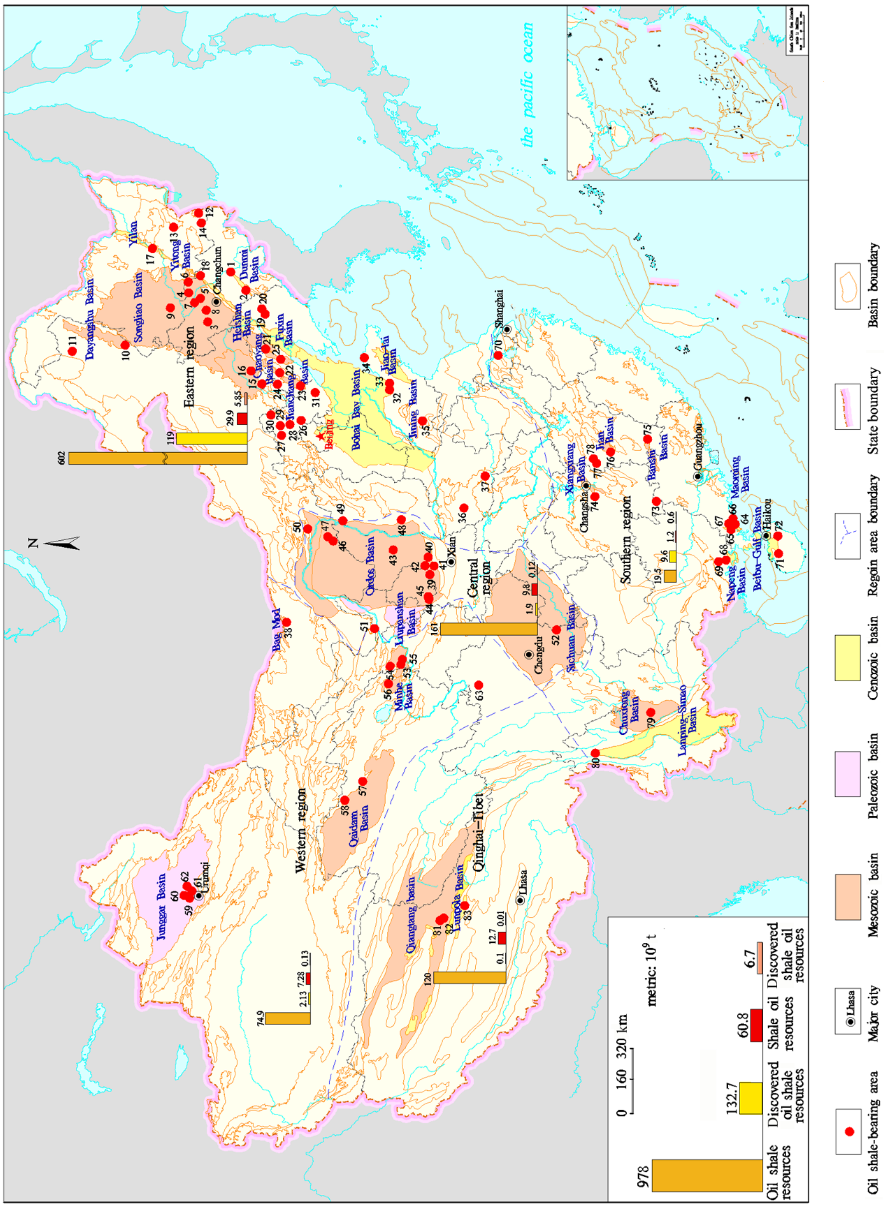
the pacific ocean
Eastern region
Central region
Western region
Southern region
Qinghai-Tibet
Songliao Basin
Ordos Basin
Sichuan Basin
Junggar Basin
Qaidam Basin
Qiangtang Basin
Bohai Bay Basin
0 160 320 km
metric: 10⁹ t
978
132.7
60.8
6.7
Oil shale resources
Discovered oil shale resources
Shale oil resources
Discovered shale oil resources
Oil shale-bearing area
Major city
Mesozoic basin
Paleozoic basin
Cenozoic basin
Regoin area boundary
State boundary
Basin boundary

Fig. 7. Distribution of oil shale resources in China. Oil shale-bearing areas: 1 – Huadian; 2 – Meihe; 3 – Changling; 4 – Fuyu-Changchunling; 5 – Qianguo-Northern Nong'an; 6 – Sanjingzi-Dalinzi; 7 – Shenjingzi; 8 – Xiaohelong; 9 – Prediction area of Songliao Basin; 10 – A'Rongqi; 11 – E'Lunchun; 12 – Laoheishan; 13 – Linkou; 14 – Luozigou; 15 – Aohanqi; 16 – Naiman; 17 – Dalianhe; 18 – Shulan; 19 – Fushun; 20 – Shimenzhai; 21 – Fuxin; 22 – Chaoyang; 23 – Jianchang; 24 – Lingyuan; 25 – Yixian; 26 – Dage; 27 – Sichakou; 28 – Fengshan; 29 – Qingquan; 30 – Jiangjiaying; 31 – Lulong; 32 – Changle; 33 – Anqiu; 34 – Huangxian; 35 – Yanzhou; 36 – Luanchuan; 37 – Tongbaiwucheng; 38 – Bagemaode; 39 – Binxian; 40 – Tongchuan; 41 – Chunhua; 42 – Intra Binxian and Tongchuan; 43 – Intra Tongchuan and Zichang; 44 – Huating; 45 – Congxin; 46 – Yijinhuoluoqi; 47 – Dongsheng; 48 – Puxian; 49 – Baode; 50 – Shiguai; 51 – Zhongningzhongwei; 52 – Yibin-neijiang; 53 – Yaojie; 54 – Tanshanling; 55 – Haishiwan; 56 – Xiaoxia; 57 – Dameigou; 58 – Yuqia; 59 – Yuqia; 60 – Yaomoshan; 61 – Lucaogou; 62 – Northern margin of Bogda Mountain; 63 – A'Ba; 64 – Maoming; 65 – Gaozhou; 66 – Dianbai; 67 – Prediction area of Maoming Basin; 68 – Napeng; 69 – Qinzhou; 70 – Jintan; 71 – Danzhou; 72 – Changchang; 73 – Ningyuan; 74 – Xiangxiang; 75 – Aanyuan; 76 – Aocheng; 77 – Pingxiang; 78 – Yichun; 79 – Chuxiong; 80 – Weixi; 81 – Tongbori; 82 – Biluocuo; 83 – Jiangjiacuo.

approximately 978 billion tons, i.e. about 61 billion tons of in-place shale oil. The discovered oil shale resources comprise approximately 133 billion tons, i.e. about 7 billion tons of in-place shale oil (Table 3). So, oil shale resources in China are rich. However, only part of them has been explored, although in recent years exploration has been quite extensive and a number of new oil shale deposits have been discovered. The amount of discovered oil shale resources has increased a lot, but the overall extent of exploration is still very low. Only 14% of oil shale resources have been investigated.

**Table 3. Oil shale and shale oil resources in different regions of China, billion tons**

| Region | Oil shale | | | Shale oil | | |
|---|---|---|---|---|---|---|
| | Estimated total resources | Discovered resources | Potential resources | Estimated total resources | Discovered resources | Potential resources |
| Eastern China | 602.28 | 119.03 | 483.25 | 29.91 | 5.85 | 24.06 |
| Central China | 160.96 | 1.93 | 159.04 | 9.79 | 0.12 | 9.67 |
| Western China | 74.94 | 2.13 | 72.81 | 7.28 | 0.13 | 7.15 |
| Southern China | 19.46 | 9.57 | 9.89 | 1.15 | 0.55 | 0.59 |
| Qinghai-Tibet | 120.32 | 0.09 | 120.23 | 12.66 | 0.01 | 12.65 |
| Total | 977.97 | 132.75 | 845.22 | 60.78 | 6.66 | 54.12 |

Note: Estimated total resources – sum total of discovered and potential resources; Discovered resources – resources discovered during the exploration work; Potential resources – resources predicted on the basis of geological conditions but without verification.

Oil shale is mainly distributed in eastern and central China, and the Qinghai-Tibet Region in western China. With approximately 602 billion tons, oil shale resources in eastern China are the most abundant, comprising 62% of the country's total oil shale resources (Table 3). The resources in central, western and southern China and the Qinghai-Tibet Region form approximately 161, 75, 19 and 120 billion tons, making up 17, 8, 2 and 12% of China's total oil shale resources, respectively (Table 3).

### 3.2. Distribution of oil shale resources in basins of different types

According to the plate characteristics and the classification of sedimentary basins [21], the oil shale-bearing basins in China can be divided into four types: extensional basins, flexural basins, intra-plate basins and strike-slip basins.

The Mesozoic-Cenozoic oil shale-bearing basins in eastern and southern China have the tectonic attributes of extensional basins. Typical representatives are the Songliao, Bohaiwan, Maoming, Qinxian, Jurong and Beibuwan basins. Estimated at approximately 632 billion tons, oil shale resources in extensional basins are the most abundant, making 65% of China's total oil shale resources, or about 32 billion tons of in-place shale oil. Of these 632 billion tons, the amount of oil shale resources discovered in extensional basins is approximately 125 billion tons, or about 6 billion tons of in-place shale oil (Table 4).

**Table 4. Distribution of oil shale resources in basins of different types in China, billion tons**

| Basin type | Oil shale | | | Shale oil | | |
|---|---|---|---|---|---|---|
| | Estimated total resources | Discovered resources | Potential resources | Estimated total resources | Discovered resources | Potential resources |
| Extensional | 632.47 | 124.51 | 507.96 | 32.26 | 6.11 | 26.15 |
| Intra-plate | 161.08 | 1.96 | 159.12 | 9.81 | 0.13 | 9.68 |
| Flexural | 99.13 | 0.55 | 98.58 | 9.50 | 0.04 | 9.46 |
| Strike-slip | 85.29 | 5.73 | 79.56 | 9.22 | 0.38 | 8.83 |
| Total | 977.97 | 132.75 | 845.22 | 60.78 | 6.66 | 54.12 |

Note: Estimated total resources – sum total of discovered and potential resources; Discovered resources –resources discovered during the exploration work; Potential resources – resources predicted on the basis of geological conditions but without verification.

The intra-plate oil shale-bearing basins are mainly distributed in central China, and from the north to the south, the largest are Ordos, Sichun and Chuxiong. Oil shale resources in basins of this type are estimated at approximately 161 billion tons, or 16.5% of total oil shale resources, i.e. about 9.8 billion tons of in-place shale oil. Of these estimated 161 billion tons, the amount of discovered oil shale resources accounts for ca 1.9 billion tons, i.e. about 0.1 billion tons of in-place shale oil (Table 4).

The flexural oil shale-bearing basins are mostly spread in western China, typical examples are Junggar and Qiangtang [22, 23]. Oil shale resources in basins of this type are estimated at approximately 99 billion tons, or 10% of total oil shale resources, or about 10 billion tons of in-place shale oil. Of these 99 billion tons, the amount of discovered oil shale resources is approximately 0.6 billion tons, or 0.04 billion tons of in-place shale oil (Table 4).

The strike-slip oil shale-bearing basins are concentrated in the Qinghai-Tibet plate in western China, and the eastern Tancheng-Lujiang Fault Zone and its two branches. The current findings are the Lunpola Basin in western China, the Beibu Gulf and Lanping-simao basins in southern China, and the Jiaolai, Yilan-yitong, Fushun, Huadian and Meihe basins in eastern China. Compared to the above basin types, the size of this type of basins is smaller, and oil shale resources are estimated at approximately 85 billion tons, or 9% of total oil shale resources, or about 9 billion tons of in-place shale oil. Of this estimated total, the amount of oil shale resources discovered is approximately 6 billion tons, or about 0.4 billion tons of in-place shale oil (Table 4).

### 3.3. Distribution of oil shale resources of different geologic times

Oil shale deposits in China range widely in age, from the Late Paleozoic to the Cenozoic (Table 5), while the Carboniferous-Permian, Jurassic, Cretaceous and Paleogene were the most important periods as regards oil shale accumulation. Controlled by three geodynamic systems of the Paleo-Asian Ocean, the Tethys–Paleo-Pacific Ocean and the Indian-Pacific Ocean, the age of oil shale deposits becomes progressively younger from the north-west to the southeast. [23] (Fig. 7). The Upper Paleozoic oil shale includes the Lower Permian oil shale mainly distributed in the Yaomoshan, Shuimogou and Lucaogou basins in the northern area of Bogda Mountain in the southern Junggar Basin of western China, as well as a small number of Upper Carboniferous oil shale deposits in the Jining and Liupanshan basins in the northwestern region of the country.

Mesozoic oil shale deposits originate from the Jurassic and Cretaceous periods. Oil shale of Middle Jurassic age is distributed in the Qiangtang, Qaidam and Hetao basins in western China. The Lower Cretaceous oil shale is concentrated in some small basins in northeastern China, such as Dayangshu, Laoheishan, Luozigou, Yangshugou, Chaoyang and Fuxin. The Upper Cretaceous oil shale is mainly accumulated in large basins like Songliao.

The youngest oil shale deposits are of Eocene and Oligocene age and are found in the Fushun, Huadian, Yilan, Shulan and Huangxian basins in eastern China, with some secondary deposits in the Maoming and Beibu Gulf basins in southern China, as well as small occurrences in the western Lunpola Basin in northern Tibet. The Paleocene oil shale is found only in the Xiangxian Basin, and the Miocene oil shale of Neogene is only distributed in the Maoming Basin.

**Table 5. Distribution of oil shale resources of different geologic times in China, billion tons**

| Stratum | Oil shale | | | Shale oil | | |
|---|---|---|---|---|---|---|
| | Estimated total resources | Discovered resources | Potential resources | Estimated total resources | Discovered resources | Potential resources |
| Mesozoic | 818.13 | 116.86 | 701.27 | 44.89 | 5.65 | 39.25 |
| Cenozoic | 104.93 | 15.31 | 89.61 | 10.42 | 0.97 | 9.45 |
| Late Paleozoic | 54.91 | 0.57 | 54.34 | 5.47 | 0.05 | 5.42 |
| Total | 977.97 | 132.75 | 845.22 | 60.78 | 6.66 | 54.12 |

Note: Estimated total resources – sum total of discovered and potential resources; Discovered resources – resources discovered during the exploration work; Potential resources –resources predicted on the basis of geological conditions but without verification.

The results of evaluation of oil shale resources of different times show that these are mostly concentrated in the Mesozoic strata. Oil shale resources deposited in the Mesozoic, Cenozoic and Late Paleozoic are estimated at approximately 818, 105 and 55 billion tons, respectively. These figures account for respectively 84, 11 and 6% of the country's total oil shale resources, or about 45, 10 and 5 billion tons of in-place shale oil. The study established that the discovered Mesozoic, Cenozoic and Upper Paleozoic oil shale resources include approximately 117, 15 and 0.6 billion tons, or about 5.7, 1.0 and 0.1 billion tons of in-place shale oil, respectively (Table 5).

### 3.4. Distribution of oil shale resources of different grades

Shale oil resources can be determined and solutions for the reasonable development and use of oil shale provided based on oil yield evaluation. Oil shale resources with an oil yield by weight between 3.5 and 5% are estimated at 390 billion tons, i.e. 17 billion tons of in-place shale oil, or 40 and 27% of national oil shale and shale oil resources, respectively. Oil shale resources with an oil yield by weight between 5 and 10% are estimated at 461 billion tons, i.e. 30 billion tons of in-place shale oil, or respectively 47 and 50% of national oil shale and shale oil resources. Oil shale resources with an oil yield by weight higher than 10% are estimated at 126 billion tons, i.e. 14 billion tons of in-place shale oil, or 2 and 23% of national oil shale and shale oil resources, respectively. In-place shale oil resources with an oil yield by weight higher than 5% account for 73% of total shale oil resources in the country. These results demonstrate that oil shale in China is of medium to high grade.

In strata from the Late Paleozoic to the Mesozoic to the Cenozoic, the oil shale grade increases and, hence, oil yield increases, but the size of deposits decreases. This study found that oil shale in most of the current Late Paleozoic and Mesozoic basins has a low oil yield (4–5% on average), while in a few basins the oil yield of oil shale is high (more than 8%). Oil shale in most of the Cenozoic oil shale-bearing basins has a medium oil yield (6–8% on average), but in a few basins the oil shale oil yield is high (more than 8%) (Table 1).

Among the few Late Paleozoic oil shale-bearing basins, the oil yield of oil shale in the Jining Basin is the highest (16.5%), but the area of the basin is very small. The oil yield of Yaomoshan oil shale in the large Junggar Basin is medium, and the oil yield of Liupanshan oil shale is very low.

There have been found numerous Mesozoic oil shale-bearing basins in China, such as Songliao, Minhe, Yangshugou, Heishan, Chuxiong, Fuxin, Jianchang and Hetao, in which the oil yield of oil shale is very low. However, in some basins such as Laoheishan, Qiangtang and Qaidam, the oil yield of oil shale is high, being particularly high in the Laoheishan Basin (15%).

Among the Cenozoic oil shale-bearing basins, the oil yield of oil shale in the Huangxin, Lunpola, Linkou and Huadian basins is very high, being the highest in the Huadian Basin (24.8%). In the other Mesozoic basins, such as Yilan, Maoming, Qinxian, Napeng, Bohaiwan, Fushun and Shulan, the oil shale oil yield is medium, averaging generally between 6 and 8%.

## 4. Overview and prospects of the oil shale industry in China

The shale oil industry in China began in 1928 when the Fushun shale oil factory in Liaoning Province was built. So, this branch of China's industry has a history of more than 80 years. Meanwhile the development and use of oil shale in China declined and became popular again in the late 20th century. As global oil prices fluctuated in the early 21st century, the development of China's oil shale industry ushered in a new phase, a situation of continuously increasing shale oil production, dry distillation technology improvement, and introduction of independent innovations [1]. At present, oil shale mines being developed and used in China include Fushun, Huadian, Louzigou, Longkou, Maoming, Chaoyang, Yaojie, etc., and the annual production of shale oil is approximately 0.65 million tons. The oil shale industry in China is constantly seeking a new technology to improve oil shale refining, and methods of adopting the integrated technology for oil shale comprehensive use and circular economic theory, as well as realizing oil shale use with no solid waste generation, to strive for an "environmentally friendly" industry.

In 2015, the in-situ oil shale mining technology in China made a significant breakthrough. Taking into account the characteristics of Chinese oil shale, two in-situ oil shale mining technologies were independently studied and shale oil was successfully extracted in a preliminary test. The in-situ fracturing and chemical distillation of shale oil and gas extraction were developed and studied at the Unity & Strength Co., Ltd, China, while the TS-A method of shale oil and gas extraction technology was developed and studied at Jilin University, China. These are two successful examples following the in-situ oil shale mining technology of Shell Company. The successful preliminary tests on in-situ mining technology have eliminated the bottleneck in oil shale technology development, aroused enthusiasm for oil shale research, and gave a strong motivation to further develop the oil shale industry. This will not only waive the traditional requirements for mining shallow, thick or high-grade oil shale, but will also solve the serious environmental problems brought about by the current ground dry distillation technology. The Unity & Strength Co., Ltd and Jilin University are looking for a new way to carry out an experiment on in-situ mining technology and systematically evaluate the extracted shale oil. The development and application of in-situ mining technology may signify a new technological revolution in Chinese oil shale industry.

## 5. Conclusions

On the basis of the study of the characteristics of typical oil shale deposits as well as oil shale resource potential and distribution regularities in China, the following conclusions can be drawn:

1. Oil shale in China was mainly deposited in the continental environment, its color is black to grayish black, black to gray brown or gray to dark gray. The most common minerals in oil shale are clay minerals, quartz and feldspars. The content of clay minerals has a good linear correlation with organic matter content, so, the higher the content of clay minerals, the higher the abundance of organic matter, suggesting that these minerals play a significant role in organic matter enrichment.
2. The concentration of organic carbon in Chinese oil shale is high, between 7.5 and 38%, and oil shale is mostly immature or at the low-maturity stage of thermal evolution. The organic matter of continental oil shale mainly consists of lamalginite and telaginite contributed by high palaeo-lacustrine productivity. By organic genetic type, oil shale can be divided into sapropelic, humosapropelic and saprohumic oil shale. Industrial oil shale has a medium to high oil yield and high ash content.
3. The oil shale resources in China are very abundant with a high potential for exploitation, and are mainly concentrated in 20 provinces and autonomous regions, 50 basins and 83 petroliferous shale areas. China's oil shale resources are estimated at approximately 978 billion tons, i.e. about 61 billion tons of in-place shale oil, ranking the country second in the world for shale oil resources.
4. Oil shale is mainly distributed in eastern and central China and the Qinghai-Tibet Region in western China. Oil shale resources in extensional basins are the most abundant, followed by those in intra-plate, flexural and strike-slip basins.
5. The age of Chinese oil shale deposits ranges widely, from the Late Paleozoic to the Cenozoic, and becomes progressively younger from the northwest to the southeast. Oil shale resources are mostly concentrated in the Mesozoic and Cenozoic strata and are estimated at approximately 818 and 105 billion tons, respectively. The Carboniferous-Permian, Jurassic, Cretaceous and Paleogene were important periods in terms of oil shale accumulation.
6. The distribution of oil shale grade in different strata is regular, from the Upper Paleozoic to the Mesozoic to the Cenozoic, while oil yield increases but the size of oil shale deposits decreases. In-place shale oil resources with an oil yield by weight higher than 5% account for 73% of the country's total shale oil resources, indicating that oil shale in China is of medium to high grade with good prospects for development.

## Acknowledgements

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