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Geology of the petroleum and coal deposits in the North China basin, eastern China

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ABSTRACT

The North China basin evolved initially from a rifted intracratonic graben system on the east-central Sino-Korean platform during the Jurassic and Cretaceous Yanshanian orogeny. The basin reached its maximum stage of development in the Neogene owing to rift reactivation by the Himalayan orogeny. As indicated by geophysical data, extensional rifting within the basin is still active today.

After consolidation of the Precambrian crystalline basement at the end of Early Proterozoic, the site of the present-day North China basin was tectonically relatively stable from Late Proterozoic to Late Paleozoic. During that period, the Archean and Early Proterozoic basement was affected chiefly by epeirogenic movements in association with the sedimentation of littoral to neritic marine and continental platform carbonate and detrital sedimentary sequences of the Late Proterozoic, Cambrian to Middle Ordovician, and Late Carboniferous to Permian ages. From the beginning of Late Ordovician to the end of Early Carboniferous, the platform sedimentary cover was subjected to extensive weathering and a long period of erosion. Major extensional tectonism began with the Late Triassic Indosinian orogeny, continued into the Jurassic and Cretaceous Yanshanian orogeny, and culminated in Late Cretaceous to Early Paleogene. As a result, the basin developed into its present form through block-faulting of the north-northeast-, northeast-, and northwest-trending fracture systems. Of these, the north-northeast fracture system was the most active and controlled the sedimentation of the nonmarine basin-fill. During the late Eocene to early Oligocene Himalayan orogeny, development and enlargement of the north-northeast-trending fault blocks were extensive and associated locally with igneous activity. Throughout the basin, the listric-normal growth faults are generally characterized by tilting of sedimentary units along downward flattening fault planes on the footwall side and depositional overlap on the hanging wall side. Of these six depressions described in this report, the Central Bohai, Dongpu-Kaifeng, and Liaodong Gulf-Liao River depressions are the only grabens which are bounded by faults on both sides. The syntectonic deposits of the North China basin consist of fluvial, deltaic, and lacustrine sedimentary rocks of which the fine-grained types became source and cap rocks for oil and gas and the medium- to coarse-grained types became reservoir rocks.

The thickness of the stratigraphic interval beneath the minimum burial depth for the generation of petroleum from source rocks ranges from 400 m in the lower reach of the Liao He River depression to as much as 1,900 m in the Jizhong depression. Most of the oil and gas deposits were generated under geothermal gradients ranging from about 40° to 50° C per kilometer. The major petroleum source rocks are confined in the Eocene-Oligocene Shahejie

Formation. Carboniferous-Permian coal beds in the south part of the basin provide the major supply of natural gas. The petroleum is trapped by faults, anticlines, facies changes, and unconformities. Crude oil from Tertiary source rocks is high in paraffin and low in sulfur content. Current petroleum exploration is concentrated in the Jizhong, Dongpu-Kaifeng, Huanghua, Jiyang, Central Bohai (Bo Zhong), and Liaodong Gulf-Liao River depressions. Production from North China basin ranks second after the Songliao basin; most production is from the Upper Proterozoic and Ordovician carbonate buried-hill reservoirs in the Jizhong and Liaodong Gulf-Liao River depressions; and from the Tertiary delta-front and channel sandstone reservoirs. Buried hills may be favorable reservoirs in the Liaodong Gulf and Central Bohai depressions; the Cambrian and Ordovician carbonate rocks are most favorable in the Jiyang and Huanghua depressions. The total ultimate recoverable reserves are estimated to be about 7×10^9 barrels of oil chiefly from the Jizhong, Jiyang, Huanghua, and the lower part of the Liao He in the Liaodong Gulf-Liao River depression. Significant gas resources are indicated in the southern part of North China basin.

The thickest good quality coal beds are present largely in the Benxi and Taiyuan Formations of Late Carboniferous age and the Shanxi, Lower Shihezi, and Upper Shihezi Formations of Permian age. A tentative estimate of the bituminous and anthracite coal resources in the North China basin is approximately 110 billion metric tons, which represents approximately one-third of the total coal resources in the basin. According to U.S. Geological Survey guidelines on the classification and estimation of coal resources (Wood and others, 1983), most of the mineable coal beds would be excluded from coal resource consideration, because they have been buried deeper than 1,800 m.

INTRODUCTION

The North China basin is located in the east-central Sino-Korean platform and evolved from an intracratonic rift system during the Mesozoic Yanshanian and Cenozoic Himalayan orogenies (table 1) (Ma, Liu, and Su, 1984; Huang and others, 1980, p. 32-35). Most of the basin is confined on the shore, but its northeastern part extends partially into the offshore of Bohai. The basin extends from the lower Liaohe River to Kaifeng for about 1,200 km and has a maximum width of about 450 km (Ma and others, 1982, p. 103). From the northeast to the southwest, the basin is made up of the Liaodong Gulf-Liao River, Central Bohai, Jiyang, Huanghua, Jizhong, Lingqing, and Dongpu-Kaifeng depressions (figs. 2 and 3) (table 2). It is bounded on the north by the Yan Shan foldbelt, on the south by the Taikang upland in central Henan Province, on the west by the Taihang Shan, and on the east by the Luxi uplift, Bo Hai, and Liaodong Bandao (figs. 1, 2, and 3). The basin covers about 213,000 km^2 and has been filled with about 836,000 km^3 of strata ranging in age from Late Proterozoic to Cenozoic (Wang and others, 1983, table 4-10-2, p. 327).

Petroleum and coal resources are substantial in the North China basin. Since the 1950s, the petroleum deposits of the basin have been extensively explored and developed. During the past decade, petroleum production from Tertiary, Paleozoic, Proterozoic, and Archean reservoirs ranks second in Chinese petroleum output. The coal deposits are in the Carboniferous-Permian and the Jurassic-Cretaceous sedimentary sequences. Carboniferous and Permian coal has been mined extensively locally around the basin border margin in Shandong, Hebei, and Henan provinces since the early part of this century. The current status of coal mines near the basin is not known.

The principal purpose of this report is to provide a regional synthesis of the North China basin with a perspective on geologic factors controlling its petroleum and coal deposits. The petroleum and coal geology of the basin is well documented in numerous Chinese and English publications used in this report on the basis of accurate data and sound interpretation. 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 (Wu and others, 1978) is used for those names not listed in the Gazetteer. In some cases, a converson from the Wade-Giles system to Pinyin is shown in parentheses. Also some prominent geographic names in other forms of transliteration are in shown parentheses.

REGIONAL SETTING

The North China basin covers most of the Bo Hai and parts of the administrative provinces of Hebei, Shandong, Anhui, Henan, Liaoning (figs. 2 and 3). As mentioned, this basin contains the Jizhong, Huanghua, Jiyang, Central Bohai (Bo Zhong), Liaodong Gulf (Wan)-Liao River (He), Lingqing, and Dongpu-Kaifeng depressions; among these, only the Lingqing depression, at present, is nonproductive with respect to petroleum and coal (figs. 2 and 3).

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	C_1	
	Cambrian	570		Xingkaiian (Hsingkaiian)
Proterozoic	Sinian	770		Yangziian (Yangtzeian)
	Qingbaikou	1100		
	Jixian	1400		?
	Nankou	1700		Wulingian
	Changcheng Hutuo	1950		Zhongtiaoian (Chungtiaoian)
	Wutai	2500		Wutaiian
Archean	Fuping			Fupingian

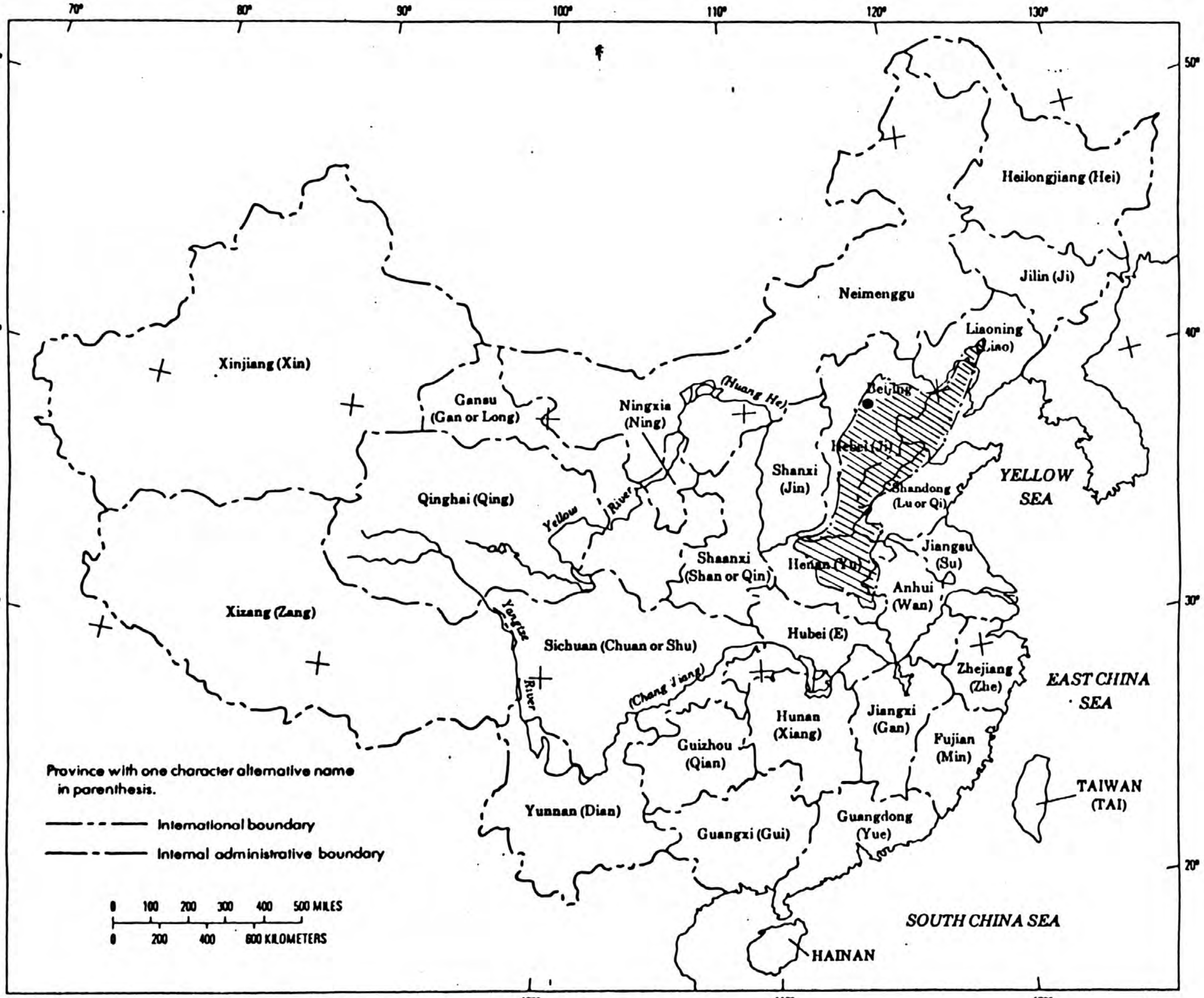


Figure 1. Index map of China showing the location of study area.

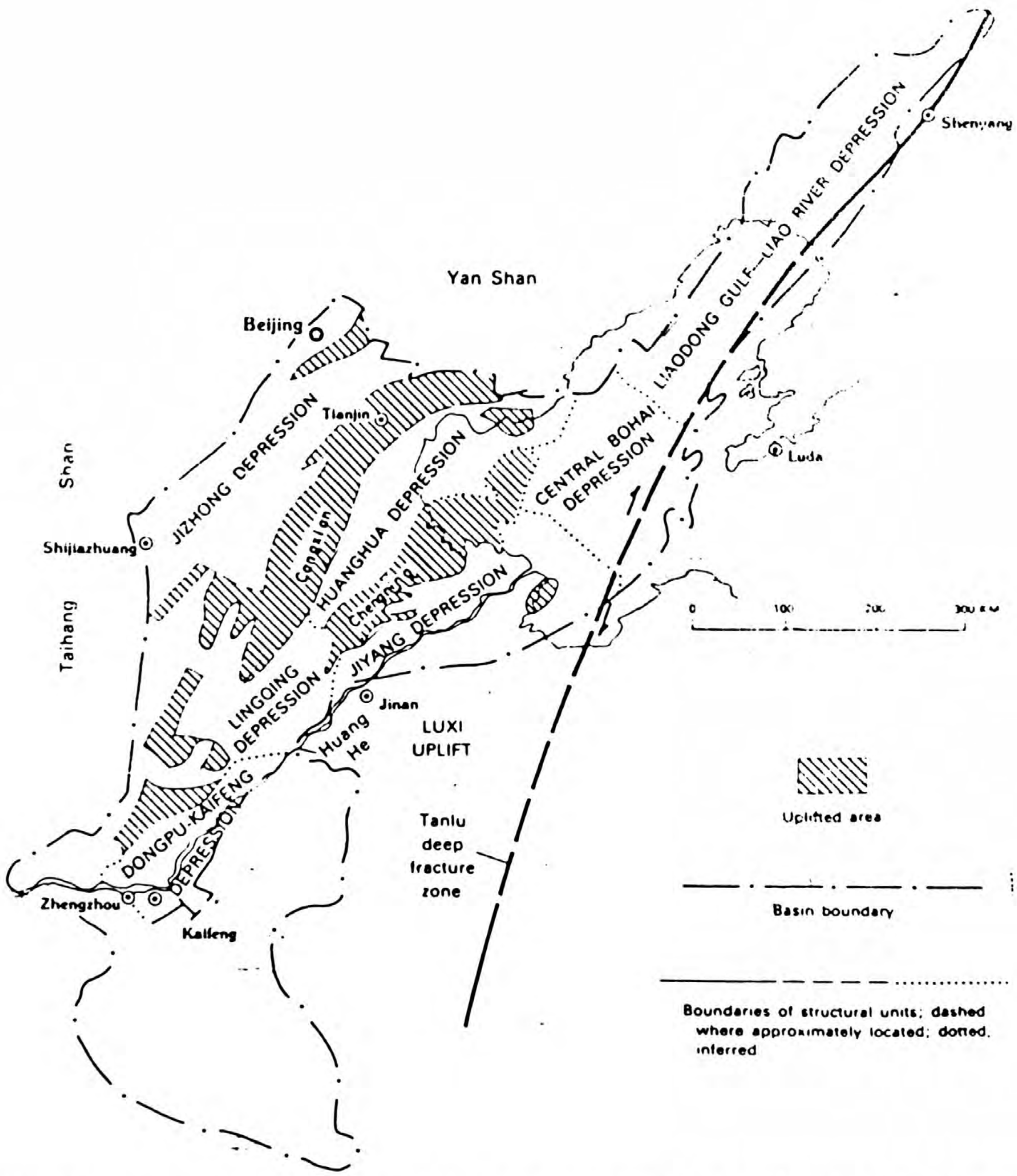


Figure 2. Principal depressions in the North China basin, Eastern China (after Wang and others, 1983; Figure 4-9-15, p. 254).

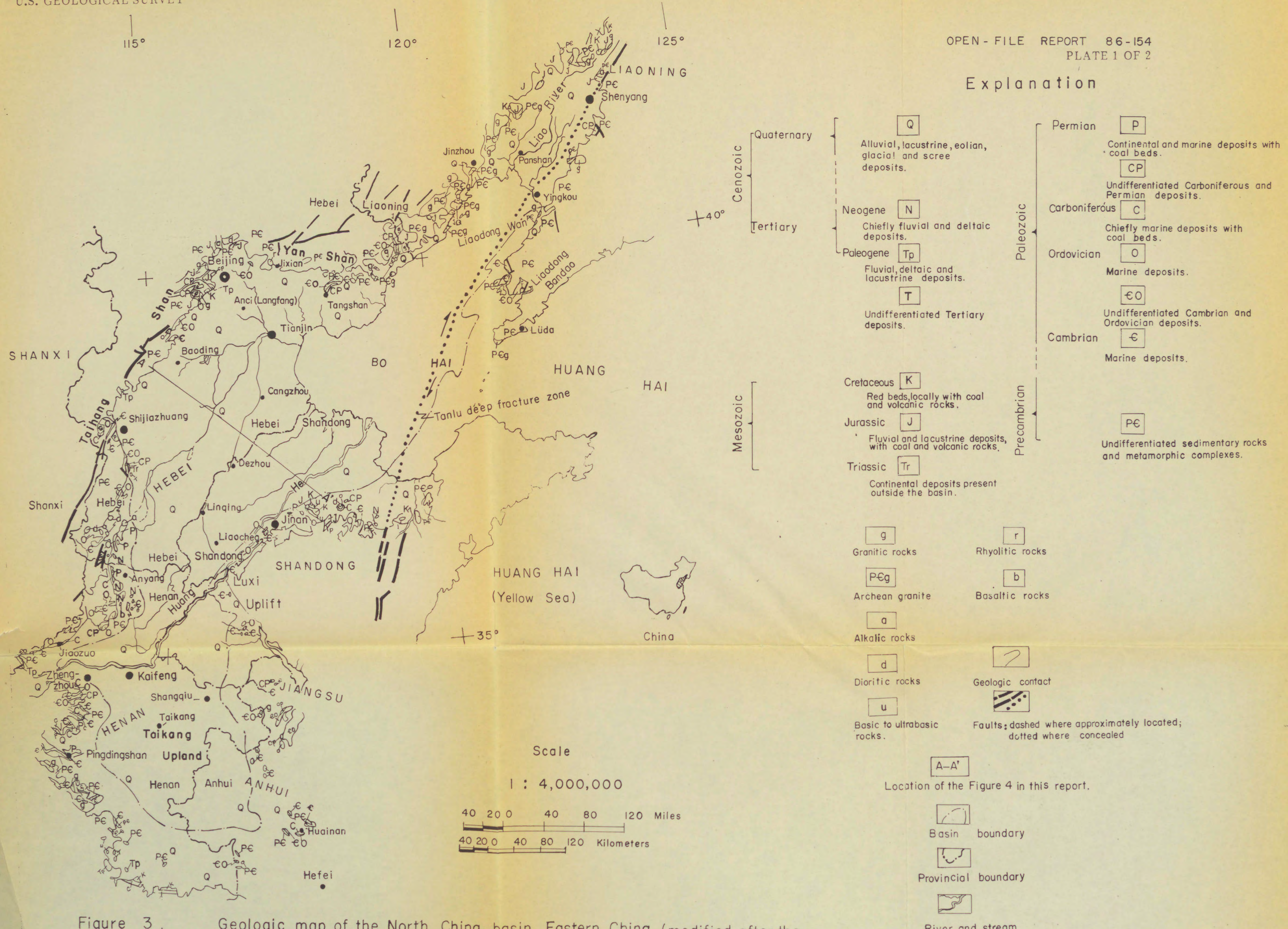


Figure 3. Geologic map of the North China basin, Eastern China (modified after the Chinese Academy of Geological Sciences, 1976, Geologic Map of the People's Republic of China; 1 : 4,000,000)

The Precambrian crystalline basement of the North China basin is one of most stabilized cratonic units of China and contains Archean and Early Proterozoic rocks. Consolidation of the basement occurred at the end of Early Proterozoic time about 1,850 Ma ago (Wang and Qiao, 1984; Ma, Zhang, Bai, and Suo, 1984). Drilling records indicate that Upper Proterozoic platform sedimentary rocks of the Changcheng through Sinian systems attain a maximum thickness in the Jizhong depression (table 2). Generally, the remaining depressions contain thin Upper Proterozoic strata, except the Jiyang depression where Upper Proterozoic rocks are missing (Hao and Zhang, 1984). These Precambrian rocks are unconformably overlain by marine Cambrian and Ordovician carbonate sequences, marine and continental Carboniferous and Permian coal-bearing sequences, continental Jurassic and Cretaceous coal-bearing sequences, and locally by Jurassic and Cretaceous volcanic rocks. Throughout the basin, these Paleozoic and Mesozoic rocks are unconformably overlain by thick Tertiary strata.

From the beginning of Late Ordovician to the end of Early Carboniferous, North China basin was part of an ancient emergent landmass and experienced intense weathering and erosion. As the basin subsided in Late Carboniferous and continued into Early Permian, the site of the present day basin was covered by shallow marine and shoreline deposits. During Late Triassic time, the North China basin acquired its initial depositional framework by a northeast-trending rift system, accompanied by local calc-alkaline and granitic intrusions, the presence of northeast-trending Late Triassic Taihung Shan faulted highland on the west, and the rejuvenated pre-Mesozoic Taulu deep fracture zone on the east. The basin finally acquired its present day individuality by intense rifting in Late Cretaceous to early Tertiary time. It received thick syntectonic deposits containing petroleum source rocks (Ma, Liu, and Su, 1984).

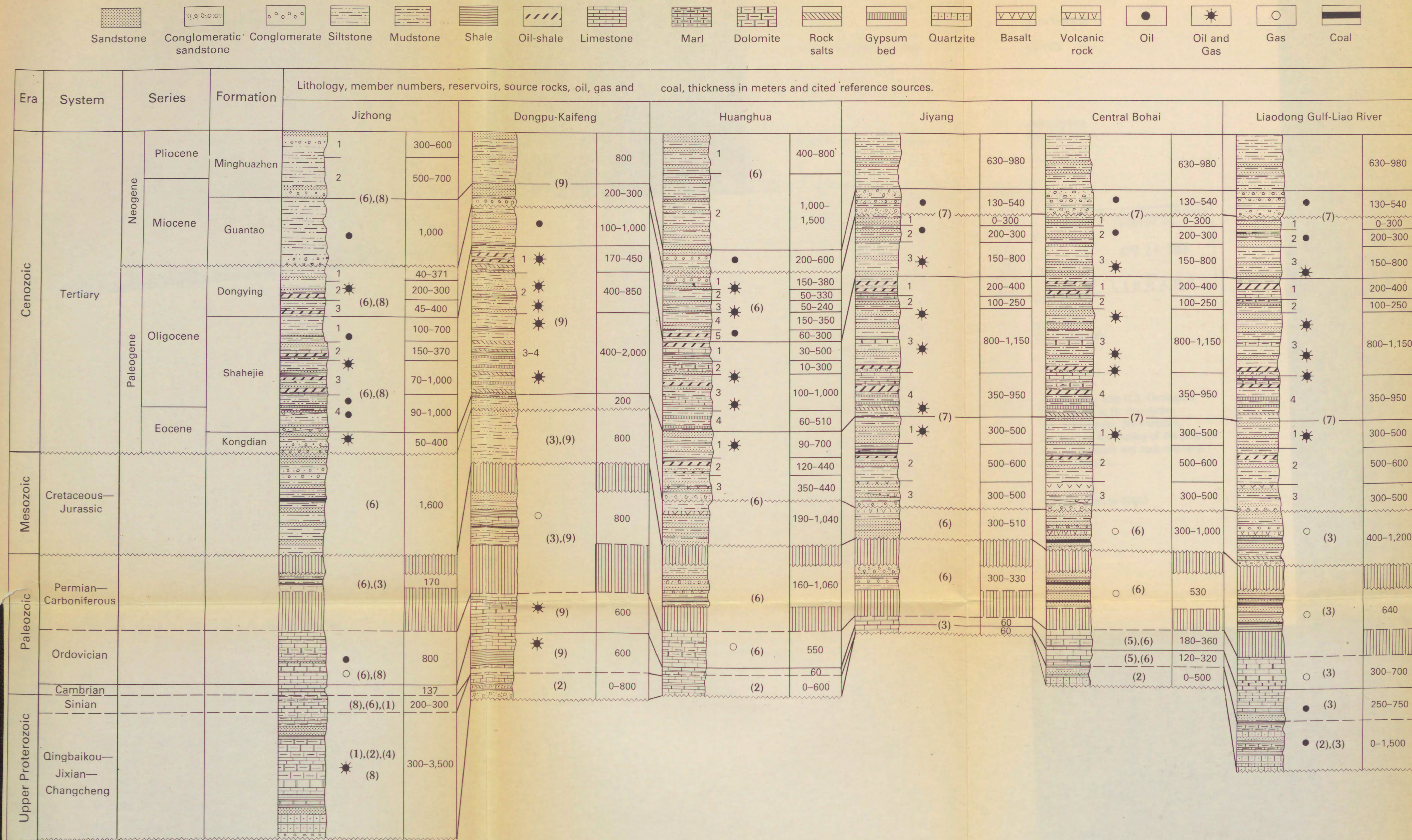
STRATIGRAPHY

The stratigraphy of the North China basin is based chiefly on drilling records. A summary of the stratigraphy of the basin, except for Quaternary deposits, is shown in table 2. Quaternary deposits about 175 to 727 m thick and extensively disconformable cover the bedrock throughout the basin (Regional Stratigraphic Editorial Section of the Hebei Province and the Tianjin Region, 1979, v. 2). A stratigraphic description of this topic herein consists of pre-Tertiary and Tertiary sequences.

Pre-Tertiary

The pre-Tertiary stratigraphic sequences consists of metamorphic and sedimentary rocks of the Precambrian through the Mesozoic age. A concise description of these rocks is given as well as shown in table 2, except for the Precambrian crytalline basement rocks.

The Precambrian crystalline basement rocks of the basin consist of Archaean gneissic granite, granulite, amphibolite and gneiss, and Early Proterozoic greenschist, quartzite, phyllite, slate, dolomitic marble, marble, quartz keratophyre, and metamorphosed conglomerate and basic volcanics (Ma, Zhang, Bai, and Suo, 1984, p. 225-236; Wang and Qiao, 1984, p. 600-601). This le 2. Bedrock Stratigraphy in the Principal Depressions of the North China Basin, Eastern China



(1) Chinese Academy of Geological Sciences, 1982, An Outline of the Stratigraphy in China: Beijing, China, Geological Publishing House, Stratigraphy of China, v. 1, 445 p. (in Chinese with English abstract).

(2) Hao Shihsheng and Zhang Changgen, 1984, The Primary Hydrocarbon Characteristics of the Middle–Upper Proterozoic in the Northern Part of North China: Beijing Petroleum Symposium, September 1984. Reprint, 31 p.

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

(4) Pei Qi and Wang Xiepei, 1984, Significant Role of Structural Fractures in Renqin buried-hill Oil Field in Eastern China: American Association of Petroleum Geologists Bulletin, v. 68, n. 8; p. 971–982.

(5) Regional Stratigraphic Editorial Section of the Hebei Province and Tianjin Region, 1979, [Stratigraphy of the Hebei Sheng and Tianjin Shi]: Beijing, China, Geological Publishing House, [Regional Stratigraphic Tables of the North China], v. 1, 312 p. (in Chinese).

(6) Regional Stratigraphic Editorial Section of the Hebei Province and Tianjin Region, 1979, [Stratigraphy of the Hebei Sheng and Tianjin Shi]: Beijing, China, Geological Publishing House, [Regional Stratigraphic Tables of the North China], v. 2, 228 p. (in Chinese).

(7) Scientific Research Institute of Petroleum Exploration and Development, Ministry of Petroleum Industry and Institute of Geology and Palentology, Academia Sinica, 1978, Early Tertiary Gastropod Fossils from Coastal Region of Bohai: Beijing, China, Science Press, 33 pls., 157 p. (in Chinese with English Summary).

(8) Zha Quanheng, 1984, Jizhong Depression, China—Its Geologic Framework, Evolutionary History, and Distribution of Hydrocarbon: American Association of Petroleum Geologists Bulletin, v. 68, n. 8, p. 983–992.

(9) Zhongyuan Petroleum Exploration Bureau, 1980, [Structural Outline Map of the Dongpu Depression]; 1:200,000; one sheet with composite columnar stratigraphic section, 1:10,000 (in Chinese).

Mesozoic strata of the basin are represented by undifferentiated Jurassic to Cretaceous continental sequences. In the lower part of the sequences, the continental strata consist of light-brown, grayish-green, dark-purplish-red, and sandy mudstone and purplish-red, grayish-green sandstone, locally intercalated with coal beds in the Huanghua and Central Bohai depressions and with oil shale in the Liaodong Gulf-Liao River depression. The middle part of the sequences consists of light-gray, grayish-green sandstone, dark-purple, grayish-green and brown mudstone, and dark-gray to black shale intercalated with coal beds and volcanic rocks in the Jizhong, Central Bohai, and Liaodong Gulf-Liao River depressions. The upper part of the sequences consists of purplish-red to brownish-red sandstone, conglomeratic sandstone, and blackish-gray to dark-purple mudstone intercalated with volcanic rocks in the Huanghua and Jiyang depressions. Plant fossils are abundant. The thickness of the Mesozoic unit ranges from 190 to 1,600 m in the principal depressions (table 2).

Tertiary

Tertiary strata of the basin have been studied in detail by extensive seismic work and exploratory drilling during the past decade. In ascending order, the Tertiary sequences consist of the Eocene Kongdian Formation, the Eocene-Oligocene Shahejie Formation, the Oligocene Dongying Formation, the Miocene Guantao Formation, and the Miocene-Pliocene Minghuazhen Formation (table 2). A lithologic description of those stratigraphic units within individual principal depressions is given under the Paleogene and Neogene, respectively.

Paleogene

The Kongdian Formation unconformably overlies the Jurassic to Cretaceous strata throughout the basin (table 2). In the Jizhong and Dongpu-Kaifeng depressions, this formation is undivided and consists chiefly of fluvial and shallow lake deposits of light-brown, dark-red, dark-brown and black mudstone and sandstone. Conglomeratic sandstone is found locally in the Jizhong depression. In the remaining depressions, the Kongdian Formation is divided, in ascending order, into the third, second, and first members (table 2). In the Huanghua depression, the third member is composed of 350 to 440 m of brown, reddish-brown and sandy mudstone, basaltic flows, and a basal conglomeratic sandstone which grades upward into grayish-brown to reddish-brown mudstone, siltstone, and sandy mudstone. Approximately 300 to 500 m of red sandstone, mudstone, and basal conglomeratic sandstone interbedded with basaltic flows represent the third member in the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions (table 2). The second member of the Kongdian Formation consists of 120 to 440 m of dark-gray to dark-grayish-green shale intercalated with grayish-gray shale, oil shale, and thin-bedded sandstone in the Huanghua depression; and of about 500 to 600 m of gray mudstone and sandstone intercalated with carbonaceous shale, oil shale, and thin coal beds in the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions (table 2). Fresh water gastropods are found in the second member of the formation throughout the depression. The youngest member of the Kongdian Formation in the Huanghua depression is made up of 90 to 700 m of dark-purple to reddish, feldspathic sandstone and mudstone intercalated with grayish-green sandy shale in the upper part, and local beds of conglomeratic sandstone with basalt and gypsum-bearing mudstone. About 300 to 500 m of red sandstone and mudstone form the first member of the Kongdian Formation in the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions (table 2).

The Shahejie Formation consists chiefly of shallow- to deep-lake deposits and, in ascending order, is divided into the fourth, third, second, and first members (table 2). In the Jizhong depression, the fourth member comprises 90 to 1,000 m of light-gray to dark-gray mudstone intercalated with basaltic flows, light-gray to gray sandstone, and conglomeratic sandstone grading upward into gray to dark-gray mudstone, and white gypsum beds intercalated with gray, thin-bedded siltstone and purplish-red mudstone. In the Dongpu-Kaifeng depression, the fourth and third members are undifferentiated (table 2) and consist of 400 to 2,000 m of gray to dark-gray and purplish-red mudstone and siltstone intercalated with salt beds, gypsum beds, and shale. In the Huanghua depression, the fourth member of the Shahejie comprises 60 to 510 m of bluish-gray, dark-gray gypsum beds and grayish-green mudstone intercalated with siltstone and local sandstone. In the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions, the fourth member of the Shahejie Formation generally consists, in the lower part, of 150 to 500 m of red mudstone; in the middle part, of 100 to 300 m of bluish-gray mudstone intercalated with gypsum beds and salt beds; and in the upper part, of 100 to 150 m of gray mudstone intercalated with reef limestone, dolomite, and oil shale (table 2) (Scientific Research Institute of Petroleum Exploration and Development, Ministry of Petroleum Industry; Institute of Geology and Paleontology, Academia Sinica, 1978, fig. 2).

In the Jizhong depression, the third member of the Shahejie is made up of 70 to 1,000 m of gray to dark-gray mudstone, gray fine-grained sandstone, black oil shale, light-brown dolomitic limestone, and dolomite grading upward into gray to dark-gray mudstone intercalated with sandy mudstone, light-gray thin-bedded sandstone and black oil shale. Plant fossils and conodonts are abundant. In the Huanghua depression, the third member of the Shahejie comprises 100 to 1,000 m of dark-gray, black mudstone intercalated with oil shale, sandstone, shale, gray limestone, marl, and reef-limestone. The third member of the Shahejie in the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions, consists, in the lower part, of 100 to 150 m of gray mudstone intercalated with sandstone and oil shale as well as with basal conglomeratic sandstone; in the middle part of 400 to 600 m of gray to dark-gray mudstone intercalated with siltstone, sandstone, and dolomite; and in the upper part, of 300 to 400 m of gray, fossiliferous mudstone intercalated with sandstone (Scientific Research Institute of Petroleum Exploration and Development, Ministry of Petroleum Industry, and Institute of Geology and Paleontology, Academia Sinica, 1978, fig. 2) (table 2).

The second member of the Shahejie in the Jizhong depression consists chiefly of 150 to 370 m of light-gray, calcareous, thin- to thick-bedded sandstone intercalated with purplish-brown, reddish-brown and grayish-green mudstone. In the northern part of the Jizhong, the lower part of the second member is represented locally by thin-bedded shale, oil shale, dark-gray reef-limestone, dolomitic limestone and marl, which laterally grade into light-gray sandstone and reddish-purple mudstone. In the Dongpu-Kaifeng depression, the second member of the Shahejie comprises 400 to 850 m of light-gray to gray, calcareous sandstone and reddish-brown, dark-purple mudstone intercalated with gray limestone and gypsum-bearing mudstone. In the Huanghua depression, the second member of the Shahejie is made up of 10 to 300 m of gray to dark-gray fossiliferous dolomite and purplish-red mudstone, laterally grading into calcareous siltstone and lenticular sandstone with basal conglomeratic sandstone locally. In the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions, the second member of the Shahejie consists of 100 to 250 m of variegated sandstone and siltstone intercalated with carbonaceous shale and dolomite (table 2). Gastropods are abundant throughout the basin.

The first member of the Shahejie in the Jizhong depression consists of 100 to 700 m of reddish-brown to brown mudstone intercalated with grayish-green, purplish-gray mudstone and light-gray, thin-bedded sandstone. In the Dongpu-Kaifeng depression, the first member of the Shahejie comprises, in the lower part, 170 to 450 m of mudstone intercalated with salt beds; and in the upper part, mudstone intercalated with oil shale, reef-limestone, and siltstone. In the Huanghua depression, the first member of the Shahejie is made up of 30 to 500 m of dark-gray to gray, calcareous oil shale, shale, gray limestone, and reef-limestone intercalated with grayish-green mudstone and locally with calcareous sandstone. In the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions, the first member of the Shahejie is composed of 200 to 400 m of gray mudstone intercalated with oil shale and limestone containing abundant gastropods and ostracods.

The Dongying Formation consists of shallow-lake, deltaic and fluvial deposits, which throughout the basin are unconformably overlain by the Miocene Guantao Formation. Generally the Dongying is divided, in ascending order, into the third, second, and first members in the Jizhong, Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions. The Dongying in the Dongpu-Kaifeng depression is undivided, and in the Huanghua depression, the Dongying is divided into five members (table 2).

In the Dongpu-Kaifeng depression, the Dongying Formation consists of 100 to 1,000 m of red siltstone, sandstone, and mudstone intercalated with dark, carbonaceous mudstone in the lower part. In the Huanghua depression, the fifth member of the Dongying is composed of 60 to 300 m of dark-gray, black mudstone intercalated with grayish-green oil shale; the fourth member, of 150 to 350 m of gray, dark-gray mudstone intercalated with light-gray, gray sandstone; the third member, of 50 to 240 m of light-gray, grayish-green sandstone intercalated with gray, dark-gray, grayish-green, sandy mudstone; the second member, of 50 to 330 m of gray, dark-gray mudstone intercalated with light-gray, grayish-green siltstone and some very fine-grained sandstone; and the first member, of 150 to 380 m of light-gray, grayish-green and fine- to medium-grained sandstone intercalated with conglomeratic sandstone and mudstone (table 2). This unit contains abundant fossils of fish, plants, ostracods, gastropods, pollen, and spores.

In the Jizhong depression, the third member of the Dongying consists of 45 to 400 m of reddish-brown to brown mudstone intercalated with gray, reddish-brown and thin-bedded sandstone, calcareous shale and oil shale. In the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions, the third member of the Dongying comprises 150 to 800 m of gray to dark-gray, carbonaceous mudstone intercalated with variegated sandstone. The second member of the Dongying in the Jizhong depression is made up of 200 to 300 m of gray, reddish-brown and greenish-gray mudstone intercalated with grayish-brown, brown and light-gray sandstone, black shale, and brownish-gray oil shale. In the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions, the second member of the Dongying consists of 200 to 300 m of variegated mudstone intercalated with gray, fine- to coarse-grained sandstone with abundant gastropods. The first member of the Dongying in the Jizhong depression comprises 40 to 371 m of reddish-purple, reddish-brown and purple mudstone intercalated with gray, grayish-green, grayish-brown and purplish-gray mudstone and light-gray, thin-bedded sandstone with abundant fossil fauna. In the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions, the first member of the Dongying is made up of 0 to 300 m of red mudstone intercalated with gray sandstone containing abundant gastropods and charophytes.

Neogene

The Guantao Formation is represented chiefly by fluvial and deltaic sequences that are distributed throughout the principal depressions of the basin (table 2). The Guantao is present in the western part of the Jizhong depression where it consists of 1,000 m of brown to reddish-brown mudstone, light-gray, grayish-green, light-yellow, and very fine- to medium-grained sandstone intercalated with gray, grayish-green, brown, purplish-gray, and thin-bedded mudstone and a light-gray, medium- to coarse-grained basal sandstone and conglomeratic sandstone. Pollen, spores, and plant fossils are abundant. In the Dongpu-Kaifeng depression, the Guantao is made up of 200 to 300 m of light-gray sandstone intercalated with mudstone and a basal conglomeratic sandstone. In the Huanghua depression, the Guantao consists, in the lower part, of light-gray, thick-bedded sandstone intercalated with grayish-green, thin-bedded mudstone and siltstone with abundant ostracods and fossil plants; in the middle part, of light-grayish-green siltstone intercalated with cross-bedded conglomeratic sandstone and grayish-green mudstone; and in the upper part, of light-gray, grayish-green, cross-bedded sandstone. The thickness of this unit ranges from 200 to 600 m. In the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions, the lithologic description of the Guantao is based on subsurface drilling data in the Jiyang depression and the Chengning area of the Hebei province (Regional Stratigraphic Editorial Section of the Hebei Province and Tianjin Region, 1979, v. 2, p. 153). As stated, the Guantao consists, in the lower part, of light-gray, coarse-grained sandstone intercalated with conglomeratic sandstone and grayish-green, reddish-purple mudstone; and in the upper part, of light-gray conglomeratic sandstone intercalated with grayish-green, thin-bedded, sandy mudstone and clayey siltstone. Thickness of this unit ranges from 130 to 540 m.

The Minghuazhen Formation conformably overlies the Guantao Formation throughout the basin (table 2) and is represented by fluvial and deltaic deposits. In the Jizhong depression, the Minghuazhen is divided, in ascending order, into the second and first members. The second member in this depression is made up of 500 to 700 m of light-reddish-brown to yellowish-brown mudstone intercalated with grayish-green, light-gray, grayish-yellow and thin-bedded mudstone, fine- to coarse-grained sandstone, and conglomeratic sandstone. The first member consists of 300 to 600 m of variegated very fine- to medium-grained conglomeratic sandstone intercalated with light-gray, grayish-yellow, medium- to coarse-grained sandstone and mudstone. In the Dongpu-Kaifeng depression, the Minghuazhen is undivided and comprises about 800 m of brownish-yellow, grayish-green siltstone and mudstone intercalated with sandstone. In the Huanghua depression, the Minghuazhen Formation is divided, in ascending order, into the second and first members. The second member is made up of 1,000 to 1,500 m of reddish-brown to grayish-green, thick-bedded mudstone intercalated with light-gray, grayish-green, cross-bedded, fine-grained sandstone. The first member comprises 400 to 800 m of gray, grayish-green sandstone intercalated with conglomeratic sandstone, grayish-green, reddish-brown, reddish-purple, and sandy mudstone, and thin-bedded siltstone. In the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions, the lithology of the Minghuazhen is described on the basis of subsurface data from the Chengning area to the west of the Jiyang depression. As stated, the Minghuazhen is undivided and generally consists of 630 to 980 m of variegated mudstone, siltstone, and sandstone grading upward into grayish-green, yellowish-brown mudstone and siltstone intercalated with fine-grained sandstone bearing calcite and iron-manganese concretions.

STRUCTURE AND EVOLUTION OF THE BASIN

Since the consolidation of the Archean and Early Proterozoic crystalline basement during the Zhongtiaoian (Lulianqian) orogeny (table 1) (Yang, Cheng, and Wang, 1986; table 20-1, p. 257), the present-day North China basin was tectonically relatively stable, and an east-west trending fracture system was prominent in the region. From Late Proterozoic to Late Paleozoic, the Archean and Early Proterozoic basement of the basin was affected chiefly by epeirogenic movements in association with the sedimentation of littoral to neritic marine and continental platform carbonate and detrital sedimentary sequences of the Late Proterozoic, Cambrian to Middle Ordovician, and Late Carboniferous to Permian ages. From the beginning of Late Ordovician to the end of Early Carboniferous, the platform sedimentary cover was subjected to a lengthy period of extensive weathering and erosion. The Caledonian orogeny and the early phases of the Variscan orogeny had little effect on the landmass of the present-day North China basin. From Late Carboniferous to Early Permian, moderate subsidence of the basin with sea transgression produced littoral marine coal-bearing sedimentary sequences. As sea regression proceeded in Late Permian, the area of the present-day basin was gradually uplifted, and deposition of a series of continental coal-bearing sedimentary sequences was widespread in the lowland areas (Han and Yang, 1980, p. 92-152).

During the Late Triassic Indosinian orogeny, the North China basin acquired its incipient depositional framework by a series of taphrogenic events throughout the basin. The regional fracture system in the early stage of basin development trended northeast, north-northeast, and northwest. The author believes that during the Late Triassic Indosinian extensional tectonics, the Taihang Shan highland on the west was formed, and the Tanlu deep fracture zone on the east was rejuvenated under an early compression shear, followed by extensional as well as compressing shear stresses. Both of these fracture zones have a north-northeast trend. The northwest fracture system in the basin was formed synkinematically by tensile stresses applied in a northwest-southeast oriented stress field. From Late Jurassic to Early

Cretaceous time, the northeast, north-northeast fracture systems, and to some extent the northwest fracture system, were enlarged by extensional tectonics. The taphrogenic activities were accompanied by acidic intrusives, calc-alkaline lava flows, and fault-blocks throughout the North China basin. Generally, the north-northeast fracture system was active during detrital sedimentation of Jurassic and Cretaceous age and controlled the structural development of the individual depressions of the North China basin during the Cenozoic. During the late part of the the Yanshanian orogeny, from Late Cretaceous to early Paleogene time, these fault blocks were uplifted, intensely broken, and subsided as part of a regional downwarp. Throughout the basin, the Late Cretaceous and Paleocene sequences are generally missing, and the outcrops in the basin underwent a rather long period of weathering and denudation (table 2).

During the Cenozoic, the North China basin underwent more intense extensional faulting and differential movement of the fault blocks, followed by regional downwarping. These structural features are well documented in publications by Ma, Deng, Wang, and Liu (1982); Ma and others (1983); Ding (1984); Deng and others (1984); Fei and Wang (1984); Li (1982, 1984); Li and Xue (1983); Liu and others (1981), Zha (1984); and Hellinger and others (1985). The basic tectonic data and interpretations provided by these publications contributed significantly to this report.

Many Chinese geologists recognize that Mesozoic tectonic patterns have controlled the structural development of the basin during Cenozoic time. In the early phase of the Himalayan orogeny from late Eocene to early Oligocene time, an extensive block-faulting system of grabens and horsts in the central portion of the North China basin occurred (fig. 4). Subsequently, this graben and horst system was enlarged along the general trend of the rejuvenated north-northeast and northeast fracture systems. Ma, Deng, Wang, and Liu (1982, p. 105) suggested that the characteristic Paleogene structures of the basin are the fault blocks which have been tilted along downward-flattening growth listric normal faults. In the basin, half-grabens are prominent; full-grabens, although present, are asymmetrical in profile because of the different amounts of dip separation on their bounding faults. Paleogene syntectonic deposits of the fluvio-lacustrine and fluvio-deltaic environments reached a maximum thickness of about 4,541 m in the Jizhong depression, 4,500 m in the Dongpu-Kaifeng depression, 5,490 m in the Huanghua depression, and about 5,750 m in the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions (table 2). Tholeiitic basaltic flows accompanied the Paleogene sedimentation throughout the basin, reaching a cumulative thickness of 550 m in the lower Liao He River and the Central Bohai (Ma, Deng, Wang, and Liu, 1982, p. 105). The northwest-trending fault system in the basin is in oblique direction to the north-northeast graben trend and locally shows a transversal structure, which offsets the graben system. The end of the early phase of the Himalayan orogeny is indicated by a basin-wide angular unconformity between the Oligocene and Miocene strata (table 2).

During the Neogene, the North China basin acquired its present configuration by regional basin-wide subsidence, which in general followed the tectonic grain of the Paleogene rift system. The Neogene sedimentary cover has much wider coverage than the Paleogene strata and reaches a maximum thickness of 2,300 m in the Jizhong depression, 1,100 m in the Dongpu-Kaifeng depression,

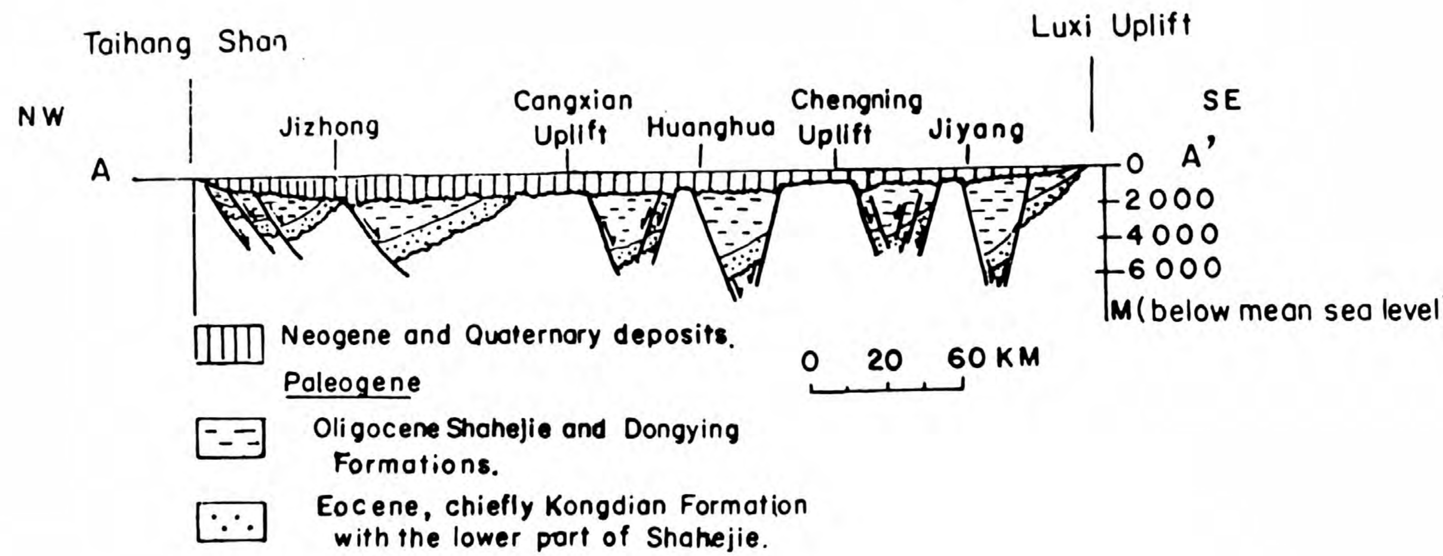


Figure 4. Cross section across the central part of the North China basin (modified after Ma and others, 1982; Figure 3, p. 106).

600 m in the Huanghua depression, and about 980 m in the Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions (table 2).

Geophysical data indicate that the North China basin, specially in the Bohai region, is underlain by a relatively warm and highly attenuated crust and lithosphere (Ma, Liu, and Su, 1984, p. 619-620) (figs. 5, 6, and 7). Hellinger and others (1985) concluded that the Cenozoic depocenters in the basin coincided with the areas of thin pre-Cenozoic crust. In contrast, Quaternary subsidence appears to have been greatest where the present thickness of the pre-Cenozoic crust is greatest. Hellinger and others (1985, p. 356) further stated that the present crustal structure, geologic history, and Cenozoic sediment-fill of the basin suggest a nearly constant crustal thickness of about 40 km at the onset of rifting in the middle Eocene. Ma, Liu, and Su (1984, p. 619) suggest that an electrically conductive low-velocity layer underlies the basin at a depth of 15 to 20 km. This layer may represent a transition zone between the brittle and ductile deformation into which extensional brittle normal faulting may be assimilated in this zone. The foci of shallow earthquakes lie above this low rigid layer, but the underlying viscoelastic lower crust deforms slowly by lateral creep during inhomogeneous mantle upwelling. Ma, Liu, and Su (1984, p. 620) further mentioned that during the basin evolution a fundamental control of extensional structures is the process of upward advection of the astheno-sphere up to a depth of 50 to 80 km.

PETROLEUM AND COAL DEPOSITS

Petroleum and coal are the most important energy resources in the North China basin. After a systematic search in the lower reaches of the Huang He in the late 1950's to early 1960's, petroleum was discovered in Tertiary strata of the Zhanhua sag in the Jiyang depression in 1961 (figs. 2 and 3), and production began in 1962 (Zhai and Zha, 1982; Meyerhoff, 1982, p. 260-261). Since then, extensive onshore drilling has led to the discovery of numerous commercially producing oil and gas wells in the Jiyang, Huanghua, Jizhong, Dongpu-Kaifeng, and Liaodong Gulf-Liao River depressions (fig. 2). Offshore exploration began in the late 1960's with the participation of the Japan-China Oil Development Corporation (Optr). The Haisi field from the Minghuazhen Formation was discovered in the Bohai Wan west of the Central Bohai depression in 1970 (Petroconsultants LTD, 1981). The same company has made several new discoveries of commercial oil and gas wells in the Central Bohai depression during the period from 1981 to 1984 (Petroconsultants LTD, 1984).

Deposits of high quality bituminous and anthracite coal of Permian and Carboniferous ages and bituminous coal of Cretaceous and Jurassic ages have been recorded in the basin. Commercial underground coal mines are actively operated near the border of the basin, chiefly in the Hebei, Shandong, and Henan Provinces.

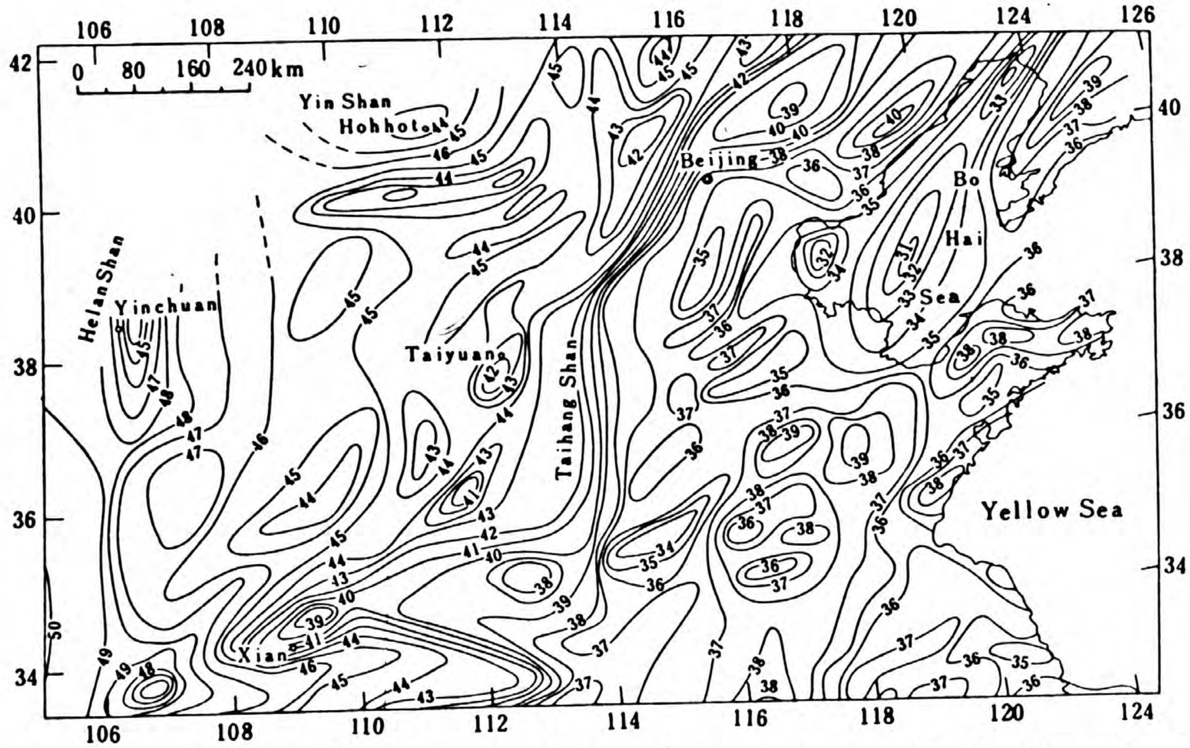


Figure 5. Isopachs in kilometers, of the earth's crust in the North China basin and adjacent areas (after Ma, Deng, Wang, and Liu, 1982; Figure 7, p. 112).

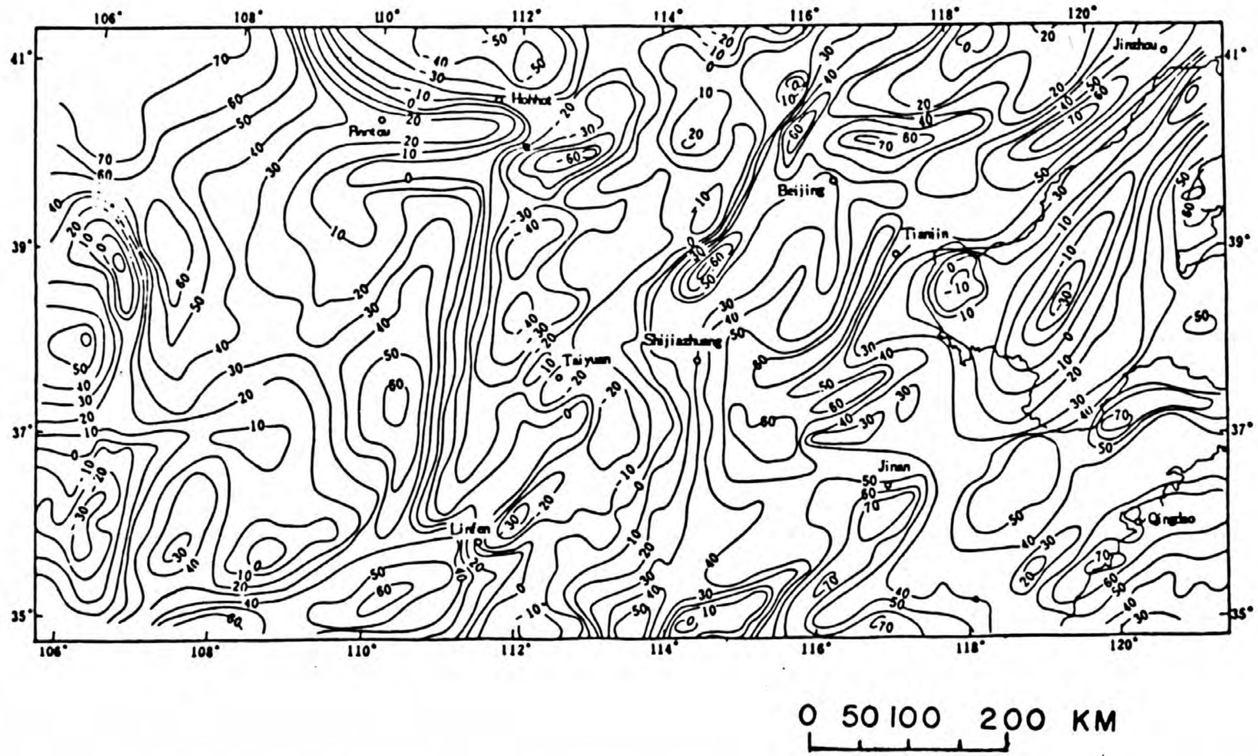


Figure 6. Distribution of anomalous root gravities in the North China basin and adjacent areas (after Deng and others, 1984; Figure 8, p. 257).

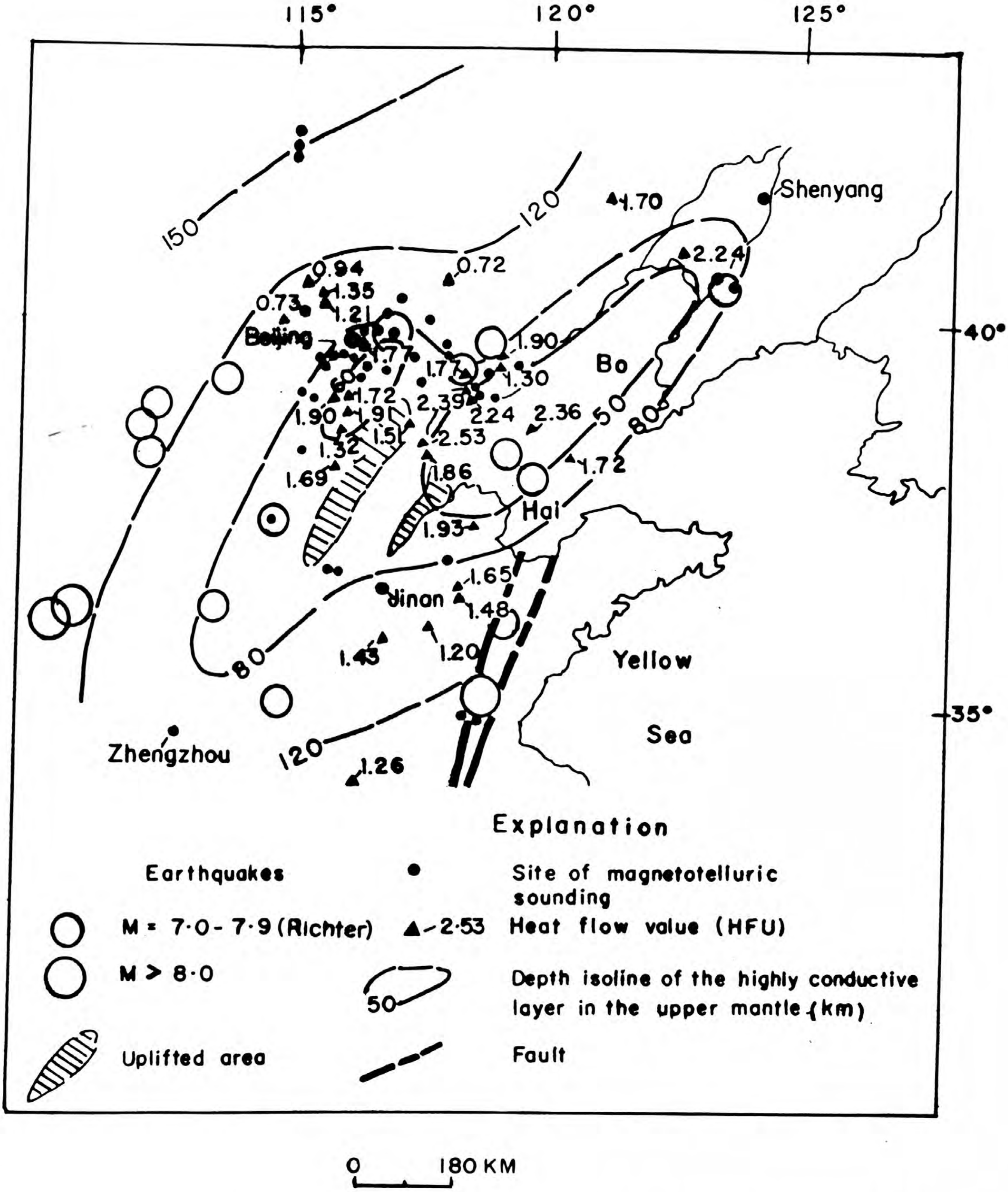


Figure 7. Depth isolines to the asthenosphere in the North China basin and adjacent areas (after Ma and others, 1984; Figure 9, p. 618).

Petroleum

General Statement

The petroleum deposits in the North China basin are concentrated in the Jizhong, Dongpu-Kaifeng, Huanghua, Jiyang, Central Bohai, and Liaodong Gulf-Liao River depressions (table 2) (fig. 2). Most of the oil and gas production from the reservoirs of various types of trap in the basin has been generated from the source rocks of the Tertiary sedimentary sequences (Masters and others, 1980). In addition, gas accumulation has been reported from Cretaceous and Jurassic strata in the Central Bohai and the Liaodong Gulf-Liao River depressions, and from the Permian and Carboniferous strata in the Dongpu-Kaifeng depression. Late Proterozoic (Jixian) oil and gas deposits have been reported in the northern part of the Jizhong depression. The following discussion gives details of the source, reservoir, seal, and trap within each principal depression.

Jizhong Depression

For the past decade, the Jizhong depression has been one of the most extensively explored areas in the North China basin. The depression is a half-graben structure. The depression is bounded by the Taihang Shan on the west, the Cangxian uplifted block on the east, the Yan Shan on the north, and uplifted fault blocks on the south (figs. 2 and 8) and covers an area about 25,000 km^2 (Zha, 1984, p. 983). The sedimentary cover of the Jizhong depression ranges in thickness from 2,000 to about 13,000 m, of which about 7,000 m consists of Tertiary strata. In the Tertiary sequence the Paleogene beds reach a thickness of about 4,500 m (table 2). However, in the northern part of the depression, Li and others (1984, p. 9) reported that the Tertiary sequences reach a maximum thickness of about 10,000 m.

Source rocks

In the Jizhong depression, principal source rocks for petroleum deposits are confined to continental saline lake deposits of mudstone, shale, and oil shale of the Paleogene Shahejie and Dongying Formations. Secondary source rocks in the basin consist of the continental Cretaceous and Jurassic coal-bearing series, the continental and marine Permian and Carboniferous coal-bearing series, and the marine Lower Paleozoic and Upper Proterozoic carbonate rocks, shale, and mudstone (table 2).

The Shahejie Formation contains the most favorable strata for generating oil and gas deposits throughout the North China basin. In the Jizhong, the third member of the Shahejie contains the best quality source rocks in the depression. The second best source rocks are confined in the sequences of the second, first, and fourth members of the Shahejie, as well as the second member of the Donging Formation. The source beds are generally concentrated in the Bieguzhuang-Guxinzhuang area of the northern part of the depression, the Renqiu area of the central part of the depression, and the Jingqiu area of the southern part of the depression (fig. 8). Zha (1984, p. 988) estimated that the maximum thickness of the Paleogene source beds was more than 1,000 m in the central part of the Jizhong. Generally in the Jizhong, the thickest and most favorable source beds were deposited along the downthrown side of

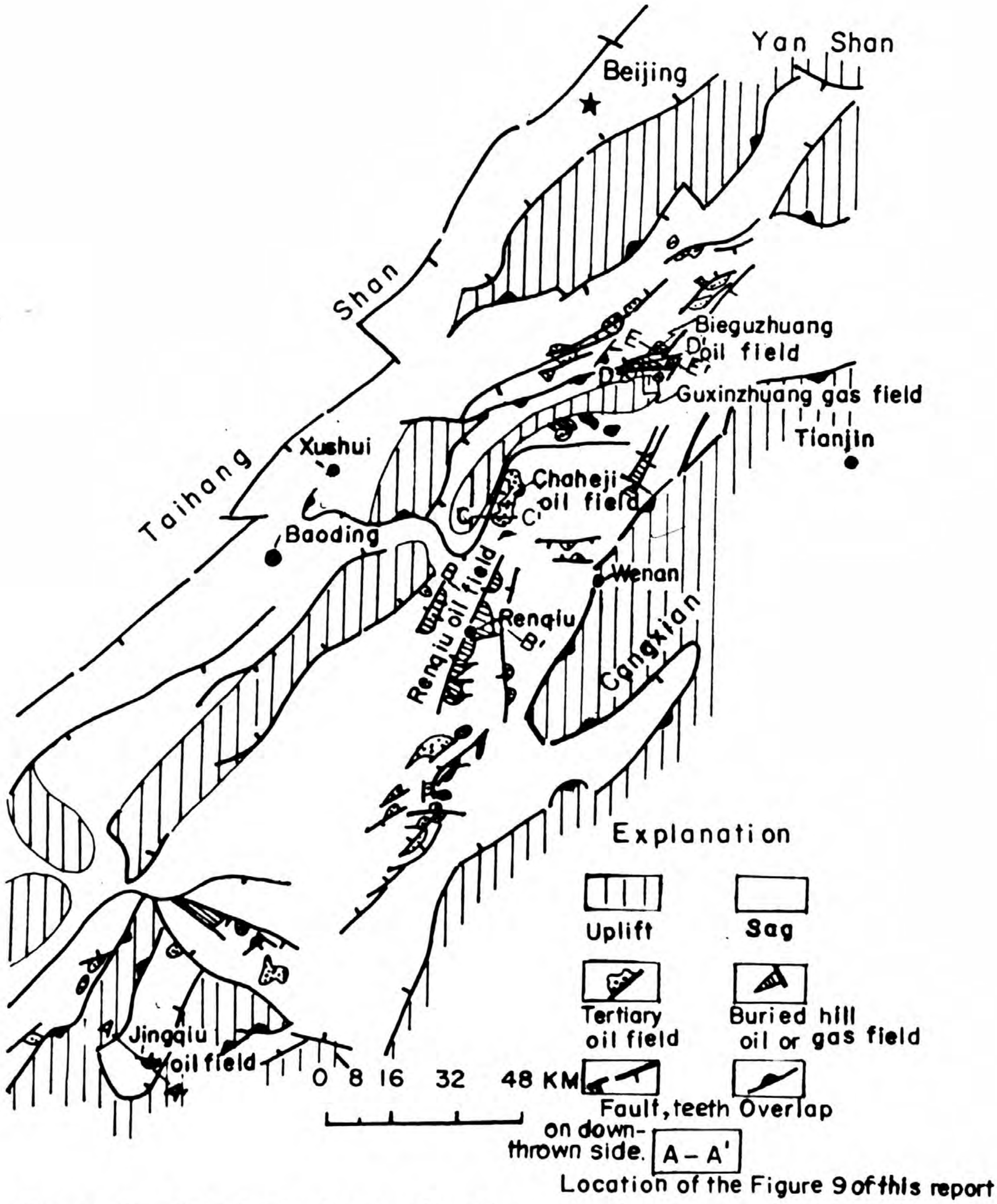


Figure 8. Principal structural units and oil and gas fields in the Jizhong depression, North China basin (modified after Wu and Liang, 1984; Figure 1).

the growth fault blocks. This syntectonic sedimentation of the source rocks produced a favorable condition for subsequent oil and gas generation and preservation.

In the Chaheji and the Jingqin oil fields of the Jizhong depression (fig. 8), the organic carbon content of the source rocks ranges from 0.41 to about 1 weight percent, and the total hydrocarbon content ranges from 250 to 689 ppm (Wu and Liang, 1984, p. 11 and 15-16) (fig. 8). The minimum depth of oil and gas maturation is 2,800 m. Peak generation was attained between the depths of 2,800 and 4,600 m, which corresponds respectively to the vitrinite reflectance values of 0.5 and 1.1 percent (Wu and Liang, 1984; Li and others, 1984) (fig. 9). Li and others (1984) indicated that the temperatures required to generate oil and gas from the source rocks ranged from 97° to 150° C. Methane gas was produced at a depth greater than 4,600 m and a corresponding temperature greater than 150°C. Kerogen is a dominant humus type III in the northern part of the depression and a mixed humus-sapropel type II mainly in the central and southern parts of the depression (Zha, 1984, p. 988).

In the Jizhong depression, the Lower Cretaceous source rocks are the 580 m of lacustrine sequence consisting of the fossiliferous, gray to grayish-green mudstone intercalated with thin-bedded carbonate rocks in the vicinity of Shijiazhuang southwest of the Jizhong depression (Hu and others, 1982, p. 5). The organic carbon content of this unit ranges from 0.80 to 1.12 percent. The asphalt extract content ranges from 650 to 1,500 ppm, whereas the total pyrolyzed hydrocarbon content ranges from 550 to 940 ppm.

Petroleum source rocks also include the grayish-green, black mudstone of the Permian-Carboniferous coal-bearing series, carbonate rocks of the Cambrian and Ordovician age, and the black shale, marl, and limestone of Late Proterozoic Jixian and Qingbaikou age. Subsurface samples in the central and southern parts of the Jizhong provide basic data on the organic carbon content and asphalt extract of the Upper Proterozoic source rocks (Hao and Zhang, 1984, p. 9). In the central Jizhong, the organic carbon content of shale and marl ranges from 0.36 to 1.12 percent and the asphalt extract ranges 90 to 289 ppm. In the limestone sample, the organic carbon content ranges from 0.3 to 0.44 percent and the asphalt extract ranges from 83 to 347 ppm. In the southern Jizhong, the organic carbon content of shale ranges from 0.15 to 0.55 percent and the asphalt extract ranges from 57 to 180 ppm. The limestone sample from one locality yielded an organic carbon content of 0.15 percent and an asphalt extract of 73 ppm. Hao and Zhang (1984, p. 7-8) considered that these source rocks in the Jizhong had reached a wet gas stage of maturation. Nevertheless, several oil-bearing Upper Proterozoic sandstone units have been encountered in some exploratory wells, and 38 oil shows have been reported in the Yan Shan folded belt north of the North China basin (Hao and Zhang, 1984, p. 8). Zha (1984, p. 992) herein believed that the oil and gas pools in the Cambrian, Ordovician, and Late Proterozoic reservoirs in the Jizhong were possibly derived from source rocks of their respective carbonate rock reservoirs.

On the basis of the sterane and terpane stereoisomers, Zhang and others (1983, p. 89-99) considered that the crude oil in the Upper Proterozoic carbonate rock reservoirs of the Renqiu oil field came from the first and and third members of the Shahejie Formation, whereas the crude oil in the Ordovician carbonate rock reservoirs came from the Kongdian Formation.

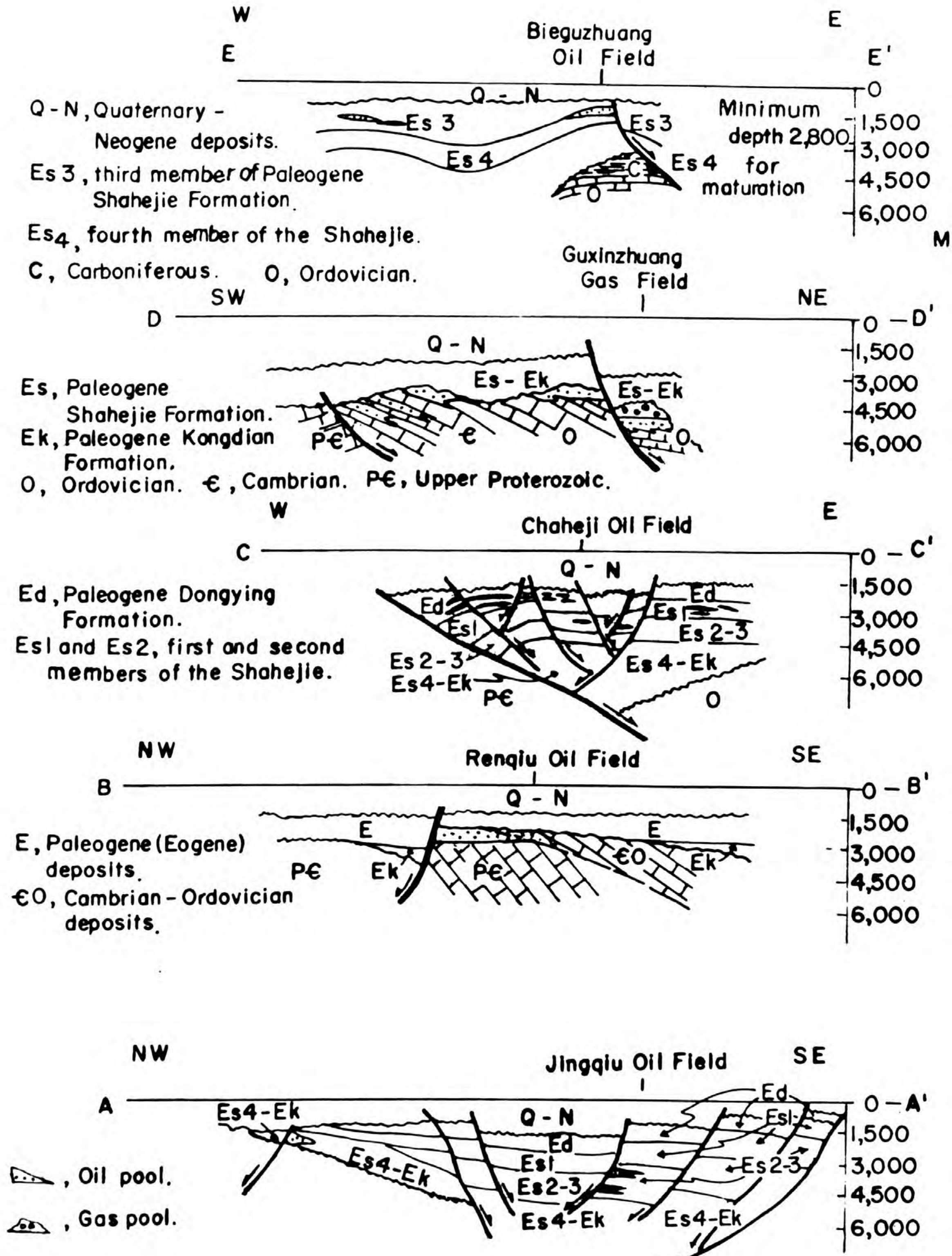


Figure 9. Schematic cross sections of principal oil and gas fields in the Jizhong depression, North China basin (modified after Wu and Liang, 1984; and Petroconsultants LTD, 1982).

Reservoir rocks

In the Jizhong depression, potential reservoir rocks of petroleum deposits are the sandstone, conglomerate, and carbonate rocks of the Upper Proterzoic, Paleozoic, Jurassic-Cretaceous, and Tertiary sedimentary sequences. Wu and Liang (1984) reported that 18 oil fields have been discovered in the depression, and of these fields, three have been studied somewhat in detail by Wu and Liano (1984) and two have been described by Petroconsultants LTD (1983) (table 3). Principal reservoir rocks in these fields are the sandstone, conglomerate, dolomite, limestone, and quartzite of Late Proterozoic Changcheng and Jixian, Cambrian, Ordovician, and Tertiary age (table 3).

The oldest reservoir rock in the Jizhong is quartzite of the Changcheng age (table 3) (Petroconsultants LTD, 1982). This rock is generally fractured, with poor porosity and permeability, and it produces 210 to 430 BOPD. Dolomite of Jixian age is the principal oil-bearing reservoir rock in the Renqui buried-hill oil field (approximate lat 38°45' N., long 116°00' E) (figs. 8 and 9). This reservoir contains a network of fractures which have been enlarged by dissolution (Bai and Wang, 1984, p. 43-55; Fei and Wang, 1984; Yang and Li, 1980, p. 57-64) and have good porosity and permeability (Petroconsultants LTD, 1982) (table 3). The average daily output from the Jixian dolomite varies from 1,400 to 7,150 BOPD per well. Fei and Wang (1984) mentioned that the reservoir consists of northeast-, north-northeast-, and northwest-trending fractures, which, due to enlargment by dissolution, provide good channels for oil migration and accumulation. The karstification of the Jixian dolomite occurred between the late stage of the Yanshanian orogeny in Late Cretaceous and Eocene sedimentation. During the initial phase of the Cenozoic extensional tectonics, the pre-Tertiary strata in the Jizhong were differentially uplifted and then subsided to be buried by Paleogene source rocks. Fei and Wang (1984) further stated that as the growth faults in the Late Proterozoic carbonate rocks developed, individual fault blocks in the depression were raised simultaneously 400 m in the Eocene and 1,300 m in the Oligocene. The Jixian dolomite reservoir of the Renqiu field has 800 meters of closure (fig. 9).

The Cambrian and Ordovician limestone and dolomite in the Jizhong depression are good reservoirs because of having fairly well developed fractures and solution features and local fault breccias. The Renqiu oil field consists of four satellite buried-hill accumulations named the Baxian, Hejian, Yanling, and Yongqing fields (Petroconsultants LTD, 1982) (table 3) (fig. 9). The Cambrian and Ordovician carbonate rocks in these buried-hill oil fields have good secondary vugs, caverns, and fractures with good permeability. Petroconsultants LTD (1982) estimated that the ultimate recoverable reserves of the Renqiu oil field are 2,000,000,000 BO. Cambrian and Ordovician limestone is probably the major reservoir in the Guxinzhuang gas field (approximate lat 39°10' N, long 116°30' E) where an initial test flow of about 35,000 MCFGD with a small amount of oil was reported from the Ordovician fractured limestone (Petroconsultants LTD, 1982) (table 3) (fig. 9).

Numerous reports have been published on the buried-hill oil and gas pools in the carbonate rocks of the North China basin (Yan and others, 1980; Yan and Zhai, 1981; Li, 1980; Fei and Wang, 1984; and Zha, 1984) (fig. 9). Yan and others (1980, p. 9) mentioned that excellent buried-hill oil and gas

Table 3. Physical properites of the reservoirs, types of trap, and cap rocks in the prominent oil and gas fields of the Jizhong Depression, North China basin.

Field name	Reservoir rock and age	Physical Properties			Trap type	Cap rock and age	Remarks
		Porosity (%)	Permeability (md)	Sorting			
Bieguzhuang	Barrier bar quartzose sandstone (E_{s4}), Eocene and Oligocene.	28	158	good to fair	Structural - horst block in a faulted anticline; NE and EW normal faulting systems with 500-600 m displacement and a closure of 600 m in an area of 7 km^2.	Mudstone (E_{s3}), Oligocene; 50-240 m thick.	Oil and gas pools at depth, 1,200-1,800 m; sealed by E_{s3} mudstone; pay zone 50-60 m thick, and formed in late E_{s2}. Source rock, E_{s4} dark shale (Wu and Liang, 1984; p. 4-9) (Li and others, 1984).
Chaheji	Channel sandstone (E_{s1}) and E_{d3}), Oligocene.	22-28	100-500	good	Lithologically pinching out and anticline broken by NNE and EW normal faulting systems with 100-300 m displacement; and a closure of 800 m in an area of 80 km^2.	Mudstone (E_{d2}), Oligocene.	Generally pay zone 10-20 m thick. Normal faults act as oil and gas supply channel. Wells near the faults, 700 BOD and 36,000 MCFGD with lighter oil and heavier gas and formed in Late Oligocene-Early Miocene. E_{s3}, source rock (Wu and Liang, 1984; p.11-14).
Jingqiu	Delta front quartzose sandstone (E_{s2} and E_{s3}), Oligocene.	16	425	fair	Faulted nose structure cut by EW normal faulting system with a closure about 150 m in an area of 13.5 km^2.	Anhydrite-rock salt and mudstone (E_{s2}), Oligocene; 100-150 m thick.	Oil pool near the center of source area. The source rocks, dark mudstones in E_{s3} contain organic carbon, 0.41 to 0.71%, and average hydrocarbon content is 250 ppm. Pool formed in the Miocene Guantao time (Wu and Liang, 1984; p. 15-17).
Renqiu	Dolomite and limestone of the Ordovician, Cambrian and Late Proterozoic age as well as Late Proterozoic Changcheng quartzite.	Good secondary vugs, caverns and fractures in carbonate rocks. Poor fractures in quartzose.	Good in carbonate rocks, and poor in quartzose.	---	Structural-stratigraphic; buried hills with unconformity and subsequent folding and faulting providing the entrapment of about 200 km^2.	Mudstone and anhydrite, Eocene-Oligocene.	Discovery in 1975. Third most productive field in China. 2,740 m to top pay. Reservoir bearing interval up to 850 m or 2,790. Ultimate recoverable 2,000,000,000 BO (Petroconsultants LTD, 1982).
Guxinzhuang	Limestone, fractured and weathered; Ordovician.	Vugs and fractures.	good	---	Structural-stratigraphic, buried hills with faulting system.	Mudstone (E_k)(E_s), Eocene-Oligocene.	Gas field. Depth to top pay, 3,389 m. Gross thickness of reservoir interval, 190 m. Initial test flow rate for a single well may reach 35,000 MCFGD with a small amount of crude oil (Petroconsultants LTD, 1982).

E_k, Paleogene Kongdian Formation. E_{s4}, E_{s3}, E_{s2} and E_{s1}: fourth, third, second and first members of Paleogene Shahejie Formation. E_s, Paleogene Shahejie Formation. E_{d2}, second member of Paleogene Dongying Formation.

pools required special geologic conditions. These pools must have formed in a depression containing extensive source beds which unconformably overlie the carbonate rock terrane or are in fault contact with it. The carbonate rocks must have well developed vugs, fractures, and caverns and have excellent cap rocks. Moreover, the carbonate rocks must have a relatively large closure in an area with relatively stagnant hydrodynamic conditions. In the North China basin, the Renqiu buried-hill oil field possesses all of these unique geological conditions (figs. 8 and 9). This buried-hill oil pool is located in a large fault block bounded on the west by a west-dipping growth fault. The Upper Proterozoic and Lower Paleozoic carbonate reservoir rocks are tightly sealed by Paleogene shale, mudstone, and evaporite. The pools are massive, bedded, wedge-shaped and irregular in shape (Zha, 1984, p. 990; Yan and others, 1980). Zha (1984) further mentioned that in the Jizhong depression, the buried-hill carbonate reservoirs are covered by coal beds of the Mesozoic, Permian, and Carboniferous sequences. Moreover, oil and gas in the Tertiary source rocks migrated along the unconformity into the buried-hill carbonate reservoirs and adjacent reservoir rocks. This mode of oil and gas migration opens a new avenue for exploration of the buried-hill oil and gas pools (Zha, 1984, p. 989).

The reservoir rocks of Tertiary age in the Jizhong depression consist of quartoze sandstone and minor conglomerate. The sandstone consists chiefly of quartz grains. In the Bieguzhuang, Chaheji, and Jingqiu oil and gas fields, the sandstone has good to moderate sorting, porosity ranging from 16 to 28 percent, and permeability ranging from 100 to 500 md (Wu and Liang, 1984) (figs. 8 and 9) (table 3).

Traps and seals

Oil and gas accumulations in Tertiary sandstone reservoirs are trapped in structural anticlines, terraces, rollover anticlines, drape anticlines, and fault blocks. Accumulations also have resulted from the pinch-out of sandstone units of fluvial channel, barrier bar, and turbidite origin (fig. 9) and from sandstone units which have overlapped fault blocks. Marked lithofacies changes are common, because detrital sediments derived from surrounding highland source areas were deposted in a topographically closed depression. Therefore, the oil- and gas-bearing sandstone reservoirs generally have a limited areal extent in the Jizhong depression, and exploration has concentrated only on structural traps. Nevertheless, based on geologic data, commercial sandstone reservoirs have been found in the Jizhong (fig. 9). Thick shale, mudstone, gypsum, and salt beds form throughout the depression.

In the western part of the Jizhong depression, undiscovered oil accumulation may exist in the Cretaceous and Jurassic sandstone beds, whereas in the eastern part, undiscovered gas accumulation may exist in the Permian-Carboniferous and Cretaceous-Jurassic beds (Zha, 1984, p. 992).

Dongpu-Kaifeng Depression

The Dongpu-Kaifeng depression is a northeasterly trending graben system bordered on the west and the east by unnamed horst blocks, on the south by the Taikang upland, and on the north by the Lingqing depression (figs. 2, 3, and 10) (Lin, 1982). This depression is located in the southern part of the

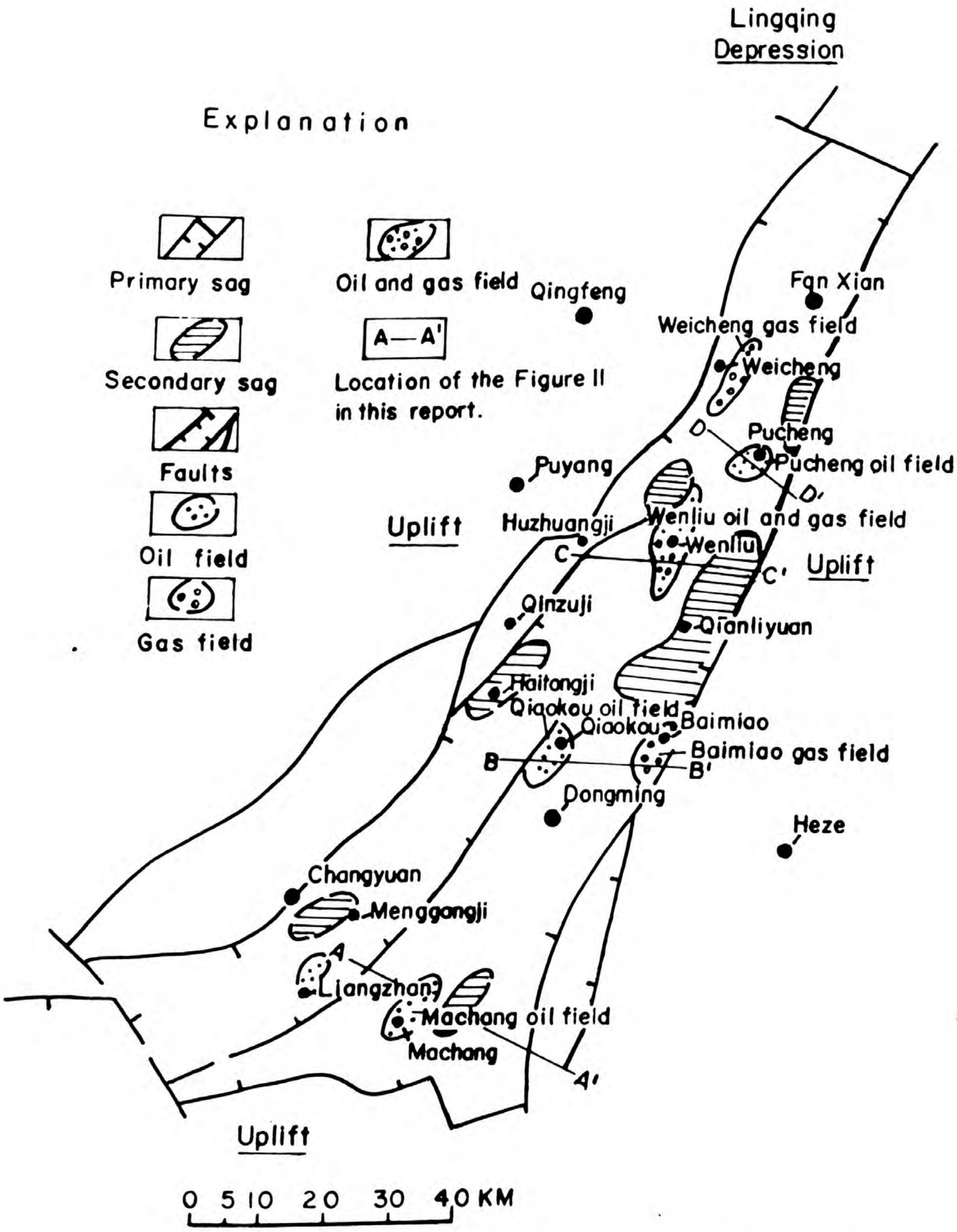


Figure 10. Principal structural units and oil and gas fields in the Dongpu-Kaifeng depression, North China basin (modified after Chen and others, 1984; Figure 2, p. 375).

North China basin and covers about 7,000 km^2, part of which is crossed by the Huang He (Yellow River) (figs. 2 and 3). The Tertiary sedimentary cover of the Dongpu-Kaifeng depression ranges in thickness from 1,270 to 5,600 m, of which 4,500 m is represented by the maximum thickness of the Paleogene sequence. The remaining sedimentary cover consists of 800 m of the Cretaceous and Jurassic sequences, 800 m of the Permian and Carboniferous coal-bearing sequence, 600 m of the Ordovician and Cambrian carbonate sequence, and 0 to 800 m of the Upper Proterozoic sequence in which the Sinian strata are missing (table 2).

Source Rocks

The principal source rocks in the Dongpu-Kaifeng depression are confined to saline lacustrine deposits of mudstone, shale, and oil shale of the Paleogene Shahejie and Dongying Formations. Secondary source rocks consist of the continental and marine Permian and Carboniferous coal-bearing series and the marine Ordovician and Cambrian carbonate rocks, shale, and mudstone.

The major oil and gas generating strata are grayish-green to gray mudstone of the third and and first members of the Shahejie Formation (Chen, Zhou, Qiu, and Guo, 1984, p. 379). Source beds are as much as 1,000 m thick in the northern, eastern, and central parts of the depression (fig. 10). Kerogen is the dominant mixed humus-sapropel type II. The peak generation of oil and gas was attained at depths between 2,400 and 4,100 m, which corresponds, respectively, to temperatures of 90°C and 145°C (Chen, Zhou, Qiu, and Guo, 1984, p. 379) (fig. 11).

The Permian-Carboniferous coal series is widely distributed in the Dongpu-Kaifeng depression and has generated a substantial amount of gas during the Late Paleogene. Generally, the thickness of the coal series in the Dongpu-Kaifeng averages about 250 m and the rank ranges from a high-volatile bituminous coal to a metaanthracite coal (Cai, 1983). In the northern part of the depression, the Permian-Carboniferous coal beds average in total 12 m thick, whereas in the southern part of the depression, the coal beds average in total 7 m thick (Zhou and others, 1985, table 2, p. 32). The total organic carbon content in the coal series averages between 1.28 and 2.81 weight percent (Cai, 1983, table 1, p. 38). At the Wenliu oil and gas field (figs. 10 and 11), Permian-Carboniferous coking coal beds are found below 4,427-m at a temperature of 152°C and a vitrinite reflectance of 1.5 percent (Cai, 1983). Zhu and Xu (1984) stated that gas generated from Permian-Carboniferous coal beds has a higher methane content (more than 95 percent), higher δC_{13} values (-27.1 to -30.3 °/oo), and larger Ar^{40}/Ar^{36} ratios (958 to 1,396) than gas generated from the Tertiary source-rock sequences.

The organic content of the Ordovician and Cambrian carbonate rocks, shale, and mudstone in the Dongpu-Kaifeng depression is generally unknown. Fu and Jia (1984) stated that the minimum total organic carbon values in the carbonate source rocks of the North China basin ranges from 0.08 to 0.2 weight percent.

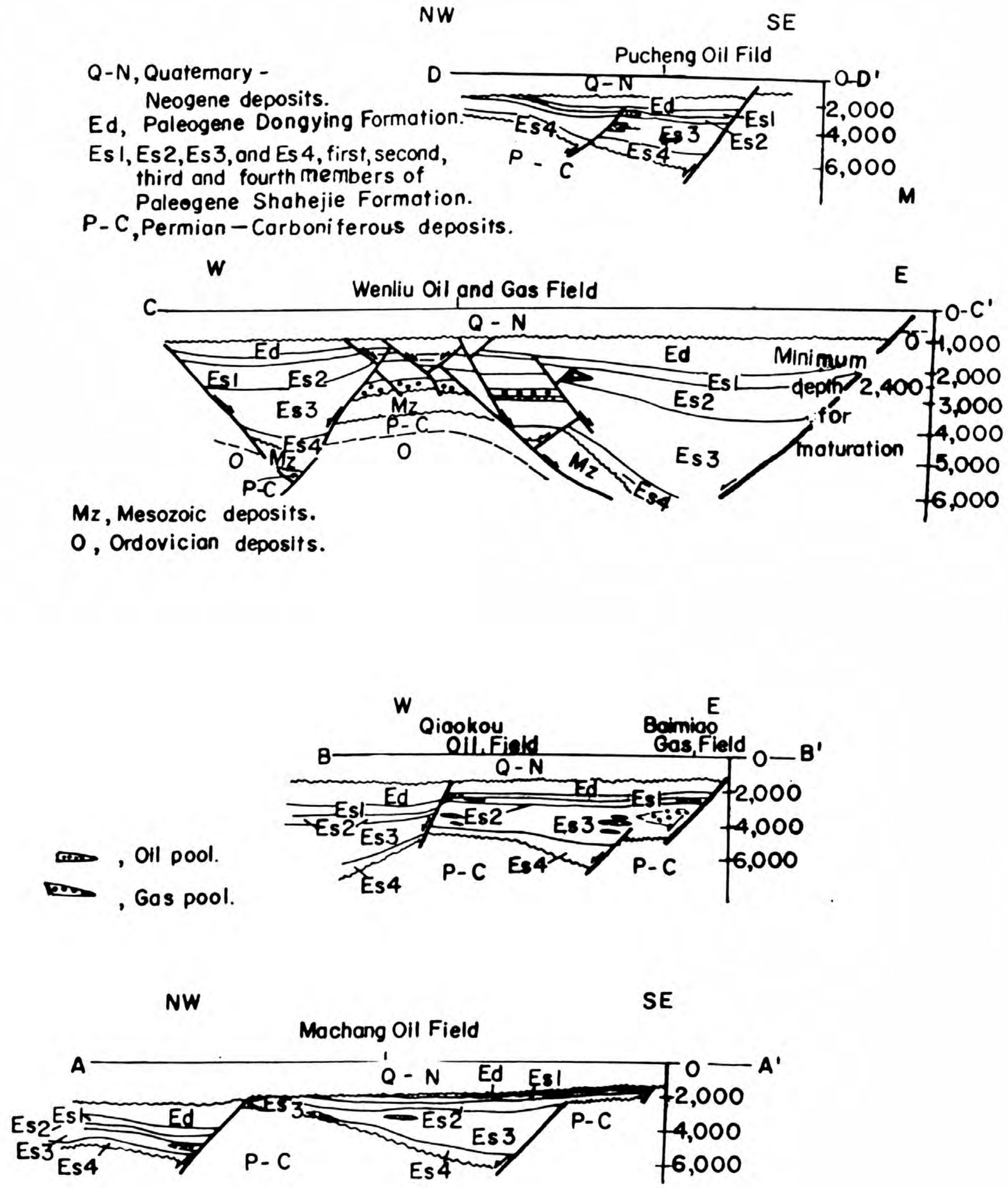


Figure 11. Schematic cross sections of principal oil and gas fields in the Dongpu-Kaifeng depression, North China basin (modified after Chen and others, 1984; Figure 2, p. 375; and Zhu and Xu, 1984; Figure 5, p. 9).

Reservoir rocks

Tertiary Paleogene sandstone and conglomeratic sandstone are the principal reservoir rocks in the Dongpu-Kaifeng depression. At present, the major fields are the Pucheng and Wenliu oil and gas fields (figs. 10 and 11). Petroconsultants LTD (1982, 1983) listed the Pucheng field as the "Dongpu" oil field and estimated an annual production of 13,870,000 BO from Paleogene sandstone in a faulted anticline. The main gas pools are located in the Wenliu field. Zhu and Xu (1984) and Chen, Zhou, Qiu, and Guo (1984), however, provide additional information on oil and gas deposits in the Pucheng, Wenliu, Weicheng, Qiaokou, Baimiao, and Machang areas and the area between Huzhuangji-Qinzuji along the west border of the depression (fig. 10).

In the Dongpu-Kaifeng depression, gas deposits generally are the principal petroleum resource. On the basis of geochemical data, Zhu and Xu (1984) have recognized three types of gas deposits in the depression: 1) gas generated from the Permian-Carboniferous coal beds, such as that at the Wenliu field, is characterized by a methane content of more than 95 percent and a low wet-gas coefficient; 2) gas generated from the Tertiary oil, such as that in the Pucheng field, is characterized by a methane content below 95 percent, lower $\delta^{13}C$ values (-38.62 to -45.4°/₀₀), and smaller Ar^{40}/Ar^{36} ratios (343-626); and 3) gas generated from Permian and Carboniferous coal and Tertiary oil, such as that in the Weicheng field, is called mixed-type gas and is characterized by methane contents between 31 to 69 percent, $\delta^{13}C$ values ranging from 32.1 to 35.00°/₀₀, and Ar^{40}/Ar^{36} ratios ranging from 780 to 868 (fig. 10).

Traps and seals

The Wenliu gas reservoir consists of sandstone and siltstone of the fourth member of the Shahejie Formation. The reservoir is completely sealed by a 600- to 800-m thick sequence of rock salt and gypsum beds in the lower part of the third member of the Shahejie Formation (Zhu and Xu, 1984, p. 9). The gas is trapped in a horst block against impervious rock-salt beds of the third member of the Shahejie (figs. 10 and 11).

In the Pucheng oil and gas field, the gas is trapped by in a fault block against sealed salt beds in the upper part of the third member of the Shahejie (figs. 10 and 11). Gas in the Weicheng had been generated from the third and fourth members of the Shahejie Formation and the Permian and Carboniferous coal beds. This gas was deposited in a similar fashion as shown in the Pucheng field (figs. 10 and 11). Fault traps and stratigraphic traps are present in the Baimiao, Qiaokou, and Machang fields. Detailed exploration is needed in the southern part of the depression where high gas potential exists.

Huanghua Depression

The Huanghua depression is a half-graben structure (figs. 12 and 13). It is located in the central part of the North China basin and is bounded by the Lingqing depression on the south, the Yan Shan foldbelt on the north, the Cangxian uplift on the west, and the Chengning uplift and the Central Bohai depression on the east (figs. 2, 12, and 13). The Huanghua depression is about 250 km in length and 50 to 100 km in width and covers about 17,000 km^2.

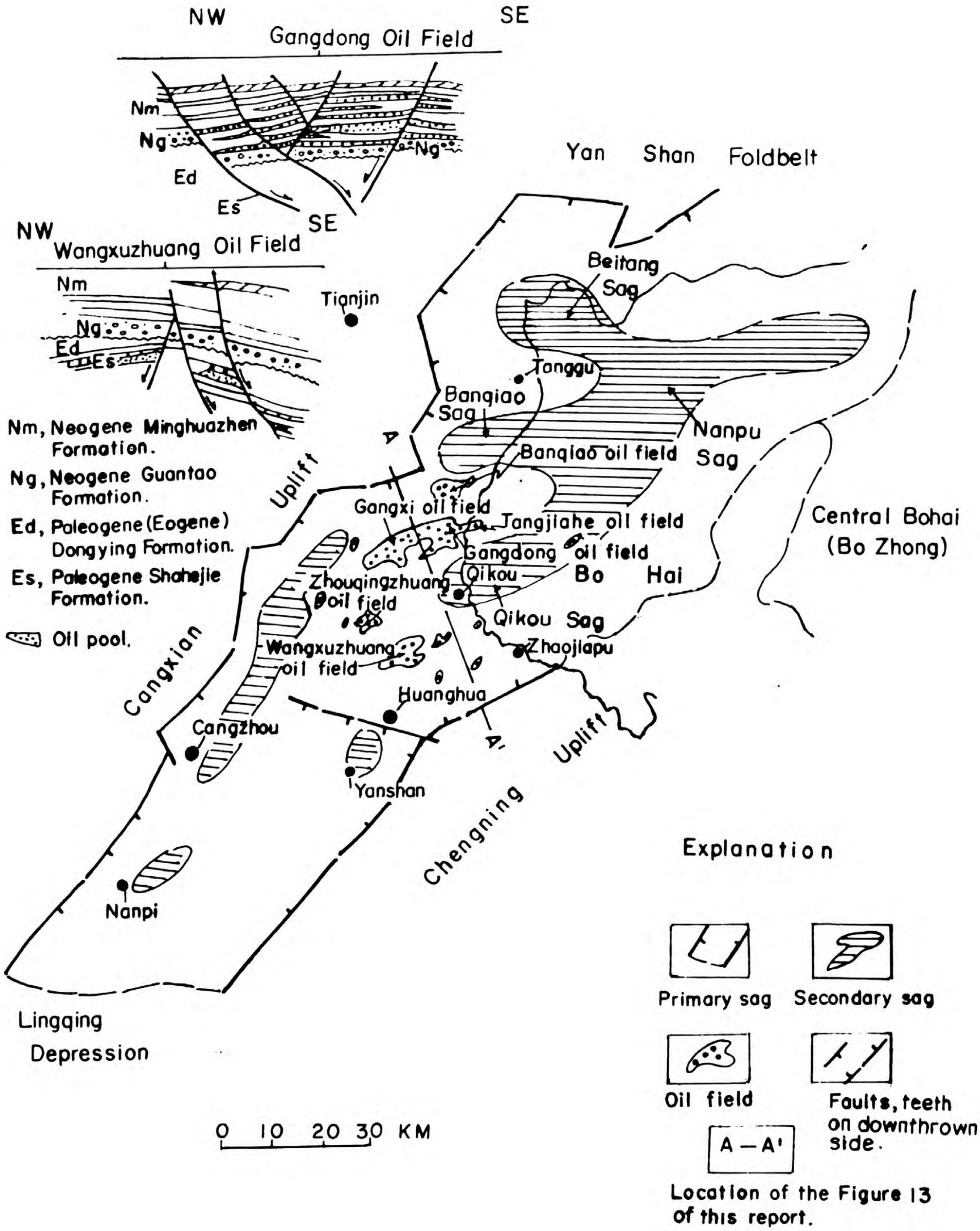


Figure 12. Principal structural units and oil fields in the Huanghua depression, North China basin (modified after Zhang and Jian, 1981; Figures 1, 3, 14 & 15, p. 141, 143, 152 & 154; and Wang and others, 1983; Figure 3-6-2, p. 162; Figure 3-7-11, p. 185; Figure 3-7-19, p. 188).

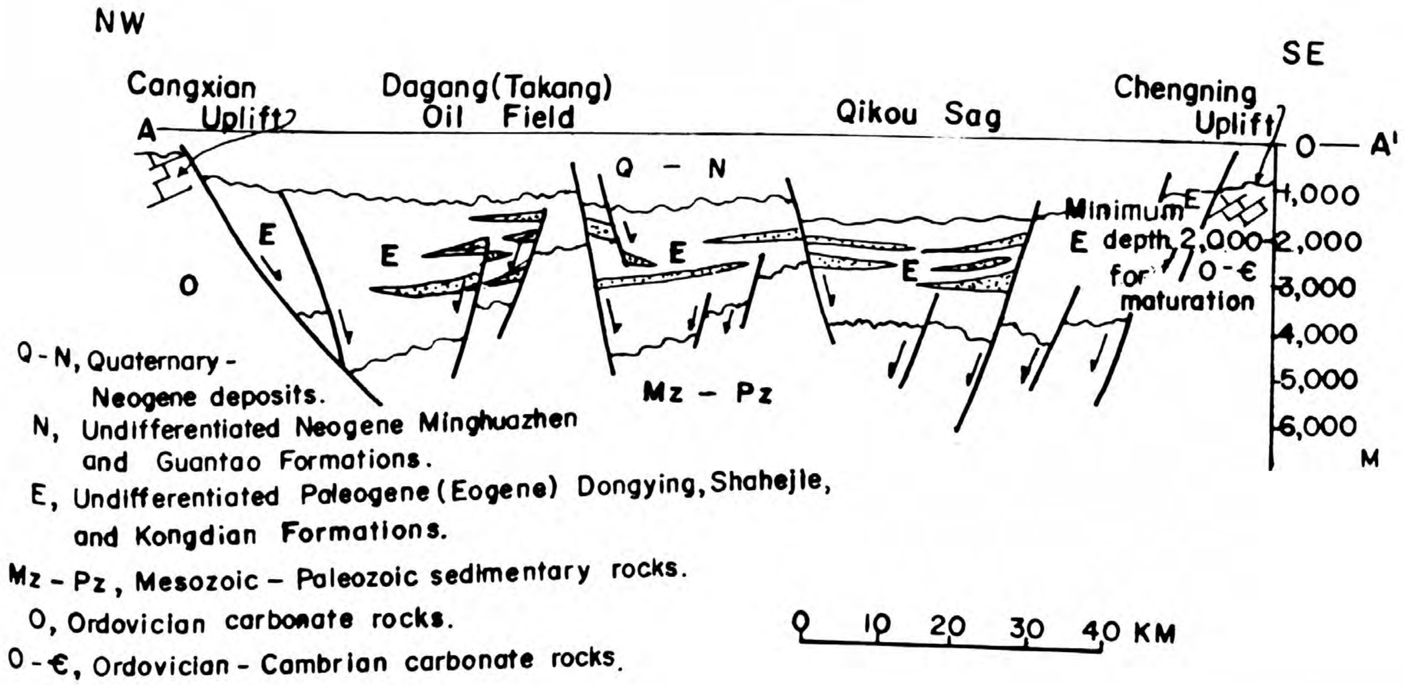


Figure 13. Schematic structural cross section through the central part of the Huanghua depression, North China basin (modified after Liu and others, 1981; Figure 7, p.62).

Four large producing sags in the depression are the Qikou, Banqiao, Beitang, and Nanpu, of which the Qikou and Banqiao contain the thickest source beds. The Dagang oil field (approximate lat 38°20' N., long 117°50' E) is situated between the Banqiao sag on the northwest and the Qikou sag on the southeast. The maximum thickness of the sedimentary cover in the Huanghua depression is about 12,000 m, of which 8,390 m is confined to the Tertiary sequence. The maximum thickness of the Paleogene sequence is 5,490 m (table 2).

Source Rocks

In the Huanghua depression, principal source rocks are confined to the continental saline lake deposits of mudstone, shale, oil shale, and marl of the Paleogene Shahejie and Dongying Formations. Additional source rocks consist of coal beds in the Permian and Carboniferous sequences and marine carbonate rocks, shale, and mudstone in the Ordovician-Cambrian and Late Proterozoic sequences (table 2).

The third, second, and first members of the Shahejie Formation contain the principal oil and gas generating strata throughout the Huanghua depression, followed by the lower part of the Dongying Formation. These source rocks are concentrated in the central part of the depression (Liang and others, 1981, p. 75). They are 1,260 m thick in the Banqiao sag and 1,560 m in the Qikou sag (fig. 12). The source rocks contain abundant diatoms, pollen, spores, ostracods, and gastropods. The organic carbon content generally ranges from 0.52 to 2.76 weight percent with an average of 1.26 percent. The asphalt extract content averages 0.13 percent. The primary pyrite content in the source rocks is generally high, as indicated by the reduction coefficient (K) from 0.2 to 0.37, and the "$S^{=}$" content from 0.13 to 0.51 percent (Liang and others, 1981, p. 75). These data indicate that the Oligocene lake was fresh to semi-alkaline, had a depth range from moderate to deep, and its sediments were deposited in a weakly reducing environment.

The evolution of organic matter in the Paleogene source rocks of the Huanghua depression was studied by Wang and others (1980), Liang and others (1981), and Liang (1985). Liang (1985) stated that oil and gas generation occurred in the Huanghua between depths of 2,000 and 4,500 m, which correspond, respectively, to temperatures of 85.5° and 171°C (fig. 13). In descending order, the hydrocarbons in this depression have the following characteristics: 1) immature heavy oil with bio-methane occurs at depths between about 2,000 and 2,400 m, which correspond to temperatures 85.5° and 97.5°C; 2) three mature oil zones associated with gas are an under-mature heavy oil, a moderately mature medium oil, and a mature light oil, and occur between depths of 2,400 and 4,000 m with corresponding temperatures 97.5° and 154°C; 3) highly mature condensate oil and wet gas occur between the depths of 4,000 and 4,500 m, which correspond to temperatures 154° and 171°C; and 4) overmature dry methane gas occurs below a depth of 4,500 m with corresponding vitrinite reflectance, 2.0 percent (Liang, 1985, fig. 1, p. 18).

Fu and Jia (1984, fig. 5, p. 14 and Table 3, p. 13) indicated that for many parts of the Huanghua depression, the Ordovician carbonate source rocks have experienced temperature between 430° and 440°C. The total organic carbon content of these rocks ranges between 0.1 and 0.2 weight percent. Information is not yet available for the Upper Proterozoic and Cretaceous-Jurassic source rocks in the depression.

Correlation between oil extracts from source rocks and crude oil in the Huanghua depression was done by Liang and others (1981). The alkane properties suggest that oil and condensate in the Banqiao field were generated from the third member of the Shahejie Formation and that oil in the Tangjiahe field was generated from the second and third members of the Shahejie.

Reservoir rocks

Principal producing reservoir rocks in the Huanghua depression are the sandstones of the Kongdian, Shahejie, Dongying, Guantao, and Minghuazhen Formations, and the oolitic, bioclastic carbonate rocks of the Shahejie Formation (Zhang and Jian, 1981). Petroconsultants LTD (1977) mentioned that productivity in the Dagang (Takang) field differs greatly from block to block, and even from well to well, probably because the reservoirs are often complicated by intricate fault blocks and abrupt facies changes (figs. 12 and 13). The so-called "Dagang (Takang) field" is a collective name for the Banqiao oil field on the north and the Tangjiahe, Gangdong, and Gangxi oil fields on the south (fig. 12). Paleogene oil-bearing limestone reservoirs, chiefly of the reef-limestone variety, generally have a complex fault structure. The limestone beds are thick and commonly show abrupt facies changes in the direction of decreasing thickness. Oil-bearing sedimentary sequences occur mainly between depths of 1,500 and 3,000 m. Petroconsultants LTD (1977) estimated that the annual production from the Dagang field in 1975 was 55,000,000 to 73,000,000 barrels.

The Dagang field was discovered in 1964. Since 1975, active exploration and drilling have continued throughout the Huanghua depression. The main Tertiary reservoirs occur in the delta front and channel sandstones which were deposited near a lacustrine shoreline. The Tertiary reef-limestone and dolomitic limestone reservoirs have secondary vugs and fractures and contain local bioherms. Generally, these oil and gas deposits are trapped by faults, rolled-over anticlines, and stratigraphic pinch-outs with mudstone seals (fig. 12).

Jiyang Depression

The Jiyang depression is located in the east-central part of the North China basin and is made up of four principal sags: Dongying, Zhanhua, Chezhen, and Huimin (figs. 2 and 14). These sags are separated from each other by uplifts (fig. 14). This depression is bounded by the Luxi uplift on the south and the east, the Bo Hai on the north, the Chengning uplift on the west, and the Lingqing depression on the southwest (figs. 2, 3, and 14). The Jiyang is a half-graben structure which consists of numerous normal fault blocks throughout the depression. The depression covers about 17,000 km^2, of which 5,700 km^2 are occupied by the Dongying sag (Tang, 1979, p. 14). The maximum thickness of the sedimentary cover in the Jiyang is about 11,310 m, of which 7,270 m are confined to the Tertiary sedimentary sequence. The oil- and gas-bearing Paleogene sedimentary fill in the Jiyang ranges from 2,900 to 5,750 m (table 2).

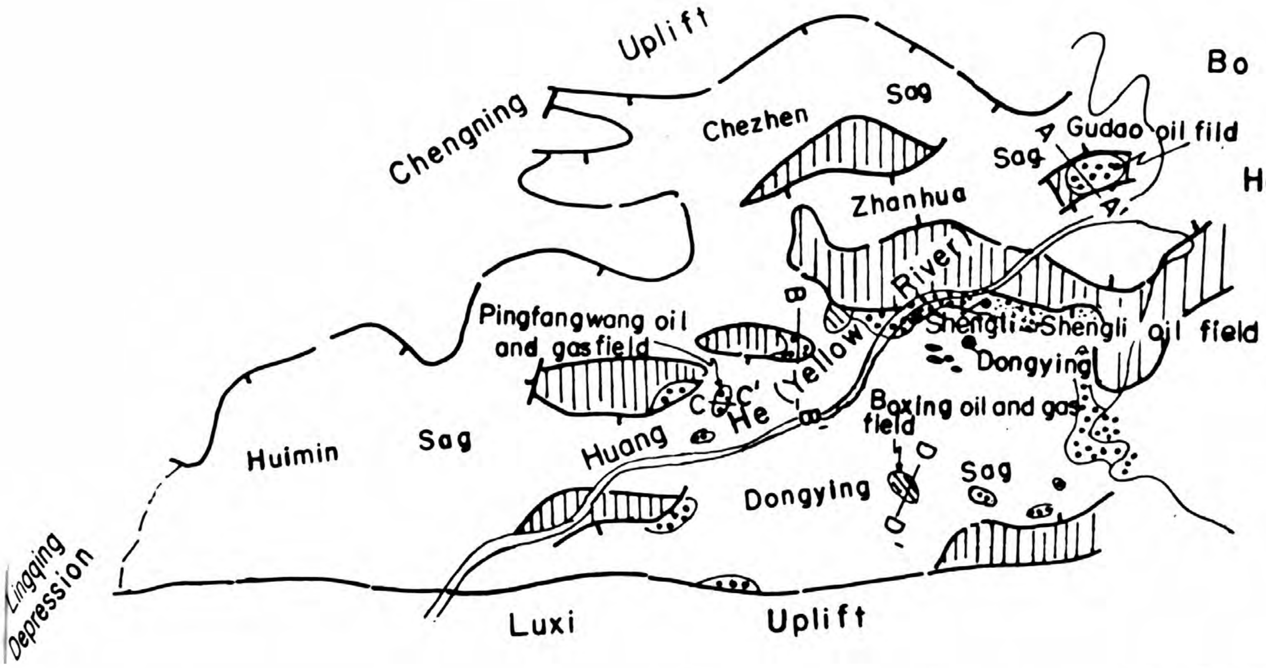


Figure 14. Principal structural units and oil fields in the Jiyang depression, North China basin (modified after Shuai and others, 1984; Figures 1 & 19; Chen and Wang, 1980; Figure 1, p. 472; and Petroconsultants LTD, 1982).

Explanation

Uplift | Sag | Tertiary oil field | Buried hill oil field | Fault | A–A' Location of the Figure 15 of this report.

Scale (approximate)

0 24 48 72 96 120 KM

Source rocks

In the Jiyang depression, principal source rocks are confined to the fluvio-lacustrine fresh to saline water deposits of mudstone, shale, and oil shale of the Paleogene Kongdian and Shahejie Formations. The total thickness of the source rocks is approximately 1,000 m in the Jiyang depression (Zhou, 1981; Chen and Wang, 1980). The third, second, and first members of the Shahejie Formation contain the major oil and gas generating strata (Zhou, 1981, p. 26-38; Chen and Wang, 1980, p. 473). These source rocks are characterized by a total hydrocarbon content of 400 to 1,000 ppm; the asphalt extract to total organic carbon ratio is greater than 100 milligram/gram, and the total hydrocarbon to total organic carbon ratio is greater than 30 milligram/gram (Wang and others, 1983, p. 130). Kerogen is a predominant humus-sapropel Type II, indicated by a H/C ratio of 1.10 to 1/35 and a O/C ratio of 0.06 to 0.18, showing the lower aquatic organisms and higher terrestrial plants in source rocks (Wang and others, 1983, p. 131).

The average geothermal gradient in the Jiyang depression is 3.6°C/100 m, and the average surface temperature is 14.2°C (Chen and Wang, 1980, p. 39). On the basis of samples collected from the middle of the third member of the Shahejie Formation in the Dongying sag (Zhou, 1981, p. 39-47; Wang and others, 1983, p. 131-132), the mature stage for generation of oil and gas occurred between the depths of 2,200 and 3,000 m with corresponding temperatures 93° and 122°C (fig. 15). In this depth range, total hydrocarbons increased from 200 to 1,000 ppm, and nonhydrocarbons decreased sharply from 80 to 50 percent. The CPI (Carbon Preference Index) value of n-alkanes dropped from 1.90 to 1.40 indicating an increase of stable n alkanes in the hydrocarbons, and the montmorillonite was transformed into illite causing a reduction in porosity of mudstone from 15 to 5 percent. Inevitably the water was formed by this transforming process and forced a large amount of preexisting hydrocarbons out from the source rocks. Zhou (1981, p. 39) and Chen and Wang (1980, p. 39) indicated that the lighter hydrocarbons were formed at depths ranging from 3,000 to 3,800 m with corresponding temperatures 122° and 155°C. Condensate and wet gas formed generally below 4,000 m. These data are conformable with data given by Liang (1985) for the maturation of organic matter in the Huanghua depression.

On the basis of the paraffin chromatography and pristane/phytane ratios, oil extract and crude oil correlation for the Jiyang depression has been done to show that oil from the Gudao field was generated from source rocks of the third member of the Shehejie Formation (Chen and Wang, 1980, p. 479, table 3).

Reservoir rocks

Principal producing reservoir rocks in the Jiyang depression are sandstone and conglomeratic sandstone of the Paleogene Shahejie and Dongying Formations, the Neogene Guantao and Minghuazhen Formations, and the Cretaceous and Jurassic sequences; and the carbonate rocks of Paleogene and Ordovician ages (Chen and Wang, 1980, Table 1, p. 473; Shuai and others, 1984).

The Tertiary sandstone and conglomeratic sandstone in the Jiyang depression were deposited in a fluvial environment and are widely distributed in a sinuous, elongated pattern with a considerable thickness variation.

Commonly the sandstone is rich in feldspar and loosely cemented. This reservoir is present in the Gudao oil and gas field (approximate lat 37°52' N., long 118°45' E) in the Zhanhua sag (figs. 14 and 15) (Chen and Wang, 1980). The porosity of the reservoir sandstone in the Gudao field ranges from 30 to 32 percent and the effective permeability for oil ranges from 510 to 2,440 md (Chen and Wang, 1980, p. 486). However, the production capacities and the physical properties of the reservoir differ considerably between individual sandstone bodies in the wells (Chen and Wang, 1980). These textural changes are attributed to variations of the sedimentation condition in the fluvial environment.

The Gudao field covers 70 km^2. The oil and gas pools occur in sandstone of the Miocene Guantao Formation at a depth of 1,180 m (Petroconsultants LTD, 1983). The oil and gas deposits are trapped by drape structure which overlies a horst block (fig. 14). The top seal consists of mudstone and shale. Laterally, the reservoir sandstone pinches out into shale and mudstone. The initial recoverable oil reserves were estimated to be 700,000,000 barrels in 1979, and the initial recoverable gas reserves were estimated to be 2,000,000 million ft^3 in 1983 (MMCF) (Petroconsultants, LTD, 1983).

In the Jiyang depression, petroleum deposits also occur in sandstone bodies above and below the Neogene-Paleogene unconformity, such as the oil and gas pools located between the Oligocene Dongying Formation and the Miocene Guantao Formation in the Huimin sag (Shuai and others, 1984) (table 2) (fig. 15).

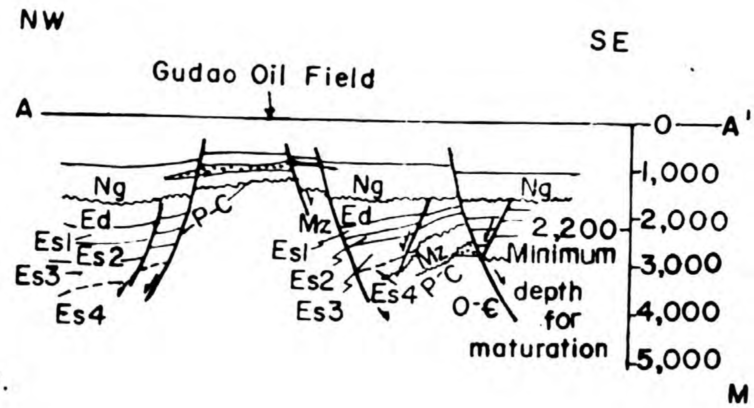
Oil pools of lenticular Cretaceous-Jurassic sandstone bodies have provided a stable production in the Jiyang depression (Shuai and others, 1984, p. 7).

The oil and gas pools of a Paleogene bioherm-type reservoir in the Jiyang depression are represented by the Pingfangwang field of the Dongying sag (approximate lat 37°21' N., long 117°57' E.) (Petroconsultants LTD, 1982; Ma and others, 1982; Shuai and others, 1984, p. 4) (fig. 15). A Paleogene bioherm consists chiefly of the Serpula-Cladesiphonia sinensis-bearing limestone of the fourth member of the Shahejie Formation. This oil- and gas-bearing reef limestone overlies source beds of the third member of the Shahejie Formation. The reservoir interval in the Pingfangwang field is about 160 m thick with a porosity range from 36 to 43 percent. The depth to top pay is 1,410 m deep (Petroconsultants LTD, 1983). The average daily output per well was reported in 1982 to be several hundred tons of oil (Petroconsultants LTD, 1982). Buried-hill oil and gas pools with good reservoir properties occur in the Ordovician dolomite (Shuai and others, 1984, p. 3-4).

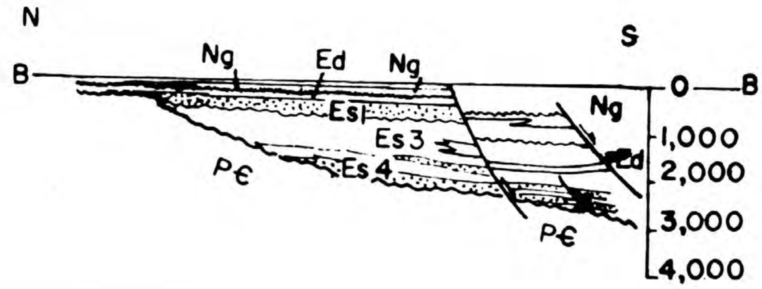
Central Bohai (Bo Zhong) Depression

The Central Bohai (Bo Zhong) depression is located in the northern part of the North China basin and is bounded by the Liaodong Gulf-Liao River depression on the north, the Jiyang depression on the south, the Huanghua depression on the west, and the Tanlu deep fracture zone on the east (figs. 2 and 16). This depression is a graben structure (Li, 1984, fig. 3, p. 997; Chen and others, 1983, figure 7, p. 119) and covers about 16,000 km^2. The water depth in Bo Hai varies from about 18 to 50 m. The maximum sedimentary cover of the Central Bohai depression is about 11,000 m thick of which about

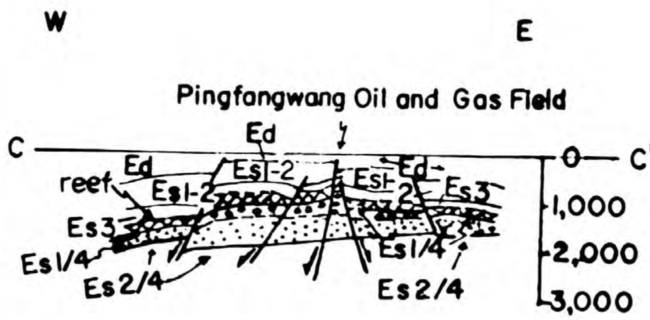
Ng, Neogene Guantao Formation.
Ed, Paleogene (Eogene) Dongying Formation.
Es1, Es2, Es3, & Es4, first, second, third, and fourth members of Paleogene Shahejie Formation.
Mz, Mesozoi deposits.
P-C, Permian - Carboniferous deposits.
O-Є, Ordovician - Cambrian deposits.



PЄ, Precambrian rocks.
, Oil pool.



Es1-2, undifferentiated first and second members of Paleogene Shahejie Formation.
Es 1/4, upper part of the fourth member of Shahejie Formation.
Es2/4, lower part of the fourth member of Shahejie Formation.
, Gas pool.



Ek, Paleogene Kongdian Formation.
O, Ordovician carbonate rocks.

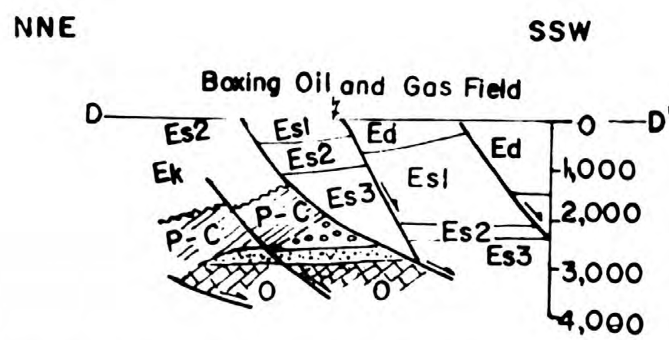
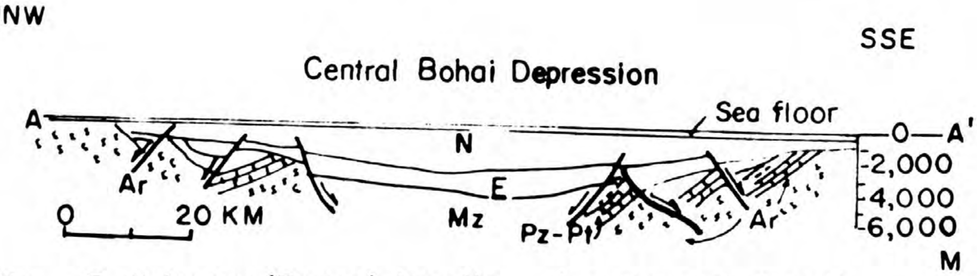


Figure 15. Schematic cross sections of some oil and gas fields in the Jiyang depression, North China basin (modified after Chen and Wang, 1980; Figure 1, p. 472; and Shuai and others, 1984; Figures 2, 5, & 6).



N, Neogene deposits. E, Paleogene (Eogene) deposits. Mz, Mesozoic deposits.
Pz-Pt, undifferentiated Paleozoic and Proterozoic sedimentary rocks.
Ar, Archean rocks.

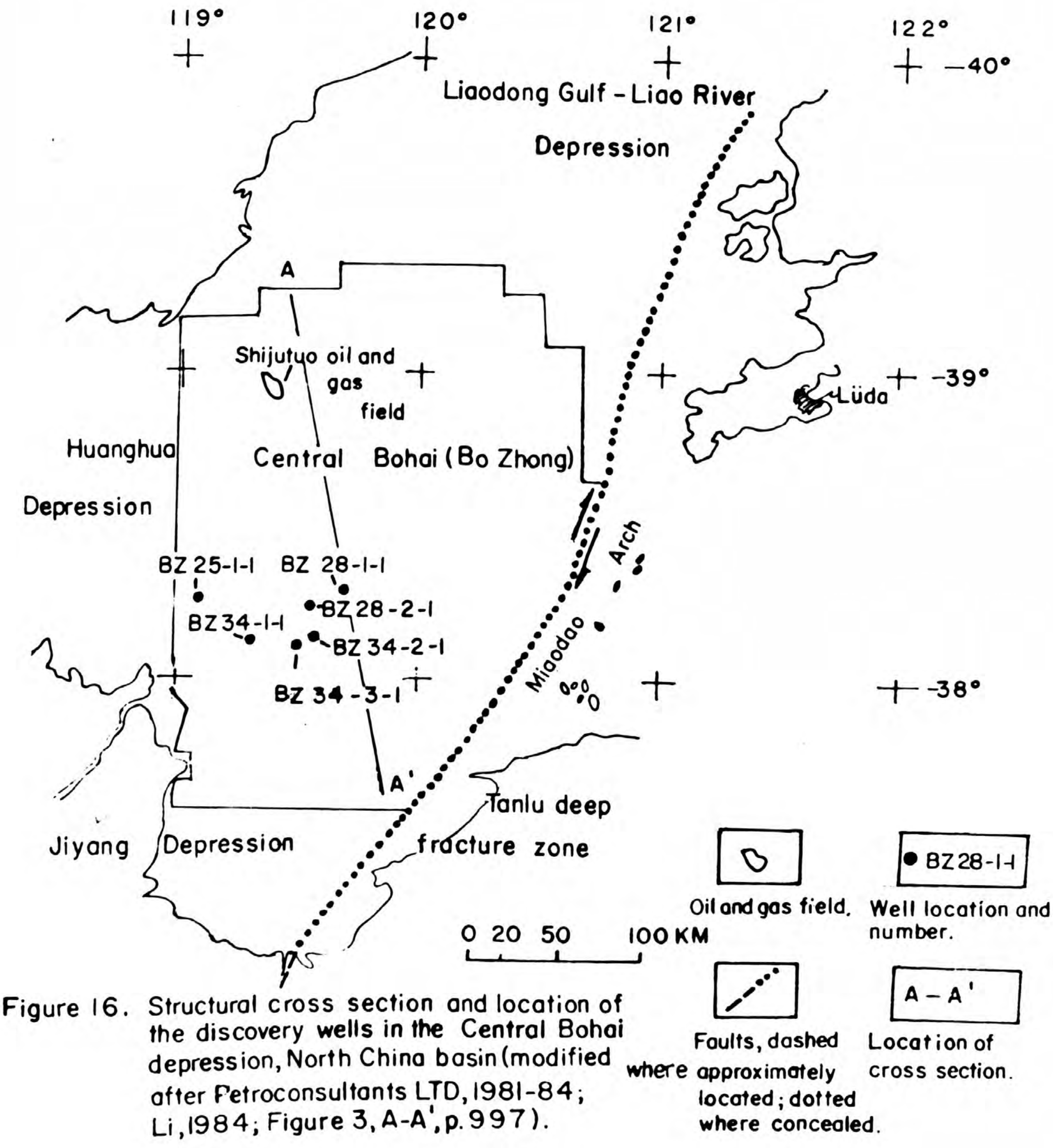


Figure 16. Structural cross section and location of the discovery wells in the Central Bohai depression, North China basin (modified after Petroconsultants LTD, 1981-84; Li, 1984; Figure 3, A-A', p. 997).

7,270 m are confined to the Tertiary sequences. Paleogene sediments attain a maximum thickness of 5,750 m. Pre-Tertiary sedimentary rocks are about 2,710 m thick (table 2). Li Jiaqi (1984) identified 13 potential oil- and gas-bearing sags and 10 buried-hill types of reservoirs in the Central Bohai. These sags are separated from each other by uplifts. The depth to the top of the buried-hill reservoirs is generally less than 3,000 m (Li, 1984, p. 23).

Source Rocks

In the Central Bohai depression, principal source rocks consist of lacustrine and paludal swamp deposits of dark-gray mudstone, shale, and oil shale of the Paleogene Kongdian, Shahejie, and Dongying Formations. The third, first, and fourth members of the Shahejie, however, contain the major oil and gas generating strata (Petroconsultants LTD, 1983; Xu and others, 1983).

Secondary source rocks are grayish-green mudstone and shale of Cretaceous and Jurassic ages and coal beds of Permian and Carboniferous ages. Hu and others (1982) inferred that oil and gas generated from the coal series is present throughout the Central Bohai depression, as indicated by oil seeps and asphalt deposits from the coal-bearing formations in nearby areas. Oil and gas also may have been generated from Ordovician and Cambrian carbonate rocks of the depression.

Reservoir rocks

During the past several years, the Japan-China Oil Development Corporation and the China Petroleum Corporation have intensely explored the Central Bohai depression and have discovered oil and gas pools in the Tertiary, Cretaceous, and Jurassic sandstone, in Tertiary basalts and andesite, and in Paleogene, Ordovician and Cambrian limestone and dolomite (Petroconsultants LTD, 1981, 1983 and 1984). The potential reservoir rocks of the depression are the sandstone, conglomeratic sandstone, and volcanic rocks; the Upper Proterozoic dolomite and limestone; and the Archean plutonic and metamorphic rocks (table 2) (fig. 16) (Li Desheng, 1984).

The Tertiary sandstone reservoirs of the Central Bohai are present in the following discovery wells: Bo Zhong 34-1-1 (lat 38°08'17" N; long 119°19'16" E), Bo Zhong 34-2-1 (lat 38°08'00" N.; long 119°34'00" E.), Bo Zhong 34-3-1 (lat 38°06'15" N.; long 119°30'23" E.), and Bo Zhong 28-2-1 (lat 38°14'N.; long 119°32' E.) (fig. 16). Of these wells, the 3,823 m-deep Bo Zhong 34-2-1 with a net reservoir thickness of 83 m shows better initial test results. The test flow rate from the Bo Zhong 34-2-1 is about 12,200 BOPD and 6,700 MCFGD with a gas/oil ratio of 550 scf/bbl (Petroconsultants LTD, 1983). Oil and gas have accumulated in both structural and stratigraphic traps.

The Tertiary limestone, basalt, and andesite reservoirs are located in the Shijutuo field (Petroconsultants LTD, 1984) (fig. 16). According to Petroconsultants LTD (1984), the Shijutuo field (lat 38°56'24" N.; long 119°23'04" E.) is still being developed and is presently 1.2 km in length. The Bo Zhong 2 well in the Shijutuo field, drilled in 1975, has a total depth of 3,097 m. Here the Tertiary limestone, basalt, and andesite have been fractured and produce oil and gas from have a 30-m thick reservoir interval. The initial test flow rate of the Bo Zhong 2 well is 1,120 BOPD and 1,300 MCFGD. In 1976, production tests from the single-well No. 9 platform were reported to yield 3,322 BOPD. In 1981, the 7-well No. 10 platform, located 1.2 km to the west, yielded 7,300 BOPD in production tests. The oil output from a single well completed in the basalt and andesite reservoir was reported to be 700 to 2,000 BOPD. Porosity in the igneous reservoirs is produced by well developed fractures and fumaroles. The API gravity of the oil is 27° and the gas/oil ratio is 1,160 cf/bbl (Petroconsultants LTD, 1984).

The Cretaceous and Jurassic sandstone reservoir of the Central Bohai depression is located in the Bo Zhong 25-1-1 well (lat 38°15'51" N.; long 119°06'02"E.). The Bo Zhong 25-1-1 well was discovered in 1981 and is currently being evaluated (Petroconsultants LTD, 1981). The depth to the top of the reservoir is 3,355 m, and the maximum thickness of the reservoir is reported to be 4 m. The initial flow rate in this well was 2,628 BOPD and 953 MCFGD (Petroconsultants LTD, 1981).

In 1981, oil and gas were discovered in a buried hill of the Ordovician and Cambrian limestone by the Bo Zhong 28-1-1 well (lat 38°17'N.; long 119°45' E.) (Petroconsultants LTD, 1981). The total depth of this well is 3,334.5 m. The depth to the top of the reservoir is 2,975 m, and the gross thickness of the reservoir interval is 323 m. The interval between 3,200 and 3,300 m had an initial flow rate of 7,600 BOPD (Petroconsultants LTD, 1981). This offshore discovery has a production potential of about 200,000 to 300,000 BOPD (Petroconsultants LTD, 1981).

Liaodong Gulf-Liao River Depression

The Liaodong Gulf-Liao River depression is a graben system located along the lower reach of Liao He River and most of the Liaodong Gulf in the extreme northern part of the North China basin (figs. 2 and 17). This depression covers about 34,000 km^2, of which about 12,400 km^2 is occupied by the lower reach of the Liao He (Zheng, 1984, p. 1). The maximum sedimentary fill in the depression is 14,540 m of which about 7,270 m is confined to the Tertiary sequence. The maximum thickness of Paleogene sedimentary rocks is 5,750 m (table 2). The pre-Tertiary strata are about 4,790 m thick (table 2), and the Quaternary sediments are about 727 m thick (Institute of Geology, Academia Sinica, 1958). During the past decade, petroleum exploration and development have been concentrated along the lower part of the Liao He River. The lower reach of the Liao He consists of the eastern, western, and Damintun sags of which the eastern and western sags are separated by a central rise of Archean granite (fig. 17). The principal producing oil and gas fields are located in the western sag, and the Damintun sag are controlled by a series of northeast-trending normal fault blocks(fig. 17).

Source Rocks

In the lower part of the Liao He River depression, principal source rocks are the lacustrine dark-gray mudstone and oil-shale of the Paleogene Shahejie and Dongying Formations. The third, fourth, and first members of the Shahejie Formation contain the major oil and gas source rocks (Zheng, 1984, p. 13-14; Wu, 1982, p. 154). Secondary source rocks in this depression are the black,

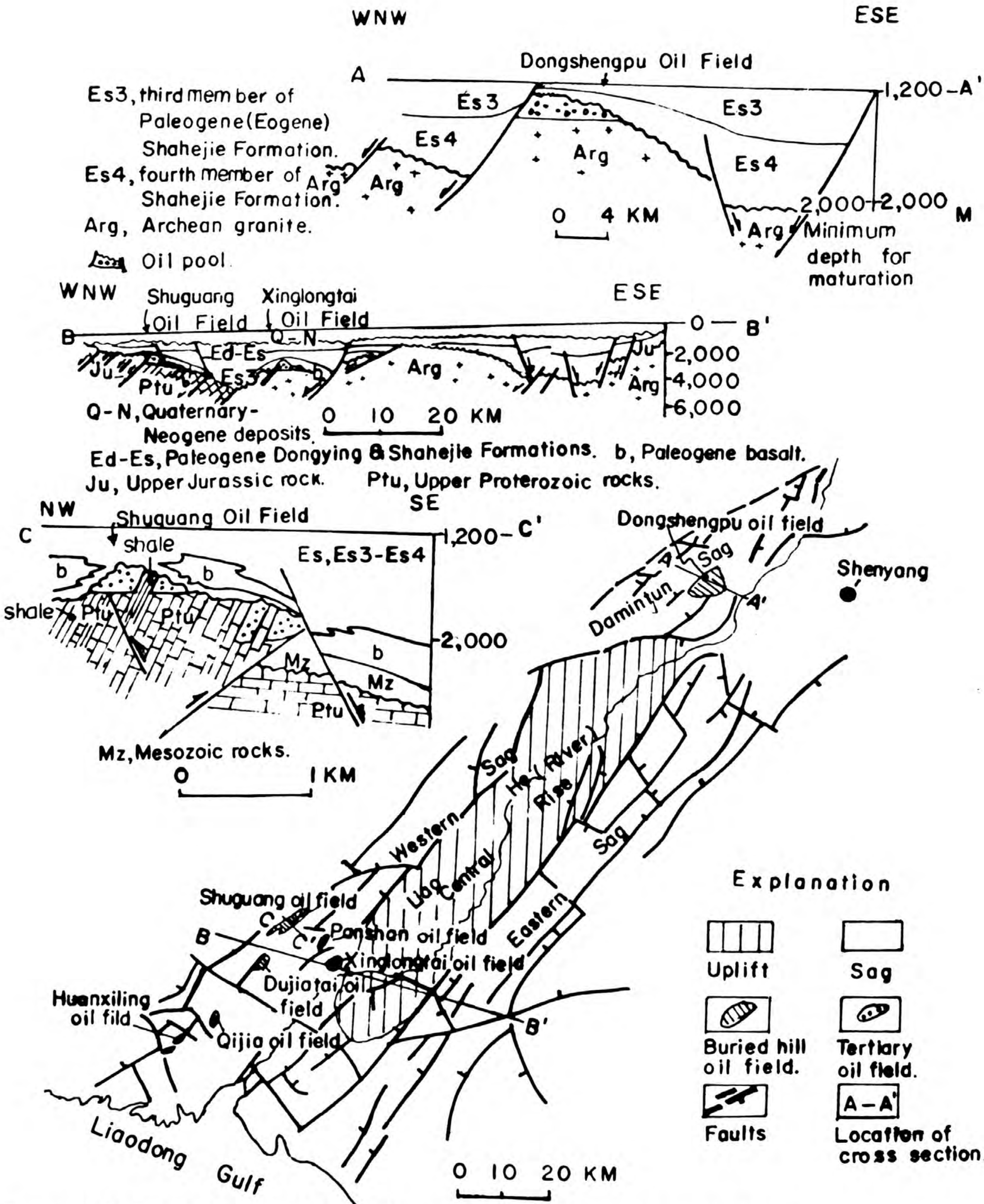


Figure 17. Principal structural units, oil field distribution, and cross sections in the low reach of Liao He (River) of the Liaodong Gulf-Liao River depression, North China basin (modified after Zheng, 1984; Figures 1, 2, 3, & 4, p. 3-7).

grayish-green mudstone and shale of Cretaceous and Jurassic ages and coal beds of Permian and Carboniferous ages. The source rocks in the Shahejie Formation are reported to be more than 1,750 m thick over 65 to 85 percent of the depression (Zheng, 1984, p. 14). In these source rocks, the organic carbon content ranges from 1.74 to 2.81 weight percent; the asphalt extract content is from 547 to 1,029 ppm; the total hydrocarbon content ranges from 150 to 1,428 ppm; the hydrocarbon/organic carbon ratio ranges from 1.07 to 3.42 percent, and reduced sulfur is generally more than 0.5 percent (Zhang, 1984, p. 14). The kerogen consists of the sapropel type I and mixed humus-sapropel type II (Zheng, 1984). Wu and Lu (1983, table 2, p. 21) indicated that the peak generation of oil occurred between the depths of 2,000 and 2,400 m. The geothermal gradient in C° per 100 m, ranges from 3.29° to 4.65°C in the western part of the depression and from 3.5° to 4.04°C in the eastern part of the depression (fig. 17). Wang and others (1983, p. 121, table 2-4-23) recognized a maximum geothermal gradient of 5°C/100 m. The variation in geothermal gradient is due to local igneous activity which had accompanied sedimentation of the Tertiary source rocks (Wu and Lu, 1983).

By means of a comparison of oil extracts and crude oils, pristane/phytane ratios and total hydrocarbon chromatography suggest that the oil accumulations in the depression were generated from the source rocks of the Paleogene Shahejie Formation (Zheng, 1984, p. 14).

Reservoir rocks

The principal reservoir rocks in the Liaodong Gulf-Liao River depression are: 1) sandstone of the Kongdian, Shahejie, Dongying, and Guantao Formations, 2) Cretaceous and Jurassic andesite, tuff, and volcanic breccia, 3) Upper Proterozoic dolomite, dolomitic limestone, and quartzite, and 4) Archean granite. The potential reservoir rocks are Permian and Carboniferous sandstone and volcanic rocks and Paleogene, Ordovician-Cambrian, and Upper Proterzoic limestone and breccia (table 2) (fig. 17) (Zheng, 1984; Ma and others, 1982; Zhai and Zha, 1982). The most productive oil and gas reservoirs in this depression are the carbonate rock, volcanic rock, quartzite, and granite located in the buried hill accumulations of the Qijia, Shuguang, Dujiatai, Dongshengpu, and Xinglongtai oil fields (fig. 17) (Zheng, 1984, fig. 1, p. 3).

The Tertiary sandstone reservoir is located in the Panshan oil field (lat 41°10' N.; long 122°00' E.) (Petroconsultants LTD, 1981) (fig. 17). This field was discovered in 1964, and was developed over a 100-km^2 area between 1969 and 1975. By 1976, the average yield per well was 354 BOPD (Petroconsultants LTD, 1981).

The Cretaceous and Jurassic andesite and tuff reservoirs are located in the buried-hill of the Oijia oil field (Zheng, 1984. fig. 1, p. 3) (fig. 17). The andesite and tuff of the buried-hill accumulation contain numerous fractures, fumaroles and isolated caves. The bulk porosity of these rocks is given to be greater than 10 percent, and the permeability is less than 1 md (Zheng, 1984, p. 13).

The upper Proterozoic dolomite and quartzite reservoirs are located in the Shuguang and Dujiatai buried-hill oil fields (fig. 17).

The Shuguang oil field was discovered in 1979 and covers 25 km^2 (fig. 17). Dolomite of Upper Proterozoic age is the principal reservoir rock. The initial yield per well in the Shuguang field was 4,260 BOPD. New discovery wells drilled in the northwestern part of Shuguang field in 1982 had initial yields of 700 BOPD per well (Zheng, 1984).

Reservoir porosity in dolomite ranges from 6.1 to 20.7 percent, and the gas permeability is as much as 1,092 md (Zheng, 1984; p. 9). The upper part of the dolomite generally is intensely leached. The leached zone overlies a solution-fracture zone characterized by a criss-cross network of fractures and paternoster-shaped cavities at the intersections of the fractures. The solution-fracture zone forms the most productive part of the buried-hill oil and gas pools in the Liaodong Gulf-Liaó River depression.

The Shuguang buried-hill oil pools are located on a horst block which has been covered by Paleogene source beds of the third and fourth members of the Shahejie Formation. This horst block is bounded on the west by a pre-Tertiary west-dipping, northeast-trending normal fault and on the east by a Tertiary north-dipping normal fault (Zheng, 1984, p. 6-7) (fig. 17). The horst block was broken by two intersecting pre-Tertiary upthrust faults (fig. 17). On the west and east flanks of the buried-hill, the Shahejie source beds directly overlie Paleogene basalt, which locally unconformably overlies Cretaceous and Jurassic breccia. The reservoir dolomite is intercalated with sandy dolomite, shale, marlstone, quartzose sandstone, and conglomerate and generally dips northwestward at about 41°. The shale and marl form excellent seals, which have partitioned the Shuguang field into four reservoirs identified as Shugu 1 and Shugu 40 in the east and Shugu 112 and Shugu 98 in the west (Zheng, 1984, p. 6) (fig. 17).

The Shugu 1 and Shugu 40 dolomite reservoirs are divided by marlstone beds. Here the depth to the top of the pay is 1,684 m, the depth to the oil-water contact is 2,000 m, the gross thickness of the reservoir is about 316 m, and the production rate of a single well ranges from 700 to 4,260 BOPD (Zheng, 1984, p. 6-7). In the west, the Shugu 98 and Shugu 112 sandy dolomite, quartzose, sandstone, and conglomerate reservoirs are separated by black shale beds. Here the depth to the top of the pay is 1,401 m, the depth to the oil-water contact is 1,630 m, the gross thickness of the reservoir is about 229 m, and the production rate of a single well ranges from 350 to 700 BOPD (Zheng, 1984, p. 7).

The Dujiatai oil field was discovered in 1980, and quartzite is the principal reservoir rock. The initial yield per well in this field ranges from 700 to 1,400 BOPD (Zheng, 1984, p. 2). The quartzite contains numerous fractures. Zheng (1984, p. 12) estimated from thin sections that the bulk porosity of the quartzite ranges from 0.4 to 7.7 percent, and the air permeability through the quartz intergranular-pore spaced ranges from 5 to 10 md. Microfractures between 79 and 290 microns wide occupy 60 to 100 percent of the quartzite reservoir (Zheng, 1984, p. 2).

The Archean granite reservoirs are located in the Xinglongtai and Dongshengpu buried-hill oil and gas fields (fig. 17).

The Xinglongtai oil and gas field, discovered in 1972, consists of gas-capped buried-hill oil pools in the deeply weathered Archean granite, Cretaceous and Jurassic breccia, and Paleogene conglomerate of the third member of the Shahejie Formation. The oil and gas accumulations are sealed by a normal fault along the northwest flank of the field (Zhai and Zha, 1982, fig. 8, p. 3-6). Initial production from this field was 210 to 700 BOPD and 3,531,000 CFGPD (Zheng, 1984, p. 2). Zhai and Zha (1982, p. 3-6) mentioned that the granite reservoirs of the buried-hill pools produce about 420 BOPD per well. Zheng (1984, p. 13) estimates the porosity of the deeply weathered and highly fractured gneissic granite to be 8 percent.

The Dongshengpu oil and gas field was discovered in 1983. Granite is the principal reservoir in this buried-hill oil and gas pool. This field is controlled by a horst block which is bounded by a Mesozoic-Paleogene normal fault with a 1,400-m displacement on the west and by a northeast-trending Late Paleogene normal fault with about 200 to 400 m of displacement on the east (fig. 17) (Zheng, 1984, fig. 3, p. 5). Generally the minimum depth to the top of the production is 2,600 m. The closure of the buried hill granite is 800 m across an area of 15 km^2 (Zheng, 1984, p. 4). The entire reservoir is covered by blackish-gray source beds of the third and fourth members of the Paleogene Shahejie Formation. Zheng (1984, p. 13) estimates that the porosity of the weathered, gneissic granite reservoir is 8 percent. The daily output from a single well, Sheng 11, was 10,500 BOPD and 3,354,450 CFGPD (Zheng, 1984, p. 2).

Potential

The North China basin covers about 213,000 km^2 in which 94,400 km^2 is occupied by the six principal producing depressions. An estimate of sediment fill in these six depressions is 472,000 km^3, which represents about 56 percent of the total sedimentary volume fill. Adequate quantities and richness of the source rocks appear to be present throughout the North China basin. On the basis of a statement given by Gan, Li, and Zhan (1982), the author roughly estimates that the total discovered crude oil reserves in the North China basin amount to about 14×10^9 barrels of oil versus an undiscovered amount of 3×10^9 barrels of oil, which are located chiefly in the Jizhong, Jiyang, Huanghua, and Central Bohai depressions. The total ultimate recoverable reserves are estimated to be about 7×10^9 barrels of oil, which are principally from the Jizhong, Jiyang, and Huanghua depressions and the lower part of the Liao He River of the Liaodong Gulf-Liao River depression. Significant gas resources are shown in the southern part of the North China basin.

Coal

General Statement

The coal deposits of the North China basin occur chiefly in the Permian and Carboniferous sequence and locally in the Cretaceous and Jurassic sequence in the Jizhong, Central Bohai, and Liadong Gulf-Liao River depressions (table 2) (fig. 3). Both the Permian and Carboniferous and the Cretaceous and Jurassic coal-bearing sequences were found in the basin during exploratory drilling for petroleum (fig. 18). The discussion of the stratigraphy of these coal-bearing sequences is based chiefly on information obtained from coal mining areas around the perimeter of the basin (Department of Coal Teaching and Researches, Wuhan College of Geology, 1981; Han and Yang, 1980).

Occurrence

The Permian and Carboniferous coal series is composed of the Late Carboniferous Benxi and Taiyuan Formations, the Early Permian Shanxi and Lower Shihezi Formations, and the Late Permian Upper Shihezi Formation (table 4). The deposition environments of these coal-bearing formations are listed in Table 4.

Table 4.--Permian and Carboniferous stratigraphy of the North China basin (modified after Department of Coal Teaching and Researches, Wuhan College of Geology, 1981, v. 2, Table III-8, p. 49; Han and Yang, 1980, v. 2, p. 101-152).

System	Series	Formation	Depositional Environment
Permian	Late Permian	Shiqianbeng	Continental red beds
		Upper Shihezi	Chiefly continental lithofacies, locally interfingering with continental and marine transitional facies during southward regression of the sea in Permian time. Fluvial, lake, marsh, and swamp deposits in north and deltaic littoral marine, lagoonal, and neritic marine in south.
	Early Permian	Lower Shihezi	
		Shanxi	Regressive deposits of neritic to littoral marine, lagoonal, deltaic, fluvial, lake, marsh, and swamp environments.
Carboniferous	Late Carboniferous	Taiyuan	Transgressive deposits of shallow marine littoral, lagoonal, deltaic, fluvial, lake, marsh, and swamp environments.
		Benxi	Transgressive deposits. Shallow sea and littoral marine enviornments.

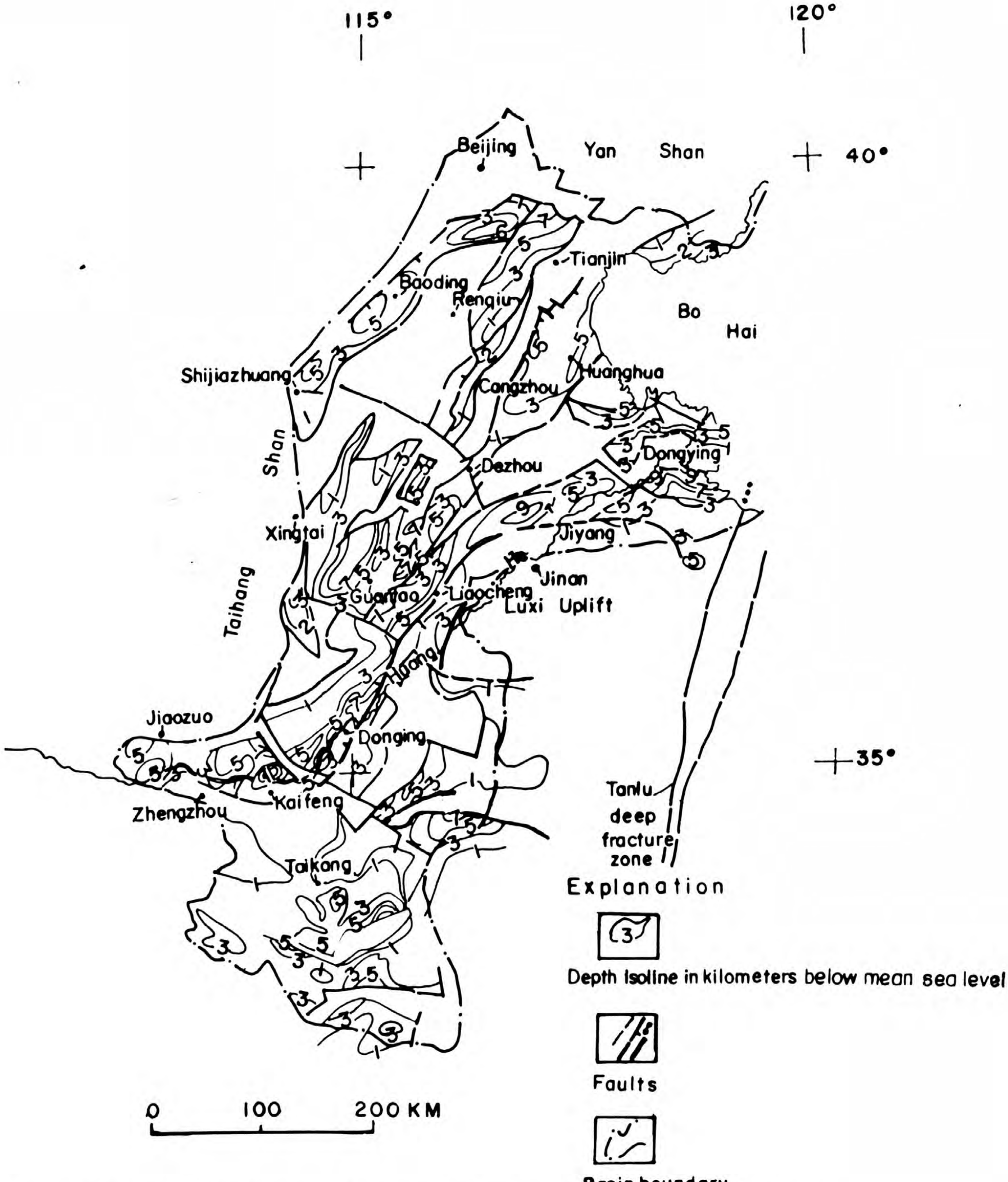


Figure 18. Depth isolines to the top of the Permian and Carboniferous strata in principal part of the North China basin (modified after Chang and others, 1981; Figure 1, p. 342).

Prior to the deposition of the Late Carboniferous Benxi Formation, the area of the present-day North China basin was a large landmass which had been exposed since Late Ordovician time. In early Late Carboniferous time, the Benxi sea encroached from the east and covered most of the area of the present-day North China basin. Detrital sediments derived from the surrounding highlands were deposited in shallow marine and littoral marine environments. In the North China basin, the Benxi Formation consists of 80 to 120 m of sandstone, siltstone, and mudstone intercalated with coal beds and local fossiliferous limestone (Department of Coal Teaching and Researches, Wuhan College of Geology, 1981, v. 2, p. 58; Han and Yang, 1980, p. 107-110).

Throughout the North China basin, the Taiyuan coal-bearing sequence was deposited during the transgression of the Carboniferous sea and the regression of the Permian. The Taiyuan Formation generally consists of 30 to 70 m of sandstone, siltstone, mudstone, and marlstone intercalated with fossiliferous limestone and thin- to thick-bedded coal of littoral marine to transitional marine origin. The Taiyuan Formation contains the best quality commercial bituminous coal deposits in the North China basin. The coal beds, which are concentrated in the northern, western, and southern parts of the basin, generally range in thickness from 5 to 10 m. Large coal mines with thick coal beds in the Taiyuan Formation are located near the basin border in the Hebei, Henan, and Shandong provinces (figs. 3 and 19).

During the Early Permian, the Late Carboniferous sea withdrew toward the south and the Shanxi coal-bearing sequence was deposited conformably on the Taiyuan Formation. In the North China basin, the Shanxi Formation is continental to transitional marine in origin and consists of less than 100 m of sandstone intercalated with siltstone, mudstone, and local beds of limestone and lenticular mudstone in the upper part of the sequence. These detrital sedimentary rocks generally contain coal beds 3 to 10 m thick that were deposited in fluvial channel, overbank, lacustrine, marsh, swamp, lagoonal, and coastal deltaic environments. Mineable, good quality bituminous coal beds in the Shanxi Formation occur in the northern, western, and southern parts of the North China basin (Department of Coal Teaching and Research, Wuhan College of Geology, 1981, v. 2, fig. III-60, p. 65) (fig. 19).

During late Early Permian to early Late Permian time, the coal-bearing sedimentary rocks of the Lower Shihezi and Upper Shihezi Formations were deposited. Generally, the Shihezi Formation conformably overlies the Shanxi Formation. In most of the North China basin, the Shihezi Formation consists of continental detrital sedimentary rocks with thin coal beds. Mineable coal beds are confined to the continental and transitional marine sequences in the southern part of the basin (Department of Coal Teaching and Researches, Wuhan College of Geology, 1981, v. 2, p. 64-67). The coal-bearing sequences of the Shihezi Formation in the southern part of the basin are near the southern and southeastern borders of the basin and confined chiefly to Henan province where they are extensively mined (fig. 3). The coal beds are generally 5 to 10 m thick but locally may be 10 to 30 m thick.

During the early Mesozoic, most of the area of the present-day North China basin was an emergent landmass, but from Late Jurassic through Cretaceous, time, the landmass was broken by northeast-trending extensional faults, which formed numerous small and shallow depressions throughout the basin. These

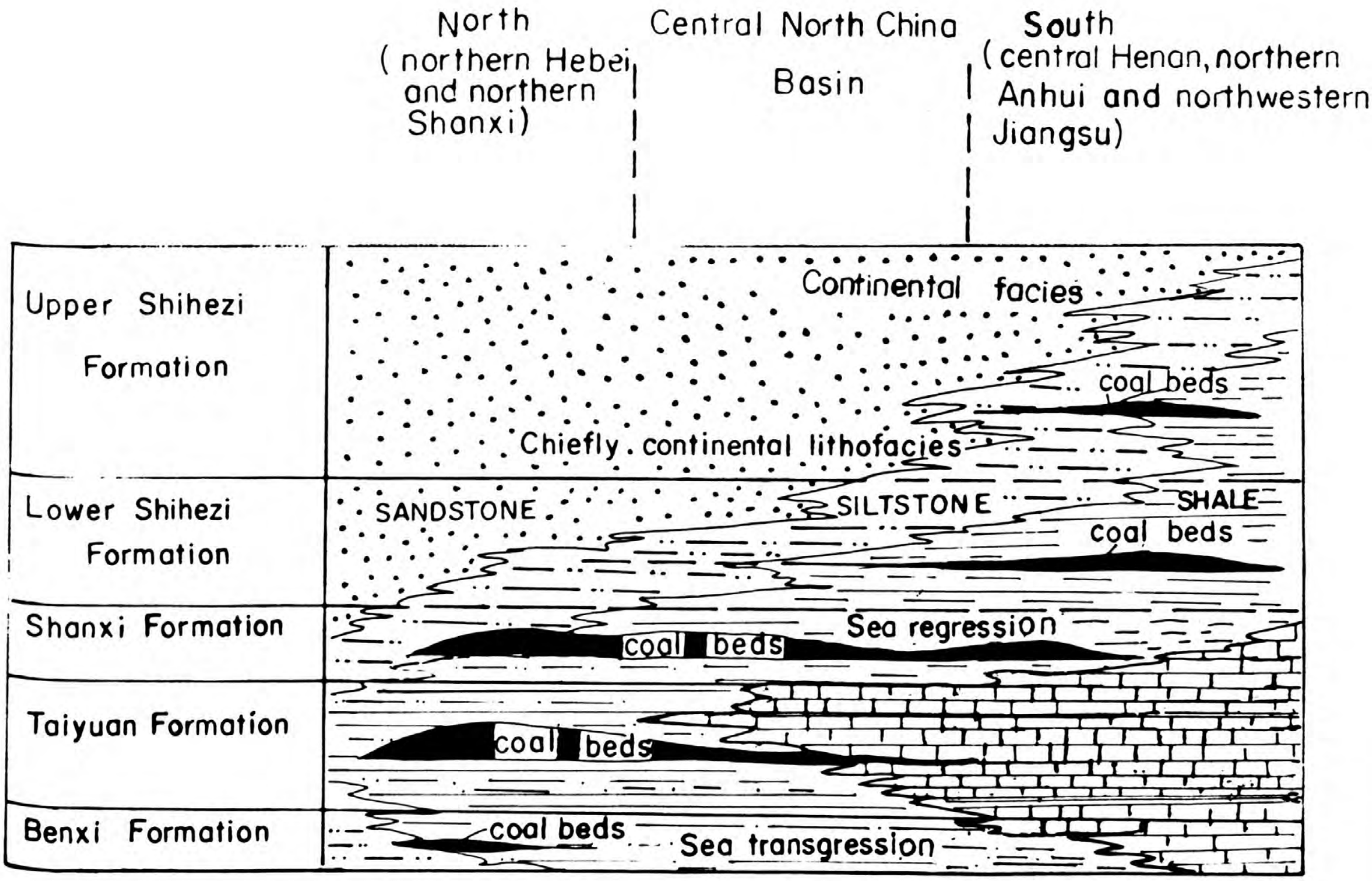


Figure 19. Schematic profile showing the lithofacies distribution of the Permian and Carboniferous coal series in principal part of the North China basin (modified after Han and Yang, 1980; Figure 4-38, p. 144).

depressions were filled with molasse deposits composed of detrital sedimentary rocks, volcanic flows, and local thin coal beds (Hu and others, 1982).

Potential

High quality bituminous and anthracite coals of Permian and Carboniferous age are concentrated in the northern, western, and southern parts of the basin. Generally, the burial depth to the top of the Permian and Carboniferous sequence ranges from about 1,500 m to more than 6,000 m (Chang and others, 1981) (figs. 3 and 18). Most of the mineable coal beds are deeper than 1,800 m (6,000 ft) and therefore are excluded from coal resource consideration (Wood and others, 1983; p. 23-24). Nevertheless, coal beds in the Permian and Carboniferous systems have been the major source beds for natural gas in the Dongpu-Kaifeng depression (figs. 10 and 11) (Zhu and Xu, 1984). Based on guidelines for classification and estimation of coal resources (Wood and others, 1983, p. 32-38), total Permian and Carboniferous coal resources in the North China basin are estimated to be 170 billion metric tons, which represents approximately more than one-third of the total coal resources in northern China (International Petroleum Encyclopedia, 1985, p. 30).

SUMMARY AND CONCLUSIONS

The intracratonic North China basin was initiated by differential rifting and regional block faulting, accompanied by gravity slumping, during the latest episode of the Yanshanian orogeny in Late Cretaceous to early Paleogene time. Geophysical data and igneous activity in the region suggest that the extension was caused by upward advection of the asthenosphere. As a result of the high geothermal gradients in the basin, source rocks of the Paleogene Shahejie Formation reached an early maturation. Later, during the late Paleogene and early Neogene, oil and gas migrated from the source rock through permeable detrital rocks and along fractures, faults, and unconformities.

Thick coal beds in the southern Permian and Carboniferous sequence are the major source rocks for natural gas. The gas fields in the Dongpu-Kaifeng depression can help to guide further exploration for additional gas resources in the Dongpu-Kaifeng depression and many adjacent depressions of the region.

Tertiary delta-front sandstone, Upper Proterozoic Cambrian and Ordovician dolomite, and Archean granite are the dominant reservoirs in the basin. The dolomite and granite reservoirs are situated in fault-controlled buried hills that are covered by source beds of the Paleogene Shahejie Formation. Future discoveries from buried-hills of the Archean granite are likely in the offshore part of the Liaodong Gulf-Liao River, Central Bohai (Bo Zhong), and Jiyang depressions. Future oil may also be found in the buried-hills of Lower Proterozoic and Upper Proterozoic dolomite in the Jizhong and Huanghua depressions.

Most of the coal beds are generally excluded as an energy resource because the overburden is very thick. Nevertheless, coal-bed methane may be a major gas resources, especially in the southern part of the basin.

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