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SEDIMENTOLOGICAL INVESTIGATIONS OF THE SHENGLI RIVER-CHANGSHE MOUNTAIN OIL SHALE (CHINA): RELATIONSHIPS WITH OIL SHALE FORMATION

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Recently a new oil shale belt was discovered in the Changshe Mountain area, northern Tibet, China. This belt, combined with the oil shale zone found in the Shengli River area, represents a large marine oil shale resource in China. Three facies associations have been recognized concerning the deposition of oil shale in the Qiangtang basin: fluvial-delta, tidal flat-lagoon and shallow marine facies associations. Oil shales were mainly deposited in lagoonal environments. The deposition of the Shengli River-Changshe Mountain oil shale may be controlled by many factors, such as sea level change, differential palaeotopography and palaeoclimate change. Sea level rise and consequent marine incursion may change the aquatic environment of pre-existing lagoon. Differential palaeotopography may control the lateral distribution of oil shale seam, while palaeoclimate change may be partially responsible for the vertical facies change from oil shale to gypsum-salt deposition.

Introduction

The importance of oil as a source of energy and as a chemical feedstock is well known. However, the world reserves of oil are finite. As a result, the supply of oil has become a worldwide problem in recent decades.

In China, with increasing production insufficient to meet growing demands, oil supply and demand imbalances are intensifying. It is possible that oil will become a restraining factor for China's economic growth. In 2006, China had to import ca 145 million tonnes of crude oil, and

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ca 156 million tonnes in 2007. The world's high crude oil price and lack of appreciable oil reserves stimulate the development of the oil shale industry and exploration for oil shale resources. Marine oil shale, as an alternative resource awaiting exploitation, has received much attention.

Recently, a new marine oil shale zone was discovered in the Changshe Mountain area, northern Tibet, China. This zone, combined with the oil shale zone found in the Shengli River area, represents a large marine oil shale resource in China. In this paper, we present primary sedimentological investigations of these oil shales. In addition, relationships between sedimentology and oil shale distribution are also examined in and around the Shengli River mine site in the Qiangtang basin. The aim is to determine the depositional factors influencing the geometry and thickness of oil shale seams.

Geological setting

The Qiangtang block, marked by the Hoh Xil-Jinsha River suture zone to the north and the Bangong-Nujiang suture zone to the south, respectively, consists of the North Qiangtang depression (North Qiangtang sub-basin), the central uplift and the South Qiangtang depression (South Qiangtang sub-basin) (Fig. 1a) [1]. During Early Cretaceous time, the Bangong ocean closed by northward subduction beneath the Qiangtang terrane [2], resulting in a large-scale regression in the Qiangtang basin [1]. During this interval, the South Qiangtang depression was uplifted entirely, while the North Qiangtang depression was still a depositional area. Sedimentary rocks of this stage are mainly made up of sandstone, shale, marl, oolitic limestone, mudstone and oil shale.

The Shengli River-Changshe Mountain oil shale zone is located in the southern part of the North Qiangtang depression, northern Tibet plateau, China (Fig. 1a), where Lower Cretaceous marine deposits are widely spread [3], including the Upper part of the Suowa Formation (or the Shengli River Fomation in this paper), the Xueshan Formation and the Bilong Binghe Formation. The Shengli River Formation is the major oil shale-bearing sequence in the Qiangtang basin.

Discovery process of the Shengli River-Changshe Mountain oil shale zone

In May 2006, the Shengli River oil shale deposit was discovered in the Qiangtang basin (Fig. 1) [4]. Geologic survey and preliminary analysis of oil shale samples showed that deposition occurred in a relatively anoxic marine environment [4–5], with a length of 2.5 km along the east-west direction and a width of 16 m (9 m thick) along the north-south direction.

In 2007, a feasibility study on the prospect for the Shengli River oil shale was undertaken by Chengdu Institute of Geology and Mineral Resources. Detailed geologic survey and excavation of trial trenches indicated that resources of the Shengli River oil shale may amount to ca. 0.45 billion tonnes, with a length of 30 km along the east-west direction and a width of 10 km along the north-south direction (Fig. 1).

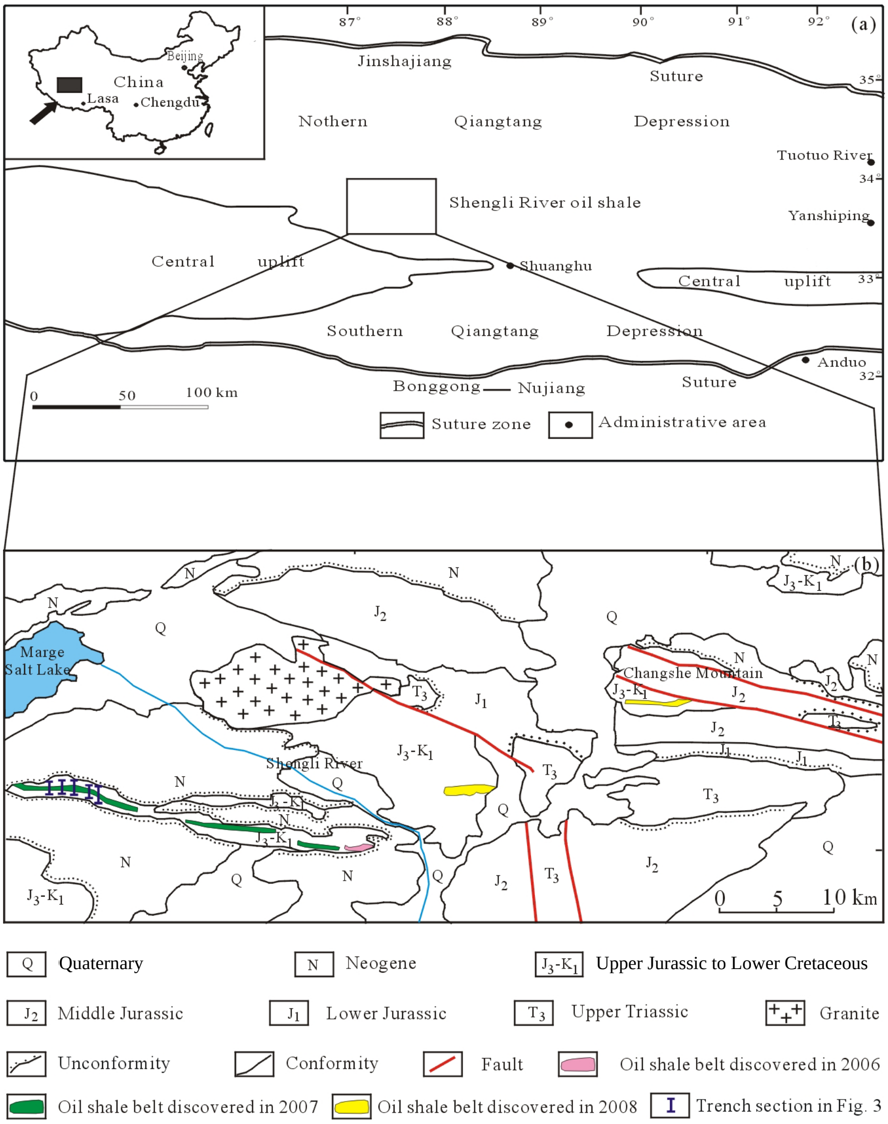

Fig. 1. (a) Generalized map, showing location of study area. (b) Simplified geological map of the Shengli River area, showing location of oil shale section.

In 2008, detailed investigations were carried out on a large prospective area. A new oil shale zone was discovered northeast of the Shengli River zone and the Changshe Mountain area (Fig. 1). This zone, combined with the oil shale zone found in the Shengli River area, constitutes a large oil shale zone (the Shengli River-Changshe Mountain oil shale zone). This zone is exposed for a distance of more than 50 km in the east-west direction and 30 km in the north-south direction (Fig. 1). Thus, by investigation level the proved reserves of the Shengli River-Changshe Mountain oil shale have been estimated to exceed 1 billion tonnes, being potentially the largest marine oil shale resources in China. These oil shales are characterized by high total organic carbon (TOC) content (15.05%–20.34%), S_2 values (103.27–129.12 mg HC/mg rock) and tar content (3.5%–16.3%) [4–5]. Therefore, studies of the Shengli River oil shale are important for assessing petroleum prospects in the Qiangtang basin and the overall significance of marine oil shale researches in China.

Sedimentary facies associations during the deposition of oil shale

The Shengli River-Changshe Mountain oil shale was formed in the Early Cretaceous [3]. During this interval, large-scale regressions could have taken place in the Qiangtang basin region. The depo-center was located in the north-western part of the North Qiangtang depression, showing an asymmetric shape, i.e. deep in the west, and shallow in the east [1]. Three facies associations were recognized on the basis of sedimentary structures, lithology and fossils, including fluvial-delta, tidal flat-lagoon and shallow marine facies associations.

Fluvial-delta facies association is represented by the Xueshan Formation in the Qiangtang basin. The Xueshan Formation is mainly composed of sandstone and mudstone with minor conglomerate. The lower units are mainly composed of mudstone and intercalated quartz sandstone with salt, brackish and fresh-water fossils, indicating a delta environment [6]. The upper units are typically conglomeratic with characteristics of fluvial deposition. The overall facies of the Xueshan Formation indicate a shallowing-upward trend [1]. The facies association is exposed in the northern and southern margins of the North Qiangtang depression (Fig. 2).

Tidal flat-lagoon facies association occurs in the Shengli River Fomation and is characterized by oil shale, marl and gypsum salt intercalated with micritic limestone and coquina [1]. The middle and lower units are mainly composed of oil shale and marl (Fig. 3). They are vertically stacked into repetitive cycles. The oil shale seams are grey black in colour, with well lamination and abundant fossils. Sedimentary structures such as horizontal bedding, ripple bedding and rhythmic bedding are well developed, indicating a lagoonal environment. The marl layers are grey in colour, with algal material. Sedimentary structure such as horizontal bedding and ripple bedding is also well developed. Euryhaline bivalve and dwelling burrow were found in marl layers, indicating a tidal flat environment. The upper units of the Shengli River Formation are mainly composed of grey white gypsum salt intercalated with micritic limestone (or marl) (Fig. 3). Sedimentary structures such as lattice structure and finely-laminated bedding are well developed and indicate a hot and arid lagoon environment. The facies association is exposed in the central district of the North Qiangtang depression (Fig. 2).

Shallow marine facies association is represented by the Bailong Binghe Formation, mainly comprising marl, mudstone, calcarenite and shale. The Bailong Binghe Formation is characterized by abundant bivalve and ammonite fossils. Worm trails are also present in local areas. Sedimentary structures such as horizontal bedding and convolute bedding are well developed and indicate a shelf to restricted platform facies environment. The facies association is exposed in the western part of the North Qiangtang depression (Fig. 2).

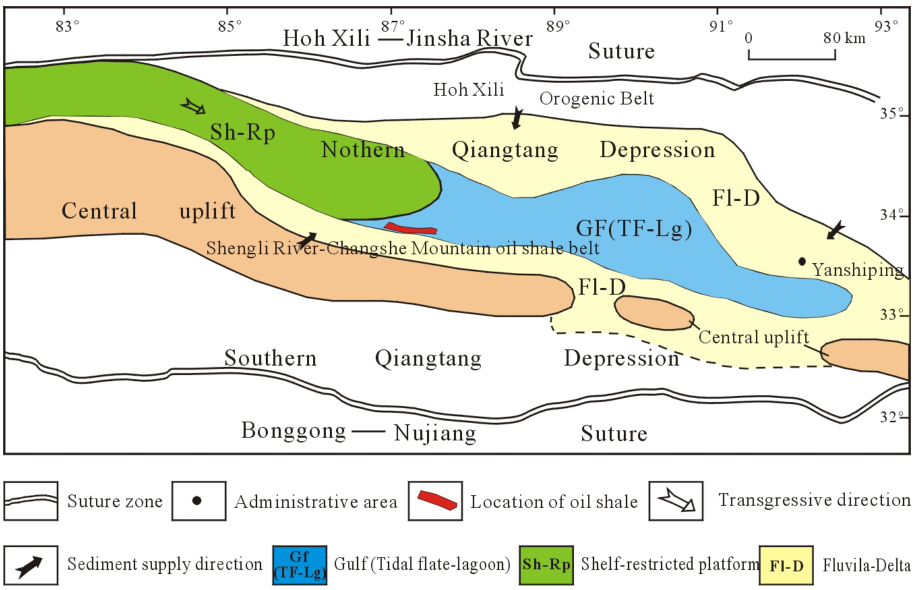

Fig. 2. Palaeogeographic map of the Qiangtang basin during the deposition of oil shale, showing that the oil shale was mainly deposited in the margin of the palaeo-lagoon (modified from reference [6]).

Effects of palaeoenvironment on oil shale

The Shengli River-Changshe Mountain oil shale was mainly deposited in a lagoonal environment. This environment may be affected by many factors, such as sea level change, differential compaction and palaeoclimate change. These factors controlled the deposition of oil shale.

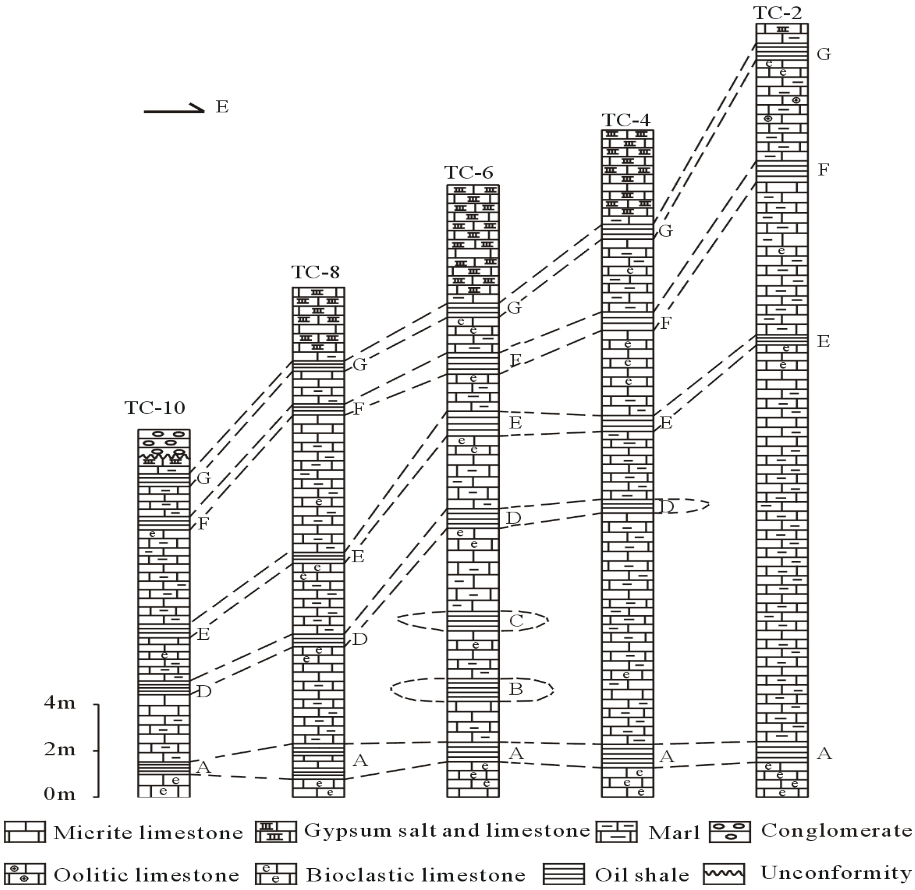

Fig. 3. Trench section comparison of oil shales in the Qiangtang basin, showing gradual lateral variation of oil shale seams.

Sea level change

As discussed above, large-scale regressions could have taken place in the Qiangtang basin during the Early Cretaceous time. As a result, when the relative sea level was low, a barrier-lagoon system was formed in the Shengli River area [1]. Thus, the Shengli River area was isolated from the sea by a palaeotopographic high (Marguo Chaka uplift) [1]. Subsequently, a wide lagoonal area developed behind the protecting barriers. Oil shales from the Shengli River-Changshe Mountain area were mainly deposited in the lagoonal environment. TOC content of oil shales is high [5] corresponding to high productivity. Additionally, abundant pyrite crystals were also found in oil shales, indicating anoxic environments during the deposition of oil shale. The combination of high productivity and anoxic environment was in favour of the deposition of oil shale.

Influenced by regional tectonics, sea level fluctuations in the Qiangtang basin were frequent during the Early Cretaceous time [1]. Local transgressions could have occurred in the Qiangtang basin during the deposition of marl (the overlying strata of the oil shale seams) [1]. Barriers were submerged as they continued to undergo transgression, resulting in the open-ocean environment in the Shengli River area. The marls have relatively low $^{87}Sr/^{86}Sr$ ratios (0.70755-0.70781) [4] like oil shales (0.70787-0.70822) [4], supporting a local transgression. Sea level rise and consequent marine incursion may change the aquatic environment of pre-existing lagoon, ending the deposition of oil shale. Frequent sea level change responded to repetitive cycles of oil shale and marl deposition.

Differential palaeotopography

A gradual lateral variation in oil shale seam is an important feature of the Shengli River-Changshe Mountain oil shale. This characteristic is clearly exhibited in the trench case. The oil shale sequence consists of seven intervals in trench TC-6, named A, B, C, D, E, F and G from the lower to upper seams, respectively (Fig. 3). However, only A, D, E, F, and G seams are identified in trenchs TC-8 (west of the trench TC-6) and TC-4 (east of the trench TC-6) (Fig. 3), revealing a limited distribution for the B and C seams. In addition, lateral variation in oil shale seam can be also clearly exhibited in the D seam case. This seam can be identified in the west trenches (e.g. TC-10, TC-8, TC-6, and TC-4) with a thickness of 0.59 m to 0.93 m. However, the thickness of this seam gradually thins from trench TC-6 to trench TC-4, and then the oil shale seam is gradually replaced by marl layer in trench TC-2, revealing a wedge shaped sediment body.

The lateral variation in oil shale seam can be attributed to differential paleotopography. Palaeo-topographic low areas have more accommodation space than less compressible areas, so are subjected to more oil shale deposition. Tectonic palaeo-geography [4] reveals that study area of TC-6 stands for a palaeo-topographic low, where the thickness of the D oil shale seam is 0.93 m, potentially the thickest interval of this seam. Differential palaeotopography is only a localised effect because seams such as E seam, thicken and thin in different parts of the study area (Fig. 3).

Palaeoclimate change

The Shengli River Formation in the Shengli River area can be divided into two informal units based on the rock assemblages. The lower unit extends from the base of the Shengli River Formation to the top of G oil shale seam and upper unit is the interval from the top of G oil shale seam to the top of the formation (Fig. 3).

A number of spores and pollen grains, including *Apiculatisporites*, *Reticulisporites*, *Jiaohepollis*, *Chasmatosporite*, and *Ephedripites* cf. *notensis*, were identified in the oil shale samples. Gymnosperm pollens clearly dominate the assemblage (80%) with *Chasmatosporite* the most abundant of all. The occurrence of *Chasmatosporite* in very large numbers has been interpreted by many authors to indicate deposition in warm to hot, sub-humid environments [7–8]. We thus infer that the climate of the Qiangtang basin region during the deposition of oil shale was probably warm and sub-humid. The occurrence of *Apiculatisporites* and *Jiaohepollis* in relatively large numbers in oil shale samples also supports a warm and humid or sub-humid environment during the deposition of oil shale in the Qiangtang basin.

In addition, a number of spores and pollen grains, including *Apiculatisporites*, *Perinopollenites*, *Classopollis*, *Cerebropollenites* cf. *papilloporus*, and *Cerebropollenites*, were identified in the upper unit of the Shengli River Formation. Gymnosperm pollens grains are clearly the dominant component, with *Classopollis* the most abundant of all, usually comprising 60-70% of the miospore association. The occurrence of *Classopollis* in very large numbers has been reported by many authors to indicate hot and arid or semi-arid, often coastal environments [9-10]. Considering that there occurs a relatively thick gypsum-salt bed in this unit, it is probable that the climate of the Qiangtang basin region during the upper unit deposition was hot and arid.

The variation in composition between lower unit and upper unit palynofloras that have been noted may reflect palaeoclimate change. This change may be partially responsible for the vertical facies change from oil shale to gypsum-salt deposition.

Conclusions

1. The Shengli River-Changshe Mountain oil shale zone represents a large marine oil shale resource in China with a proved reserve of ca. 1 billion tonnes.
2. Three facies associations may be identified during the deposition of oil shale in the Qiangtang basin: fluvial-delta, tidal flat-lagoon and shallow marine facies associations. Oil shales were mainly deposited in lagoonal environments.
3. The deposition of the Shengli River oil shale may be controlled by many factors, such as sea level change, differential palaeotopography and palaeoclimate change. Sea level rise and consequent marine incursion may change the aquatic environment of pre-existing lagoon. Differential palaeotopography is only a localised effect, controlling the lateral distribution of oil shale seams, while palaeoclimate change may be partially responsible for the vertical facies change from oil shale to gypsum-salt deposition.

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