UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Petroleum geology of the Songliao basin, Northeast China

by

K. Y. Lee

Open-File Report 86-502

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

1986

CONTENTS

ILLUSTRATIONS

TABLES

Petroleum geology of the Songliao basin, Northeast China

By K. Y. Lee

ABSTRACT

The Songliao basin of Northeast China covers about 260,000 km^2 with a sedimentary rock fill of about 1,560,000 km^3. It lies generally within lat 42°20' to 49°20' N. and long 120°00' to 128°00' E.

This large basin evolved on a Variscan folded cratonic basement marginal to the Da Hinggan Ling* Variscan eugeosyncline foldbelt on the west and northwest, the Xiao Hinggan Ling and the Zhangguangcai Ling Variscan eugeosyncline foldbelt on the northeast and southeast, and the Kangping hills of the Precambrian Nei Mong shield axis of the Sino-Korean platform on the south. It acquired its general form by the continental rifting fragmentation during the Late Triassic Indosinian orogeny. Subsequently, it reached full development through the Late Jurassic to Early Cretaceous extensional graben development, followed by the Middle Cretaceous basin-wide subsidence and syndepositional growth normal faulting during the Yanshanian orogeny (fig. 2). The basin acquired further elements of its present configuration during the Neogene Himalayan orogeny.

The sedimentary cover of Songliao basin consists chiefly of the the Late Jurassic to Neogene fluvial and lacustrine detrital sedimentary rocks. Triassic and Early Jurassic strata are generally missing throughout the basin. The cratonic basement consists of undifferentiated platform metamorphic and sedimentary rocks of Precambrian to Permian ages. The Late Jurassic strata are represented by 500 to 1,300 m of a coal-bearing series, which is generally thicker in the east and southeast parts of the basin. As shown in detailed studies, the Cretaceous strata are widespread throughout the basin. During the sedimentation of the Middle Cretaceous sedimentary rocks, two high-water-lake stages, covering areas from 87,000 to 200,000 km^2, are recorded in the first members of the Qingshankou and the Nenjiang Formations, respectively. As the lake water regressed during Qingshankou and Yaojia times, the Daqing delta system formed on a gently southward-dipping paleoslope.

Principal structural units in the present-day Songliao basin are the West Slope, North Plunge, Central Depression, Northeast Uplift, Southeast Uplift, and Southwest Uplift (fig. 3). Current petroleum producing areas are concentrated in the Central Depression and the Southeast Uplift.

Potential petroliferous source rocks in the Songliao basin are shale, oil shale, and mudstone of the Qingshankou, Nenjiang, Yaojia, Quantou, and Denloukou Formations of Cretaceous age, as well as the Upper Jurassic shale of the coal-bearing series. Of these, the most favorable source rocks are confined to the first members of the Qingshankou and Nenjiang Formations. Three major kerogen types, I, II, and III, are defined. Type I is sapropelic

---

* Mountain range

and consists chiefly of lipids. Type III is typically humic and consists chiefly of vitrinite derived from higher terrestrial plants. Type II, a mixed type, ranks chemically between the sapropelic type I and the humic type III. It is subdivided into type IIA and IIB. Type IIA is rich in lipids; however type IIB is rich in aromatic matter. Type I matured successively earlier than types II and III (Yang and others, 1985, p. 1114, fig. 5, p. 1119, and 1121).

Four stages of oil and gas generation are defined by Yang, Li, and Gao (1985, p. 1119-1120). Burial depth of the mature to highly mature stages ranges from 1,300 to 2,900 m. Both the formation temperature and the heat flow are high. The mean geothermal gradient of the main producing area is 4.2°C/100 m. The average earth heat flow is 1.70 x 10^{-6} $cal/cm^2/sec$. The source rock and crude oil correlation is shown by the $\delta^{13}C$ value of stable carbon isotopes.

Reservoir rocks of the principal producing pay zones consist chiefly of delta front fine-grained sandstone. In descending order, the reservoirs of the Songliao basin are grouped into the upper Heidimaio, the middle Shaertu, Putaohua, and Gaotaizi, and the lower Fuyu, Yangdachengzi, and Nongan. The prominent producing pay zones are confined in the Shaertu, Putaohua, and Gaotaizi reservoirs of the Daqing delta complex in which an expected reserve is about 5 billion barrels of oil. Of these three, the Putaohua contains about 70 percent of the total, 3.5 billion barrels of oil. It is made up chiefly of the first member of the Yaojia Formation in the Daqing delta depositional system, which, tentatively, is correlated with Ma's Xingshugang delta (Ma, 1985).

The Daqing oil field of the Central Depression is a supergiant field. Oil and gas in the reservoirs are trapped by anticlinal and nose-shaped folds, fault barriers, and lithofacies changes, which are then sealed by overlying shale and mudstone. Simultaneous oil and gas maturation, migration along carrier beds, and structural trap formation were responsible for the formation of the giant Daqing oil field from the Late Mingshui to Late Yian time.

Petroleum potential of Songliao basin is substantial. International Encyclopedia (1985) lists the original oil in-place of Daqing oil field as about 21.9 billion barrels. Future new discoveries are favorable in the delta front sandstone of the Quantou and Denlouku Formations in the southern part of the basin.

INTRODUCTION

Songliao basin of Northeast China is a rhombic-shaped depression running northeasterly across the central portions of both Heilongjiang and Jilin provinces and the northern part of Liaoning province (fig. 1). Initially it evolved from extensional stresses on a Variscan folded cratonic basement during the latest episode of the Indosinian orogeny in Late Triassic time (table 1) (Ma, Liu, and Su, 1984; Huang, 1984). The cratonic basement of

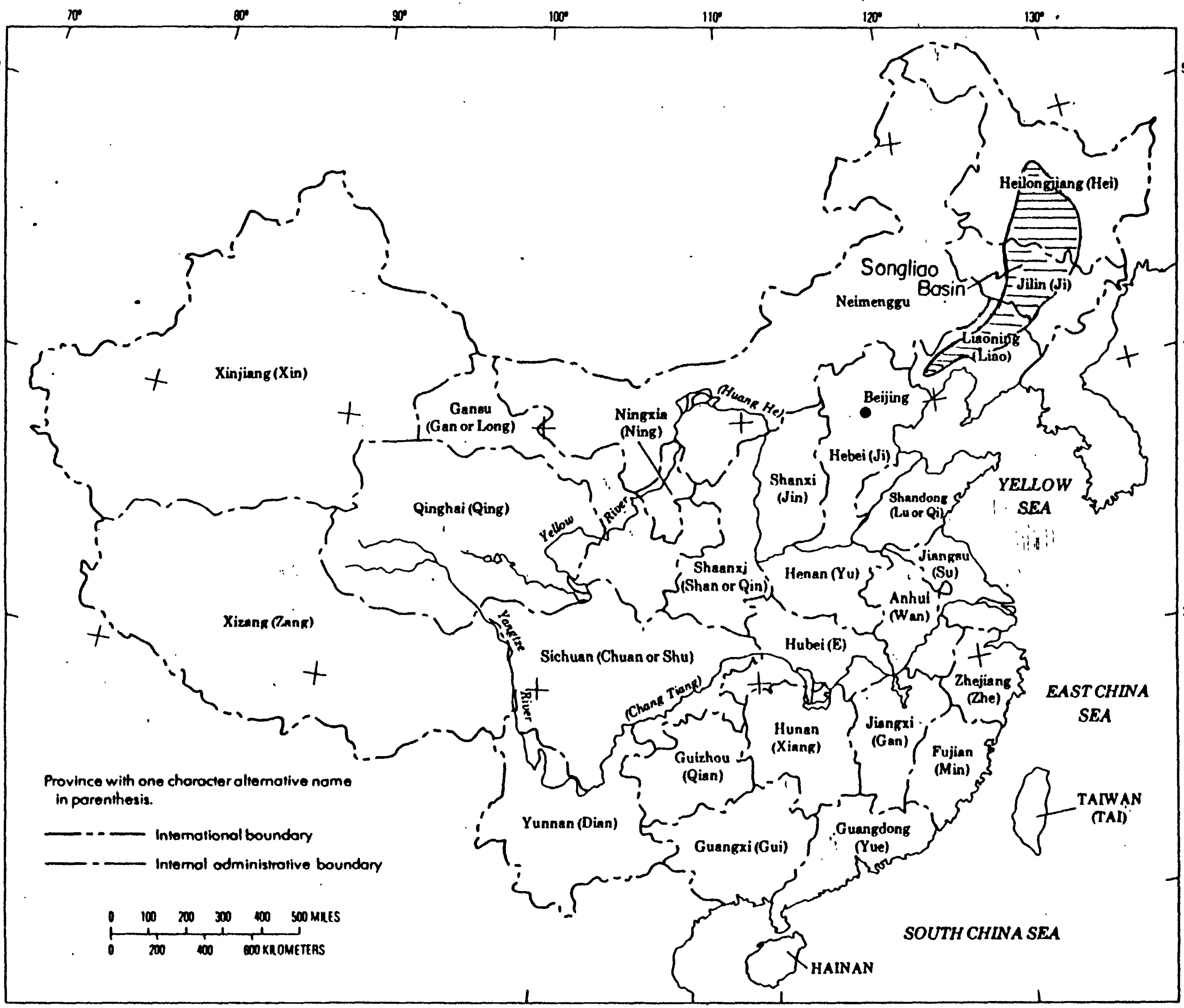

Figure 1. Index map of China showing the location of study area.

Table 1.—Orogenic cycles of China (After Huang and others, 1980, table 4, p. 106).

Geologic chronology		Isotopic age (m.y.)	Orogenic cycles	
Cenozoic	Quaternary	1.5	H_2	Himalayan (H)
	Tertiary	67	H_1	
Mesozoic	Cretaceous	137	Y_3	Yanshanian (Yenshanian) (Y)
	Jurassic	190	Y_2 Y_1	
	Triassic	230	I	Indosinian (I)
Paleozoic	Permian	280	V_4	Variscan (V)
	Carboniferous	350	V_3 V_2	
	Devonian	405	V_1	
	Silurian	440	C_2	Caledonian (C)
	Ordovician	550		
	Cambrian	570	C_1	
Proterozoic	Sinian	770		Xingkaiian (Hsingkaiian)
	Qingbaikou	1100		Yangziian (Yangtzeian)
	Jixian	1400		?
	Nankou	1700		Wulingian
	Changcheng Hutuo	1950		Zhongtiaoian (Chungtiaoian)
	Wutai	2500		Wutaiian
Archean	Fuping			Fupingian

the basin borders the Da Hinggan Ling* Variscan eugeosyncline foldbelt on the northwest and west, the Xiao Hinggan Ling and the Zhangguangcai Ling Variscan eugeosyncline foldbelt on the northeast and the southeast; on the south it is in contact with the Kangping hills of the Precambrian Nei Mong shield axis of the Sino-Korean platform (fig. 2)(Huang and others, 1980, fig. 18-b, p. 29-33). The basin reached full development through extensional graben development and syndepositional growth faulting from Late Jurassic to Middle Cretaceous time during the Yanshanian orogeny. It acquired its present configuration during the latest episode of the Late Cretaceous Yanshanian and the movements of the Neogene Himalayan extensional orogenies (table 1).

The basin filled with Late Jurassic coal-bearing sedimentary sequences and with Cretaceous to Quaternary fluvial and lacustrine detrital sediments derived from the adjacent highlands (fig. 2). Petroleum resources are substantial, and output of the basin ranks first in China. The petroleum source rocks are mudstone and shale, chiefly of Early to Middle Cretaceous age. The reservoir rocks are mostly the fluvial channel and delta-front fine-grained sandstones of Middle Cretaceous age. Information on coal resources of the Songliao is not available, but generally coal beds in the basin are too deeply buried for the reserve consideration.

Regional Setting

Songliao basin occupies an area about 260,000 km^2 and contains a volume of sedimentary rock amounting to about 1,560,000 km^3; it is confined within lat 42°20' to 49°20' N. and long 120°00' to 128°00' E. It is bounded on the northwest by the Da Hinggan Ling, on the northeast by the Xiao Hinggan Ling, on the southeast by the Zhangguangcai Ling, and on the south by the Kangping Hills (fig. 2). The Songliao was one of the largest lake basins in the Asian continent in Cretaceous time. From Triassic to Middle Jurassic, the basin was an emergent landmass, and, subsequently, because of the Yanshanian movement, it subsided receiving coal-bearing detrital sediments in Late Jurassic time. The Late Jurassic and Cretaceous sedimentary cover reaches a maximum thickness of more than 8,000 m (table 2), overlying the pre-Mesozoic metamorphosed crystalline platform basement. Extensive systematic petroleum exploration began in the late 1950's, and a concentrated development program began in the late 1960's (Meyerhoff, 1982, p. 244-250).

Purpose, Scope, and Method of the Report

The primary purpose of this report is to provide a synthesis of selected current literature on petroleum geology of Songliao basin in order to understand geologic factors relating to a resource assessment. The Pinyin system from the Gazetteer of the People's Republic of China (Defense Mapping Agency, 1979) is used for Chinese name transliteration, and the Chinese Dictionary is used for geographic names not listed in the Gazetteer.

---

* Mountain range

STRATIGRAPHY

Based on information from surface and subsurface investigations and geophysical surveys, the stratigraphy of the basin is divided, in ascending order, into the pre-Jurassic, Jurassic, Cretaceous, Tertiary, and Quaternary sedimentary sequences (table 2) (fig. 2). The Triassic and Lower to Middle Jurassic strata are reported to be missing. Although Chen Chin (1980) stated the presence of the Middle Jurassic strata, Yang and others (1983) and Wang and others (1983, p. 237-240) do not recognize the presence of Middle Jurassic beds in the basin. The most prolific petroleum source beds are found in the Cretaceous sequences, as discussed in detail below.

Pre-Jurassic

The stratigraphy of the pre-Jurassic strata consists of undifferentiated platform metamorphic and sedimentary rock complexes ranging in age from Precambrian to Permian. The rock assemblages of the pre-Jurassic basement in the basin consist chiefly of Precambrian gneissic granite, quartzite, schist, marble, and amphibolite; of Silurian and Devonian quartzose sandstone, crystalline limestone, hornfels, slate, phyllite, conglomerate, and tuff interbedded with pyroclastic rocks; and of Carboniferous to Permian crystalline limestone, quartzite, slate, shale, breccia, and hornfels intruded by biotite and biotite-hornblende granites (Institute of Geology, Academia Sinica, 1958, p. 123-124).

Jurassic

The Jurassic system of Songliao basin is represented by Upper Jurassic continental coal-bearing sedimentary sequences and is concentrated in the Grabens throughout the basin (fig. 2). In the lower part, the rock assemblages consist of light-gray to gray coarse-grained and feldspathic sandstone, conglomeratic sandstone, shale, and mineable coal beds with basal tuff, andesite, and conglomerate; and in the upper part, of light-brown sandstone, quartzite, mineable coal, and andesite. The unit is about 550 m thick but is as much as 1,300 m thick in the eastern part of the basin (Wang and Liu, 1980, p. 252-254; Intitute of Geology, Academia Sinica, 1958, p. 121-124; Liu, 1983).

Cretaceous

The Cretaceous system has been studied in detail during the past decades. This system is widely distributed throughout the basin, and in the central part of the basin, it consists of more than 6,000 m of fluvial and lacustrine detrital sediments derived from the adjacent highlands. In this report, the system is divided, in ascending order, into the Lower, Middle, and Upper Series (table 2) (Ma, Yang, Ding, and Guan, 1984; Wang and Liu, 1980, table 16-II, p. 276; Gu, 1982; Chen and others, 1982). Wang and Liu (1980) propose that the Songhua Jiang Group represents the Middle and Upper Series. This discussion on the Cretaceous stratigraphy emphasizes depositional environments and lithofacies distribution relative to the subsequent discussion on petroleum migration and accumulation (table 2).

Lower Cretaceous

The Lower Cretaceous strata of the Songliao basin lie unconformably on the Upper Jurassic volcanic series in the grabens as well as on the basement, and are represented by the Denlouku Formation. In ascending order, the Denlouku Formation is divided into four members. The first member consists of 119 to 220 m of grayish-green sandstone and mudstone with basal conglomeratic sandstone. The second member is composed of 309 to 700 m of grayish-green and black mudstone, shale, and tuffaceous sandstone. The third member consists of 250 to 621 m of grayish-green and gray mudstone and sandstone interbeds. The fourth is made up of 134 to 212 m of grayish-green and dark-gray, tuffaceous sandstone and mudstone interbeds (table 2). During sedimentation of the Denlouku Formation, the central part of the basin was a northeast-trending landmass, and the eastern and western flanks of this landmass bordered graben-faulted troughs. The first and second members of the Denlouku were deposited within the troughs, but the third and fourth members later partially overlapped the top of the landmass (Wang and others, 1983, p. 237-240). The thickest Denlouku sedimentary beds of 1,700 m are recorded in the western trough, which is located about 50 km northwest of the city of Anda in the south-central part of Heilongjiang province. Generally, Wang and Liu (1980, p. 274) consider that the Denlouku lake sediments cover only small areas.

Middle Cretaceous

The Middle Cretaceous strata lie conformably on the Lower Cretaceous sedimentary rocks. In ascending order, the Middle Cretaceous is represented by the Quantou, Qingshankou, Yaojia, and Nenjiang Formations, which contain the most prolific source and reservoir rocks in the Songliao basin (table 2). During high-water times, the lake water coverage ranged from 87,000 to 200,000 km^2 (Wang and others, 1983, table 2-4-22, p. 113).

The Quantou Formation is divided, in ascending order, into the first, second, third, and fourth members (Chen, 1980; Ma and others, 1984) (table 2). The first member consists of 356 to 651 m of light-gray and grayish-green fine- to medium-grained, feldspathic sandstone with basal conglomeratic sandstone, grading upward into reddish-blue to red silty mudstone, which laterally changes into coarse-grained and conglomeratic sandstone toward the basin border. The second member is made up of 212 to 417 m of mudstone and shale interbeds, locally intercalated with black mudstone, gray siltstone, and sandstone. The volume of the sandstone increases near the basin rim. The third member is composed of 451 to 672 m of gray sandstone and siltstone and variegated mudstone, which grades upward into grayish-green and black mudstone. The fourth member consists of 65 to 98 m of reddish-brown sandstone intercalated with mudstone, shale, and oil shale. Fossil fauna of the Quantou Formation consist of ostracods, fossil fish, and plants. During the Quantou time, the lake-water coverage greatly expanded, accompanied by large scale graben-faulting throughout the basin. The third and fourth members extensively overlapped older sedimentary sequences (Wang and others, 1983, p. 240).

The Qingshankou Formation is divided, in ascending order, into three members (table 2) (Chen, 1980; Ma, Yang, Ping, and Guan, 1984). The second and third members are combined in the lithologic description. The first member of the Qingshankou is characterized by 72 to 131 m of black mudstone and shale with basal oil shale (fig. 3). Banded siderite and pyrite grains are present. This member grades upward into siltstone in the uppermost part of the sequence. This member is mainly represented by lacustrine deposits of fine clastic sediments with some sandstone interbeds near the basin border. Ostracods are abundant. The second and third members are composed of 273 to 503 m of black, gray, and green shale, limestone, siltstone, and mudstone in the central part of the basin, grading laterally toward the northwest into alternate sandstone, conglomeratic sandstone, and mudstone near the basin border. Ostracods and conchostracans are rich. During Qingshankou time, the lake became fully developed and was accompanied by subsidence of the Central Uplift landmass. Sedimentation of the Qingshankou sequences generally reached a rate of deposition greater than that of sediment influxes, as characterized by the predominance of lacustrine, mudstone, shale, and fluvial deltaic sandstone.

The Yaojia Formation is divided, in ascending order, into three members (table 2) (Ma, Yang, Ding, and Guan, 1984). The second and third members are combined in the lithologic description. The first member of the Yaojia consists of interbeds of gray to grayish-green siltstone and sandstone and dark-purple to reddish-green mudstone, which range from 0 to 78 m thick. This unit grades upward into the second member of the formation. The second and third members are characterized by 72 to 150 m of grayish-green and reddish-green shale and mudstone, which laterally change into gray, feldspathic sandstone, siltstone, and mudstone with some conglomerate near the basin border (table 2). According to Wang and others (1983, p. 240), the Yaojia second and third members were deposited in a deep lake to fluvial deltaic environment, which continued through most of the time span of the overlying Nenjiang Formation. Fossil fauna consist chiefly of pelecypods, gastropods, ostracods, and charophytes, in which ostracods are sporadic in this formation.

The Nenjiang Formation is the most extensively distributed formation in the Songliao basin. It is also called the "Fulongquan Formation" by Chen Chin (1980, p. 239, fig. 4). Chen gave the Nenjiang age as Early Late Cretaceous as well as Late Early Cretaceous. However, in this report, the author prefers the classification and correlation by Wang and Liu (1980, p. 276, table 16-II) and designates a Late Middle Cretaceous age for the Nenjiang (table 2).

In ascending order, the Nenjiang Formation is divided into five members (table 2) (Ma, Yang, Ding, and Guan, 1984; Chen, 1980). The first three members are characterized by the presence of lucastrine to deltaic and fluvial lithofacies, whereas the second two members are indicated by well sorted fine- to medium-grained fluvial sandstone and the absence of distinct deltaic lithofacies. The first member consists of 27 to 222 m of light-gray to grayish-black mudstone, shale, and oil shale, locally interbedded with light-gray siltstone to fine-grained sandstone. The oil shale generally is located in the basal part of the unit and is very rich in fossil fauna. Calcareous concretions are abundant in the shale and mudstone. The second member is made up of 170 to 251 m of gray and black shale, oil shale, and mudstone, grading upward into black mudstone interbedded with siltstone, which laterally changes into siltstone. Chen Chin (1980) stated that conchostracans are concentrated along bedding planes of oil shale. Other fauna include pelecypods, gastropods, ostracods, and fragments of fish and plants. The third member comprises 70 to 131 m of gray to black mudstone and shale intercalated with thin-bedded reef-limestone, bioclastic limestone, and marl. This sedimentary sequence grades upward and laterally through salty mudstone and argillaceous siltstone into fine- and medium-grained sandstone near the basin border. Ostracods, gastropods, and pelecypods are common. The fourth member consists of 234 to 304 m of grayish-green shale, mudstone, siltstone, and sandstone in alternate sequences, in which thin-bedded calcareous sandstone is in the lower part and dark purplish-red mudstone is in the upper part (Chen, 1980, p. 241). Fossil fauna are ostracods, brachiopods, and pelecypods. The fifth member is made up of 0 to 355 m of grayish-green dark-purple and red massive mudstone shale and siltstone intercalated with grayish-green fine- to medium-grained sandstone. Fossil fauna are scarce.

Upper Cretaceous

The Upper Cretaceous strata lie unconformably on the Middle Cretaceous sedimentary rocks and are represented, in ascending order, by the Sifangtai and Mingshui Formations, which were deposited in a waning lake stage (table 2).

The Sifangtai Formation is widely distributed in the Songliao basin and consists of 0 to 394 m of alternate grayish-green, red mudstone, siltstone, and some sandstone. Calcareous conglomerate beds are near the base containing mollusks and ostracods.

The Mingshui Formation is divided, in ascending order, into two members. The first member consists of 0 to 243 m of alternate black, dark purplish-red and grayish-green mudstone, shale, and sandstone, which locally contain the basaltic flow near the base. This member is characterized by the presence of black shale beds in the upper and middle parts with a thin pyrite layer at the base (Chen, 1980, p. 241). Ostracods, conchostracans, gastropods, and pelecypods are present. The second member is composed of 0 to 354 m of orange-red to variegated mudstone intercalated with conglomerate. Gastropods and pelecypods are common in association with scattered ostracods, plants, and charophytes (Chen, 1980, p. 242).

Tertiary

The Tertiary system of Songliao basin consists of continental deposits of detrital sediments derived from the adjacent highlands. In ascending order, this system is divided into the Paleogene and Neogene series. At present, a detailed study of Tertiary stratigraphy is not available. The Paleogene unconformably overlies the Cretaceous and is represented by the Yian Formation. The Neogene of the basin is represented, in ascending order, by the Daan and Taikang Formations (table 2).

The Yian Formation consists of 0 to 221 m of light-brown coarse-grained sandstone and basal conglomeratic sandstone grading upward through grayish-green and black mudstone and shale with lignite beds into black, grayish-green mudstone and siltstone, and, locally, with tuffaceous and andesitic volcanic flows and pyroclastic rocks.

The Daan Formation unconformably overlies the Yian Formation (table 2), but, locally, conformably (Chen, 1980, p. 242). It comprises 0 to 93 m of light-gray to gray conglomeratic sandstone and sandstone grading upward into gray mudstone and siltstone. Chen Chin (1980, p. 242) mentions that this formation unconformably overlies the Cretaceous in the western and southern parts of the basin. Fossils are scarce. The Taikang Formation is in contact conformably with the Daan and consists of 0 to 122 m of light-gray, loose basal conglomerate and sandstone grading upward into siltstone and mudstone. Fossils are made up of plant remains and ostracods.

Quaternary

The Quaternary system of Songliao basin is undifferentiated and consists of 40 to 133 m of glacial outwash sand and gravel and fluvial red, greenish-gray clay intercalated with calcareous concretions, grading upward into silt and light-yellow clayey sand and gravel. This sequence is probably disconformably covered by alluvial clay, silt, and channel sand and gravel, and, locally, by peat beds.

STRUCTURE

The Songliao basin was a stable structural block in the Precambrian time (Wang and Qiao, 1984; Li and Xue, 1983). Subsequently, the Songliao was covered by Paleozoic platform sedimentary rocks and evolved by accretion into an integral part of the Neimeng-Da Hinggan Ling and the Xiao Hinggan Ling-Zhangguangcai Ling Variscan fold systems (Huang and others, 1980) (figs. 2 and 3). In the Songliao basin, the Variscan fold systems of the basement entailed three anticlinoriums and two synclinoriums trending N. 25°-40° E. (Yang, 1983, p. 187). The basin was uplifted with granite intrusion during the late episode of the Variscan orogeny (table 2). The initial depositional framework of the Songliao was formed by north-northeasterly-trending extensional fault systems during the late episode of the Indosinian orogeny in the Late Triassic. During the Late Jurassic and Early Cretaceous Yanshanian orogeny, the basin reached its full development stage with the formation of three northeastern deep fault systems, which consist of the Nenjiang-Baicheng deep fault zone along the west basin border, the Yilan-Yitong deep fault zone along the east basin border, and the Sunwu-Shuangliao in the central part of the basin (fig. 2) (Yang, 1983, p. 188). These fault systems controlled the development of the basin-fills during the lacustrine sedimentation of the Qingshankou, Yaojia, and Nenjiang Formations in the Middle Cretaceous (Yang, 1985; Wang and others, 1983; Ma and others, 1982). Subsequently, the basin acquired its present configuration with various types of anticlinal and synclinal folds and normal and strike-slip faults during a late phase of the Yanshanian orogeny from the Mingshui to the Yian (Yang, 1985) (table 2).

The structure of the basin is classified into six major structural units, based on structural patterns, areal distribution, development status within the basin, variation in thicknesses of sedimentary beds, and surface-structural characteristics of the sedimentary cover (fig. 3) (Wang and others, 1983, p. 241; Ma, Liu, and Su, 1984). These six units are the West Slope, North Plunge, Central Depression, Northeast Uplift, Southeast Uplift, and Southwest Uplift, of which subunits are given for five of those six structural units but details are not available.

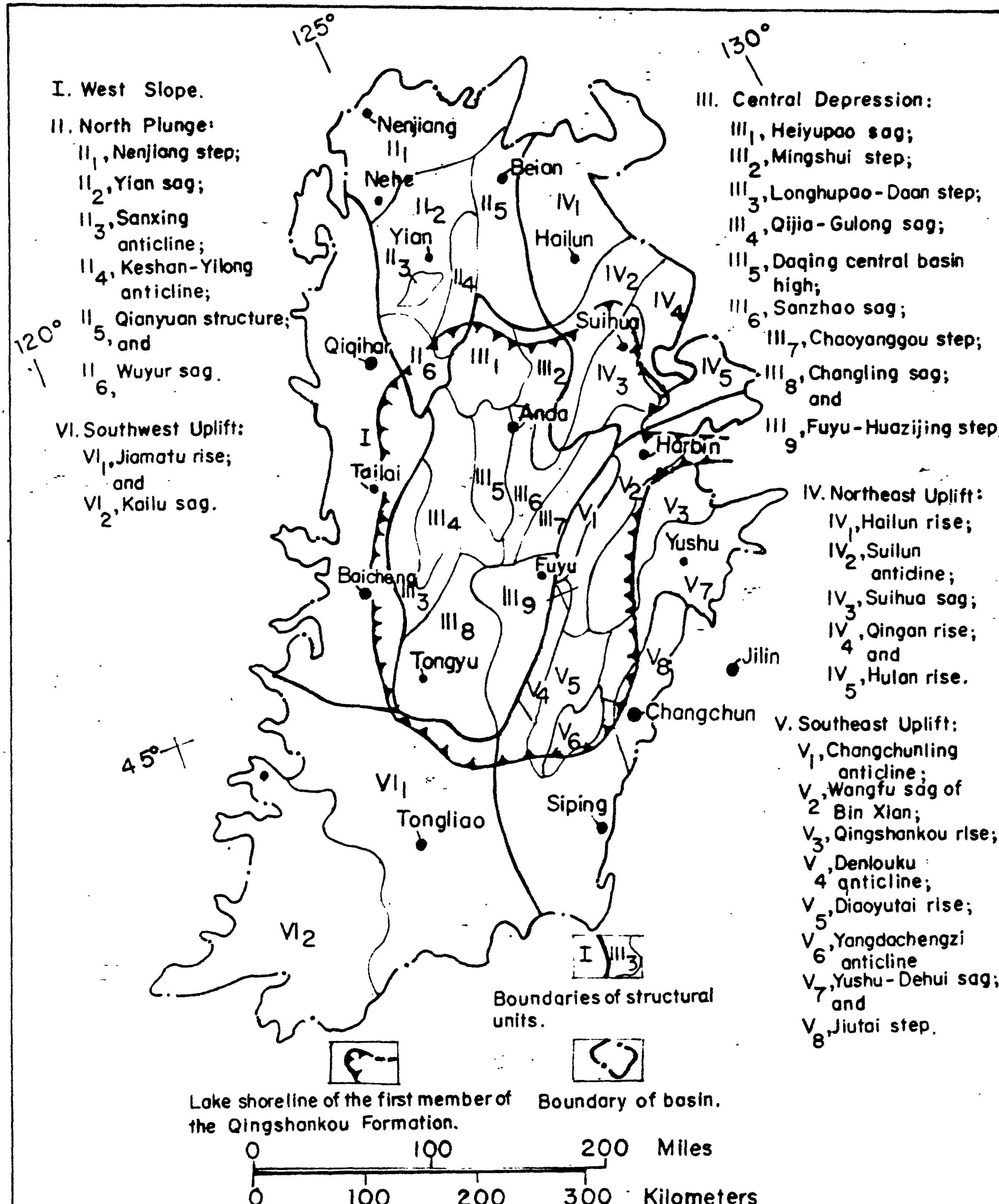

Figure 3. Structural units and lake shoreline of the first member of Qingshankou Formation in the Songliao basin, Northeast China (modified after Wang and others, 1983; Figure 4-9-4, p. 242; and Yang and others, 1985; Figure 3, p. 1116).

West Slope

The West Slope is situated in the western part of Songliao basin. According to Wang and others (1983, p. 241), the basement in this area has a flat surface with small-scale graben structures. The burial depth of the basement ranges from 500 to 2,000 m. The sedimentary rock cover was folded into a regional large-scale monocline which gently dipped basinward to the area of the Central Depression. The monocline contains numerous small-scale, nose-shaped structures. The second and third members of the Quantou Formation overlap old strata toward the basin border (fig. 3). Throughout this area, facies changes and stratigraphic pinch-outs are generally common.

North Plunge

The North Plunge is herein named after the crystalline basement of the area, which plunges southward. The unit consists of six subunits. They are the Nenjiang step, Yian sag, Sanxing anticline, Keshan-Yilong anticline, Qianyuan structure, and the Wuyur sag (fig. 3). The burial depth of the basement ranges from 300 to 3,000 m (Wang and others, 1983, p. 241-242). The sedimentary cover was folded mostly into the nose-shaped structures. In this area, northeast and east-west fault systems are commonly present, and the Quantou sedimentary strata overlap the older beds toward the north (Wang and others, 1983, p. 242).

Central Depression

The Central Depression contains the Daqing oil field of Songliao basin and covers about 29,000 km^2 (fig. 3) (Wang and others, 1983, p. 241; Yang 1985). This unit is made up of the following nine subunits, the Heiyupao sag, Mingshui step, Longhupao-Daan step, Qijia-Gulong sag, Daqing central basin high, Sanzhao sag, Chaoyanggou step, Changling sag, and Fuyu-Huazijing step (fig. 3). Of these subunits, the Daqing central basin high is located in the central part of the Central Depression. Yang Wanli (1985, p. 1101-1102) stated that from the Late Cretaceous Mingshui to the Late Paleogene Yian time, the Daqing central basin high was intensely folded and faulted; this subunit comprises seven principal anticlines separated by saddles and broken by about 600 northwesterly striking normal faults; and closures of these anticlines range generally from 775 to 900 m in an area of 2,800 km^2. Generally, the basement of this depression has a burial depth ranging from 4,000 to 7,000 m, locally reaching 9,000 m, and has been cut and broken chiefly by graben faults (Ma, Liu, and Su, 1984, fig. 2, p. 612; Wang and others, 1983, p. 241). Geophysical data show that in the central part of the unit the earth's crust is relatively thin with a high heat-flow value (HFU) (figs. 2 and 3) (Ma, Liu, and Su, 1984, fig. 7, p. 616 and fig. 9, p. 618). The Cretaceous sedimentary sequences are complete in succession and were folded into an anticlinal structure, which was truncated by numerous northwestern normal faults (Yang, 1985, p. 1102-1103).

Northeast Uplift

The Northeast Uplift began to form at the end of the Mingshui Formation and consists of the Hailun rise, Suilun anticline, Suihua sag, Qingan rise, and Hulan rise (fig. 3). The sedimentary cover is more than 3,000 m thick.

A complete stratigraphic sequence is located in the Suihua sag (Wang and others, 1983, p. 241).

Southeast Uplift

The Southeast Uplift formed during the latest episode of the Yanshanian orogeny in Late Cretaceous; subsequently, eight subunits developed throughout the area. These are the Changchunling anticline, Wangfu sag of Bin Xian, Qingshankou rise, Denlouku anticline, Diaoyutai rise, Yangdachengzi anticline, Yushu-Dehui sag, and Jiutai step (fig. 3). Wang and others (1983, p. 241) reported that the Lower to Middle Cretaceous strata are 3,500 m thick in the Wangfu sag of Bin Xian and the Yushu-Dehui sag.

Southwest Uplift

The Southwest Uplift is a graben-faulted block of Late Jurassic age and consists of the Jiamatu rise and the Kailu sag (fig. 3). In this area, the Yaojia and Nenjiang Formations are extensively distributed. Most of the area is untested (Wang and others, 1983, p. 243).

BASIN EVOLUTION

As mentioned before, the presence of three northeast-trending deep fault systems in Songliao basin controlled the subsequent development of the major structural units as well as the sedimentary fill of the basin. From Late Jurassic to Late Cretaceous, the basin underwent three principal stages of development: intense extensional rifting with graben faulting from Late Jurassic to Early Cretaceous; in the Middle Cretaceous, basin-wide subsidence due to further extensional basin fragmentation; and a final basin waning stage due to uplifting of the central, northeastern, and southeastern parts of the basin during the latest episode of the Yanshanian orogeny from the Mingshui to the Yian (Ma and others, 1982; Ma, Liu, and Su, 1984; Yang, 1985; Ma, 1985).

Since its initial extensional rifting in Late Triassic to Early Jurassic, Songliao basin underwent fragmentation and expansion associated with extensive igneous activity. During the early episode of the Yanshanian orogeny in Late Jurassic to Early Cretaceous time, the basin became intensely rift- and graben-faulted with wide emplacement of intermediate and acidic magma, creating a central uplift belt separating the basin into two northeast-trending faulted sags, one in the east and the other in the west (Ma and others, 1982, p. 293). Both sags were filled with Jurassic fluvial and marsh deposits of detrital sediments with thick coal beds and volcanic rocks and Early Cretaceous purplish-red mudstone, shale, and coarse detrital sandstone and conglomeratic sandstone. Total thickness of the Late Jurassic and Early Cretaceous sequences reached a maximum of about 3,000 m (table 2).

In the Middle Cretaceous, the areal coverage of Songliao basin expanded to more than 200,000 km^2 (Wang and others, 1983, p. 240). Especially at the time of deposition of the Qingshankou, Yaojia, and Nenjiang Formations, the central uplift belt subsided, in association with the growth of the preceding rift- and graben-faults in the basin, to form the Central Depression with the merging of its eastern and western faulted sags (Ma and others, 1982, p. 293). During that time the Songliao lake formed with a bottom surface which was gently sloping down toward the depocenters (fig. 2). Generally, the basin subsidence rate was over over 0.1 mm per year, as given by Ma and others (1982), and an average area of the deeper lake facies was estimated to be 50,000 km^2 with deposits of 500 to 800 m of dark mudstone.

During the sedimentation of the Qingshankou and Yaojia Formations, three large deltaic deposits developed in the northern, western, and southwestern parts of the lake basin (Ma and others, 1982). Delatic deposits are not reported in the eastern part of the basin, however. Of these three deltas, the northern delta, located in the northern part of the Central Depression, is the most prolific for petroleum production. This delta is also called the "Daqing delta" by Chungyu Wu (1982). The author believes that the Daqing delta includes Ma's Xingshugang delta formed in Early Yaojia time, which is equivalent to the Yaojia-1 lobe shown as below, and Heiyupao delta (Wang and others, 1983, fig. 4-9-3, p. 239) formed in Late Qingshankou time. Wu (1982, p. 12) considered that the Daqing delta developed during a period of lake regression, which occurred between two major lake transgressive events, as indicated by the first members of the Qingshankou and Nenjiang Formations, respectively (table 2) (fig. 3). The Daqing delta consists of detrital sediments derived from the highlands to the north. It extends from the swamp and marsh of the Heiyupao sag southward to the site of Putaohua and continues to project into the center of the basin (Ma, 1985; Wu, 1982, p. 12). The delta covers an area about 20,000 to 44,000 km^2 and consists of more than 200 lobes of elongate tongue-like and bird-foot shapes with a total thickness of 500 to 600 m (Wu, 1982, p. 12; Ma and others, 1982, p. 299). The longest lobe, Yaojia-1, is about 200 km and indicates that, during the sedimentation of Yaojia Formation, the paleoslope of depositional framework was gentle, less than 0.5 m per km along the fluvial plain, less than 0.1 m per km on the deltaic plain, and about 0.8 m per km along the delta front (Wu, 1982, p. 12). Development of the Daqing delta depositional system is the most important geologic factor, accounting for about 70 percent of the total reserves of petroleum deposits in Songliao basin. During early Nenjiang time, the lake basin reached full development with overlapping deposition in the western, northern, and northeastern parts of the basin (Ma and others, 1982, p. 293).

In Late Cretaceous, the Songliao lake gradually reached its waning development stage. From the Late Cretaceous Mingshui to the Late Paleogene Yian time, the tectonic activities in the basin reached a culminating stage (Yang, 1985, p. 1101) (table 2). Generally, the Late Cretaceous strata are missing in the northeastern and southeastern parts of the basin because of regional uplift in the east half. The center of subsidence shifted westward, and throughout the basin, the alluvial and fluvial deposits dominated (Ma and others, 1982, p. 293).

PETROLEUM DEPOSITS

The petroleum deposits of Songliao basin have been well documented during the past several years (Masters and others, 1980; Xu and Wang, 1981;

Meyerhoff, 1982; Ma and others, 1982; Wang and others, 1983, p. 237-243; Ma Yang, Ding, and Guan, 1984; Yang, 1985; Yang and others, 1985; Ma, 1985). Since 1959, with the discovery of three commercial oil and gas wells in the Central Depression, the so-called "Daqing oil field" of Songliao basin has developed into one of the giant oil and gas fields of the world. In this report, discussion will emphasize the geologic factors controlling the formation of oil and gas resources of nonmarine origin. Most of the producing fields are concentrated in the Central Depression of the basin (figs. 2 and 3).

Source Rocks

The potential sources rocks in Songliao basin are the Late Jurassic coal-bearing series and the Cretaceous shale, mudstone, and oil shale. Detailed investigations by Chinese petroleum geologists indicate that the organic matter-rich Middle Cretaceous fine detrital sediments are solely responsible for the generation of almost all oil and gas deposits in the basin. The Middle Cretaceous source rocks are concentrated, in ascending order, in the Qingshankou, Yaojia, and Nenjiang Formations. The most favorable source rocks are the eutrophic fresh to brackish water lake deposits of the black mudstone, shale, and oil shale of the first member of the Qingshankou and Nenjiang Formations. Generally, favorable source rocks are the black, gray and green shale and mudstone of the second and third members of Qingshankou Formation. The less favorable source rocks are the lake marsh and swamp deposits of grayish-green and reddish-green shale and mudstone of the second and third members of the Yaojia Formation, as well as the mudstone and shale of the Quantou Formation (tables 2 and 3) (Yang and others, 1985, table 1 and fig. 1, p. 1113). On the basis of organic geochemical characeristics of source rocks, Yan, Li, and Gao (1985) classified and defined the kerogen in Songliao basin into three major types: I, II, and III, of which type II is subdivided into subtypes IIA and IIB (table 3).

The type I kerogen is sapropelic and consists chiefly of lipids derived from lake-dwelling organisms and higher terrestrial plants (Yang and others, 1985, p. 1112-1121). The H/C atomic ratio of the kerogen is larger than 1.4, and the O/C ratio is less than 0.1 (table 3). The hydrogen index derived from the source rock by pyrolysis is larger than 650, and the oxygen index is less than 25 (Yang and others, 1985, table 2, p. 1114). The characteristics of n-alkane and isoprenoid are shown in table 3. Yang, Li, and Gao (1985, p. 1112) further state that by pyrolysis at 450°C, the amount of hydrocarbon produced from the kerogen is more than 42 percent. Generally, type I has a small number of free radicals and a high potential for the genesis of petroleum.

The type II kerogen of the basin chemically ranks between the sapropelic type I and the humic type III. Type II generates a less amount of hydrocarbon as compared with type I and is a mixed type derived from a mixture of two different precursors: the lipid-rich lake-living organisms and the aromatic-rich higher plants (Yang and others, 1985, p. 1114). On the basis of elemental analysis and pyrolysis hydrogen and oxygen indices (Yang and others, 1985, table 2, p. 1114), type II is subdivided into type IIA and type IIB (table 3). Type IIA is rich in lipids of which the liptinite content ranges from 50 to 90 percent. Yang and others (1985, p. 1114) show in table 2 that type IIA kerogen has an H/C atomic ratio of 1.0-1.4, an O/C ratio of 0.10-0.15, and hydrogen and oxygen indices of 450-650 and 25-50, respectively. Type IIB is

Table 3.--Organic geochemical characteristics of the source rocks in Songliao basin, northeast China (after Yang, Li, and Gao, 1985; Tables 2, 3 and 5, p. 1114 and 1117; Wang and others, 1983, p. 126-128).

Formation and Member	Kerogen elemental analysis: H/C (Atomic ratio)	Kerogen elemental analysis: O/C (Atomic ratio)	Type of kerogen	Depositional environment and source rocks	Organic matter: Organic carbon (%)	Organic matter: Extracts (%)	Organic matter: HC content (ppm)	Group components (%): Saturated HC	Group components (%): Aromatic HC	Group components (%): Non-HC	Group components (%): Bitumen	n-Alkane: C number of main peak	n-Alkane: $\frac{C_{21} + C_{22}}{C_{28} + C_{29}}$	Isoprenoid: Pristane/nC_{17}	Isoprenoid: $\frac{\text{Pristane}}{\text{Phytane}}$	$\frac{\text{Saturated HC}}{\text{Aromatic HC}}$
First member of Qingshankou, first member of Nenjiang Formations	>1.4	<0.10	I	Deep lake. Black mudstone and shale	1.5- 8.4	>0.1	>1,000	39.9- 61.3	15.2- 25.2	12.9- 24.0	1.1- 8.0	C_{19} C_{21} C_{23}	2.0- 10.0	<0.5	1.2-1.8	2.2- 8.4
Second and third members of Qingshankou Formation	1.00- 1.40	0.10- 0.15	II A	Deeper lake- Shallow lakeshore Gray and green shale and mudstone	0.5- 1.5	0.03- 0.1	300- 1,000	30.0- 60.0	15.0- 21.9	19.8- 25.3	2.0- 8.0	C_{20} and C_{27}	2^+	0.5-1.0	1.2^+	2^+
	0.80- 1.00	0.15- 0.2	II B		0.1- 0.5	0.01- 0.03	50- 300	25.7- 32.3	15.9- 30.0	22.7- 56.3	2.0- 14.8					
Quantou and Yaojia Formations	<0.8	>0.2	III	Lake basin marsh and swamp Grayish-green and reddish-green shale and mudstone	0.1- 2.0	<0.01	<50	8.0- 28.3	9.1- 22.3	22.6- 66.4	4.8- 15.0	C_{25} C_{27} C_{29}	<2	>1.0	<1.2	<2.0

HC, Hydrocarbon

rich in aromatic matter in which the vitrinite content ranges from 50 to 90 percent. It has an H/C atomic ratio of 0.8-1.0, an O/C ratio of 0.15-0.20, a hydrogen index of 100-150, and an oxygen index larger than 50.

Type III kerogen of the basin generates the least amount of hydrocarbon as compared with type I and type II kerogens. It is typically humic and consists of up to 90 percent of the vitrinite derived from higher terrestrial plants (Yang and others, 1985, p. 1113-1121). This type of kerogen is hydrogen-poor and oxygen-rich; the H/C atomic ratio is less than 0.8, and the O/C ratio is larger than 0.2 (table 3). The hydrogen index is less than 100, and the oxygen index is larger than 50 (Yang and others, 1985, table 2, p. 1114).

The maturation sequences of the preceding kerogen types are determined by the thermal simulation experiment of kerogen and thermogravimetric analysis. Type I matured successively earlier than types II and III (Yang and others, 1985, fig. 5, p. 1119 and 1121). Principal source rocks are concentrated in the Qijia-Gulong sag and the Sanzhao sag of the Central Depression (figs. 2 and 3) and attain a thickness ranging from 500 to 700 m (Wang and others, 1983, p. 203). Yang, Li, and Gao (1985, p. 1120) state that the sapropelic kerogen of source rocks in Songliao basin has generated more oil than gas with a high production capacity at the peak of generation.

During hydrocarbon evolution from the source rocks in the basin, both the formation temperature and the heat flux are high. The average earth heat flux is 1.70 x 10^{-6} cal/cm^2/sec, and the mean geothermal gradient in the main producing area is 4.2°C/100 m (Yang and others, 1985, p. 1120). Four stages of oil and gas generation are defined by Wang and others (1983, p. 128) and Yang, Li, and Gao (1985, p. 1119-1120) (table 4). They are the 1) immature, 2) mature, 3) highly mature, and 4) overmature stages (fig. 2). During the immature stage, the kerogen begins to degrade and produces chiefly biochemical methane. The total hydrocarbon/organic carbon ratio maintains a relatively low value, and vitrinite reflectance is less than 0.5 percent (table 4). During the mature stage, the kerogen degrades in large quantities and produces mainly heavy oil. The total hydrocarbon/organic carbon ratio increases from about 30 mg/g to 120-160 mg/g. During the highly mature stage, kerogen is pyrolyzed due to the effect of strong thermodynamic action (Yang and others, 1985, p. 1120). A large amount of light oil and wet gas is generated. The total hydrocarbon/organic carbon ratio decreases to less than 50 mg/g. During the overmature stage, hydrocarbon production is generally low, and a large amount of dry gas is generated. Because of the carbonation of source rocks, kerogen becomes black with the increase of vitrinite reflectance (table 4).

In Songliao basin, the geothermal gradient has a considerable vertical variation because of the thick black shale of the second member of the Nenjiang Formation, which is like a quilt extensively draped over the basin. Because this black shale has excellent heat insulation properties, and the overpressure occurred at a depth where the source beds are located, much heat is concentrated in the source beds of the first members of the Qingshankou and Nenjiang Formations (Yang and others, 1985, p. 1120). Yang, Li, and Gao (1985, p. 1120) indicate that the geothermal gradient of the formations above the second member of Nenjiang Formation is 2.7°C/100m, and below the second member of Nenjiang Formation it is 7.6°C/100 in the first member of the Formation and 7.8°C/100m

Table 4.--Evolution of the source rocks in Songliao basin, northeast China (after Wang, Zhang, Zhang, and Tan, 1983, p. 128-129; Yang, Li, and Gao, 1985, p. 1119-1121)

Stage	Characteristics of oil and gas	Burial depth (m)	Formation T°C	Total hydrocarbon / Organic carbon (mg/g)	Odd-Even Predominance (OEP)	Pristane / Phytane	Vitrinite reflectance (%)	Remarks on equivalent depths
Immature	Chiefly methane	<1,100 - 1,300	<60-70°	<30	>1.20	<1	<0.5	Yang, Li, and Gao (1985, p. 1120) state that during the heavy oil stage, the threshold depth of oil generation was from 1,100-1,300 m to 1,700-1,900 m in the Central Depression. In the Gulong sag, oil generation depth can be down to 2,300 m. In the Central Depression during the light oil and wet gas stage, burial depth ranged from 1,700 to 2,700 m and during the dry gas stage, from 2,700 to 4,600 m. Peak of the mature stage was between the time of deposition of the upper Mingshui and the upper Yian Formations (Yang, 1985, p. 1105).
Mature	Heavy oil	1,300-1,900	70-90°	30 increasing to 120-160	<1.20	>1	0.5-1.0	
Highly mature	Light oil and wet gas	1,900-2,900	90-120°	<50	1.0-1.1		1.0-2.0	
Overmature	Chiefly dry gas	>2,900	>120°	Very low			>2.0	

in the first member of the Qingshankou Formation. In the Quantou Formation, the geothermal gradient is as low as 3.1°C/100m. It increases to 3.7°C/100m further downward to the Denglouku Formation. Yang, Li, and Gao (1985, p. 1120) consider this increase of geothermal gradient to be due to a high heat flux resulting from thermotectonic doming which had continued into the early phase of basin development.

The source rock and crude oil correlation in Songliao basin is shown by the $\delta^{13}C$ value of stable carbon isotope (Wang and others, 1983, table 2-4-20, p. 110). Yang, Li, and Gao (1985, p. 1117) have provided the $\delta^{13}C$ values of sapropelic kerogen from the basin as -25.5 to -29.1 ‰ and that of the extracts from the source beds as -26.7 to -29.6 ‰. They concluded that the source of the precursor of the oil was freshwater algae. Generally, typical characteristics of the crude oil of the basin are the high content of wax and nickel and the low content of sulfur and vanadium. Physical properties of Daqing oil are: the viscosity of crude oil at 50°C is 10-40 cp and the subsurface viscosity is 5-10 cp; the specific gravity of surface crude oil at 20°C is 0.83-0.88; and the pour point of degassed crude oil is 25-30°C (Yang and others, 1985, p. 1117). Yang (1985, p. 1106-1107) mentions that during migration through the pores of the carrier bed, some chemical constituents are lost because of oil and gas absorbed by molecules on the surface of rock and mineral grains.

Reservoirs

The reservoir rocks of Songliao basin are fluvial and deltaic sandstone consisting of quartz, feldspar, and detrital clastics (Yang, 1985, p. 1103). Principal producing pay zones, however, are composed chiefly of delta front fine-grained sandstone (table 5). Major reservoirs are the Heidimiao, Shaertu, Putaohua, Gaotaizi, and Fuyu in the Central Depression; and the Yangdachengzi and Nongan in the Southeast Uplift (fig. 3) (table 2) (Wang and others, 1983, table 4-9-1; Ma, Yang, Ding, and Guan, 1984, fig. 1). Wang and others (1983, p. 240-241), Ma, Yang, Ding, and Guan (1984), and Yang (1985) grouped these reservoirs into the upper assemblage of the Heidimao; the middle assemblage of the Shaertu, Putaohua, and Caotaizi; and the lower assemblage represented by the Fuyu, Yangdachengzi, and Nongan. The highest producing pay zones of the basin are from the Shaertu, Putaohua, and Gaotaizi reservoirs (Yang, 1985, p. 1103). In descending order, discussion of these reservoirs follows.

The Heidimiao reservoir of the upper assemblage consists chiefly of the floodplain, distributary channel, and delta-front deposits of the poorly to well-sorted, fine- to medium-grained sandstone of the third and fourth members of Nenjiang Formation (table 2). Oil and gas were generated from the first and second members of the Nenjiang, trapped by lithofacies changes and fault barriers in syncline, and sealed by shale and mudstone of the fourth and fifth members of this formation (Wang and others, 1983, p. 240-241; Ma, Yang, Ding, and Guan, 1984).

The Shaertu, Putaohua, and Gaotaizi reservoirs of the middle assemblage consist chiefly of delta front and prodelta to offshore lacustrine deposits of fair to well sorted fine-grained sandstone of the Daqing delta complex (tables 2 and 5). These three reservoirs, of about 5 billion barrels of oil, provide the principal pay zones for the Daqing oil field. Among them, the Putaohua reservoir contains up to 70 percent of the total, or 3.5 billion barrels of oil (Ma, 1985, p. 1123). The thickness of the reservoirs gradually decreases from the northern delta front to the southern prodelta area accompanied by an increase in the number of sandstone beds as well as of a decrease in the thickness of the individual sandstone beds. As the shale content increases southward, the porosity and permeability of the reservoir sandstone become poorer (table 5).

Daqing oil field is located in the Daqing central basin high of the Central Depression (fig. 6). The Daqing central basin high contains seven oil and gas pools, which, from north to south, are named and shown in figure 1 of Yang's report (1985, p. 1102): Lamadian, Shaertu (Saertu), Xingshugang, Gaotaizi, Taipipingtun, Putaohua, and Aobaota. Each of these pools is confined in an anticline structure and is made up of the Shaertu, Putaohua, and Gaotaizi pay zones; vertically, the distribution of the oil and water is shown with the appearance of an upper thickened oil section over an oil-water transition section, and the properties of crude oil change greatly from the inner oil-bearing limit, laterally becoming quite poor (Yang, 1985, table 1, p. 1102). The effective source beds for generating oil and gas deposits of the Daqing are the shale and mudstone of the first, second, and third members of the Qingshankou Formation and the first member of the Nenjiang Formation (table 2) (Wang and others, 1983, table 4-9-1, p. 241). Oil and gas were expelled from the source rocks and migrated through the sandstone carrier beds, as well as the structural fractures, to enter the traps and then accumulate in the reservoirs. Generally, in the Daqing basin high, the oil and gas were sealed by shale and mudstone of the second member of the Nenjiang Formation (Yang and others, 1985, p. 1120-1121). In the north part of the Daqing high, oil and gas were trapped by an anticlinal structure, locally, with northeastern strike-slip fault barriers, whereas in the south part of the area, they were trapped in lenticular and sheet sandstone bodies by lithofacies changes associated with anticline structure and growth fault barriers (Yang, 1985). However, in the surrounding sags of the Daqing basin high, the oil and gas occur in nose-like structures of syncline folds (Yang, 1985; Ma, 1985). Yang (1985, p. 1110) concludes that the stages of oil and gas generation, expulsion, secondary migration in carrier beds, and accumulation in the reservoir occurred concurrently with the development history of structural trap growth in the Daqing area during the time span from the Late Mingshui to the Late Yian (table 2).

The Fuyu, Yangdachengzi, and Nongan reservoirs of the lower assemblage consist of fluvial and deltaic deposits of fine-to-medium lenticular and sheet sandstone bodies of the Quantou Formation (table 2). Generally, the porosity averages about 20 percent and permeability averages about 150 md. These reservoirs occupy a north-south basement high area with a relatively thin earth's crust in the central part of Songliao basin (figs. 2 and 6). Source rocks of the Fuyu and Yangdachengzi oil and gas deposits are chiefly of the Qingshankou shale, oil shale, and mudstone; the Nongan oil and gas deposits are generated from the shale and mudstone, probably of the Lower Cretaceous Denlouku and Upper Jurassic ages (table 2). In addition, the mudstone, shale, and oil shale of the fourth member of the Quantou Formation generates oil and gas deposits for all three reservoirs (table 2) (Ma, Yang, Ding, and Guan, 1984, p. 11). The oil and gas in these reservoirs were sealed by mudstone

Table 5.--Depositional environments and physical properties of the reservoir sandstone in the Daqing delta complex of Songliao basin, northeast China (modified after Wu, 1982; Ma, 1985).

Depositional environments	Thickness (m)		Porosity (%)	Permeability (md)	Shale content (%)	Age	Remarks
	Gross	Individual					
Deltaic plain	10	4-8				2nd and 3rd members of the Qing-shankou Formation upward to 1st, 2nd, and 3rd members of the Yaojia Formation (table 2)	Distributary channel sand bodies parallel to each other; convex-bottom, flat top and symmetrical lenses; chiefly medium to fine. Shale and mudstone between channels (Wu, 1982, p. 12).
Delta front	6-16	2-6	22-25	300-800	12-14		Principal pay zones in mouth bars with coarsening-upward; and subaqueous elongated, banded and lenticular distributary channel sand bodies with fine-upward, extending far into deep water area as carrier beds into source rocks, such as the Yaojia-1 tongue-shaped lobe of the Putaohua reservoir, about 200 km in length; chiefly fine-grained sandstone (Wu, 1982, p. 12; Ma, 1985, p. 1124-1125) (table 2).
Prodelta to Offshore lake	4-6	3	20	300-400	18		

and shale of the Quantou Formation and trapped by anticline and nose-shaped structure locally, with fault barriers along the slopes of the structural high (table 2). In the Fuyu, Mutou and Xinli oil fields (Ma, Yang, Ding, and Guan, 1984; fig. 16), the oil and gas also were trapped by fault barriers in the updip and by lithofacies changes in the downdip (Ma, Yang, Ding, and Guan, 1984, p. 11-17). The exploration for oil and gas deposits of the lower assemblage reservoirs is still in a preliminary stage, and it is expected that further exploratory drilling will discover new oil and gas pools in those reservoirs (Ma, Yang, Ding, and Guan, 1984, p. 15-17).

Potential

Petroleum potential of Songliao basin is substantial. Principal producing oil and gas fields are concentrated in the central and southeastern parts of the basin. Of these, Daqing oil field of the Daqing central basin high in the Central Depression ranks as one of the world's giant oil fields and has produced an average of more than 1 million barrels of oil per day since 1976, about half of China's daily oil production. Original oil in-place at Daqing is estimated to be about 21.9 billion barrels, of which 30 percent is likely to be recovered by existing production methods; enhanced recovery processes are currently being considered for use in Daqing field (International Encyclopedia, 1985, p. 10-11 and 21).

Generally, detailed stratigraphic information and data on exploratory drilling are not available within individual structural units of the basin; therefore, an estimate of the ultimate petroleum recovery from the basin is not provided in this report. The author believes, however, that future new discoveries are favorable in the delta-front sandstone of the Quantou and Denkouku Formations in the southern part of the basin.

SUMMARY AND CONCLUSIONS

Songliao basin of Northeast China evolved on a Variscan folded cratonic basement by extensional continental fragmentation during the latest episode of the Late Triassic Indosinian orogeny. Subsequently, Songliao reached its full development stages through extensional graben-faulting from Late Jurassic to Early Cretaceous and growth faulting in the Middle Cretaceous. The basin acquired its present configuration by extensional tectonics during the Late Cretaceous Yanshanian and the Cenozoic Himalayan orogenies.

In the Middle Cretaceous, the basin reached the full development stage during the lacustrine-fluvial sedimentation of the first members of the Qingshankou and Nenjiang Formations. In high-water stages of the first members of these two formations, the lake covered an area ranging from 87,000 to 200,000 km^2 and was fed by the influx of detrital sediments from the adjacent highlands. The depocenters of these members coincided with the subsidence center of the basin along a north-northeast linear rift of the Qijia-Gulong and Changling sags in the Central Depression. The lake water hence was enclosed in an anaerobic environment favorable for the preservation of organic matter, forming an excellent source for petroleum generation.

The lipid-rich kerogen types I and IIA generated most of the hydrocarbon. Maturation sequences of kerogen types are determined by Yang, Li, and Gao (1985, p. 1119 and 1121) to be the type I which matured successively earlier than types II and III. Principal source rocks, 500 to 700 m thick, are confined to the first members of the Qingshankou and Nenjiang Formations and are concentrated in the Qijia-Gulong and Sanzhao sags of the Central Depression. The sapropelic kerogen source rocks have generated more oil than gas with a high production capacity at the peak of generation.

During the hydrocarbon evolution from the source rocks, both the formation temperature and heat flux were high. The geothermal gradient has considerable vertical variation because of the thick black shale of the second member of Nenjiang Formation, which is like a quilt extensively draped over the basin providing excellent heat insulation (fig. 2).

The reservoir rocks of the principal producing pay zones consist chiefly of delta front fine-grained sandstone. The greatest producing pay zones of the basin are in the Shaertu, Putaohua, and Gaotaizi reservoirs of the Daqing delta complex in the Central Depression. Daqing delta formed and developed during a period between two major high-water events as indicated by the first members of the Qingshankou and Nenjiang Formations. The delta sandstone was deposited on a gentle paleoslope and consists of more than 200 lobes extending into the center of the basin with a total thickness of 500 to 600 m in an area approximately 20,000 to 44,000 km^2. Of these lobes, the Yaojia-1 lobe is about 200 km long and the major sandstone body of the Xingshugang delta, which contains the most productive pay zone of the Putaohua reservoir. The Putaohua reservoir ranges from 40 to 60 m thick (Ma, 1985). In the reservoirs oil and gas are trapped by anticlinal and nose-shaped folds, fault barriers, and lithofacies changes, and sealed by shale and mudstone. During the time span from the Late Mingshui to the Late Yian, simultaneous oil and gas maturation, expulsion, migration, and structural trap formation were responsible for the formation of the Daqing giant oil field.

The petroleum potential of the basin is substantial. International Encyclopedia (1985) lists the original oil in-place at Daqing at about 21.9 billion barrels. The author believes that future discoveries are favorable in the deltaic sandstone of the Quantou and Denlouku Formations in the southern part of the basin.

REFERENCES CITED

Chen Chin, 1980, Nonmarine setting of petroleum in the Songliao basin of northeastern China: Journal of Petroleum Geology, v. 2, no. 3, p. 233-264.

Chen Piji, Li Wenben, Chen Jinhua, Ye Chunhui, Wang Zhen, Shen Yanbin, and Sun Dongli, 1982, Stratigraphic classification of Jurassic and Cretaceous in China: Scientia Sinica Series B, v. 25, no. 11, p. 1227-1248.

Chinese Academy of Geological Sciences, 1975, Geologic Map of Asia: Beijing, China, Cartography Press, 1:5,000,000, 20 sheets (in Chinese with English legend).

Defense Mapping Agency, 1979, Gazetteer of the People's Republic of China: Geographic Names Data Base Division, Washington, D.C. 20315, 919 p.

Gu Zhiwei, 1982, Distribution and development of nonmarine Mesozoic bivalves and formation in China: Scientia Sinica Series B, v. 25, no. 4, p. 438-452.

Huang Jiqing (T. K. Huang), 1984, New research on the tectonic characteristics of China: Chinese Academy of Geological Sciences Bulletin, no. 9, p. 5-18; (in Chinese with English Abstract).

Huang Jiqing (T. K. Huang), Ren Jishun, Jiang Chunfa, Zhang Zhengku, and Qin Deyu, 1980, The geotectonic evolution of China [brief explanation of 1:4,000,000 geotectonic map of China]: Beijing, China, Science Press, 120 p. (in Chinese with English translated Contents).

Institute of Geology, Academia Sinica, 1958 [Regional stratigraphy of China] Supplement: Beijing, China, Science Press, 190 p. (in Chinese).

International Petroleum Encyclopedia, 1985, China Outlook, China open door to equipment technology, v. 18, p. 7-33, PennWell Publishing Co., Box 1260, Tulsa, OK 74101, 392 p.

Li Desheng and Xue Shuhao, 1983, The eastern China Mesozoic-Cenozoic basins and hydrocarbon occurrence: Acta Geologica Sinica, v. 57, no. 3, p. 224-234 (in Chinese with English abstract).

Liu Xun, 1983, The sedimentary formations and tectonic development of the Meso-Cenozoic in Eastern China: Regional Geology of China, no. 4, p. 5-22 (in Chinese with English abstract).

Ma Li, 1985, Subtle oil pools in Xingshugang delta, Songliao basin: American Association of Petroleum Geologists Bulletin, v. 69, no. 7) p. 1123-1132, 17 figs.

Ma Li, Yang Jiliang, Ding Zhengyan, and Guan Zengmiao, 1984, The lower oil-bearing formations in Songliao basin: Beijing Petroleum Geology Symposium, September, 1984, Reprint, 17 p., 16 figs.

Ma Li, Ge Taisheng, Zhao Xueping, Zie Taijun, Ge Rong, and Dang Zhenrong, 1982, Oil basins and subtle traps in the eastern part of China: American Association of Petroleum Geologists Memoir 32, Halbouty, M. T., ed., p. 287-315, 22 figs.

Ma Xingyuan, Liu Guodong, and Su Jian, 1984, The structure and dynamics of the continental lithosphere in north-northeast China: Annales Geophysicae, v. 2, no. 6, p. 611-620.

Masters, C. D., Girard, O. W., Jr., and Terman, M. W., 1980, A perspective on Chinese petroleum geology: Southwestern Legal Foundation, Proceedings, Exploration and Economics of the Petroleum Industry, v. 18, p. 199-225.

Meyerhoff, A. A., 1982, Petroleum basins of the Union of Socialist Soviet Republics and the People's Republic of China and the politics of petroleum: Petroleum Exploration Society of Australia, Distinguished Lecture Series, 341 p., 140 figs.

Wang Hongzhen and Liu Benpei, 1980 [Historical Geology]: Beijing, China, Science Press, 352 p. (in Chinese).

Wang Hongzhen and Qiao Xiufu, 1984, Proterozoic stratigraphy and tectonic framework of China: Geological Magazine, v. 121, no. 6, p. 599-614.

Wang Shangwen, Zhang Wanxuan, Zhang Honfu, and Tan Shidian, 1983 [Petroleum Geology of China]: Beijing, China, Petroleum Industry Press, 348 p. (in Chinese).

Wu Chungyu, 1982, Mesozoic and Cenozoic lake deltas and oil-gas distribution in eastern China: Scientific Research Institute for Petroleum Exploration and Development, Reprint, Beijing, China, 25 p.

Xu Shice and Wang Hengjian, 1981, Deltaic deposits of a large lake basin, in Petroleum Geology in China, Mason, J. F., ed., PennWell Publishing Co., Tulsa, OK, p. 202-213.

Yang Jiliang, 1983, [Geologic structure related to the oil and gas deposits in the Songliao basin]: in [Tectonics and evolution of the Mesozoic and Cenozoic basins in China], Zhu Xia ed., Beijing, China, Science Press; p. 187-197.

Yang Wanli, 1985, Daqing oil field, People's Republic of China, a giant field with oil of nonmarine origin: American Association of Petroleum Geologists Bulletin, v. 69, no. 7, p. 1101-1111, 10 figs. 9 tables.

Yang Wanli, Li Yongkuang, and Gao Ruiqi, 1985, Formation and evolution of nonmarine petroleum in Songliao basin, China: American Association of Petroleum Geologists Bulletin, v. 69, no. 7, p. 1112-1122, 7 figs., 7 tables.

Yang Zuxu, Long Xinyen, Chen Fengchi, and Cui Xuezhou, 1983, Structural zones and distribution of oil and gas fields in the Songliao basin: Acta Petrolei Sinica, v. 4, no. 2, p. 1-8 (in Chinese with English abstract).

Zhang, W. Y., Chief Compiler, 1983, The marine and continental tectonic map of China and its environs: Beijing, China, Science Press, 1:5,000,000, 6 sheets (in Chinese and English editions).