Shahejie–Shahejie/Guantao/Wumishan and Carboniferous/Permian Coal–Paleozoic Total Petroleum Systems in the Bohaiwan Basin, China (based on geologic studies for the 2000 World Energy Assessment Project of the U.S. Geological Survey)

Scientific Investigations Report 2011–5010

U.S. Department of the Interior
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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

On the cover: Bohaiwan basin (outlined in red) in a regional setting. From Allen and others (1997).

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[Tables 1–15 follow References Cited]

Conversion Factors

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
barrel (bbl) (petroleum, 1 barrel = 42 gal)	0.1590	cubic meter (m^3)
gallon (gal)	0.003785	cubic meter (m^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	6.290	barrel (bbl) (petroleum, 1 barrel = 42 gal)
cubic meter (m^3)	264.2	gallon (gal)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Letter Symbols for Units of Measure

BBO	billion barrels of oil (bbl × 10^9)
BBOE	billion barrels of oil equivalent
BOE	barrel of oil equivalent
TCFG	trillion cubic feet of gas
T	metric ton

Definitions

Thousand	$=10^3$
Million	$=10^6$
Billion	$=10^9$
Trillion	$=10^{12}$

1 BOE	=1 barrel of crude oil (42 gallons)
	=6,000 cubic feet of natural gas
	=1.5 barrels of natural gas liquids

Shahejie–Shahejie/Guantao/Wumishan and Carboniferous/Permian Coal–Paleozoic Total Petroleum Systems in the Bohaiwan Basin, China (based on geologic studies for the 2000 World Energy Assessment Project of the U.S. Geological Survey)

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Foreword

This report was prepared as part of the 2000 World Energy Assessment Project of the U.S. Geological Survey (USGS). For this project, the world was divided into 8 regions and 937 geological provinces. The provinces were then ranked according to the discovered oil and gas volumes within each (Klett and others, 1997). Then, 76 "priority" provinces (exclusive of the United States and chosen for their high ranking) and 52 "boutique" provinces (exclusive of the United States and chosen for their anticipated petroleum richness or special regional economic importance) were selected for appraisal of oil and gas resources. The petroleum geology of these priority and boutique provinces is described in this series of reports.

The purpose of this effort is to aid in assessing the quantities of oil, gas, and natural gas liquids that have the potential to be added to reserves within the next 30 years. These volumes either reside in undiscovered fields whose sizes exceed the stated minimum-field-size cutoff value for the assessment unit (variable, but must be at least 1 million barrels of oil equivalent) or occur as reserve growth of fields already discovered.

The total petroleum system, which constitutes the basic geologic unit of the oil and gas assessment, includes all genetically related petroleum that occurs in shows and accumulations (discovered and undiscovered) that (1) have been generated by a pod or closely related pods of mature source rock and (2) exist within a limited mappable geologic space, alone with the essential mappable geologic elements (source, reservoir, seal, and overburden rocks) that control the fundamental processes of generation, expulsion, migration, entrapment, and preservation of petroleum. The minimum petroleum system is that part of a total petroleum system encompassing discovered shows and accumulations together with the geologic space in which the various essential elements have been proved by these discoveries.

An assessment unit is a mappable part of the total petroleum system in which discovered and undiscovered fields constitute a single, relatively homogeneous population such that the chosen methodology of resource assessment based on estimation of the number and sizes of undiscovered fields is applicable. A total petroleum system may equate to a single assessment unit. If necessary, a total petroleum system may be subdivided into two or more assessment units if each assessment unit is sufficiently homogeneous in terms of geology, exploration considerations, and risk to assess individually.

A graphical depiction of the elements of a total petroleum system is provided in the form of an events chart that shows the times of (1) deposition of essential rock units; (2) trap formation; (3) generation, migration, and accumulation of hydrocarbons; and (4) preservation of hydrocarbons.

A numeric code identifies each region, province, total petroleum system, and assessment unit; these codes are uniform throughout the project and will identify the same type of entity in any of the publications. The code is as follows:

Example	
Region, single digit	**3**
Province, three digits to the right of region code	3**127**
Total petroleum system, two digits to the right of province code	3127**01**
Assessment unit, two digits to the right of petroleum system code	312701**01**

The codes for the regions and provinces are listed in Klett and others (1997).

Oil and gas reserves quoted in this report are derived from Petroconsultants' Petroleum Exploration and Production database (Petroconsultants, 1996) and other area reports from Petroconsultants, Inc., unless otherwise noted.

Figures in this report that show boundaries of the total petroleum system(s), assessment units, and pods of active source rocks were compiled by using geographic information system (GIS) software. Political boundaries and cartographic representations were taken, with permission, from the ESRI (Environmental Systems Research Institute) (1992) ArcWorld 1:3 million digital coverage; they have no political significance and are displayed for general reference only. Oil and gas field centerpoints, shown in these figures, are reproduced, with permission, from Petroconsultants (1996).

Abstract

This report discusses the geologic framework and petroleum geology used to assess undiscovered petroleum resources in the Bohaiwan basin province for the 2000 World Energy Assessment Project of the U.S. Geological Survey (U.S. Geological Survey World Energy Assessment Team, 2000). The report also refers to several later papers (published between 2001 and 2004) that offer additional perspectives.

Two total petroleum systems have been identified in the Bohaiwan basin of northeastern China. The Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System, the major total petroleum system in the basin, involves oil and gas generated from mature pods of lacustrine source rock. In general, the mature pods of source rock are associated with six major rift-controlled subbasins that from northeast to southwest are named as follows: (1) Liaohe, (2) Bozhong, (3) Huanghua, (4) Jiyang, (5) Jizhong, and (6) Linqing/Dongpu. The entire Bozhong subbasin and parts of the Huanghua and Liaohe subbasins are located in Bohai Bay. The term Bohai Bay as used in this report follows the usage of Hu and others (1989) and Hu and Krylov (1996). The primary source rock of the total petroleum system is Member 3 of the Eocene and Oligocene Shahejie Formation, and secondary source rocks are Member 2 of the Paleocene and Eocene Kongdian Formation, Members 4 and 1 of the Shahejie Formation, and Member 3 of the Dongying Formation. The majority of the oil and gas fields in the Bohaiwan basin are closely associated with the six subbasins and their mature source rock pods. The most productive sandstone reservoirs in the Bohaiwan basin are located in the Shahejie Formation (Members 1–4), Oligocene Dongying Formation (largely Members 2 and 3), and Miocene Guantao Formation. Also, the Bohaiwan basin has very productive carbonate reservoirs such as the Middle Proterozoic Wumishan Formation, Cambrian Fujunshan and Mentou Formations, and Ordovician Fengfeng and Majiagou Formations. Locally, Archean crystalline basement rocks are important oil reservoirs. Most oil and gas generated from the Shahejie and Kongdian Formations are trapped in large faulted roll-over anticlines, compaction (drape) anticlines, and tilted fault blocks (buried hills). Subtle traps consist of faulted anticlinal noses that may be associated with facies-change, unconformity, or diagenetic stratigraphic traps.

Two assessment units are defined in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System: (1) a Tertiary lacustrine assessment unit consisting of sandstone reservoirs interbedded with lacustrine shale source rocks and (2) a pre-Tertiary buried hills assessment unit consisting of carbonate reservoirs that are overlain unconformably by lacustrine shale source rocks.

The second total petroleum system identified in the Bohaiwan basin is the Carboniferous/Permian Coal–Paleozoic Total Petroleum System, a hypothetical total petroleum system involving natural gas generated from multiple pods of thermally mature coal beds in five of the six subbasins. Low-permeability sandstone in the Lower Permian Shanxi and Shihezi Formations and possibly Carboniferous coal beds are the reservoir rocks. Most of the natural gas is inferred to be trapped in continuous accumulations near the center of the subbasins. This total petroleum system is largely unexplored and has good potential for undiscovered gas accumulations. One assessment unit, coal-sourced gas, is defined in this total petroleum system.

Acknowledgments

Cumulative production and selected characteristics of oil and gas fields used in this report were obtained from unpublished Bohaiwan basin oil- and gas-field data (oil industry compilations, unpub. data, 1996). Moreover, English translations of the following volumes contained many fundamental facts and interpretations used in this report: (1) Shengli oil field (Editorial Committee of Petroleum Geology of the Shengli Oil Field, 1987) (hereinafter referred to as ECPG–Shengli, 1987); (2) Liaohe oil fields (Ge and Editorial Committee of Petroleum Geology of the Liaohe Oil Fields, 1989) (hereinafter referred to as Ge and ECPG–Liaohe, 1989); (3) Huabei oil field (Editorial Committee of Petroleum Geology of the Huabei Oil Field, 1987) (hereinafter referred to as ECPG–Huabei, 1987); (4) Dagang oil field (Editorial Committee of Petroleum Geology of the Dagang Oil Field, 1987) (hereinafter referred to as ECPG–Dagang, 1987); and (5) Oil- and gas-bearing areas on the continental shelf and its neighboring regions, part I, offshore Bohai (Editorial Committee of Petroleum Geology of Oil- and Gas-Bearing Areas on the Continental Shelf and its Neighboring Regions, 1987) (hereinafter referred to as ECPG–Continental Shelf, 1987).

Eric Morrissey, USGS (Reston, Va.), drafted and (or) revised all the figures used in the report except figure 2, which was drafted by Susan Walden, USGS (Denver, Colo.).

Introduction

The Bohaiwan basin (3127; USGS World Energy Assessment Project numeric code) in northeastern China is the largest petroleum-producing region in China (Klett and others, 1997). The basin consists of six rift-controlled subbasins (Liaohe, Bozhong, Huanghua, Jiyang, Jizhong, and Linqing/

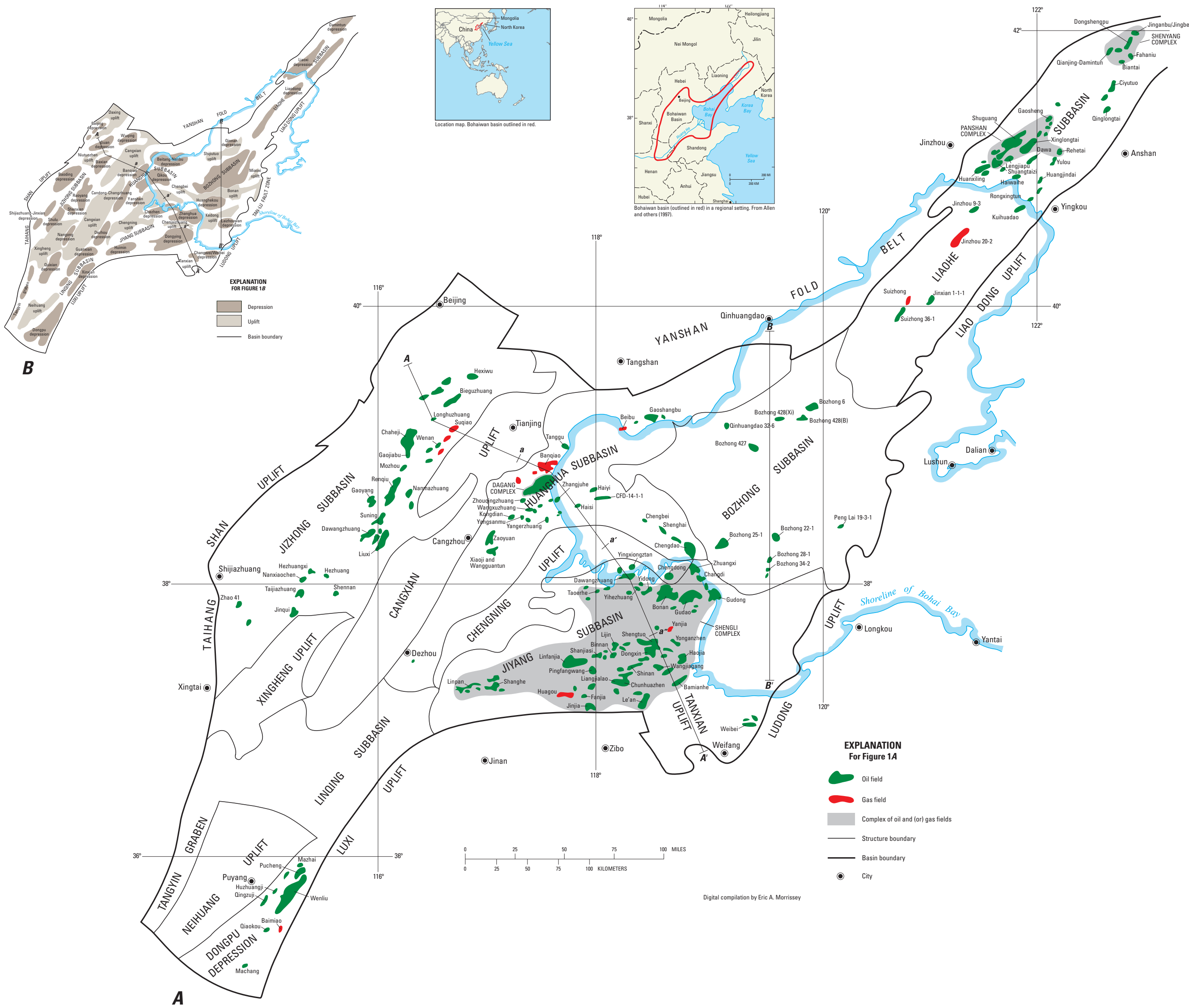


Figure 1. Maps of the Bohaiwan basin showing (*A*) selected oil and gas fields and structural domains and (*B*) structural depressions and uplifts. Figure 1*A* is from Hu and Krylov (1996). Figure 1*B* is from Chang (1991, fig. 1, p. 99) and Allen and others (1997, fig. 3, p. 954) and published with permission of Elsevier. Cross section *A–A′* is shown in figures 2*A* and *B*, and cross section *B–B′* is shown in figure 3. Due to differences in projection, scale, and accuracy of latitude-longitude grids, the location of some cities and features in this figure may not be consistent with their location in other figures in this report.

Dongpu[1]), all of which produce oil and gas (fig. 1*A*,*B*). These subbasins and several adjoining uplifts in the Bohaiwan basin are shown along with locations of oil and gas fields in figure 1. The general structural styles of the subbasins and adjoining uplifts in the Bohaiwan basin are shown on the geologic cross sections in figures 2 and 3. In addition, more than 50 smaller structural depressions (sags), commonly flanked by tilted fault-block uplifts (buried hills), are recognized throughout the basin (Chang, 1991; Allen and others, 1997).

Oil was first discovered in the Jiyang subbasin in 1961 at the giant Dongxin field. This field and approximately 72 additional fields subsequently discovered in the Jiyang subbasin constitute the large Shengli producing complex (Scott, 1990) (fig. 1*A*). In the early 1980s, exploration began in earnest in

[1] The Linqing subbasin at the south end of the Bohaiwan basin consists of the Dongpu, Guanxian, Quixian, and Xinxian depressions and the Tangyin graben (figs. 1*A*,*B*). For discussion purposes, the Linqing subbasin and the oil- and gas-bearing Dongpu depression are combined in this study and called the Linqing/Dongpu subbasin.

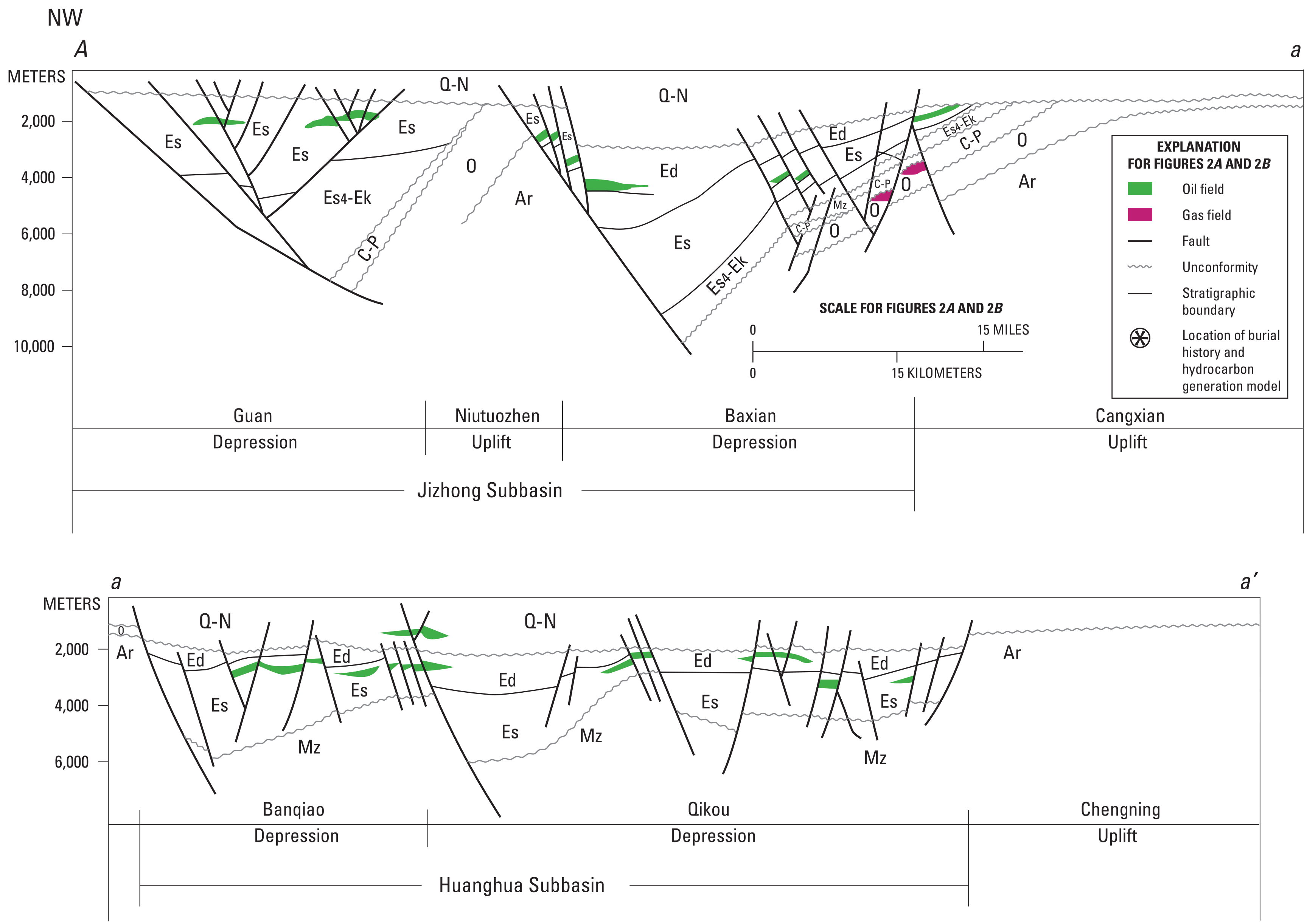


Figure 2*A*. Northwest part of geologic cross section *A–A′* through the Jizhong, Huanghua, and Jiyang subbasins in the Bohaiwan basin (from Hu and Krylov, 1996). See figure 1 for the line of section and figure 2*B* for the explanation of formations.

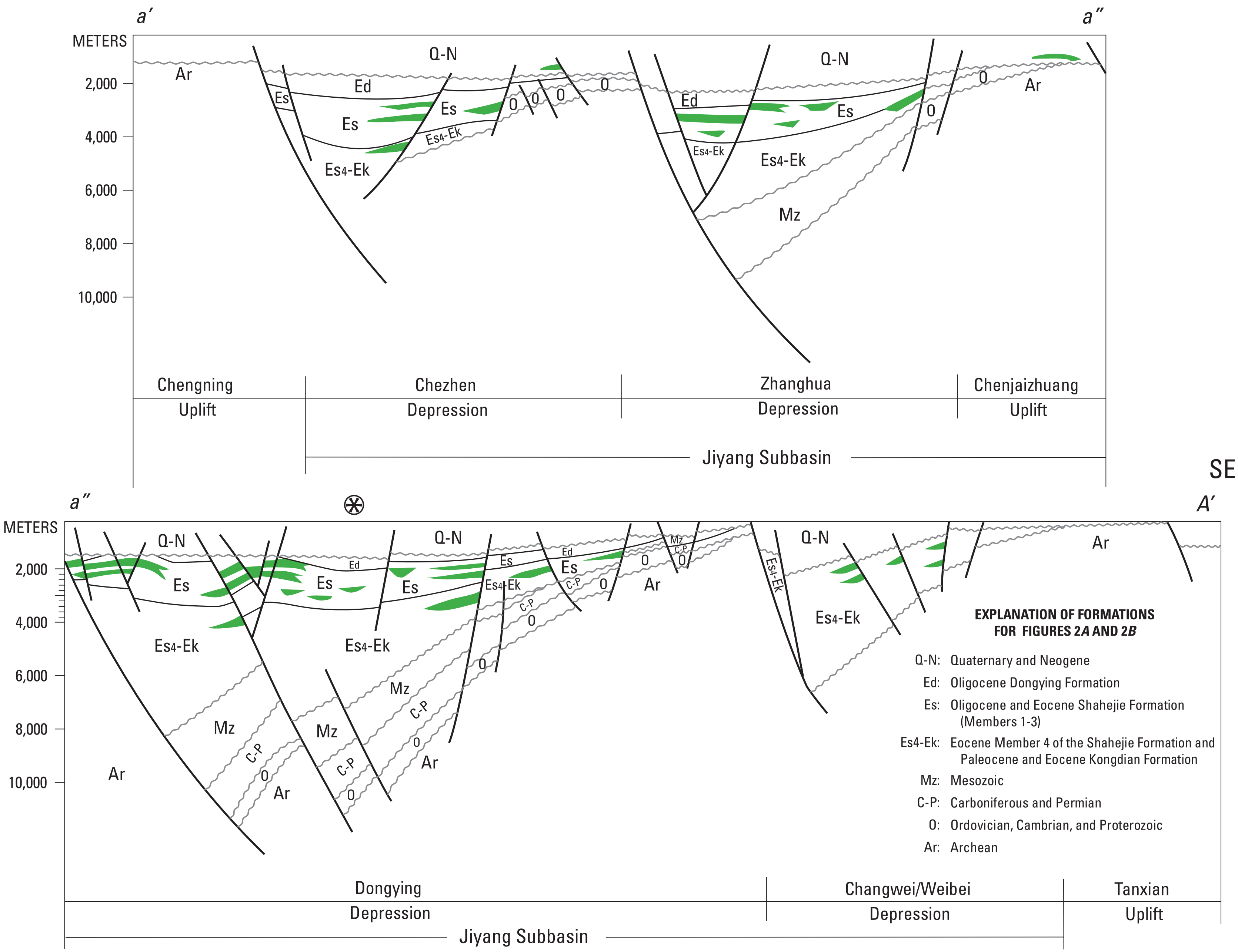


Figure 2*B*. Southeast part of geologic cross section *A–A′* through the Jizhong, Huanghua, and Jiyang subbasins in the Bohaiwan basin (modified from Hu and Krylov, 1996). See figure 1 for the line of section.

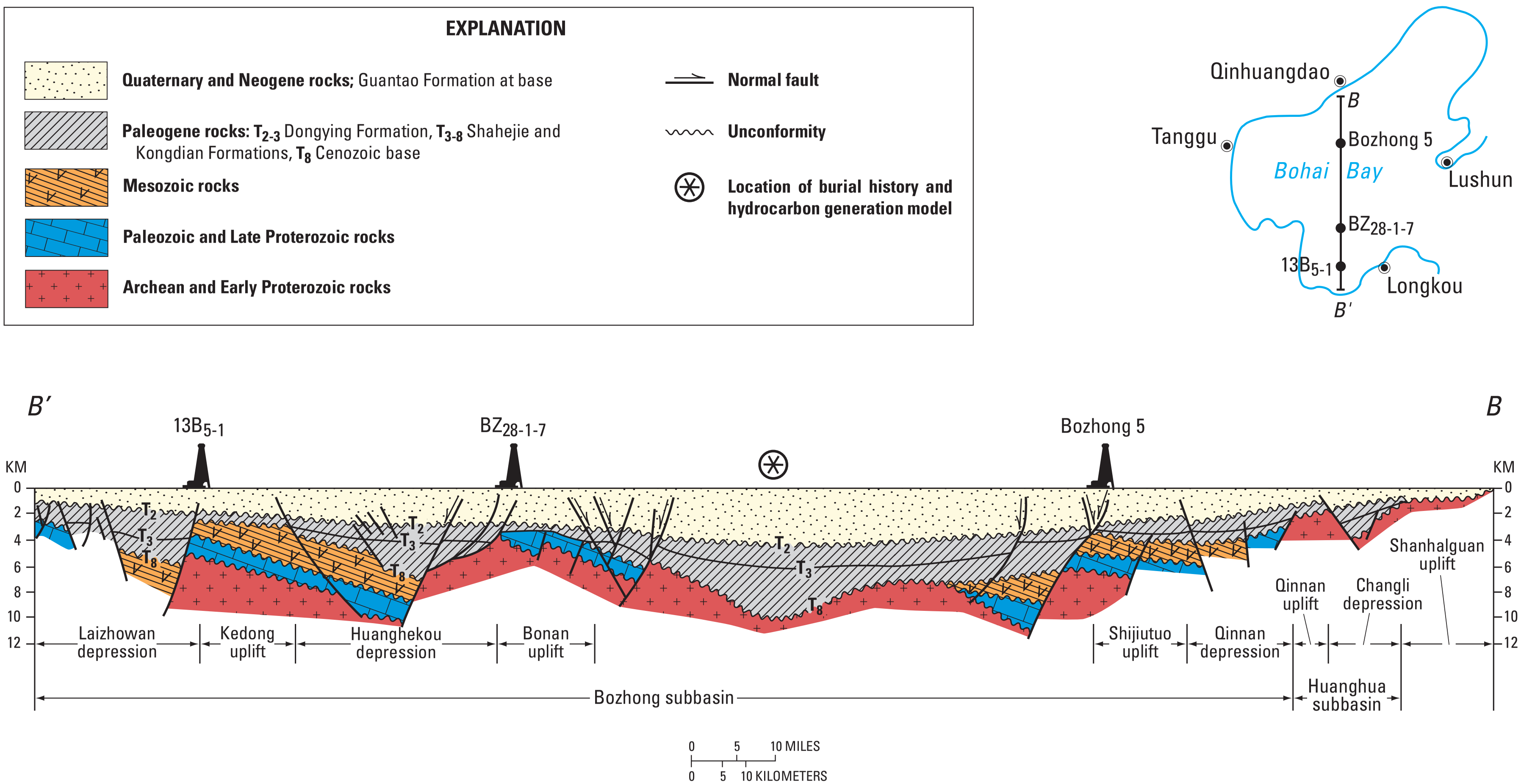


Figure 3. Geologic cross section *B–B′* through the Bozhong subbasin in the Bohaiwan basin (modified from Editorial Committee of Petroleum Geology of Oil- and Gas-Bearing Areas on the Continental Shelf and its Neighboring Regions, 1987). Line of section is also shown in figure 1.

the Bohai Bay part of the Bohaiwan basin and resulted in oil and gas discoveries in the Bozhong (1981) and Liaohe (1984) subbasins. Through the second quarter of 1996, the Bohaiwan basin had a known petroleum volume (cumulative production + remaining reserves) of 27.3 billion barrels of oil equivalent (BBOE) (Klett and others, 1997). The term "known petroleum volume" as used by Klett and others (1997) for the entire Bohaiwan basin is synonymous with the term "known recoverable" (also defined as cumulative production + remaining reserves) used for oil fields presented later in this report.

A Paleogene lacustrine black shale and mudstone unit (Member 3 of the Shahejie Formation, fig. 4), representing one of several stages of maximum expansion of subbasin-centered lakes, is the major source rock. Paleogene and Neogene nonmarine sandstones constitute the major reservoir rocks, especially where they are interbedded with lacustrine black shale and mudstone source rocks. Also, Paleozoic and Middle to Late Proterozoic marine limestone and dolomite and highly weathered Archean crystalline basement rocks are important reservoirs (fig. 4). The Paleogene and Neogene nonmarine sandstone reservoirs were deposited in deltaic and fluvial sequences that flanked subbasin-centered lakes and in turbidite sequences in the central parts of the lakes. The lower Paleozoic and Proterozoic marine limestone and dolomite reservoirs were deposited as peritidal and shallow-water shelf carbonates on a stable craton.

Technically, each of the six subbasins in the Bohaiwan basin, with one or more pods of active source rock, constitutes a separate total petroleum system because the subbasins are separated from one another by structurally high fault blocks (horst blocks) that are largely impervious to the migration of oil and gas. Furthermore, multiple petroleum systems may exist in each subbasin as suggested by the presence of several important source-rock intervals in the basin, such as three members of the Shahejie Formation, one member of the Kongdian Formation, and one member of the Dongying Formation. However, rather than separate total petroleum systems being assigned to each subbasin and (or) to each major source-rock interval, they are combined in this report into a single total petroleum system. The Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System recognized in this report very adequately expresses the dominance of the Shahejie Formation source rocks, the highly productive Shahejie Formation and Guantao Formation sandstone reservoir rocks, and the Wumishan Formation carbonate reservoir rock. Recognition of a single total petroleum system is further justified by the similarity in physical and chemical properties of the Bohaiwan basin oils (tables 1–6; Chen and others, 1996).

The Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System (312701) contains all of the discovered oil and gas in the Bohaiwan basin. The oil and gas in this total petroleum system are trapped in conventional accumulations (see the definition by Klett and others, 2000).

The hypothetical Carboniferous/Permian Coal–Paleozoic Total Petroleum System (312702) is based on data presented by Chang and others (1981) and Xu and Shen (1996). This total petroleum system is named for a moderately to deeply buried sequence of Carboniferous and Permian coal beds, which is the source-rock interval, and Paleozoic sandstone-and-coal-bearing units (Permian and Carboniferous) that are considered to be the reservoirs. Most of the gas in this hypothetical total petroleum system is inferred to be trapped in continuous accumulations (see the definition by Klett and others, 2000).

Province Geology

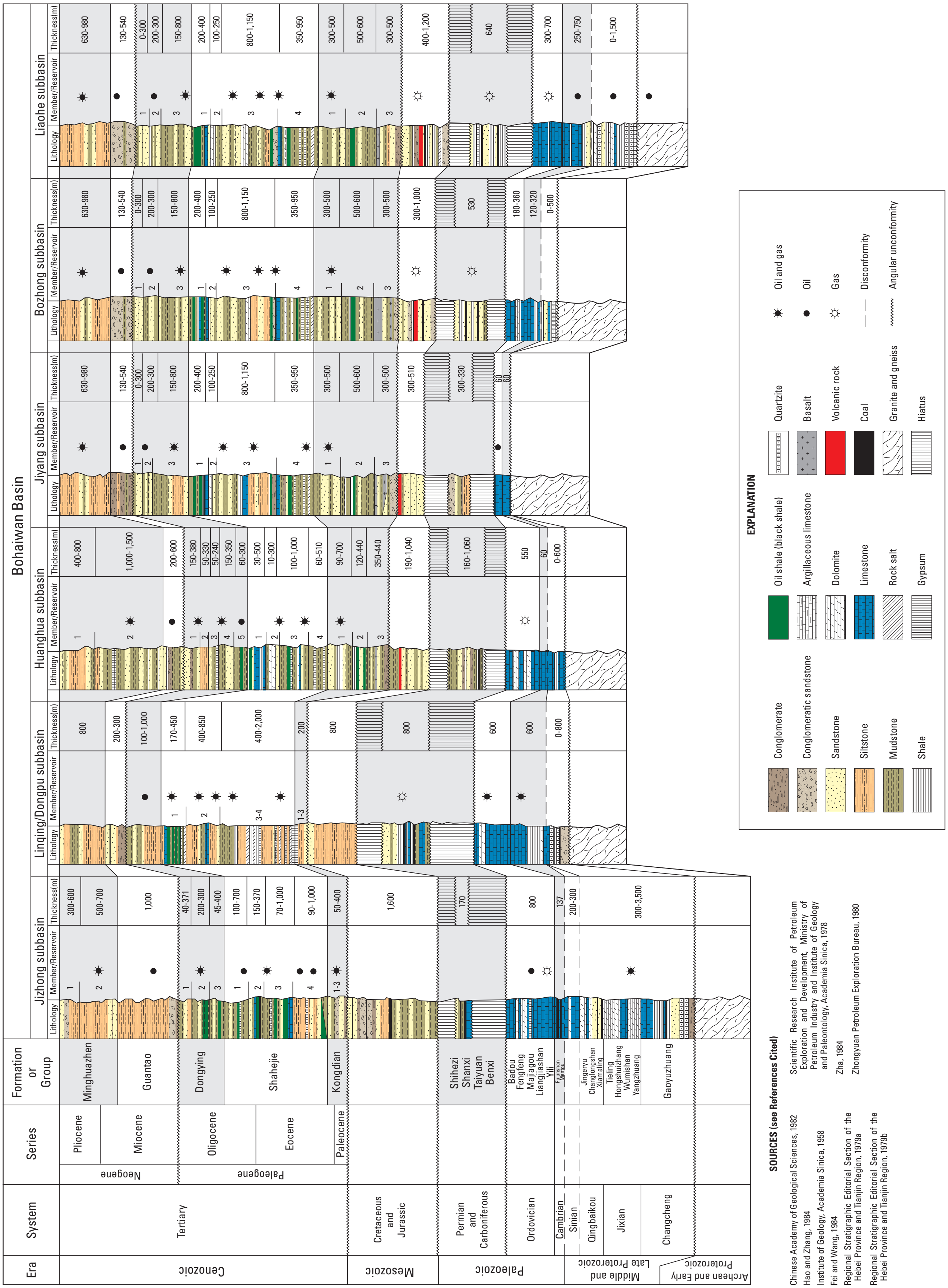
Geographic Setting

The Bohaiwan basin is situated in Hebei, Henan, Liaoning, and Shandong Provinces of eastern China (fig. 1). Approximately 25 percent of the basin is located beneath Bohai Bay,[2] a shallow marine embayment of the north end of the Yellow Sea. North Korea is within 200 kilometers (km) of the northeast end of the basin and Mongolia is within 550 km of the northwest end. A low-relief (<100 meters (m) above mean sea level) alluvial and coastal plain bordering Bohai Bay characterizes the present-day topography. The Huang He (Yellow River) flows northeastward across the basin and empties into the south end of Bohai Bay, where it has built a delta. Several other large rivers flow across the basin, including the Liao He that empties into the north end of Bohai Bay. Surface air temperatures are hot (>20°C) in the summer and cold (<0°C) in the winter.

Stratigraphic Setting

Sedimentary fill as thick as 10 km is preserved in one or more depressions (sags) of the Jiyang, Jizhong, and Bozhong subbasins (figs. 2, 3). In ascending order, the major stratigraphic units in the Dongying depression of the Jiyang subbasin are as follows: (1) unnamed Cambrian and Ordovician strata (200–500 m); (2) unnamed Carboniferous and Permian strata (500–1,200 m); (3) unnamed Mesozoic strata (800–2,500 m); (4) Paleocene and Eocene Kongdian Formation (Members 1–3) and Eocene Shahejie Formation (Member 4) (1,400–6,000 m); (5) Eocene and Oligocene Shahejie Formation (Members 1–3) (400–1,600 m); (6) Oligocene Dongying Formation (200–800 m); and (7) unnamed Neogene and Quaternary strata (500–2,000 m) (Hu and Krylov, 1996) (fig. 2). The 1,200-m thickness for the Carboniferous and Permian strata indicated by Hu and Krylov (1996) is probably too great when compared with thickness estimates of 450 to 770 m cited by ECPG–Shengli (1987) and of 300 to 330 m cited by Lee (1989) (fig. 4).

[2]The term "Bohai Bay" as used in this report follows the usage of Hu and others (1989) and Hu and Krylov (1996).



SOURCES (see References Cited)

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Figure 4 (facing page). Stratigraphy of the subbasins in the Bohaiwan basin (modified from Lee, 1989). These stratigraphic sections originally were compiled by Lee from the sources listed.

Representative stratigraphic sections for each of the six subbasins are shown in figure 4. These stratigraphic sections were compiled by Lee (1989) from a variety of sources. Modifications to Lee's (1989) original compilation include the following: (1) the addition of the Paleocene to the lower part of the Kongdian Formation as reported by Allen and others (1997); (2) the upward revision of the Eocene-Oligocene boundary to the middle of Member 2 of the Shahejie Formation as reported by ECPG–Shengli (1987) and Allen and others (1997); (3) the addition of oil and gas symbols to the Miocene-Pliocene Minghuazhen Formation as reported by Gong and others (1998) and Jin and McCabe (1998); (4) the addition of several lithologic units such as sandstone reported by Tian and others (1996); and (5) the addition of Archean rocks to several subbasins as reported by Zhao and others (1999).

Tectonic Setting

The Bohaiwan basin is a large (~200,000 km^2) intracratonic rift basin composed of Precambrian, Paleozoic, Mesozoic, and Tertiary sedimentary rocks underlain by Precambrian crystalline basement rocks and overlain by unconsolidated Quaternary sediments. The basin is largely surrounded by mountain ranges and uplifts composed of a variety of Precambrian, Paleozoic, and Mesozoic rocks. Complex block faulting in the subsurface has little, if any, surface expression (figs. 2, 3). Block-faulted pre-Quaternary rocks in the subsurface define a "dogleg-shaped" basin consisting of a rhomboid-shaped central area and narrow northeast- and southwest-tapering extensions (fig. 1; Allen and others, 1997). The length of the basin between its narrow southwest and northeast extensions is approximately 1,100 km and the width of the basin at its rhomboid-shaped central area is approximately 400 km (fig. 1). The basin is underlain by Archean and Early Proterozoic metamorphic rocks that constitute the North China (Sino-Korean) block or craton (Tian and others, 1992; Yin and Nie, 1996). Archean and Early Proterozoic metamorphic rocks, Middle and Late Proterozoic to lower Paleozoic sedimentary rocks, and Jurassic and Cretaceous volcanic rocks are exposed in uplifts that flank the west (Taihang Shan uplift) and north (Yanshan fold belt) sides of the basin and parts of the east (Ludong and Liao Dong uplifts) and south (Luxi uplift) sides (fig. 1*A*) (Tian and others, 1992; Allen and others, 1997). The 2,500-km-long, left-lateral(?) Tan-Lu fault zone (fig. 5) bounds the east side of the Bohaiwan basin (Yin and Nie, 1996; Kimura and others, 1990).

A complex basin evolution involved the following events: (1) several stages of Proterozoic and early Paleozoic shelf sedimentation (~1,700 to 458 Ma); (2) early to middle Paleozoic regional subaerial exposure and erosion (~458 to 320 Ma); (3) late Paleozoic foreland basin(?) sedimentation and contractional deformation(?) (~320 to 250 Ma); (4) Mesozoic contractional deformation, extensional deformation, and volcanism (~240 to 230 Ma and ~160 to 70 Ma); (5) early Tertiary (Paleogene) extension and rifting (~55 to 24 Ma); and (6) late Tertiary (Neogene) to recent post-rift subsidence (~22 Ma to present) (Hu and others, 1989; Allen and others, 1997).

Shallow-marine carbonates and local sandstone of Middle to Late Proterozoic, Cambrian, and Ordovician age were deposited on the North China block (fig. 5) when it was part of Gondwanaland (Lin and others, 1985). After a 130- to 150-million-year (m.y.) interval of post-Middle Ordovician epeirogenic uplift, subaerial erosion, and northward drift, the North China block collided with, and accreted to, the Mongol-Okhotsk terrane (Altaids) (fig. 5) in Late Carboniferous to Early Permian time (Yin and Nie, 1996; Sengör and Natal'in, 1996). Allen and others (1997) suggested that southward-directed thrusting generated by the collision may have formed a foreland basin on the North China block. Late Carboniferous and Permian shallow-marine limestone, continental terriginous clastic rocks, and coal beds (Lin and others, 1995) were deposited in the foreland basin. However, contractional tectonism accompanying the collision does not appear to have left a recognizable structural imprint on Proterozoic and early Paleozoic sedimentary rocks of the North China block.

The complex Mesozoic history of the Bohaiwan basin area is marked by contractional and extensional deformation, plutonism, and volcanism. Late Triassic collision (Indosinian orogeny) between the North China and South China (Yangtze) blocks uplifted most of the Bohaiwan area so that very few Triassic strata were preserved (Yin and Nie, 1996). Late Jurassic to Early Cretaceous contraction (Yanshanian orogeny) is recorded in basement-involved, fold-and-thrust belts with associated plutonism along the north (Yanshan fold belt) and west flanks (Taihang Shan uplift) of the basin (Kimura and others, 1990; Davis and others, 1996). Nonmarine Mesozoic red beds in the Bohaiwan basin may represent deposits of a foreland basin that accompanied this contraction (Hsü, 1989). Pre-Cenozoic decollement structures and overthrusts reported on seismic profiles crossing Bohai Bay (Zhu Xia *in* Hsü, 1989) provide additional evidence for contraction at this time. The plate tectonic setting of the contraction is uncertain, but possibilities include (1) gravitational collapse and southward spreading of the Mongol-Okhotsk terrane during subduction beneath the Siberia (Angara) craton, (2) collision between the North China and South China blocks, (3) subduction of the Pacific plate (not shown in this report) beneath North China, and (4) combinations of the above (Davis and others, 1996; Yin and Nie, 1996; Meng, 2003) (fig. 5).

Major crustal extension that initiated the Bohaiwan basin probably began in early Late Cretaceous time and was characterized by an east-dipping, downward-flattening, breakaway

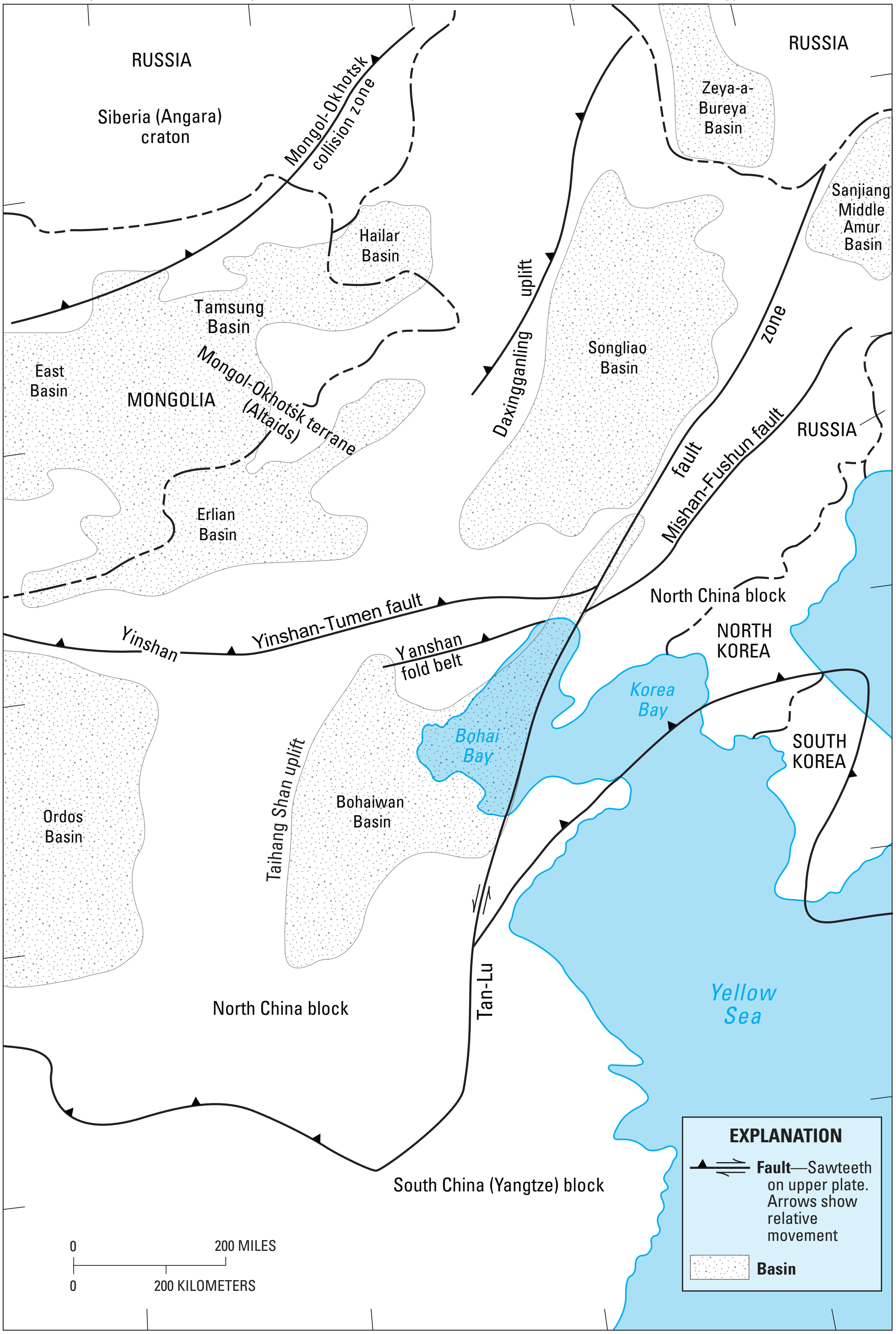

110°
115°
120°
125°
130°
50°
45°
40°
35°
30°
RUSSIA
Siberia (Angara) craton
Mongol-Okhotsk collision zone
Zeya-a-Bureya Basin
Sanjiang Middle Amur Basin
Hailar Basin
Tamsung Basin
Daxingganling uplift
Songliao Basin
East Basin
MONGOLIA
Mongol-Okhotsk terrane (Altaids)
Erlian Basin
fault
zone
Mishan-Fushun fault
RUSSIA
North China block
Yinshan-Tumen fault
Yinshan
Yanshan fold belt
NORTH KOREA
Korea Bay
Bohai Bay
SOUTH KOREA
Ordos Basin
Taihang Shan uplift
Bohaiwan Basin
Tan-Lu
Yellow Sea
North China block
South China (Yangtze) block
EXPLANATION
Fault—Sawteeth on upper plate. Arrows show relative movement
Basin
0
200 MILES
0
200 KILOMETERS

Figure 5 (facing page). Tectonic map of northeastern China and adjoining countries showing the Bohaiwan basin, North China block, and selected tectonic provinces and features. Modified from Allen and others (1997, fig. 4, p. 956) and published with permission of Elsevier. Names of selected features are from Davis and others (1996), Kimura and others (1990), Meng (2003), Yin and Nie (1996), and Sengör and others (1993).

normal fault that separated highly extended pre-Cenozoic rocks of the basin from less extended rocks of the Taihang Shan uplift west of the basin (Ma and Wu, 1987; Davis and others, 1996). The western margin of this master detachment fault system is exposed in the Taihang Shan and Yan Shan ranges as north- to northeast-trending normal faults of large displacement. Local basaltic volcanism was associated with this extension (Tian and others, 1992).

Crustal extension and rifting that began in latest Mesozoic time accelerated during late Paleocene to Eocene time and continued more or less continuously through Oligocene time to shape the present-day Bohaiwan basin (Hu and others, 1989; Allen and others, 1997). Deformation is characterized by listric normal faults that segmented the Archean basement rocks into an array of large half-grabens, tilted fault blocks, grabens, and intervening structural highs (rises and horst blocks). Thick syn-rift nonmarine deposits of alluvial fan, fluvial, and lacustrine origin filled the evolving basins. Commonly, basaltic lavas are interbedded with the syn-rift sedimentary deposits (Ye and others, 1997). Back-arc spreading caused by subduction roll-back of the Pacific plate beneath North China is the probable mechanism of basin formation (Watson and others, 1987; Hsü, 1989; Tian and others, 1992; Allen and others, 1997).

Early Cenozoic extension (late Paleocene to early Eocene) was concentrated in the southern (Linqing/Dongpu), western (Jizhong and Huanghua), and northeastern (Liaohe) parts of the basin and resulted in north-northeast-trending rift structures (Hu and others, 1989; Allen and others, 1997). Very likely, the normal faults accompanying this rifting event in the southern and western parts of the basin were controlled by, and flatten into, the east-dipping latest Mesozoic breakaway normal fault proposed by Davis and others (1996).

Basinwide extension began in the middle Eocene Epoch (Allen and others, 1997) or early Oligocene Epoch (Hu and others, 1989), during which time extensional faults propagated rapidly southward from the Liaohe subbasin area to overlap, in en echelon fashion, active rift structures in the southern and western parts of the basin. The zone of overlap between the northwest-trending rifts, each having a component of right-lateral transtension, formed pull-apart basins in the vicinity of the Jiyang and Bozhong subbasins (Allen and others, 1997). These proposed right-lateral pull-apart structures created east-west-oriented rift basins and marked crustal thinning (Ye and others, 1985). For this dextral-shear model to work, the Tan-Lu fault zone along the east side of the basin (fig. 1*B*) would have had right-lateral movement throughout the Tertiary. In contrast, tectonic plate reconstructions by Kimura and others (1990) and Yin and Nie (1996) suggested left-lateral displacement along the Tan-Lu fault zone (fig. 5). Active crustal extension continued throughout the basin in late Eocene and Oligocene time but was concentrated in the central (Bozhong and Jiyang subbasins) part (Ye and others, 1985; Allen and others, 1997). The estimated 30 percent of crustal extension across the Bohaiwan basin produced a 30- to 35-km-thick crust that is 5 to 10 km thinner than the crust in the adjoining Taihang Shan (Liu and others, 1978; Davis and others, 1996).

Rifting ended rather abruptly in latest Oligocene to early Miocene time and the basin evolved into a post-rift, thermal subsidence phase (Hu and others, 1989; Allen and others, 1997). Allen and others (1997) suggested that prior to thermal subsidence, contractional (or transpressional) deformation at the end of the Oligocene may have caused mild structural inversion in parts of the basin. They attributed the termination of the rifting phase to colliding of the India and Eurasia plates or colliding of the Australia and Philippine plates (none of these tectonic plates are shown in this report). Regional uplift and approximately 200 to 1,300 m of erosion predated the deposition of post-rift Neogene and Quaternary sedimentary rocks that covered most of the basin. The center of post-rift subsidence and sedimentation is coincident with the region of maximum Paleogene extension in the vicinity of present-day Bohai Bay. Thick Quaternary sediments and a record of large earthquakes delineate a west-northwest-trending zone of subsidence between Beijing and the center of Bohai Bay that may signify an active, new phase of rifting (Ye and others, 1985).

Exploration History as of June 2001

Encouraged by historical reports of local oil and gas seeps along the shores of Bohai Bay and adjoining areas, petroleum exploration began in the Bohaiwan basin about 1955. After regional geophysical surveys and the drilling of 10 dry holes (4 in Linqing/Dongpu subbasin, 3 in Jiyang subbasin, 2 in Huanghua subbasin, and 1 in Jizhong subbasin), oil was discovered in the Jiyang subbasin in 1960 or 1961 (table 1). This discovery of the giant Dongxin oil field on the Dongying faulted anticline led to development of the fourth largest field in the Shengli complex (fig. 1*A*). The giant Shengtuo and Gudao oil fields (largest fields in the Shengli complex) (fig. 1*A*) were discovered in 1964 and 1968, respectively. The third largest oil field in the Shengli complex, the Gudong field (fig. 1*A*), was discovered in 1984 near the shoreline of Bohai Bay. Oil in all these giant fields is trapped in faulted roll-over anticlines or in compaction anticlines draped over underlying tilted fault blocks (buried hills) of lower Paleozoic carbonate rocks. Reservoirs consist of lacustrine and fluvial-deltaic sandstones of Paleogene and Neogene age. The combined known recoverable of the Dongxin, Shengtuo, Gudao, and Gudong fields is between 9 and 10 billion barrels of oil (BBO) (Jin and McCabe, 1998).

The first commercial oil discoveries in the other subbasins of the Bohaiwan basin were reported as follows: Huanghua subbasin, 1962; Jizhong subbasin, 1964; Liaohe subbasin, 1964; Linqing/Dongpu subbasin, 1975; and Bozhong subbasin, 1975. In the Jizhong subbasin, the giant Renqiu oil field (fig. 1*A*), with a known recoverable of 2.3 BBO (Horn, 1990) to 2.85 BBO (Jin and McCabe, 1998), was discovered in 1975. The discovery of the Renqiu field was very significant because it established buried-hill traps (tilted fault blocks), with Proterozoic and lower Paleozoic carbonate reservoirs, as a major target for exploration (Zhai and Zha, 1982). Prior to the discovery of Renqiu, objectives for oil exploration in the Bohaiwan basin were confined to accumulations in Paleogene and Neogene lacustrine sandstone reservoirs in structural and stratigraphic traps. The major onshore oil fields in the Liaohe subbasin were discovered between 1964 and 1975 in faulted anticlines and buried hills: Huangjindai (1964); Xinglongtai in the Panshan complex (1969); Gaosheng (1975); Huanxiling (1975); and Shuguang in the Panshan complex (1975) (fig. 1*A*). Commonly, these Liaohe subbasin fields contain low-gravity oil and have a combined known recoverable of at least several billion barrels of oil (table 2; Jin and McCabe, 1998).

Beginning in 1980, the Chinese National Offshore Oil Company (CNOOC) signed several cooperative agreements with foreign companies to explore the offshore part of the Bohaiwan basin (ECPG–Continental Shelf, 1987; Han and Wang, 1997). Among the oil fields discovered on cooperative lease blocks in the Bozhong subbasin are the following: Bozhong 28-1 (date of discovery 1981); Bozhong 28-2 (date of discovery 1983); Bozhong 34-3 (date of discovery 1984); Peng Lai 14-3-1 (date of discovery 1997); and Peng Lai 19-3-1 (date of discovery 1999) (ECPG–Continental Shelf, 1987; Oil and Gas Journal, 1997; Shirley, 2000) (see fig. 1*A* for the location of several of these fields). The largest offshore oil field discovered in the Bohaiwan basin to date is the Suizhong 36-1 field (fig. 1*A*) in the Liaohe subbasin. Discovered by the Chinese in 1986, this field contains, in-place, between 1 and 2.1 billion barrels of low-gravity oil (Li, 1989; Gustavson and Xin, 1990; Jin and McCabe, 1998). In 1995, the Chinese discovered the Qinhuangdao 32-6 oil field (fig. 1*A*) in the Bozhong subbasin, their second largest offshore oil field (having in-place oil of ≈ 1 BBO) (China Oil & Gas, 1998; Appalachian Basin Report, 1998). Atlantic Richfield (now merged with British Petroleum (BP)) and Texaco (now merged with Chevron) are developing this field in cooperation with CNOOC (Appalachian Basin Report, 1998).

The onshore part of the Bohaiwan basin is now in a mature stage of exploration, having a high density of wells drilled to less than 3,500 m and about 1,400 wells drilled deeper than 3,500 m (He and others, 1998). Exploration in the Bohaiwan basin in the 1990s and early 2000s focused on the offshore area (He and others, 1998; Oil and Gas Journal Newsletter, 1999; Oil and Gas Journal, 2001), but onshore exploration for oil and gas at depths between 3,500 and 5,500 m continues (He and others, 1998; Zhang, 1999).

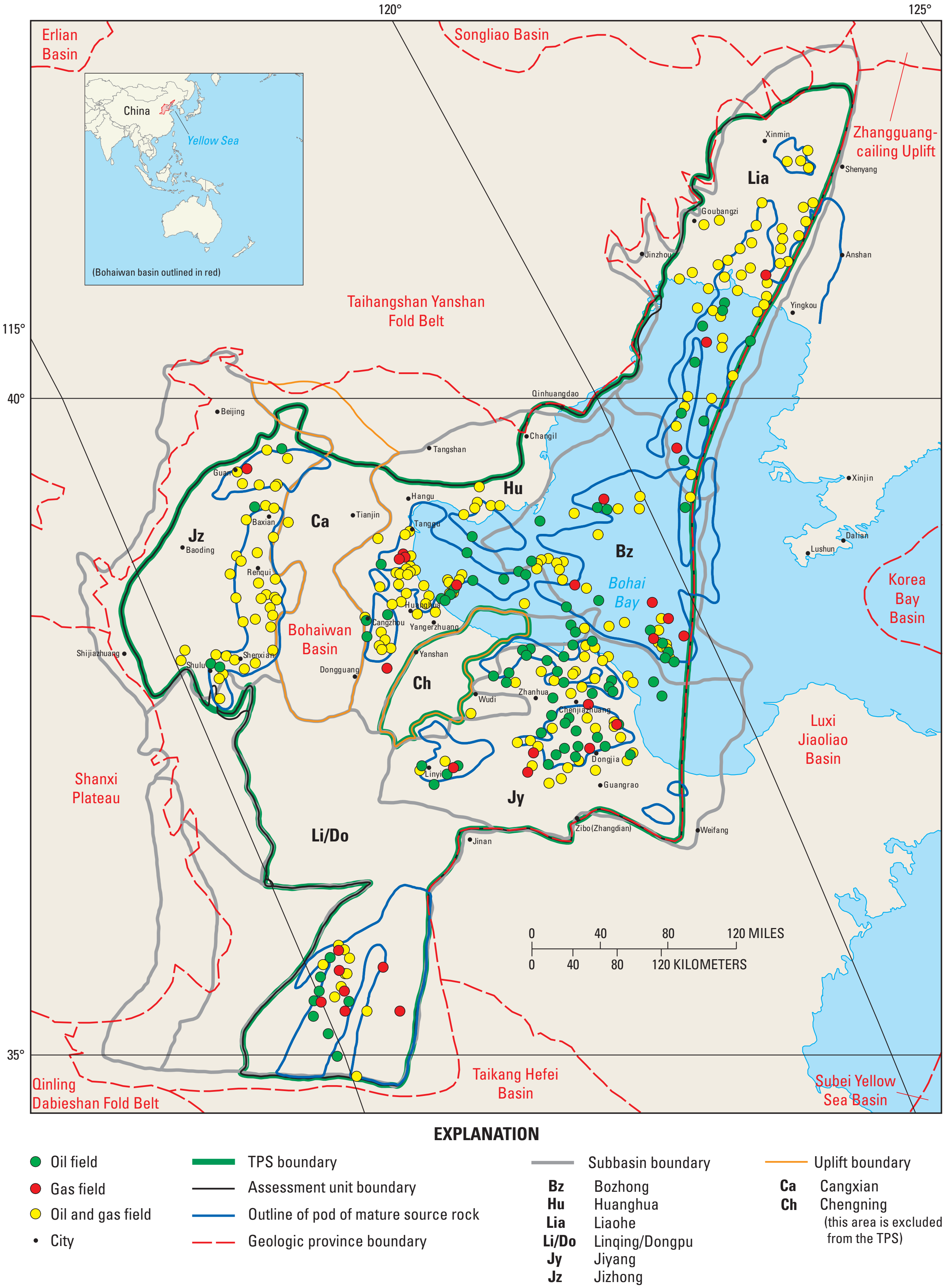
Ulmishek (1992) suggested that the Bozhong and Liaohe (offshore) subbasins have the best potential for new oil and gas discoveries. Most future discoveries in the onshore part of the Bohaiwan basin are expected to be in subtle, chiefly stratigraphic, traps. In the 1994 USGS World Energy Resources Assessment (Masters and others, 1998), known recoverable oil and gas in the Bohaiwan (North China) basin were estimated to be 15.6 BBOE (13.4 BBO and 13.4 trillion cubic feet of gas (TCFG)), whereas undiscovered oil and gas resources were estimated, at a mean value, to be 6.7 BBOE (5.4 BBO and 8 TCFG). The known petroleum volume of 27.3 BBOE reported by Klett and others (1997) consists of 24.6 BBO, 15.7 TCFG, and 0.1 billion barrels of natural gas liquids.

Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System (312701)

Petroleum Occurrence

All of the approximately 200 to 250 oil and gas fields discovered through the second quarter of 1996 in the Bohaiwan basin (tables 1–6 and fig. 6) and their known petroleum volume of 27.3 BBOE (Klett and others, 1997) are associated with the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System. Also, the majority of the known petroleum volume of 27.3 BBOE is concentrated in several giant to large fields discovered in the early and middle stages of exploration. The fields are located in each of the six fault-controlled subbasins and associated depressions where Shahejie Formation source rocks have achieved appropriate burial for

Figure 6 (facing page). Map showing the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Bohaiwan basin, pods of mature source rock, and oil and gas fields as of the second quarter of 1996. Abbreviation: TPS, total petroleum system. Due to differences in projection, scale, and accuracy of latitude-longitude grids, the location of some cities and features in this figure may not be consistent with their location in other figures in this report.


120°
125°
115°
40°
35°
Erlian Basin
Songliao Basin
China
Yellow Sea
(Bohaiwan basin outlined in red)
Zhangguang-cailing Uplift
Xinmin
Shenyang
Lia
Goubangzi
Jinzhou
Anshan
Yingkou
Taihangshan Yanshan Fold Belt
Qinhuangdao
Beijing
Changil
Tangshan
Xinjin
Guan
Hangu
Hu
Tianjin
Baxian
Ca
Tanggu
Jz
Baoding
Bz
Dalian
Lushun
Renqui
Bohai Bay
Korea Bay Basin
Huanghua
Cangzhou
Yangerzhuang
Bohaiwan Basin
Shijiazhuang
Yanshan
Shenxian
Shulu
Dongguang
Ch
Wudi
Zhanhua
Chenjiazhuang
Luxi Jiaoliao Basin
Dongjia
Linyi
Guangrao
Shanxi Plateau
Jy
Zibo (Zhangdian)
Weifang
Li/Do
Jinan
0 40 80 120 MILES
0 40 80 120 KILOMETERS
Qinling Dabieshan Fold Belt
Taikang Hefei Basin
Subei Yellow Sea Basin
EXPLANATION
Oil field
Gas field
Oil and gas field
City
TPS boundary
Assessment unit boundary
Outline of pod of mature source rock
Geologic province boundary
Subbasin boundary
Bz Bozhong
Hu Huanghua
Lia Liaohe
Li/Do Linqing/Dongpu
Jy Jiyang
Jz Jizhong
Uplift boundary
Ca Cangxian
Ch Chengning
(this area is excluded from the TPS)

oil generation (figs. 1–3). Two major reservoir intervals are recognized in the total petroleum system: (1) Tertiary sandstones of nonmarine origin that overlie, are interbedded with, or are in fault contact with Shahejie Formation source rocks and (2) Archean metamorphic rocks and Proterozoic and lower Paleozoic marine carbonates that are unconformably overlain by or are in fault contact with Shahejie Formation source rocks. Approximately 80 percent of the known recoverable oil and gas in the Bohaiwan basin reside in Tertiary sandstone reservoirs and about 10 to 20 percent reside in Proterozoic and lower Paleozoic carbonate and Archean crystalline rock reservoirs in buried hills. A small percentage of the known oil and gas reserves are located in Tertiary bioclastic carbonate reservoirs, shale reservoirs, and volcanic rock reservoirs (Chang, 1991).

Source Rocks

Introduction

Similar biomarker (terpanes, steranes, pristane, phytane), n-alkane, and $\delta^{13}C_1$ distributions from at least several hundred crude oils (from both sandstone and carbonate reservoirs) suggest that the oils in all six subbasins in the Bohaiwan basin very likely have been derived from source rocks of the same approximate age and depositional setting (ECPG–Shengli, 1987; ECPG–Continental Shelf, 1987; Liang, 1987a,b; Shi and Qin, 1987; Liu and others, 1988; Ge and ECPG–Liaohe, 1989; Chen and others, 1996). This conclusion is further supported by reasonably consistent API gravity values (≈25 to 44°) and sulfur content (<0.1 to 1.0 percent), high paraffin content (≈20 to 30 percent), and gas-oil ratios (generally less than 1,000 ft^3 of gas per barrel of oil) among most crude oils in the Bohaiwan basin (tables 1–6; Chang, 1991).

Heavy to very heavy crude oils (<10 to 20° API gravity) are common in the Bozhong, Jiyang, Liaohe, and Huanghua subbasins. Some of these oils may have high sulfur contents (1–10 percent; see tables 1, 2, and 4) because of their abundant resin and asphaltene contents. Probably most of the heavy to very heavy oils were derived from the same source rocks as the light crude oils, but were modified by additional post-emplacement processes such as evaporative loss, water washing, and extensive biodegradation (Lu and others, 1990). However, some of the heavy oils may have originated from thermally immature source rocks that were deposited in brackish to saline water (Shi and others, 1982; Liang, 1987b; Huang and others, 1990; Lu and others, 1990; Chen and others, 1994; and Chen and others, 1996).

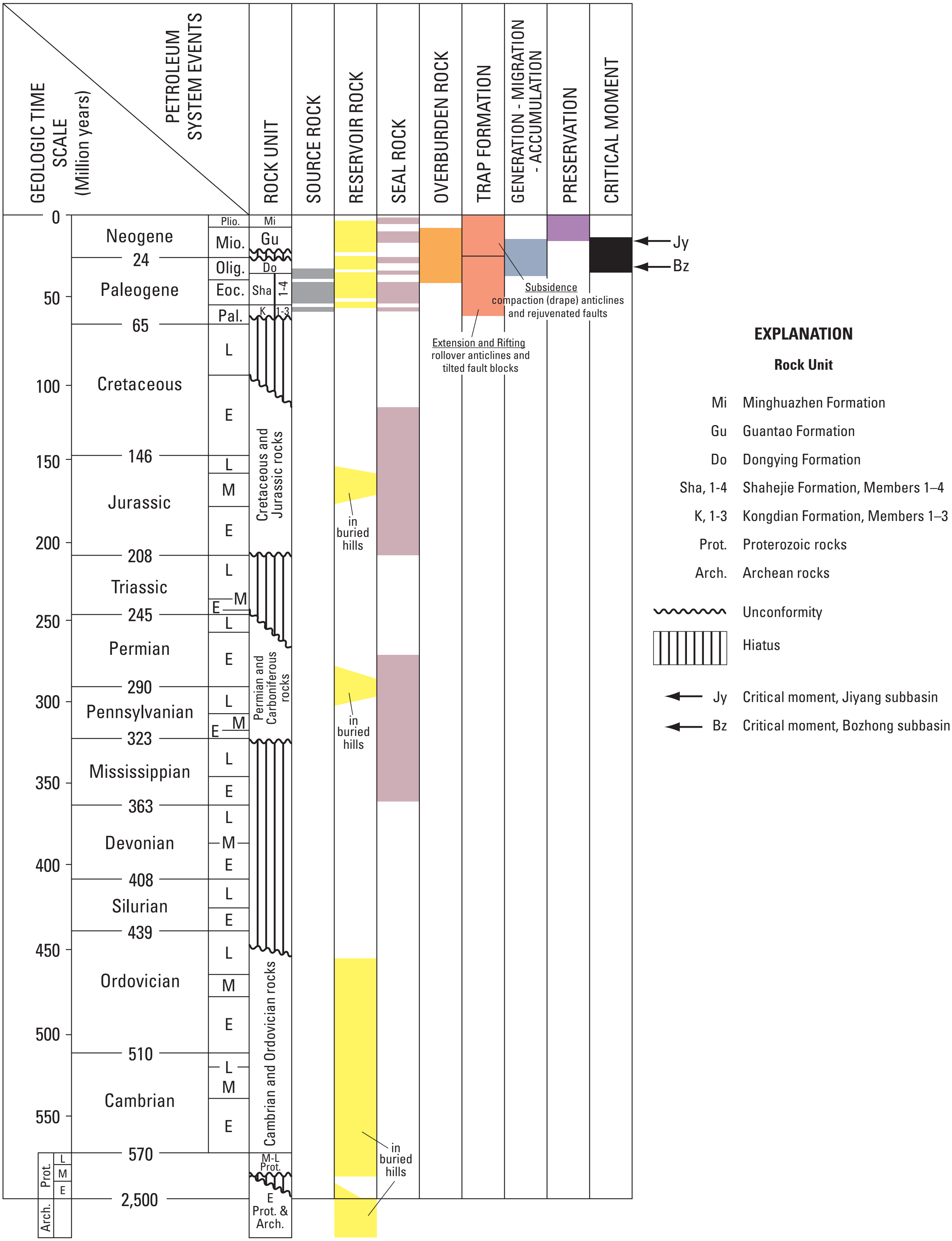
Stratigraphic Units

Member 3 of the Eocene and Oligocene Shahejie Formation is the primary source rock in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System (fig. 4). Also, Members 4 and 1 of the Shahejie Formation are important source rocks in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System, and in several subbasins they may be the primary source rocks (fig. 4). Other source rocks included in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System are Member 2 of the Paleocene and Eocene Kongdian Formation (fig. 4), an important source rock in the Huanghua subbasin, and Member 3 of the lower Oligocene Dongying Formation, probably an important source rock in the Bozhong subbasin. Members 1, 3, and 4 of the Shahejie Formation, Member 2 of the Kongdian Formation, and Member 3 of the Dongying Formation are all identified on the events chart (fig. 7) as source rocks of the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System.

Member 3 of the Shahejie Formation

Member 3 of the Shahejie Formation is the most important source rock in the Bohaiwan basin (Liang, 1987a,b; ECPG–Shengli, 1987; Liu and others, 1988; Wu and Liang, 1988; Ge and ECPG–Liaohe, 1989; Li, Yao, and Liu, 1991; Gardemal and others, 1996; Gong and others, 1998). Most of the Shahejie Formation source rocks are interpreted to be deepwater lacustrine deposits in association with widespread anoxic conditions (Hu and others, 1989; Chang, 1991; Allen and others, 1997), and Member 3 represents the most widespread of these deposits in the Bohaiwan basin (Yao and others, 1994, cited in Allen and others, 1997). Intense rifting and a climate change to wetter, more humid conditions are suggested by Hu and others (1989) and Chang (1991) as the main reasons for the abrupt expansion of lacustrine conditions. Member 3 in all six subbasins generally consists of 1,000-m-thick, deepwater lacustrine deposits primarily of dark-gray mudstone, oil shale (black shale), siltstone, and dark-gray sandstone (fig. 4) (ECPG–Shengli, 1987; Chang; 1991; Yao and others, 1994, cited in Allen and others, 1997). This extensive lacustrine system is largely freshwater (ECPG–Shengli, 1987; Chen and others, 1994), but locally the lacustrine system may have been mixed with seawater as suggested by the coexistence of freshwater and brackish-water fossils (Zhang, 1987). Beds of halite and gypsum are associated with Member 3 lacustrine deposits in the Linqing/Dongpu subbasin (Li, Yao, and Liu, 1991; Jin, 1991).

Figure 7 (facing page). Events chart for the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System. Geologic time scale based on Magoon and Dow (1994) and Magoon and Schmoker (2000). Abbreviations: Plio., Pliocene; Mio., Miocene; Olig., Oligocene; Eoc., Eocene; Pal., Paleocene; E, Early; M, Middle; L, Late.


GEOLOGIC TIME SCALE (Million years)
PETROLEUM SYSTEM EVENTS
ROCK UNIT
SOURCE ROCK
RESERVOIR ROCK
SEAL ROCK
OVERBURDEN ROCK
TRAP FORMATION
GENERATION - MIGRATION - ACCUMULATION
PRESERVATION
CRITICAL MOMENT
0
50
100
150
200
250
300
350
400
450
500
550
Neogene
24
Paleogene
65
Cretaceous
146
Jurassic
208
Triassic
245
Permian
290
Pennsylvanian
323
Mississippian
363
Devonian
408
Silurian
439
Ordovician
510
Cambrian
570
2,500
Prot.
Arch.
Plio.
Mio.
Olig.
Eoc.
Pal.
L
M
E
Mi
Gu
Do
Sha
1-4
K
1-3
Cretaceous and Jurassic rocks
Permian and Carboniferous rocks
Cambrian and Ordovician rocks
M-L Prot.
E Prot. & Arch.
in buried hills
Subsidence
compaction (drape) anticlines and rejuvenated faults
Extension and Rifting
rollover anticlines and tilted fault blocks
Jy
Bz
EXPLANATION
Rock Unit
Mi Minghuazhen Formation
Gu Guantao Formation
Do Dongying Formation
Sha, 1-4 Shahejie Formation, Members 1–4
K, 1-3 Kongdian Formation, Members 1–3
Prot. Proterozoic rocks
Arch. Archean rocks
Unconformity
Hiatus
Jy Critical moment, Jiyang subbasin
Bz Critical moment, Bozhong subbasin

Member 1 of the Shahejie Formation

Member 1 of the Shahejie Formation is another important source rock that occurs in all six subbasins (ECPG–Shengli, 1987; ECPG–Continental Shelf, 1987; Liu and others, 1988; Ge and ECPG–Liaohe, 1989; Tian and others, 1996; Hu, 1995, cited in Jin and McCabe, 1998). Similar to Member 3, Member 1 of the Shahejie Formation represents widespread lacustrine conditions; however, the dark-gray mudstone and oil-shale (black shale) source rocks in Member 1 are commonly of lower organic richness than source rocks in Member 3 because basin subsidence was slower and more uniform during the deposition of Member 1 (Yao and others, 1994, cited in Allen and others, 1997). Member 1 of the Shahejie Formation most commonly ranges in thickness from about 200 to 400 m (fig. 4). Fossil and lithologic assemblages suggest that Member 1 was deposited largely under freshwater conditions, but highly saline water was present in the Linqing/Dongpu subbasin as indicated by the presence of halite and gypsum deposits (Li, Yao, and Liu, 1991).

Member 4 of the Shahejie Formation

Member 4 of the Shahejie Formation is reported to be an important source rock in the Jiyang, Jizhong, Liaohe, and Linqing/Dongpu subbasins (ECPG–Shengli, 1987; Qian and Chen, 1990; Wu and Liang, 1988; Ge and ECPG–Liaohe, 1989; Tong and Huang, 1991; Hu, 1995, cited in Jin and McCabe, 1998). Member 4 represents the initial phase of widespread lacustrine sedimentation in the Bohaiwan basin (Hu and others, 1989; Yao and others, 1994, cited in Allen and others, 1997). Dark-gray mudstone interbedded with oil shale (black shale), siltstone, and sandstone of deepwater lacustrine origin characterize Member 4 deposits in the Jiyang subbasin, whereas dark-gray mudstone interbedded with gypsum-bearing mudstone, bioclastic limestone, and dolomite characterize Member 4 deposits in the other subbasins. Red beds, halite, and anhydrite commonly found in parts of Member 4 probably reflect a hot, dry climate (Hu and others, 1989). The presence of foraminifera and nannofossils in several carbonate units in Member 4 indicates that the lacustrine system at this time was intermittently connected with marine water (ECPG–Shengli, 1987; Allen and others, 1997). The thickness of Member 4 of the Shahejie Formation ranges generally from about 350 to 1,000 m (fig. 4).

Member 2 of the Kongdian Formation

Member 2 of the Kongdian Formation is of secondary importance as a source rock in comparison to Members 1, 3, and 4 of the Shahejie Formation. This source rock seems to be important only in the Huanghua subbasin (Liang, 1987a,b; Tian and others, 1996) and possibly in the Jizhong subbasin, where the Kongdian Formation is undivided (Wu and Liang, 1988). Member 2 source rocks consist of dark-gray to black mudstone and oil shale (black shale) and interbedded siltstone and sandstone that probably were deposited in local shallow-water lakes (Yao and others, 1994, cited in Allen and others, 1997). Lacustrine source-rock deposits in Member 2 were preceded by alluvial fan and fluvial deposits (Member 3) characterized by red and green mudstone, sandstone, and conglomerate with interbedded basalt flows. Member 1, which succeeds Member 2, has similar deposits as well as ephemeral-lake deposits characterized by dark-gray gypsum-bearing mudstone (Zhang, 1987). Member 2 ranges in thickness from about 400 to 600 m (fig. 4).

Member 3 of the Dongying Formation

The lower part of the Dongying Formation (Member 3) is also of secondary importance as a source rock in comparison to Members 1, 3, and 4 of the Shahejie Formation. This source rock may be important in the Bozhong subbasin where it consists of dark gray mudstone that probably was deposited in deeper lakes (ECPG–Continental Shelf, 1987; Gong and others, 1998; Xu, 2004).

Geochemical Characteristics

Source Rocks in Member 3 of the Shahejie Formation

Total organic carbon (TOC) content in weight percent, kerogen type, and hydrogen index (HI) values in milligrams of hydrocarbon per grams of organic carbon (mgHC/g orgC) for mudstone and oil-shale source rocks in Member 3 of the Shahejie Formation are reported in table 7. Figure 8 shows the distribution of total organic carbon in the Member 3 source rocks. The abundant organic matter in the source rocks is dominated by algae and bacteria that accumulated in the middle, deeper parts of the lake and by large quantities of terrigenous organic matter (including spores and pollen) that accumulated along the shallower margins of the lake (Hu and others, 1989; Gardemal and others, 1996).

Oil-Source Rock Correlations

Oil-source rock correlations based on biomarker distributions (isoprenoids and others), n-alkane distributions, and δ^{13} C data indicate that the Shahejie Formation (Members 1, 3, and 4) and Kongdian Formation (Member 2) (Huanghua subbasin only) are the predominant source rocks for oils in the Tertiary sandstone reservoirs and the pre-Tertiary buried-hill carbonate reservoirs. For example, as interpreted from biomarker distributions, oil in the Bozhong subbasin was derived from two main types of lacustrine source rock in Member 3 of the Shahejie Formation (Gardemal and others, 1996). One source-rock type (in the upper part of Member 3) has algal affinities, whereas the other source-rock type (in the lower part of Member 3) has higher quantities of bacteria (Gardemal and others, 1996). Also, oil from the Bozhong 28-1 field has been correlated with source rocks from Members 3 and 1 of the Shahejie Formation using biomarkers, n-alkane distributions, and δ^{13} C data (ECPG–Continental Shelf, 1987).

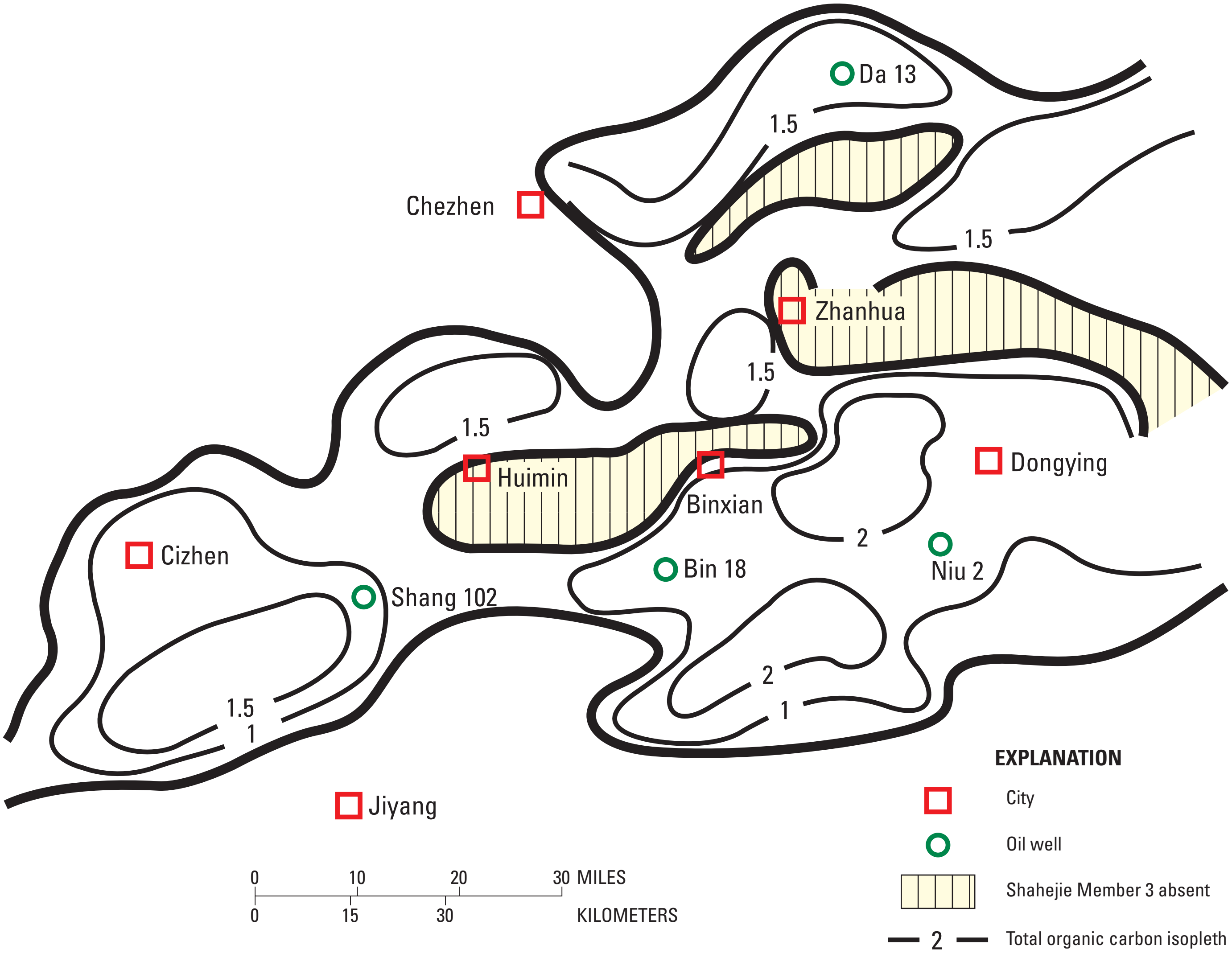


Figure 8. Distribution of the total organic carbon (in weight percent) in the lower Tertiary Shahejie Member 3 source rocks in the Jiyang subbasin of the Bohaiwan basin (from Editorial Committee of Petroleum Geology of the Shengli Oil Field, 1987).

Additional subbasins where oils from at least one field have been correlated with source rocks in Member 3 of the Shahejie Formation are as follows: (1) Huanghua subbasin (Liang, 1987a); (2) Jiyang subbasin (ECPG–Shengli, 1987; Chen and others, 1996); (3) Jizhong subbasin (Gao and others, 1987; Wu and Liang, 1988); and (4) Liaohe subbasin (Zheng, 1988; Ge and ECPG–Liaohe, 1989; Lu and others, 1990). Although Member 3 is considered to be the source rock for the oils in the Linqing/Dongpu subbasin, this interpretation is not supported by geochemical data other than by appropriately high TOC values (Qi, 1988, cited by Li, Yao, and Liu, 1991; Jin and McCabe, 1998). Another important conclusion derived from these geochemical data is that oils in the buried-hill Proterozoic and lower Paleozoic carbonate reservoirs were derived from Tertiary lacustrine source rocks (largely Member 3 of the Shahejie Formation) rather than from the marine carbonates (Zhai and Zha, 1982; ECPG–Shengli, 1987; Liu and others, 1988).

Source rocks in Members 1 and (or) 4 of the Shahejie Formation have been correlated with oils in the Bozhong subbasin (ECPG–Continental Shelf, 1987), in the Huanghua subbasin (Liang, 1987a), in the Jiyang subbasin (Shi and others, 1982; ECPG–Shengli, 1987; Chen and others, 1996), in the Jizhong subbasin (Gao and others, 1987; Liu and others, 1988; Wu and Liang, 1988), and in the Liaohe subbasin (Zheng, 1988; Ge and ECPG–Liaohe, 1989; Lu and others, 1990). The Huanghua subbasin (Liang, 1987a) is the only part of the Bohaiwan basin where geochemical evidence supports Member 2 of the Kongdian Formation as a source rock for some of the oils.

Natural Gases

Natural gases in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System consist of a mixture of hydrocarbon and non-combustible gases. The hydrocarbon gases most commonly occur as gas caps associated with oil fields and are characterized as wet gas: CH_4 ≈ 77–93 percent, C_2H_6+ ≈5–20 percent, N_2 ≈ 0.25–2 percent, and CO_2 ≈ 0.25–2 percent (ECPG–Shengli, 1987; ECPG–Huabei, 1987; ECPG–Dagang, 1987; ECPG–Continental Shelf, 1987; Ge and ECPG–Liaohe, 1989; Xu and others, 1997). Most nonassociated gas accumulations consist of dry gas with CH_4 >95 percent and C_2H_6+ ≈0–2 percent (ECPG–Dagang, 1987; Ge and ECPG–Liaohe, 1989). Small amounts of inert gases Ar and He, measured in tens to hundreds of parts per million (ppm), are mixed with the hydrocarbon gases (Ge and ECPG–Liaohe, 1989; Xu and others, 1997).

Carbon isotopes ($\delta^{13}C_1$ ≈ -55.6 to -34.6) of selected hydrocarbon gases suggest that the majority of the Bohaiwan basin gases are thermogenic in origin (Xu and others, 1997). Moreover, in the Jiyang subbasin the carbon isotopic compositions of the methane gases are very similar to those of absorbed gases in Member 3 of the Shahejie Formation, which is the proposed source rock (ECPG–Shengli, 1987). Several gases having light carbon isotopic values ($\delta^{13}C_1$ ≈ -58.2 to -56.6) probably represent a mixture of biogenic and thermogenic gases (ECPG–Dagang, 1987; Xu and others, 1997). High amounts (>15 percent) of non-combustible CO_2 and N_2 gases are present in the Huanghua and Jiyang subbasins (ECPG–Dagang, 1987; ECPG–Shengli, 1987). Gases having a high percentage of CO_2 could have resulted from one or more of the following mechanisms: (1) migration of magmatic- and (or) mantle-derived fluids during Cenozoic volcanism, (2) thermal decomposition of carbonate rocks during deep burial, and (3) decomposition of sedimentary organic matter during deep burial (Dai and others, 1996; Xu and others, 1997; Jin and others, 2004). One well in the southern Jizhong subbasin reported an H_2S content >90 percent (ECPG–Huabei, 1987).

Pods of Thermally Mature Source Rock

Pods of thermally mature source rock (having vitrinite reflectance (%R_o) of about 0.5–1.5) associated with the Shahejie and Kongdian Formations are confined to the six subbasins and the numerous associated depressions in the Bohaiwan basin (figs. 1*A*,*B*, 6). For example, in the Jiyang subbasin, Qian (1994; cited in Jin and McCabe, 1998) recognized 11 pods of mature source rock (identified as oil-source centers in their terminology) that are clustered in the Dongying, Huimin, Chezhen (Chenzheng), and Zhanhua (Zhanghua) depressions (see fig. 1*B* for location of depressions). The three pods of mature source rock in the Jiyang subbasin shown in figure 6 are centered on the Dongying, Huimin, Chezhen (Chenzheng), and Zhanhua (Zhanghua) depressions. The maximum thickness of mature source rock is about 900 m in the Dongying depression, about 400 m in the Huimin depression, and about 200 m in the Chezhen (Chenzheng) and Zhanhua (Zhanghua) depressions (ECPG–Shengli, 1987).

The Jizhong subbasin is another example where pods of mature source rock have been identified in the literature (Wu and Liang, 1988). One pod is located in the Guan depression in the northern part of the subbasin, whereas farther south, a second, larger pod is located in the Baxian, Raoyang, Shenxian, and Shulu depressions (figs. 1*B*, 6; Wu and Liang, 1988). Member 3 of the Shahejie Formation, containing thermally mature dark mudstone (oil shale and black shale) source rocks, reaches a maximum thickness of about 2,400 m in the Guan depression and about 300 to 500 m in the southern depressions (ECPG–Huabei, 1987).

Burial History, Hydrocarbon Generation, and Migration

Burial History and Hydrocarbon Generation

Burial history and hydrocarbon-generation-model studies using a 36° C/km average geothermal gradient suggest that about 2,200 to 2,500 m of overburden rocks were required to achieve the critical moment for Shahejie Formation (Member 3) source rocks in the Jiyang and Bozhong subbasins (figs. 7, 9, 10; tables 8, 9). Although seemingly thin compared with most oil-producing regions of the world (where overburden thickness is commonly ≥3,000 m), these estimated overburden thicknesses are consistent with those in other subbasins and depressions in the Bohaiwan basin, such as the Huanghua subbasin (Chen and Zhang, 1991; Li and others, 2004), the Jizhong subbasin (Li, Du, and Hu, 1991; V.F. Nuccio, unpub. data, 1999), and the Liaohe subbasin (Ge and ECPG–Liaohe, 1989). In addition to the majority of the oils that were generated from the thermal degradation of kerogen between %R_o ≈ 0.5 and 1.5, some of the heavy oils in the Bozhong, Jiyang, Liaohe, and Huanghua subbasins have been suggested to be the products of immature source rocks having %R_o ≈ 0.3–0.5 and overburden thickness ≤2,000 m (Huang and others, 1990; Lu and others, 1990; Jin, 1991; Jin and McCabe, 1998). Huang and others (1990) suggested that these immature oils may have been formed at low temperatures from organic matter that was present in organic solvents.

On the basis of burial history and hydrocarbon generation models, we conclude that the critical moment for the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Dongying depression of the Jiyang subbasin occurred in approximately middle Miocene time (≈15 Ma) (figs. 7, 9; table 8).

Burial history and hydrocarbon generation models of the Bozhong subbasin suggest that the critical moment there occurred in approximately early Oligocene time (≈30 Ma), about 15 Ma earlier than in the Jiyang subbasin (figs. 7, 10; table 9). This timing of oil generation is consistent with studies by Gardemal and others (1996). Because of their greater

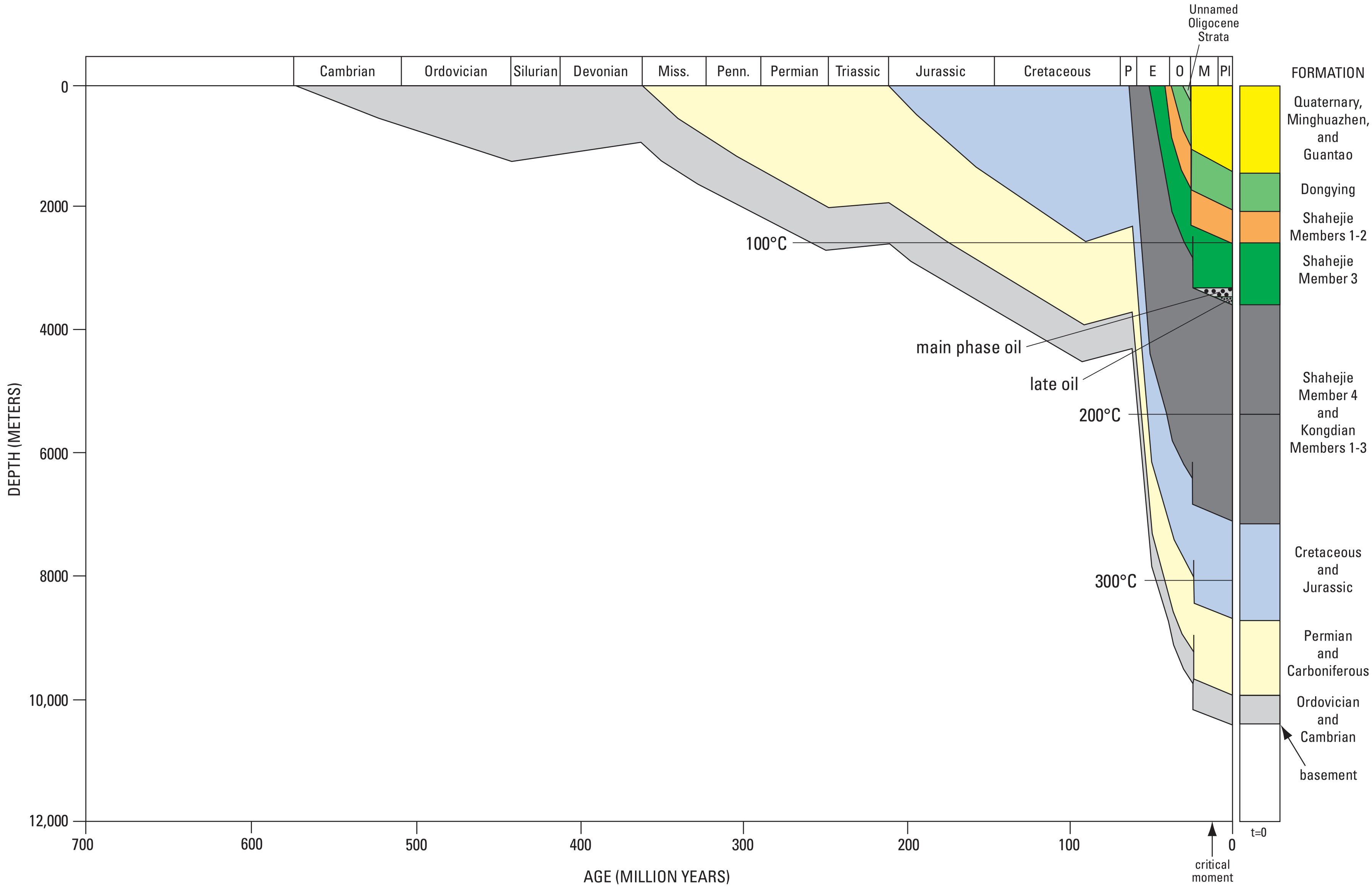


Figure 9. Burial history and hydrocarbon generation model for the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jiyang subbasin of the Bohaiwan basin. Abbreviations: Miss., Mississippian; Penn., Pennsylvanian; P, Paleocene; E, Eocene; O, Oligocene; M, Miocene; Pl, Pliocene and Quaternary; t=0, present day.

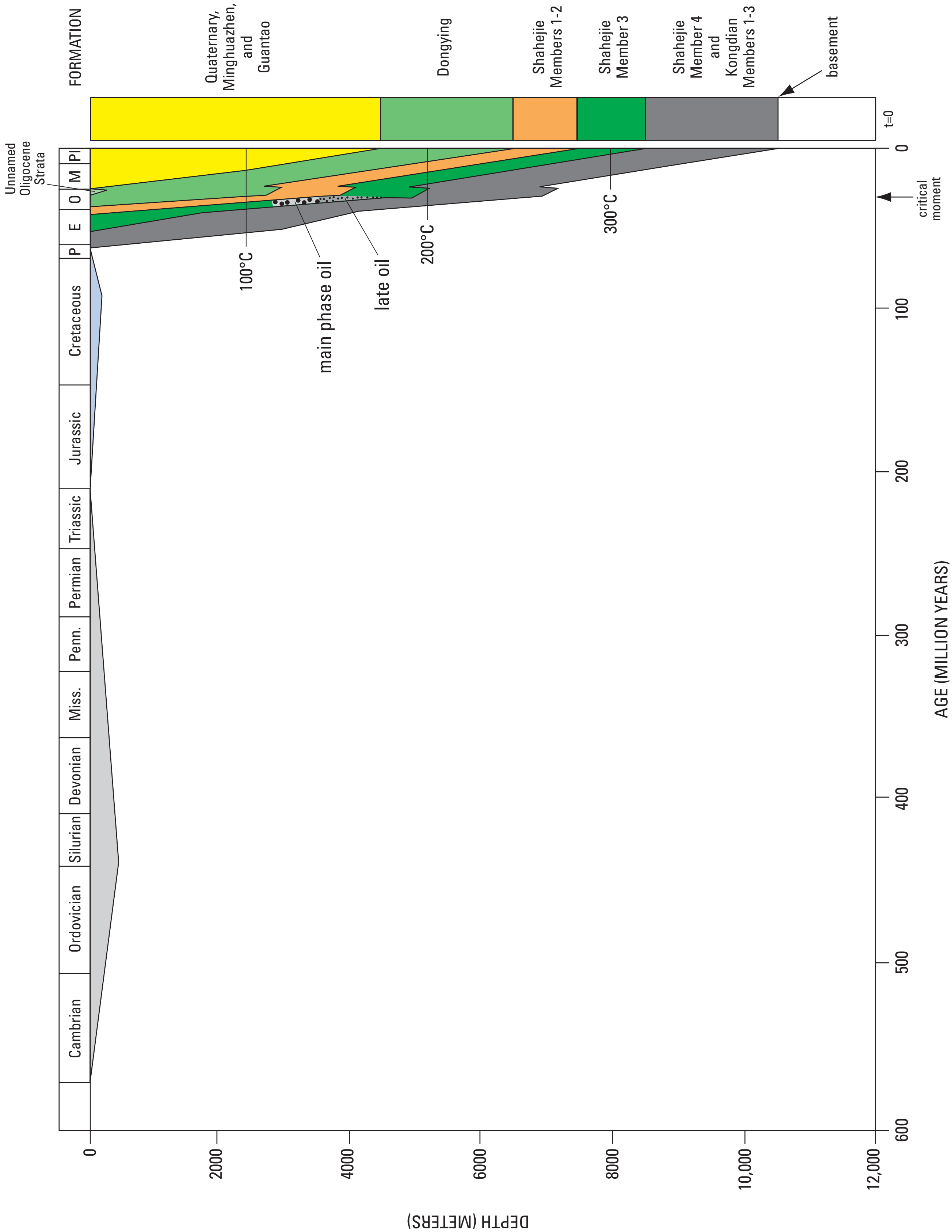

FORMATION
Quaternary, Minghuazhen, and Guantao
Dongying
Shahejie Members 1-2
Shahejie Member 3
Shahejie Member 4 and Kongdian Members 1-3
basement
t=0
Unnamed Oligocene Strata
Pl
M
O
E
P
Cretaceous
Jurassic
Triassic
Permian
Penn.
Miss.
Devonian
Silurian
Ordovician
Cambrian
100°C
200°C
300°C
main phase oil
late oil
critical moment
0
100
200
300
400
500
600
AGE (MILLION YEARS)
0
2000
4000
6000
8000
10,000
12,000
DEPTH (METERS)

Figure 10 (facing page). Burial history and hydrocarbon generation model for the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Bozhong subbasin of the Bohaiwan basin. Abbreviations: Miss., Mississippian; Penn., Pennsylvanian; P, Paleocene; E, Eocene; O, Oligocene; M, Miocene; Pl, Pliocene and Quaternary; t=0, present day.

thickness, overburden rocks in the Bozhong subbasin at the critical moment for Member 3 source rocks of the Shahejie Formation were limited to Members 1 and 2 of the Shahejie Formation and to the Dongying Formation (fig. 4, table 9). Based on tables 8 and 9, the net thickness of the combined Shahejie (Members 1 and 2), Dongying, and Guantao Formations in the Bozhong subbasin is about double the net thickness of these units in the Jiyang subbasin. This greater thickness of overburden rock may explain why the critical moment for Member 3 (Shahejie Formation) source rocks in the Bozhong subbasin is earlier than in the Jiyang subbasin.

Migration

Most of the oil in this total petroleum system was generated in fault-controlled half-grabens—classified as subbasins, depressions, and sags depending on their size—and migrated both updip along the gentle flanks of these structures and subvertically along the master fault systems (Wu and Liang, 1988; Chen and Zhang, 1991; Chang, 1991). Where a "low" central high block is flanked by two half-grabens (each having a master fault that dips toward the other), oil migration commonly was focused away from the depressions toward the "low" central high (Chen and Zhang, 1991). Oil migrated into buried hills either directly from overlying or adjoining mature Tertiary source rocks, along unconformities, or subvertically along fault zones (Zhai and Zha, 1982; Zheng, 1988). Local to short-range oil migration was dominant in each subbasin, and probably the oil migrated no farther than a few tens of kilometers from the pods of mature source rock (source centers) (Wu and Liang, 1988; Chang, 1991; Jin and McCabe, 1998). Complicated structural patterns, abrupt sedimentary facies changes, and relatively small sizes of the subbasins and depressions prevented any long-range migration.

Overburden Rocks

Overburden rocks at the critical moment for Member 3 source rocks of the Shahejie Formation in the Jiyang subbasin consisted, in ascending order, of Members 2 and 1 of the Shahejie Formation, the Dongying Formation, and the Guantao Formation (fig. 4; table 8). An estimated 300 m of upper Oligocene strata were removed prior to the deposition of the Guantao Formation (fig. 4; table 8).

Shahejie Formation Overburden

Upper Eocene and lower Oligocene Member 2 of the Shahejie Formation represents a gradually shrinking stage of the lake and is characterized by fluvial, deltaic, and shallow-water lacustrine deposits that replaced widespread deepwater lacustrine deposits of Member 3 (ECPG–Shengli, 1987). Fluvial deposits were locally derived from uplifted and eroded fault blocks that flanked the depressions. During Member 2 deposition, lacustrine environments persisted in the Chezhen (Chenzheng) and Zhanhua (Zhanghua) depressions of the Jiyang subbasin, whereas alluvial plain, swamp, and fluvial environments formed in the Dongying and Huimin depressions (ECPG–Shengli, 1987) (see fig. 1*B* for the location of the depressions). Shallow lacustrine deposits of the Chezhen (Chenzheng) and Zhanhua (Zhanghua) depressions consist of gray, dark-gray, and gray-green mudstone, siltstone, silty fine-grained sandstone, dolomitic carbonates, and local sandstone (ECPG–Shengli, 1987). Fluvial deposits (braided and meandering channels) in the Dongying and Huimin depressions consist of medium- to fine-grained sandstones and associated crevasse splay, whereas the alluvial plain deposits consist of siltstone, fine-grained sandstone, and red and green mudstones (ECPG–Shengli, 1987). Fine-grained sandstone, siltstone, and greenish-gray mudstone characterize the deltaic deposits. Local alluvial fan deposits, consisting of coarse sandstone and conglomeratic sandstone, are located around the margins of the depressions (ECPG–Shengli, 1987). Some alluvial fans prograded into the lake to form fan deltas and subaqueous fans.

Lacustrine conditions expanded and water deepened somewhat in the Jiyang subbasin during the deposition of lower Oligocene Member 1 of the Shahejie Formation so that gray to dark-gray shale and mudstone, commonly containing abundant organic matter, was the dominant lithology (ECPG–Shengli, 1987; Hu and others, 1989). Carbonate grainstone deposits as much as 10 m thick commonly accumulated in beach and barrier-bar environments along the shoreline.

Dongying Formation Overburden

The upper Oligocene Dongying Formation in the Dongying depression represents the rapid east-to-west progradation of fluvial and deltaic deposits over Member 1 of the Shahejie Formation (ECPG–Shengli, 1987). Fluvial and deltaic deposits also dominated the Dongying Formation in the Huimin depression, but the direction of progradation was from northwest to south. Shallow lacustrine deposits of green and gray mudstone and thin sandstone represent the Dongying Formation in the Chezhen (Chenzheng) and Zhanhua (Zhanghua) depressions. Local subaerial exposure of these mudstone beds in the Dongying Formation formed minor red beds.

Regional Post-Paleogene Uplift and Guantao Formation Overburden

A brief period of regional uplift and erosion at the end of the Oligocene produced a basinwide unconformity between syn-rift Paleogene strata and overlying post-rift Neogene strata (Allen and others, 1997) (fig. 4). Post-rift thermal subsidence that followed the uplift and erosion (Allen and others, 1997) produced Neogene strata that were more uniform in thickness and facies type than the Paleogene strata. In the Jiyang subbasin, the Miocene Guantao Formation, consisting of alluvial fan deposits (conglomeratic sandstone), braided fluvial deposits (sandstone), and alluvial plain deposits (red and grayish-green mudstone), rests unconformably on the Dongying Formation (Hu and others, 1989; Allen and others, 1997). The majority of the fluvial sandstones in the Guantao Formation in the Jiyang subbasin were derived from the Chengning uplift that bounds the north side of the subbasin (ECPG–Shengli, 1987) (see fig. 1*B* for the location of the depressions).

Trap Styles for Oil and Gas Fields

The locations of most of the oil and (or) gas fields discovered through the second quarter of 1996 in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System are shown in figure 6. Also, many of these fields are labeled in figure 1*A*. The trap type for many of the fields is noted in tables 1 through 6. According to Petroconsultants (1996), structural traps account for approximately 95 percent of the known oil and gas in the Bohaiwan basin, and stratigraphic traps account for the remaining 5 percent.

Structural Traps

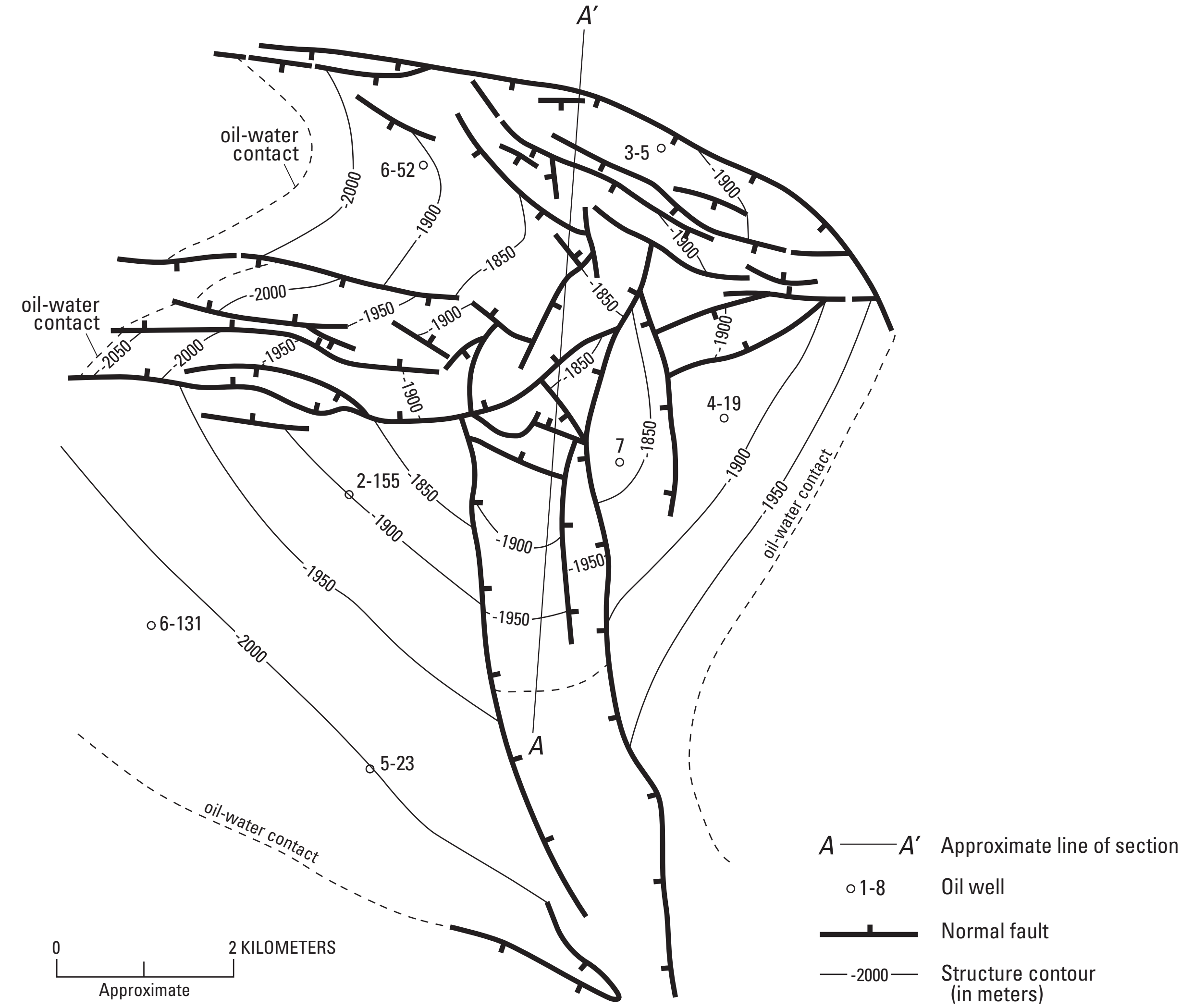
Latest Cretaceous and Paleogene extensional and transtensional tectonics in the Bohaiwan basin created numerous faulted roll-over anticlines (fig. 11), anticlinal noses, fault (horst) blocks, and tilted fault blocks that constitute the majority of the structural traps in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System (Qian and Chen, 1990; Chang, 1991; Li, Yao, and Liu, 1991) (fig. 2). Anticlinal traps have either four-way closure or three-way closure in combination with an updip fault-block seal. Additional anticlines were formed by differential compaction (drape) over fault (horst) blocks and buried hills (fig. 12) (Li, 1989; Qian and Chen, 1990; Chang, 1991) and by local diapirism owing to remobilized salt-bearing mudstone (Wang and others, 1985). Oil trapped in the compaction (sediment-drape) anticline at the giant Gudao field in the Jiyang subbasin may have had a complex history of remigration that followed episodes of nearly continuous faulting from the latest Cretaceous through most of the Neogene (Chen and Wang, 1980). Locally, structural traps probably were modified by minor Quaternary compression and inversion (Zhao and Windley, 1990), perhaps causing remigration of hydrocarbons to new sites of entrapment.

Structural traps that involve large horst blocks and tilted fault blocks with Archean crystalline reservoirs and Proterozoic and lower Paleozoic carbonate reservoirs are referred to as buried hills (Zhai and Zha, 1982; Zheng, 1988; ECPG–Continental Shelf, 1987) (figs. 2 and 13). Zhai and Zha (1982) emphasized that these “buried hills” are not hills in the geomorphological sense but rather are simply fault blocks that formed during major regional extension. According to them, most subaerial weathering of the fault blocks predated regional extension and occurred during periods of uplift and erosion between the late Ordovician and the late Mesozoic to early Tertiary. Structural traps that involve horst blocks and tilted fault blocks with Tertiary sandstone reservoirs are classified as fault traps and fault-block traps (Qian and Chen, 1990; Chen and Zhang, 1991; Tian and others, 1996).

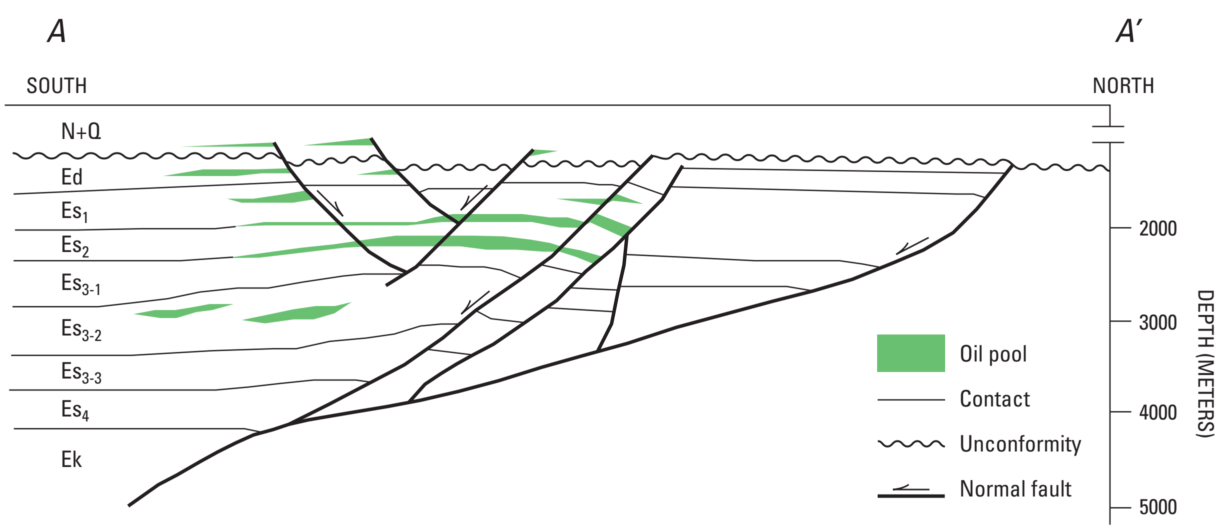
Stratigraphic Traps

In addition to structural traps, numerous stratigraphic traps are present in Tertiary strata of the Bohaiwan basin and consist of facies-change, unconformity, stratigraphic onlap, and diagenetic varieties (Ma and others, 1982; Chen and others, 1988; Shaui and others, 1988; Qian and Chen, 1990). Commonly, unconformity and facies-change stratigraphic traps form combination traps with anticlinal noses and flanks. In general the stratigraphic traps are small and subtle and thus are of secondary importance. Most stratigraphic traps were established by the end of the Eocene, but optimum trapping conditions probably were not established until lateral and top seals were more deeply buried during the Oligocene. In some cases bitumen seals have formed near the surface (due to the evaporative loss of light hydrocarbons) and trapped oil on the flanks of the subbasins (Chang, 1991).

Figure 11 (facing page). Structure contour map and cross section of the western part of the Shengtuo oil field in the Jiyang subbasin of the Bohaiwan basin. The entrapment of oil occurs in a roll-over anticline. See figure 1*A* for location of the oil field. *A*. Structure contour map on the top of Member 2 of the Shahejie Formation (modified from Editorial Committee of Petroleum Geology of the Shengli Oil Field, 1987). *B*. Cross section *A–A′*. From Jin and McCabe (1998, fig. 14, p. 356) and published with permission of Elsevier. Approximate line of section is shown in figure 11*A*. Cross section is not to scale. Abbreviations: Ek, Paleocene and Eocene Kongdian Formation; Es, Eocene and Oligocene Shahejie Formation (Members 1–4); Ed, Oligocene Dongying Formation; N+Q, Neogene and Quaternary strata.


A′
A
oil-water contact
6-52
3-5
2000
1900
1850
1950
2050
oil-water contact
4-19
7
2-155
6-131
5-23
oil-water contact
oil-water contact
0
2 KILOMETERS
Approximate
A —— A′ Approximate line of section
1-8 Oil well
Normal fault
-2000 Structure contour (in meters)

A


A
A′
SOUTH
NORTH
N+Q
Ed
Es1
Es2
Es3-1
Es3-2
Es3-3
Es4
Ek
2000
3000
4000
5000
DEPTH (METERS)
Oil pool
Contact
Unconformity
Normal fault

B

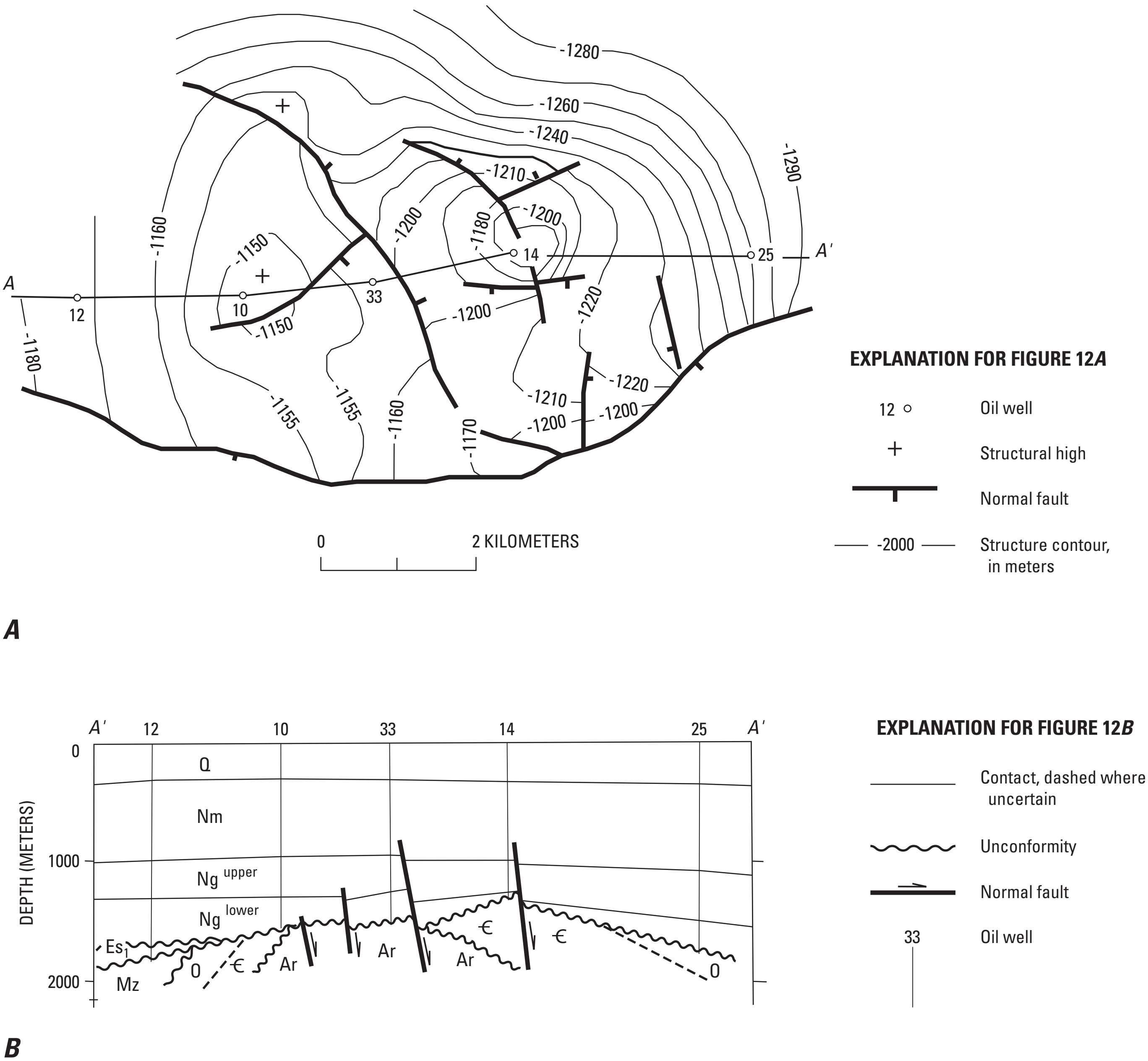
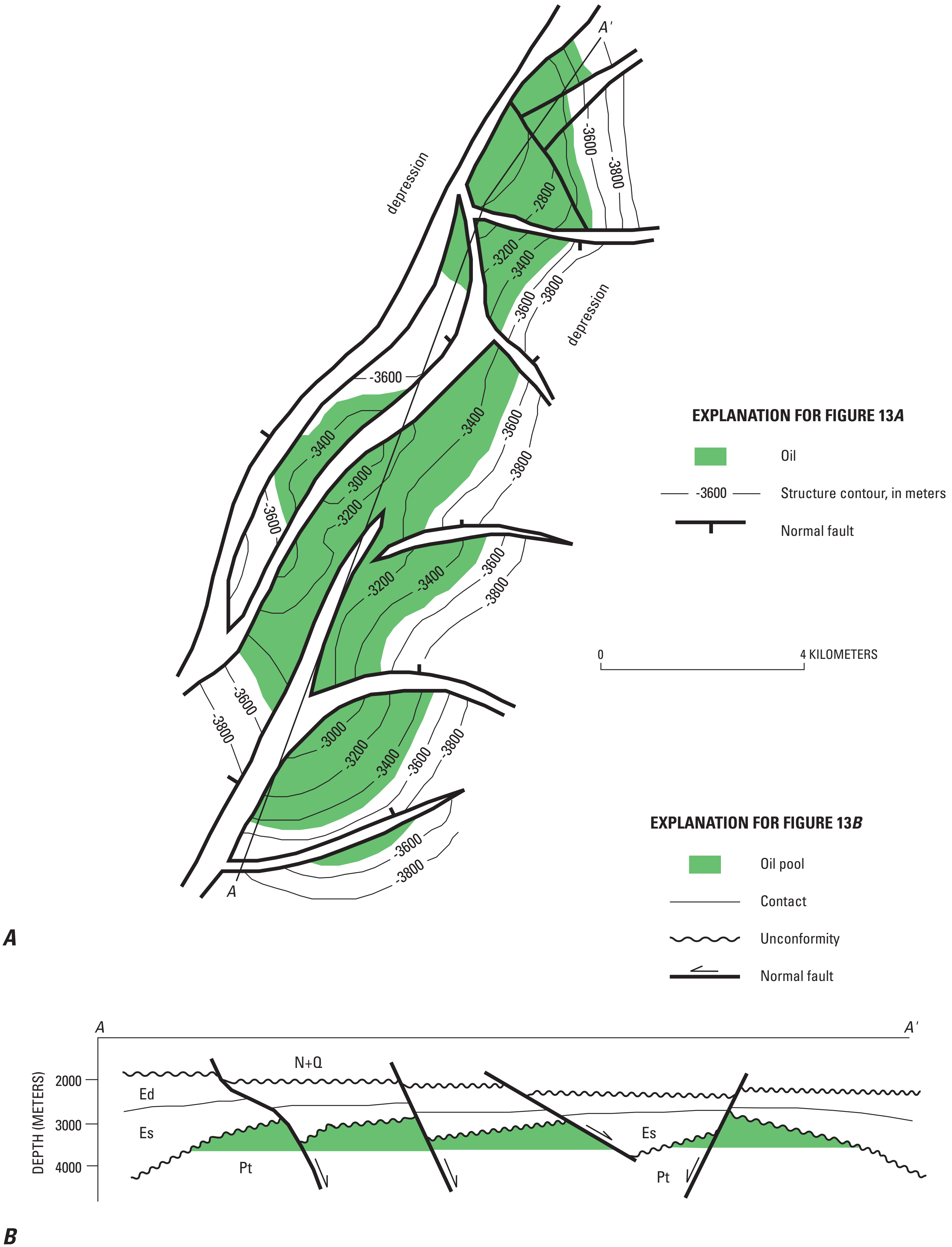


Figure 12. Structure contour map and cross section of the Chengdong oil field in the Jiyang subbasin of the Bohaiwan basin (from Editorial Committee of Petroleum Geology of the Shengli Oil Field, 1987). The entrapment of oil occurs in a compaction (drape) anticline over a basement high. See figure 1*A* for location of the oil field. *A*. Structure contour map on the base of the third sandstone of the Guantao Formation. The major reservoirs are sandstone units in the upper part of the Guantao Formation. *B*. Cross section *A–A′*. The approximate line of section is shown in figure 12*A*. Cross section is not to scale. Abbreviations: Ar, Archean granite; €, Cambrian rocks; O, Ordovician rocks; Mz, Mesozoic rocks; Es_1, Oligocene Member 1 of the Shahejie Formation; Ng^{lower}, lower part of the Miocene Guantao Formation; Ng^{upper}, upper part of the Miocene Guantao Formation; Nm, Miocene and Pliocene Minghuazhen Formation; Q, Quaternary sediments.

Figure 13 (facing page). Structure contour map and cross section of the Renqiu oil field in the Jizhong subbasin of the Bohaiwan basin. From Jin and McCabe (1998, fig. 12, p. 355) and published with permission of Elsevier. The entrapment of oil occurs in tilted fault blocks (buried hills). See figure 1*A* for location of the oil field. *A*. Structure contour map on the top of Proterozoic carbonate rocks. *B*. Cross section *A–A′*. The approximate line of section is shown in figure 13*A*. Cross section is not to scale. Abbreviations: Pt, Proterozoic carbonate rocks; Es, Eocene and Oligocene Shahejie Formation; Ed, Oligocene Dongying Formation; N+Q, Neogene and Quaternary rocks.


A′
depression
-2800
-3000
-3200
-3400
-3600
-3800
depression
A
EXPLANATION FOR FIGURE 13A
Oil
-3600
Structure contour, in meters
Normal fault
0
4 KILOMETERS
A
EXPLANATION FOR FIGURE 13B
Oil pool
Contact
Unconformity
Normal fault
A
A′
DEPTH (METERS)
2000
3000
4000
N+Q
Ed
Es
Es
Pt
Pt
B

Reservoir Rocks

Reservoir rocks in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System consist of four major types. In approximate order of importance they are as follows: (1) sandstone and conglomeratic sandstone of Paleogene age deposited in fan delta, deltaic, littoral, and subaqueous fan (turbidite) systems associated with large, deepwater to shallow-water lakes (Ma and others, 1982; Zhao and others, 1988; Li, Yao, and Liu, 1991; Gustavson and Xin, 1992; Tian and others, 1996); (2) sandstone and conglomeratic sandstone of late Paleogene and Neogene age deposited in fluvial systems (Chen and Wang, 1980; ECPG–Dagang, 1987; ECPG–Continental Shelf, 1987; Tian and others, 1996; Hurst and others, 2001); (3) highly weathered and fractured carbonates of Proterozoic and early Paleozoic age deposited under peritidal and open-shelf conditions on shallow-marine carbonate platforms (Zhai and Zha, 1982; Fei and Wang, 1984; Horn, 1990); and (4) highly weathered and fractured crystalline basement rocks of Archean age (Zheng, 1988; Tong and Huang, 1991). Although shallow-water limestone reef and grainstone deposits in Members 1 and 4 of the Shahejie Formation are locally important reservoir units in the Jiyang (Ma and others, 1982; ECPG–Shengli, 1987), Huanghua (Tian and others, 1996), and Liaohe (Lomando, 1996) subbasins, they are of secondary importance in comparison to the four major reservoir types. Also, volcanic rocks of Tertiary age are locally important reservoirs in the Liaohe subbasin (Chen and others, 1999), but overall, they are of secondary importance. Selected properties of the sandstone, carbonate, and crystalline basement reservoirs in the six subbasins are listed in tables 10 through 15.

Primary reservoirs vary among the six subbasins, but overall, the Shahejie and Guantao Formations are the dominant Tertiary sandstone reservoirs and the Wumishan Formation is the dominant pre-Tertiary carbonate reservoir.

Sandstone Reservoirs

Oil and gas are produced from sandstone reservoirs in all the subbasins of the Bohaiwan basin and in most Paleogene and Neogene stratigraphic units. Although important Tertiary sandstone reservoirs are located in the Kongdian (Member 1), Shahejie (Members 2 and 3), Dongying (Member 3), Guantao, and Minghuazhen Formations (figs. 2, 3, and 4), their relative importance varies among the subbasins. Typically, the sandstone is highly feldspathic (arkosic litharenite, lithic arkose) (ECPG–Shengli, 1987; ECPG–Dagang, 1987; ECPG–Continental Shelf, 1987; Li and others, 2004) and primary intergranular porosity is the predominant porosity type.

Jiyang Subbasin

Braided fluvial and (or) deltaic sandstones in Member 2 of the Shahejie Formation, as well as deltaic, turbidite, and shoreline sandstones in Member 3, are among the primary reservoirs in the Jiyang subbasin (Ma and others, 1982; ECPG–Shengli, 1987; Jin and McCabe, 1998). Porosity values for Member 2 sandstone reservoirs are commonly greater than 25 percent and permeability values are between 500 and 1,000 millidarcies (md) (ECPG–Shengli, 1987) (table 10). Other important sandstone reservoirs in the Jiyang subbasin are associated with the Guantao and Dongying Formations (ECPG–Shengli, 1987; Chen and Wang, 1980). In the giant Gudao oil field (fig.1*A*), fluvial sandstones in the Guantao Formation comprise individual elongate sandstone bodies that range in thickness from 4 to 12 m and have porosity ranging from 30 to 32 percent and permeability between 510 and 2,440 md (Chen and Wang, 1980) (table 10).

Liaohe Subbasin

The dominant sandstone reservoirs in the Liaohe subbasin are located in the Shahejie Formation (Members 1, 2, and 3) and the lower part of the Dongying Formation (Ge and ECPG–Liaohe, 1989; Gustavson and Xin, 1992) (table 11). The Dongying Formation sandstone reservoirs in the Suizhong 36-1 oil field (fig. 1*A*) are poorly consolidated and have porosity values between 28 and 35 percent and permeability values commonly greater than 100 md (Li, 1989).

Jizhong Subbasin

Sandstone reservoirs in the Jizhong subbasin are located in the Kongdian Formation (Member 1), Shahejie Formation (Members 1, 2, 3, and 4), and Dongying Formation (Member 3) (ECPG–Huabei, 1987; Wu and Liang, 1988; Li, Du, and Hu, 1991). Typical sandstone reservoirs in the Shahejie Formation (Members 3 and 4) have a pay thickness of 2 to 4 m (maximum 10 m), an average porosity between 25 and 28 percent, and an average permeability of about 160 md (ECPG–Huabei, 1987) (table 12). Oil-bearing sandstones in the Dongying Formation (Member 3) have moderate to poor reservoir properties that are characterized by porosity values between 19 and 27 percent and permeability values between <50 and 770 md (ECPG–Huabei, 1987) (table 12).

Huanghua Subbasin

Important sandstone reservoirs in the Huanghua subbasin are located in the Kongdian (Member 1), Shahejie (Members 1 and 3), Dongying (Member 3), Guantao, and Minghuazhen Formations (ECPG–Dagang, 1987; Chen and Zhang, 1991; Tian and others, 1996; Jin and McCabe, 1998). Guantao Formation sandstone reservoirs have a net pay thickness as great as 20 to 30 m, porosity as much as 33 percent, and permeability as high as several darcies (Li and Zhang, 1987) (table 13). In comparison, the Kongdian (Member 1) sandstone reservoirs have a total thickness of about 100 m (no net pay recorded), an average porosity of about 15 to 25 percent, and an average permeability of about 65 to 294 md.

Linqing/Dongpu Subbasin

In the Linqing/Dongpu subbasin, the most productive sandstone reservoirs for oil are located in the Shahejie Formation (Members 2 and 3) (Li, Yao, and Liu, 1991; Jin and McCabe, 1998). Oil-bearing sandstone reservoirs in Member 2 of the Shahejie Formation are commonly characterized by porosity values between 11 and 25 percent and by permeability values between 37 and 240 md (table 14). In addition, Jin and McCabe (1998) reported porosity values in Member 2 to be 24 to 25 percent and permeability values to be as high as 850 and 940 md.

Bozhong Subbasin

In the Bozhong subbasin, the Guantao and Minghuazhen Formations (fluvial origin) and the lower part (Member 3) of the Dongying Formation (deltaic origin) constitute the main sandstone reservoirs (Gong and others, 1998; Hurst and others, 2001; Xu, 2004). The combined thickness of the net pay for fluvial sandstone reservoirs in the Guantao Formation in the Peng Lai 19-3 field (fig. 1*A*) is as much as 160 m, and permeability ranges from 100 md to several darcies (Hurst and others, 2001) (table 15).

Carbonate and Crystalline Basement Reservoirs

Buried-hill oil and gas accumulations that produce from highly weathered and fractured Proterozoic and lower Paleozoic carbonate and (or) Archean crystalline basement reservoirs are present in all subbasins of the Bohaiwan basin except for the Linqing/Dongpu (Zhai and Zha, 1982). Carbonate reservoirs of importance are located in the Middle Proterozoic Gaoyuzhuang, Yangzhuang, and Wumishan Formations, the Cambrian Fujunshan and Mentou Formations, and the Ordovician Fengfeng, Liangjiashan, and Majiagou Formations (Zhai and Zha, 1982; ECPG–Huabei, 1987; Zheng, 1988; Horn, 1990; Tong and Huang, 1991) (fig. 4). The largest known buried-hill accumulations in Proterozoic and lower Paleozoic carbonates and (or) Archean basement rocks are located in the Jizhong and Liaohe subbasins.

Carbonate reservoirs consist largely of fine- to medium-crystalline dolomite and bioclastic and oolitic limestone. Generally, these carbonates have poor primary intercrystalline and intergranular porosity, and they depend on karst processes and tectonic fractures to improve their reservoir character (Zhai and Zha, 1982; ECPG–Shengli, 1987; ECPG–Huabei, 1987; Wu, 1998).

Archean crystalline-basement reservoirs consist primarily of metamorphosed granitic rocks that have been intensely weathered and fractured (Zheng, 1988; Tong and Huang, 1991; Wu, 1998). In addition to having fracture porosity, these basement reservoir rocks have secondary intergranular porosity formed by alteration of unstable minerals such as amphibolite and biotite (Tong and Huang, 1991).

Liaohe Subbasin

Dolomite in the Wumishan Formation, sandy dolomite and dolomitic quartzite of the Middle Proterozoic Tieling Formation, dolomite and quartzite of the Middle Proterozoic Gaoyuzhuang Formation, and metamorphosed Archean granitic rocks are the main reservoir rocks in the large oil fields of the Liaohe subbasin (Zheng, 1988; Ge and ECPG–Liaohe, 1989; Tong and Huang, 1991). Although secondary porosity caused by grain dissolution and intercrystalline pores is locally important, fracture porosity is the dominant porosity type (Ge and ECPG–Liaohe, 1989; Tong and Huang, 1991) (table 11). Tong and Huang (1991) noted that total porosity in the Dongshengpu oil field (fig. 1) averages 3.8 to 4.2 percent, of which about 90 percent is fracture porosity.

Jizhong Subbasin

The Wumishan Formation is the main reservoir in the giant Renqiu oil field (figs. 1*A*, 13; table 12) in the Jizhong subbasin (ECPG–Huabei, 1987; Horn, 1990). The reservoir rock consists of algal (stromatolitic) dolomite with siliceous dolomite and intercalated argillaceous dolomite that has been highly fractured and modified by karst processes. The net thickness of the entire producing interval (the Wumishan, Fujunshan (Fujushan), and Liangjiashan Formations, and several other units) is 850 m (Horn, 1990). Primary pore space in these carbonate reservoirs is nearly nonexistent because it has been occluded during a complex history of diagenetic, burial, subaerial/karst, and tectonic processes. Secondary pore space consists of intracrystalline pores, dissolution pores and vugs, microfractures, fractures, and cavities (ECPG–Huabei, 1987). Numerous high-angle fractures and small faults formed largely by late Paleozoic (Indosinian) and Mesozoic (Yanshanian) compression cut pervasively across the carbonate units and, during Paleogene extension, served as conduits for circulating meteoric water and intense karst activity (Fei and Wang, 1984). Horn (1990) reported that the fracture widths in the Renqiu reservoirs commonly range from 0.1 to 1.0 millimeters (mm) and that about 7 percent of the fractures are wider than 1.0 mm. Well logging and reservoir performance studies suggest that the Wumishan Formation reservoir at Renqiu has a bulk porosity of about 4 to 5 percent, a matrix porosity of about 3.1 to 4.2 percent, and a fracture porosity of about 0.6 to 0.9 percent (Horn, 1990). Drilling records that show sudden drops of the drill bit and (or) lost circulation of drilling fluid indicate that numerous caves and cavities are present in the carbonate reservoir (Fei and Wang, 1984). Permeability is difficult to measure because of reservoir heterogeneity, but where data are available, values range from 0.1 to 100 md, with values as high as 1,000 md in fracture zones (Horn, 1990).

Seal Rocks

The most important regional seal rocks for anticlinal traps in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum

System consist of 400- to 1,000-m-thick, gray lacustrine mudstone units in Members 1 and 3 of the Shahejie Formation (ECPG–Shengli, 1987) and a 800- to 1,200-m-thick, green to brownish-red and light-gray nonmarine mudstone unit in the Minghuazhen Formation (Chen and Wang, 1980) (figs. 4, 7). Secondary seal rocks consist of discontinuous evaporite and calcareous lacustrine mudstone units, between 100 and 150 m thick, in Members 2 and 4 of the Shahejie Formation (Wu and Liang, 1988). Numerous local mudstone units (mainly of lacustrine origin) in the Shahejie Formation also are top and lateral seals for stratigraphically trapped oil and gas in lenticular sandstone bodies (Ma and others, 1982). Fault-block accumulations, where oil and gas are trapped in sandstone reservoirs, depend on impermeable mudstone in the Shahejie Formation in adjoining fault blocks and in some cases the faults themselves for lateral seals (Chen and Wang, 1980; Ma and others, 1982; ECPG–Shengli, 1987).

Most mudstones in the Shahejie Formation also are top and lateral seal rocks for tilted fault-block (buried-hill) accumulations in carbonates and crystalline basement rocks (Zhai and Zha, 1982; Zheng, 1988; Horn, 1990). In some localities, lateral seals for buried-hill accumulations are mudstone in Carboniferous and Permian formations, Mesozoic formations, and the Tertiary Kongdian Formation (ECPG–Shengli, 1987; ECPG–Huabei, 1987). Many of the Shahejie seal rocks are also source rocks, making them conveniently located to charge adjoining buried-hill traps either along adjoining faults or along adjoining unconformities (ECPG–Huabei, 1987; Zheng, 1988).

Assessment Units

Two major assessment units are defined in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System: (1) a Tertiary lacustrine assessment unit (31270101) consisting of conventional oil and gas accumulations in sandstone reservoirs of lacustrine and fluvial origin and (2) a pre-Tertiary buried hills assessment unit (31270102) consisting of conventional oil and gas accumulations in highly fractured and weathered Proterozoic and lower Paleozoic carbonates of peritidal to shallow-marine origin and Archean crystalline basement rocks.

Tertiary Lacustrine Assessment Unit

The Tertiary lacustrine assessment unit consists of oil, associated gas, and nonassociated gas trapped in faulted rollover anticlines, compaction (drape) anticlines, anticlinal noses, fault (horst) blocks, and tilted fault blocks. The area of the assessment unit shown in figure 14 encompasses all pods of mature source rock in the subbasins but excludes the Chengning uplift between the Jiyang and Huanghua subbasins.

Although included with the assessment unit in figure 14, thermally immature regions having a relatively thin sedimentary cover such as the Cangxian uplift and the northern part of the Linqing/Dongpu subbasin may not be prospective. The Paleogene and Neogene sandstones of lacustrine (deltaic, fan delta, and subaqueous fan) and fluvial (braided and meandering channels) origin are the main reservoir units. Also included in this assessment unit are a variety of stratigraphic-trap accumulations (facies-change, unconformity, stratigraphic onlap, and diagenetic) and combination-trap accumulations. Giant oil fields (≥1 BBO) discovered in this assessment unit in the Jiyang subbasin (Dongxin, Gudao, Gudong, and Shengtuo), Huanghua subbasin (Dagang complex (Beidagang) and Chengdao), and Linqing/Dongpu subbasin (Pucheng and Wenliu) account for a combined known recoverable of 15.7 BBO (Jin and McCabe, 1998). Several major oil fields trapped largely in faulted anticlines and fault blocks in this assessment unit are the Bonan and Linpan fields (Jiyang subbasin), Wangguangtun and Zaoyuan fields (Huanghua subbasin), and Gaosheng field (Liaohe subbasin) (fig. 1*A*; tables 1, 2, and 4). This group of five major oil fields accounts for another 4.2 billion barrels of known recoverable oil (Jin and McCabe, 1998) and, when combined with the eight giant fields, accounts for 19.9 BBO or about 80 percent of the known volume of oil (24.6 BBO) of the 27.3 BBOE discovered in the basin through the second quarter of 1996 (Klett and others (1997).

Pre-Tertiary Buried Hills Assessment Unit

The pre-Tertiary buried hills assessment unit, the extent of which is shown in figure 15, involves oil and (or) gas trapped in tilted fault blocks and horst blocks where the reservoirs are Proterozoic and lower Paleozoic carbonates and Archean crystalline rocks. This assessment unit covers the same area as the Tertiary lacustrine assessment unit shown in figure 14. Giant buried-hill oil fields discovered to date in the assessment unit are Renqiu in the Jizhong subbasin and Shuguang (Shu-huan) and Jinganbu (Jing-anbao) in the Liaohe subbasin (fig. 1*A*; tables 2 and 3). These three buried-hill fields have a combined known recoverable of approximately 6.9 BBO (Jin and McCabe, 1998). When the known recoverable oil of these three giant buried-hill oil fields is combined with the known recoverable oil of the eight giant (and five major) Tertiary lacustrine oil fields, the total 26.8 BBO exceeds by about 9 percent the known volume of oil (24.6 BBO) discovered in the basin through the second quarter of 1996 (Klett and others, 1997). Eventually, the known volume of 24.6 BBO of the 27.3 BBOE (Klett and others, 1997) and (or) the known recoverable of the 11 giant oil fields and the 5 major oil fields (Jin and McCabe, 1998) must be revised to correct the discrepancy. One way the discrepancy might be corrected is to apply reserve growth to some of the oil fields used to compile the known volume of 27.3 BBOE (Klett and others, 1997). The other possibility is that the known recoverable estimates cited by Jin and McCabe (1998) are too optimistic.

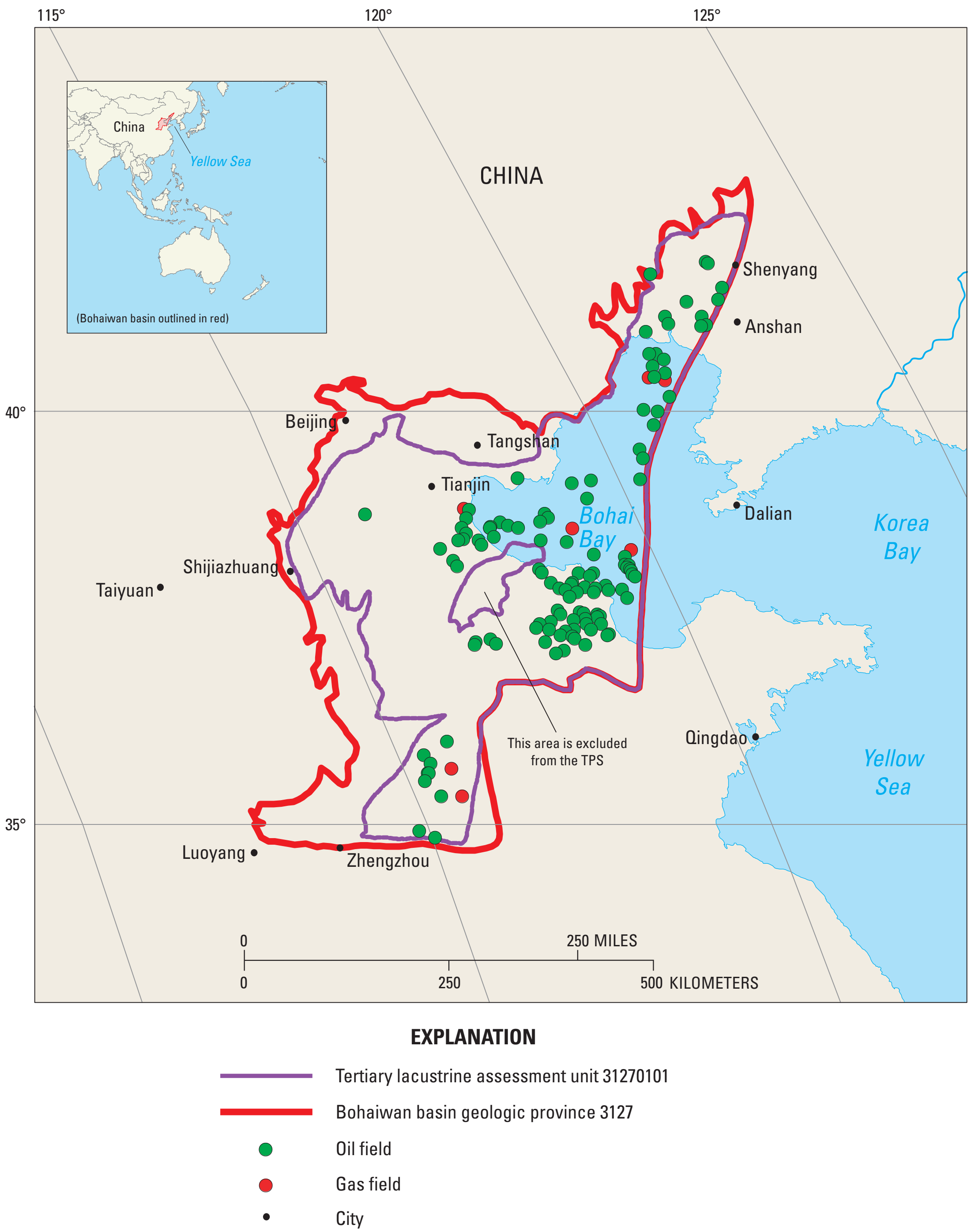


Figure 14. Map showing the area of the Tertiary lacustrine assessment unit of the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System, Bohaiwan basin. Due to differences in projection, scale, and accuracy of latitude-longitude grids, the location of some cities and features in this figure may not be consistent with their location in other figures in this report. TPS, total petroleum system.

Figure 15. Map showing the area of the pre-Tertiary buried hills assessment unit of the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System, Bohaiwan basin. Due to differences in projection, scale, and accuracy of latitude-longitude grids, the location of some cities and features in this figure may not be consistent with their location in other figures in this report. TPS, total petroleum system.

Potential Undiscovered Oil and Gas Resources as of June 2001

Onshore

The onshore part of the Bohaiwan basin is probably in the very mature stage of exploration, in which all the easily identified anticlines, fault blocks, and buried hills at shallow (≤2,500 m) and intermediate (2,500–4,500 m) depths have already been drilled. Future onshore oil and gas discoveries are expected to be found in subtle stratigraphic, structural, and combination structural and stratigraphic traps that, for example, are formed by faults and stratigraphic pinchouts with anticlinal noses that should be identifiable on high-resolution three-dimensional (3-D) seismic records. Such traps may occur in synclines or in homoclinal structures on the flanks of major anticlines and fault blocks, where fewer exploration holes have been drilled. Small to medium-size oil fields are expected in these traps.

Also, there may be potential for undiscovered small to medium-size gas fields in the Tertiary lacustrine assessment unit deeper than 4,000 m in the onshore parts of the Huanghua, Linqing/Dongpu, and Liaohe subbasins where secondary porosity in the sandstones is as high as 15 percent (He and others, 1998; Zhang, 1999). Commonly the reservoirs are overpressured (He and others, 1998).

Offshore

The offshore part of the Bohaiwan basin, particularly in the Bozhong and Liaohe subbasins, has the best potential for undiscovered oil and gas accumulations. Many medium-size to large fields have been discovered in the offshore area and, as of June 2001, CNOOC and its foreign partners had identified 19.7 BBO of proved "reserves" (Oil and Gas Journal, 2001). These estimated proved "reserves" probably represent in-place oil and include all discoveries made throughout the exploration history from 1980 to 2001 in Bohai Bay. The 9.5 BBOE cited by Xu (2004) is probably a good estimate of the known recoverable oil and gas discovered to date in the offshore part of the Bohaiwan basin. Anticlines and fault blocks in the Tertiary lacustrine assessment unit were the major exploration targets in the 1980s and 1990s (Gong and others, 1998; Shirley, 2000; Xu, 2004), but buried hills and fault blocks in the pre-Tertiary buried hills assessment unit are becoming increasingly important exploration targets (Neese and Jewell, 1998; Wu, 1998). The only buried-hill discovery in the early phase of Bohai Bay exploration was the Bozhong 28 field (Matsuzawa, 1988; Wu, 1998). Wu (1998) reported that proved petroleum reserves (known recoverable) in pre-Tertiary reservoirs account for about 4 to 5 percent of the total proved reserves in Bohai Bay; with increased drilling and high-resolution 3-D seismic data, there is great potential for additional reserves. The maximum depth to crystalline basement in Bohai Bay is about 10,000 to 12,000 m in the center of the Bozhong subbasin and about 8,000 to 10,000 m in the deepest part of the Huanghekou depression (fig. 3). Areas on the flanks of these depocenters are very prospective, but, as noted by Brad Patton (in Shirley, 2000), the reservoirs may be of lesser quality there.

Carboniferous/Permian Coal–Paleozoic Total Petroleum System (312702)

Petroleum Occurrence

The Carboniferous/Permian Coal–Paleozoic Total Petroleum System is a hypothetical total petroleum system having Carboniferous and Permian coal beds as the source rock and Permian sandstones and possibly Carboniferous coal beds as the main reservoirs. Both the reservoir and source rocks are located in subcrops of Carboniferous and Permian strata in fault blocks (buried hills), fault-bounded depressions, and broad synclines.

This hypothetical total petroleum system is proposed because of the following developments. First, preliminary investigations of several Bohaiwan subbasins indicate that Carboniferous and Permian coal measures very likely have generated large volumes of natural gas that may have accumulated in Carboniferous and Permian sandstone and coal-bed reservoirs (Chang and others, 1981; ECPG–Dagang, 1987; Ge and ECPG–Liaohe, 1989; Su, 1995). Second, several gas accumulations are recognized in Carboniferous and Permian sandstone, lower Paleozoic carbonate, and Tertiary sandstone reservoirs that are in close proximity to Carboniferous and (or) Permian coal beds. Examples of such gas accumulations are the Suqiao, Liuqiying, Guxingzhuang, and Shenxi oil and gas fields in the Jizhong subbasin (ECPG–Huabei, 1987; table 3); the Bonan oil field (Yi-155 gas well) in the Jiyang subbasin (ECPG–Shengli, 1987; table 1); and the Wenliu and Machang oil and gas fields in the Linqing/Dongpu subbasin (Dai and others, 2004; table 5). Third, the geochemical character of many of the previously cited gas accumulations further supports the derivation from Carboniferous and (or) Permian coal beds (Shi and Qin, 1987; Zhu and Xu, 1988; Xu and Shen, 1996). The geochemical characteristics that support coal-derived gases in the Bohaiwan basin are listed in the following section on source rocks. Fourth, small coalbed methane projects in mined and unmined regions of the Huanghua subbasin have had modest success that include the drilling of a 1,100-m-deep well that produced gas at a rate of 6,000 m^3/day (≈0.21 million ft^3/day) (U.S. Environmental Protection Agency, 1996).

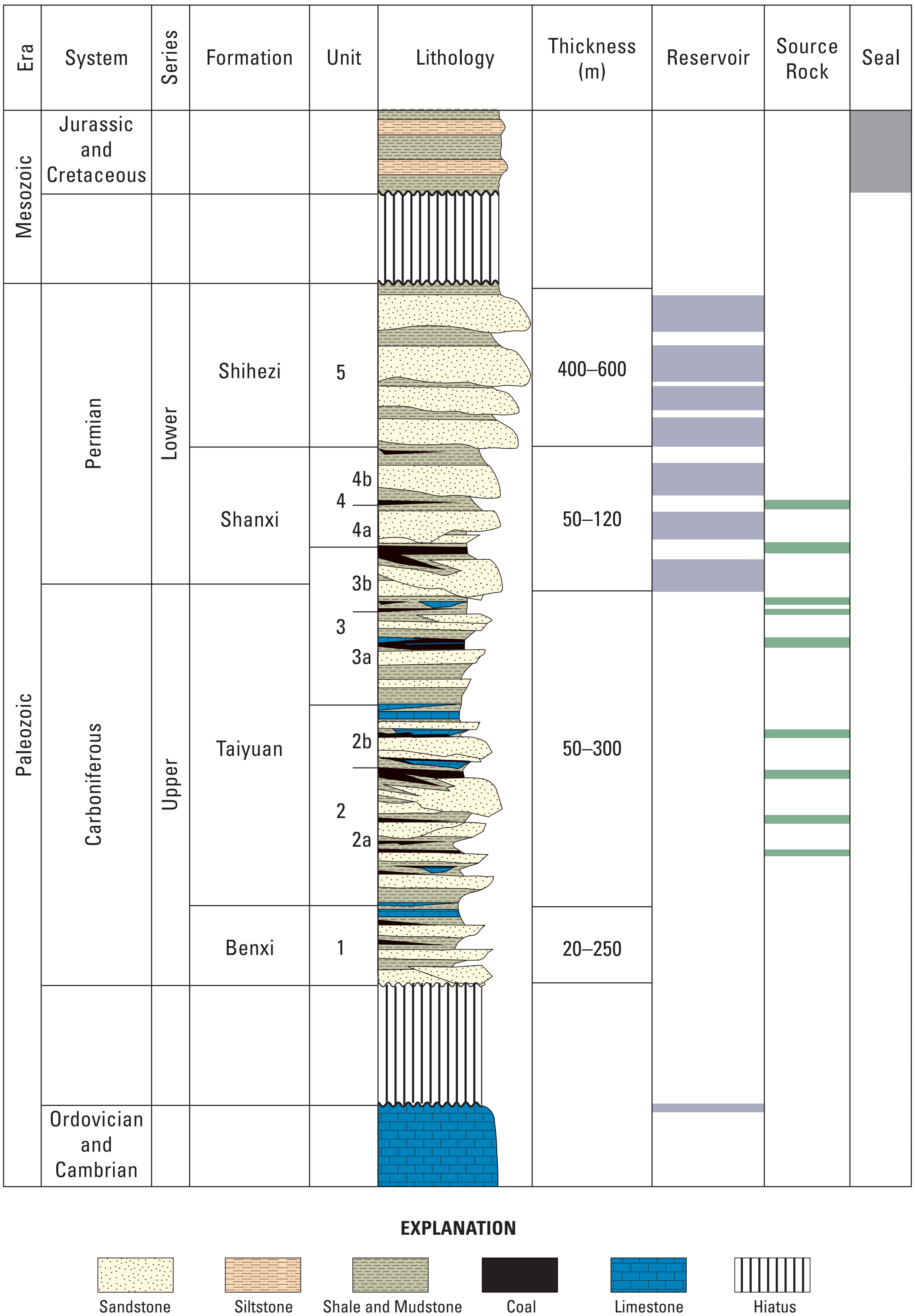


Figure 16. Partial stratigraphic column for the Bohaiwan basin showing the essential elements of the Carboniferous/Permian Coal–Paleozoic Total Petroleum System. Modified from Lin and others (1995, fig. 2, p. 126) and published with permission of CRC Press/Balkema.

Although these developments are encouraging, the Carboniferous/Permian Coal—Paleozoic Total Petroleum System is largely unexplored and will remain hypothetical until the Carboniferous and Permian coal beds are firmly established as an important source of gas for fields in the Bohaiwan basin. Meanwhile, all the previously cited gas accumulations are considered to be part of the Shahejie—Shahejie/Guantao/Wumishan Total Petroleum System.

Source Rocks

Coal beds and carbonaceous shale in the Upper Carboniferous Taiyuan Formation and the Lower Permian Shanxi Formation are the expected source rocks in the Carboniferous/Permian Coal—Paleozoic Total Petroleum System (figs. 4, 16). Carboniferous and Permian carbonaceous shale- and coal-bearing strata in the Bohaiwan basin range from 100 to 400 m thick (Chang and others, 1981; ECPG—Dagang, 1987). As many as 25 coal beds having a net thickness of 58 m and individual coal beds as thick as 9 m are present in the Taiyuan and Shanxi Formations in the Huanghua subbasin (ECPG—Dagang, 1987). Moreover, there are 30 Carboniferous and Permian coal beds in the eastern part of the Huanghua subbasin (south of Tangshan) that range in thickness from 1 to 4 m (U.S. Environmental Protection Agency, 1996). In the northern part of the Jizhong subbasin, as many as 18 coal beds have been reported in the Taiyuan and Shanxi Formations having a net thickness of 7 to 33.5 m, with individual coal beds as thick as 4.8 m (Su, 1995).

Geochemical Characteristics

Carboniferous and Permian Coal Beds

Carboniferous and Permian coal beds have TOC values that average 58.4 weight percent in the Huanghua subbasin (ECPG—Dagang, 1987) and 53.9 weight percent in the Jizhong subbasin (ECPG—Huabei, 1987). Most coal beds and carbonaceous shale are dominated by gas-prone type III kerogen, but oil-prone type II kerogen also is present (ECPG—Dagang, 1987). Similar kerogens (vitrinite and exinite macerals) were reported by Su (1995) for coal in the Suqiao-field area of the Jizhong subbasin. The methane content of 9 to15 m^3/metric ton (T) (288–480 ft^3/ton) measured in the Jizhong subbasin coal beds is comparable to other regions of the world where coalbed methane is produced (Su, 1995). Also, coal beds in the Huanghua subbasin are reported to have a high gas content that ranges from 7.5 m^3/T (240 ft^3/ton) to 9 to 15 m^3/T (288–480 ft^3/ton), with a maximum of 20 m^3/T (640 ft^3/ton) (U.S. Environmental Protection Agency, 1996).

Natural Gases

Natural gas derived from Carboniferous and Permian coal beds in the Bohaiwan basin has the following geochemical characteristics compared to gas derived from oil-prone Tertiary lacustrine source rocks: (1) drier gas (89—95 percent CH_4); (2) heavier $\delta^{13}C_1$ values (-31.1 to -26.4); (3) higher mercury content (>700 ng/m^3), and higher $^{40}Ar/^{36}Ar$ values (>950 ng/m^3) (Shi and Qin, 1987; Zhu and Xu, 1988; Xu and Shen, 1996). Oil-source rock correlations suggest that local oil and condensate in Carboniferous and Permian sandstones in the Huanghua and Jizhong subbasins were generated from carbonaceous shale and coal beds of the same age (Shi and Qin, 1987; ECPG—Dagang, 1987).

Pods of Thermally Mature Source Rock

Pods of thermally mature source rock associated with the Carboniferous and Permian coals are present throughout most of the Huanghua, Jiyang, Jizhong, and Linqing/Dongpu subbasins (Chang and others, 1981; ECPG—Dagang, 1987) (fig. 17). Carboniferous and Permian coal beds appear to be very thin in the Bozhong subbasin (ECPG—Continental Shelf, 1987) and in most of the Liaohe subbasin except at the northeast end (Ge and ECPG—Liaohe, 1989; Li and others, 1995). Carboniferous and Permian coal beds in the Huanghua subbasin have %R_o values that range from about 0.6 to 1.1 percent (ECPG—Dagang, 1987). These vitrinite reflectance values are consistent with the primarily high volatile bituminous rank of coal beds in the eastern part of the Huanghua subbasin (U.S. Environmental Protection Agency, 1996). Comparable vitrinite reflectance values are reported for Carboniferous and Permian coal beds in the Jizhong subbasin (%R_o=0.8—1.1), but in the Zhongyuan region of the Linqing/Dongpu subbasin they are much higher (%R_o=2.0—4.0) (Shi and Qin, 1987). Very likely, the %R_o=2.0—4.0 values are representative of deeply buried boundary-fault margins of half-grabens, whereas the %R_o=0.6—1.1 values are representative of moderately to shallowly buried flexural margins of half-grabens (half-graben terminology from Morley, 1995).

Burial History and Hydrocarbon Generation

On the basis of an estimated geothermal gradient of 32 to 34°C/km, the critical moment for the Carboniferous/Permian Coal—Paleozoic Total Petroleum System in deeply buried boundary-fault margins of half-grabens is estimated to be in the early Paleogene (≈50 Ma) (fig. 18). In regions where Mesozoic strata are thin to absent or where Carboniferous and Permian coal beds are less deeply buried along the flexural margins of half-grabens, the critical moment probably approaches lower Oligocene to upper Miocene time as estimated by model studies for the Shahejie—Shahejie/Guantao/Wumisham Total Petroleum System (figs. 9, 10).

Overburden Rocks

Overburden rocks at the critical moment in the Dongying depression of the Jiyang subbasin were about 5,000 m thick


120°
125°
115°
40°
35°
Erlian Basin
Songliao Basin
Zhangguang-cailing Uplift
Taihangshan Yanshan Fold Belt
China
Yellow Sea
(Bohaiwan basin outlined in red)
Xinmin
Shenyang
Lia
Goubangzi
Jinzhou
Anshan
Yingkou
Qinhuangdao
Beijing
Changli
Tangshan
Guan
Hu
Hangu
Baxian
Ca
Tianjin
Tanggu
Baoding
Jz
Renqui
Bz
Bohai Bay
Xinjin
Dalian
Lushun
Korea Bay Basin
Huanghua
Cangzhou
Yangerzhuang
Bohaiwan Basin
Shijiazhuang
Shenxian
Shulu
Yanshan
Dongguang
Wudi
Zhanhua
Chenjiazhuang
Ch
Luxi Jiaoliao Basin
Dongjia
Linyi
Guangrao
Shanxi Plateau
Jy
Zibo (Zhangdian)
Weifang
Li/Do
Jinan
0 40 80 120 MILES
0 40 80 120 KILOMETERS
This area is excluded from the TPS
Taikang Hefei Basin
Qinling Dabieshan Fold Belt
Subei Yellow Sea Basin
EXPLANATION
TPS boundary
Assessment unit boundary
Outline of pod of mature source rock
Geologic province boundary
Subbasin boundary
Bz Bozhong
Hu Huanghua
Lia Liaohe
Li/Do Linqing/Dongpu
Jy Jiyang
Jz Jizhong
Uplift boundary
Ca Cangxian
Ch Chengning
• City

Figure 17 (facing page). Map showing the Carboniferous/Permian Coal–Paleozoic Total Petroleum System in the Bohaiwan basin, pods of mature source rock, and the coal-sourced gas assessment unit. Abbreviation: TPS, total petroleum system. Due to differences in projection, scale, and accuracy of latitude-longitude grids, the location of some cities and features in this figure may not be consistent with their location in other figures in this report.

and consisted of the Permian Shihezi and Shiqianfeng Formations, unnamed Jurassic and Cretaceous strata, Paleocene and Eocene Kongdian Formation, and Member 4 of the Shahejie Formation (figs. 2*B*, 4, and 18).

Shihezi and Shiqianfeng Formations Overburden

The Lower Permian Shihezi Formation in the Huanghua subbasin consists of a 500- to 600-m-thick nonmarine unit of sandstone and pebbly sandstone, purple mudstone, and carbonaceous mudstone (ECPG–Dagang, 1987). The Shihezi Formation at this locality is overlain by the Upper Permian Shiqianfeng Formation, a 700-m-thick unit of red mudstone, siltstone, and volcanic rocks (ECPG–Dagang, 1987). The Shihezi and Shiqianfeng Formations in the Jizhong subbasin are similar in lithology to these formations in the Huanghua subbasin, but they are thinner, with a thickness of 150 to 475 m for the Shihezi and 100 to 230 m for the Shiqianfeng (ECPG–Dagang, 1987).

Jurassic and Lower Cretaceous Overburden

Jurassic and Lower Cretaceous strata in the Huanghua subbasin are composed of the following nonmarine units: (1) a 200-m-thick Lower to Middle Jurassic unit of gray mudstone, conglomerate, carbonaceous shale, and coal; (2) a 600-m-thick Middle to Upper Jurassic unit of purplish-red arenaceous mudstone, tuffaceous sandstone, and volcanic rocks; and (3) a 200-m-thick or greater Lower Cretaceous unit of predominantly brownish-red arenaceous mudstone (ECPG–Dagang, 1987). Jurassic and Lower Cretaceous rocks are as much as 3,000 m thick along the western margin of the Jizhong subbasin, but in most parts of the subbasin they are as much as 1,600 m thick (ECPG–Huabei, 1987).

Kongdian Formation Overburden

The Paleogene Kongdian Formation ranges in thickness from about 1,000 to 1,600 m in the Bozhong, Huanghua, Jiyang, and Liaohe subbasins (fig. 4) and locally is as thick as 2,500 m in part of the Huanghua subbasin (ECPG–Dagang, 1987). In contrast, the Kongdian Formation is considerably thinner in the Jizhong and Linqing/Dongpu subbasins, where it ranges in thickness from about 200 to 400 m (fig. 4). As previously discussed, the Kongdian Formation is characterized by conglomerate, conglomeratic sandstone, and red mudstone of alluvial fan origin and volcanic rocks that formed during initial stages of rifting. In the Huanghua subbasin, Member 2 of the Kongdian Formation is characterized by lacustrine deposits such as nearshore and subaqueous sandstones and gypsum- to anhydrite-bearing gray to brown mudstone that is considered to be a source rock (ECPG–Dagang, 1987).

Shahejie Formation Overburden

Member 4 of the Shahejie Formation consists of thick, widespread, lacustrine gray to brown mudstone deposits that are important source rocks in many parts of the Bohaiwan basin. The thickness of Member 4 of the Shahejie Formation ranges from about 300 to 500 m in the Linqing/Dongpu subbasin (Li, Yao, and Liu, 1991) to about 1,000 m in the other subbasins of the Bohaiwan basin (fig. 4).

Trap Styles for Gas Fields

Gas in the hypothetical total petroleum system may be trapped as continuous accumulations at or near the center of the subbasins (basin-center gas). Gas entrapment may be facilitated by updip zones of high water saturation in the Permian sandstones in a manner described by Masters (1979). Analogs to the basin-center gas accumulations proposed in the Carboniferous/Permian Coal–Paleozoic Total Petroleum System in the Bohaiwan basin may be the Changqing and Sulige gas fields in the Ordos basin (fig. 5), located about 500 to 550 km west of the Bohaiwan basin (Zhang and Yu, 1998). Although the Ordos basin, rather than being a rift basin, is a foreland basin having low-dipping, unfaulted homoclinal strata, the Changqing, Sulige, and associated gas fields are characterized by low-permeability sandstone reservoirs of Carboniferous and Permian age, by coal-bed source rocks, and by a basin-center structural setting (Zhang and Yu, 1998; Li, 2002).

Reservoir Rocks

Sandstone Reservoirs

Reservoir rocks in the Carboniferous/Permian Coal–Paleozoic Total Petroleum System are expected to consist of grayish-white, fine-grained to pebbly sandstone of fluvial and deltaic origin in the Lower Permian Shanxi and Shihezi Formations (ECPG–Huabei, 1987; Lin and others, 1995). By analogy to Carboniferous and Permian sandstones in the nearby Ordos basin, sandstones in the Shanxi and Shihezi Formations in the Bohaiwan basin probably are quartzose in composition (Li and others, 1997; Liu and others, 2002).

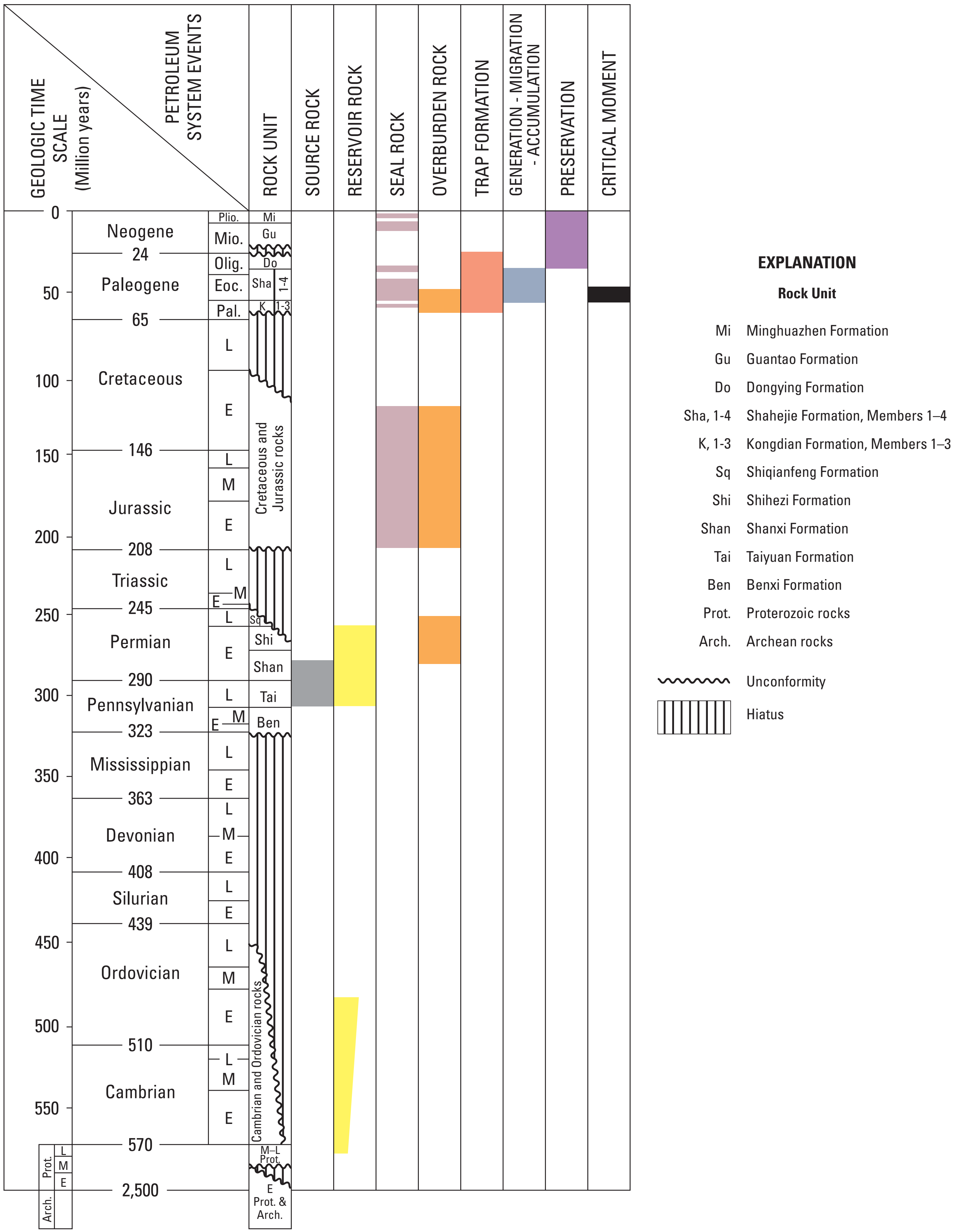

GEOLOGIC TIME SCALE (Million years)
PETROLEUM SYSTEM EVENTS
ROCK UNIT
SOURCE ROCK
RESERVOIR ROCK
SEAL ROCK
OVERBURDEN ROCK
TRAP FORMATION
GENERATION - MIGRATION - ACCUMULATION
PRESERVATION
CRITICAL MOMENT
0
50
100
150
200
250
300
350
400
450
500
550
Neogene
24
Paleogene
65
Cretaceous
146
Jurassic
208
Triassic
245
Permian
290
Pennsylvanian
323
Mississippian
363
Devonian
408
Silurian
439
Ordovician
510
Cambrian
570
2,500
Prot.
Arch.
Plio.
Mio.
Olig.
Eoc.
Pal.
L
E
M
Mi
Gu
Do
Sha
1-4
K
1-3
Cretaceous and Jurassic rocks
Sq
Shi
Shan
Tai
Ben
Cambrian and Ordovician rocks
M–L Prot.
E Prot. & Arch.
EXPLANATION
Rock Unit
Mi Minghuazhen Formation
Gu Guantao Formation
Do Dongying Formation
Sha, 1-4 Shahejie Formation, Members 1–4
K, 1-3 Kongdian Formation, Members 1–3
Sq Shiqianfeng Formation
Shi Shihezi Formation
Shan Shanxi Formation
Tai Taiyuan Formation
Ben Benxi Formation
Prot. Proterozoic rocks
Arch. Archean rocks
Unconformity
Hiatus

Figure 18 (facing page). Events chart for the Carboniferous/Permian Coal–Paleozoic Total Petroleum System. Geologic time scale based on Magoon and Dow (1994) and Magoon and Schmoker (2000). Abbreviations: Plio., Pliocene; Mio., Miocene; Olig., Oligocene; Eoc., Eocene; Pal., Paleocene; E, Early; M, Middle; L, Late.

In the Suqiao field (Jizhong subbasin), porosity in an Upper Permian sandstone reservoir at a depth of about 3,350 m ranges from about 15 to 19 percent and permeability ranges from 29 to 400 md (average 200 md) (ECPG–Huabei, 1987). These relatively high porosity and permeability values from a single locality are inconsistent with continuous gas accumulation. Therefore, additional porosity and permeability data are required from moderately to deeply buried Carboniferous and Permian sandstone units to adequately evaluate the hypothetical total petroleum system.

Coal Bed Reservoirs

Coal beds also may be reservoirs in the Carboniferous/Permian Coal–Paleozoic Total Petroleum System. Dai and others (2004) reported that Permian and Carboniferous coal beds in the Linqing/Dongpu subbasin contain a significant amount of gas pores (micropores), which could improve natural gas production. Such micropores, in addition to microfractures, are important for the storage of large volumes of adsorbed gas in coal beds (Rice and others, 1993).

Seal Rocks

The proposed seal rocks for the sandstone reservoirs in the Carboniferous/Permian Coal–Paleozoic Total Petroleum System consist largely of Mesozoic (Jurassic and Lower Cretaceous) nonmarine purplish- to brownish-red shales (not shown in fig. 4) and widespread lacustrine gray mudstone and shale of Members 1 and 3 of the Shahejie Formation (fig. 4). The Mesozoic and Shahejie Formation seal rocks commonly are 500 to 1,000 m thick in the Bohaiwan subbasins (fig. 4). The seals in the coal beds are connate water and groundwater that keep the gas from escaping microfractures and micropores.

Assessment Unit

A coal-sourced gas assessment unit (31270201) is defined in the hypothetical Carboniferous/Permian Coal–Paleozoic Total Petroleum System, where Lower Permian sandstone and possibly Carboniferous coal beds are the reservoirs. This assessment unit, whose boundary coincides with that of the total petroleum system, was not assessed by the U.S. Geological Survey World Energy Assessment Team (2000). A separate coalbed methane assessment unit may be needed at a later time if Carboniferous and Permian coal beds become a primary target for exploration in addition to the sandstone reservoirs. Because most Carboniferous and Permian strata in the Bohaiwan basin are sparsely drilled, this assessment unit has good potential for undiscovered gas fields. Drilling depths to potential traps are between 2,000 and 7,000 m (Chang and others, 1981).

Summary

All of the 27.3 BBOE of known petroleum volume in the Bohaiwan basin through the second quarter of 1996 (Klett and others, 1997) are located in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System. Member 3 of the Paleogene Shahejie Formation, which consists of about 1,000 m of deepwater lacustrine dark-gray mudstone and oil shale (black shale), is the primary source rock. Member 1 of the Shahejie Formation, consisting of about 200 to 400 m of lacustrine dark-gray mudstone and oil shale (black shale), probably is the second most important source rock. The primary reservoir rocks are Paleogene and Neogene nonmarine feldspathic sandstone and highly weathered and fractured lower Paleozoic and Middle to Late Proterozoic marine limestone and dolomite. Also, highly weathered and fractured Archean crystalline basement rocks are important reservoirs. Sandstone reservoirs, generally very fine to fine grained, represent deltaic and fluvial deposits that flanked subbasin-centered lakes and turbidite deposits that accumulated in the central parts of the lakes. Lower Paleozoic and Proterozoic limestone and dolomite reservoir rocks were deposited as peritidal and shallow-water shelf carbonates on a stable craton. The reservoir properties of these limestone and dolomite units have been greatly enhanced by pervasive weathering and the development of abundant fractures. According to Petroconsultants (1996), structural traps account for approximately 95 percent of the known oil and gas in the Bohaiwan basin, and stratigraphic traps account for the remaining 5 percent.

Two oil and gas assessment units are identified in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System: (1) a Tertiary lacustrine assessment unit and (2) a pre-Tertiary buried hills assessment unit. Both assessment units are composed of conventional petroleum accumulations.

A coal-sourced gas assessment unit is defined in the hypothetical Carboniferous/Permian Coal–Paleozoic Total Petroleum System. This total petroleum system is largely unexplored and therefore is considered to have good potential for future discoveries of natural gas. Carboniferous and Permian coal beds are the proposed source rocks and Lower Permian sandstones and possibly Carboniferous coal beds are the proposed reservoirs. Most of the natural gas in this total petroleum system is considered to be trapped as continuous basin-centered accumulations.

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Table 1. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jiyang subbasin, Bohaiwan basin (province 3127), China.

[Data are from an oil industry compilation (unpub. data, 1996). The cumulative oil and gas production values from this compilation are through about 1988, unless noted otherwise. For example, cumulative production of oil through 1994 is indicated by (94). Abbreviations: **Discovery date:** ON, onshore; OFF, offshore; **Reservoir, API Gravity,** and **Sulfur (percent):** Sha, Shahejie; Dong, Dongying; ss, sandstone; Fm, formation; **Source rock(s):** S, Shahejie Formation; **Gas-oil ratio (GOR):** ft^3 per bbl, cubic feet of gas per barrel of oil; ave., average; **Hydrocarbon type, trap:** O, oil; G, gas; O/G, oil and gas; A, anticline; AN, anticlinal nose; BH, buried hill; CA, compaction anticline; D, dome; FA, faulted anticline; FAN, faulted anticlinal nose; FCA, faulted compaction anticline; FB, fault block; FB/s, fault block/stratigraphic; S, stratigraphic; S/fc, stratigraphic/facies change; **Field status:** No prod., no production; Oper., operational. Other abbreviations: n.r., not recorded; v., very; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special reference: $^+$, Editorial Committee of Petroleum Geology of the Shengli Oil Field (1987)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
1	Shentuo (Shengtuo)	1964 ON	Shahejie (Sha I, II, III); Dongying (Dong I, II, III); Guantao; Minghuazhen	S	15.9–33°	87–411	n.r.	O/G; FA	giant/major	Oper.	834.9 (94)	n.r.
2	Guangli	1966 ON	Shahejie (Sha III, IV); Kongdian	S	21.5–29.3°	n.r.	1–2.75	O; FAN	major	Oper.	88.8 (94)	n.r.
3	Wangjiagang	1974 ON	Shahejie (Sha I, II, III)	S	30.2°	n.r.	0.34	O; FA	large	Oper.	64	n.r.
4	Gudao	1968 ON	Shahejie (Sha I, II); Dongying; Guantao; Minghuazhen; Paleozoic carbonate	S	21.5–31°	100–150	n.r.	O/G; CA	giant/medium	Oper.	551.2	n.r.
5	Chengdong	1970 ON	Guantao; Minghuazhen	S	<25.7°	53–131	0.37	O/G; D, FCA	major/v. small	Oper.	112.2	n.r.
6	Gudong	1984 ON/OFF	Shahejie; Dongying; Guantao; Minghuazhen	S	24–35°	1,814	0.3	O/G; CA	giant/v. small	Oper.	223.2	n.r.
7	Caoqiao (Le'an)	1971 ON	Shahejie (Sha I, II, III, IV); Kongdian; Guantao	S	<10–13.5°	n.r.	0.57–1.59	O/G; FAN	medium/v. small	Oper.	15.2 (94)	1.3
8	Bamianhe	1970 ON	Shahejie (Sha III, IV); Paleozoic	S	13.2–24.7°	n.r.	1.1–2.71	O/G; FB	large/small	Oper.	9.6	n.r.
9	Linfanjia	1981 ON	Dongying; Guantao	S	20.2–22°	n.r.	0.31–1.91	O/G; A	medium/small	Oper.	n.r.	n.r.
10	Bonan	1971; 1975$^+$ ON	Shahejie (Sha I, II, III); Dongying; Carboniferous (Yi-155)$^+$	S	17.5–22.3° Sha; 24–35° Dong	535 ave.	0.07–2.90 Sha; 0.1–0.6 Dong	O; FB G$^+$	major	Oper.	92.7	n.r.

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11	Shangdian	1960 ON	Shahejie (Sha II, III, IV); Dongying; Guantao	S	38–42.3°	n.r.	0.47–0.64	O/G; FAN, S/fc$^+$	major/v. small	Oper.	31.5	n.r.
12	Shunhuazhen (Chun-huazhen)	1965 ON	Shahejie (Sha II, III, IV)	S	39.6–52.5°	n.r.	n.r.	O/G; FAN	large/small	Oper.	33.2	n.r.
13	Qiaozhuang	1975 ON	Shahejie (Sha III)	S	30.4	n.r.	n.r.	O/G; FB, S/fc$^+$	v. small/v. small	Oper.	1.5	0.385
14	Gunan	1975 ON	Shahejie; Dongying; Guantao; Mesozoic (Jurassic ss)	S	30.4–35.4°	n.r.	0.02–0.66	O; FAN	small	Oper.	5.6	n.r.
15	Shanghe	1971 ON	Shahejie (Sha I, II, III, IV); Dongying	S	31.1–37°	100–535	0.22–0.61	O/G; FB	large/v. small	Oper.	33.7	n.r.
16	Dongxin	1961 ON	Shahejie (Sha I, II, III); Dongying; Guantao	S	17.5–29.3°	75–375	0.32–1.36	O/G; FA	giant/small	Oper.	321.5	n.r
17	Yonganzhen	1965 ON	Shahejie (Sha II, III, IV)	S	34.2–51.1°	250–350	<0.5	O/G; FA, FB	major/v. small	Oper.	71.1	n.r.
18	Haojia	1965 ON	Shahejie (Sha I, II, III)	S	25.7–37°	295–375	n.r.	O; FAN	medium	Oper.	21.4	n.r.
19	Lijin (Lijun)	1979 ON	Shahejie (Sha I, II, III, IV)	S	43.6–49.7°	200–300	0.1–0.2	O; FA	large	Oper.	29.9	n.r.
20	Kenli	1967 ON	Shahejie (Sha I, II); Mesozoic (Jurassic ss); Ordovician (Majiagou Fm)	S	44.9–45.4° Sha; 49.9° Ord	90–100	0.18–0.32 Sha; 0.19–0.33 Ord.	O; FCA, BH	large	Oper.	27.9	n.r.
21	Hetang (Hetan)	1986 ON	Shahejie (Sha II, III); Mesozoic	S	40.9–72.4°	n.r.	n.r.	O/G; FB	medium/v. small	Oper.	7.3	0.011
22	Liangjialao (Liangji-alou)	1964 ON	Shahejie (Sha III)	S	37–43.8°	123–230	0.16–0.20	O; FB	large	Oper.	55.6	n.r.

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23, 24	Hongliu-Ken-dong	1986 ON	Shahejie (Sha II, III); Guantao	S	29.3–36° Sha; 11.0–12.7° Guan	n.r.	0.13–0.53	O; FB	small	Oper.	10.8	0.058
25	Laohekou	1985 ON	Guantao	S	18.4°	n.r.	0.21	O/G; FB	small/v. small	Oper.	4.0	n.r.
26	Linpan	1964 ON	Shahejie (Sha I, II, III); Dongying; Guantao	S	16.5–57.2°	(730)	0.05–0.6	O/G; FB, A$^+$	major/v. small	Oper.	83.8	n.r.
27	Danjiashi	1970 ON	Shahejie; Dongying; Guantao	S	11.4–12.9°	40–85	0.58	O/G; FAN	large/v. small	Oper.	8.3	n.r.
28	Taoerhe (Gui-erhe)	1978 ON	Shahejie; Ordovician; Carboniferous	S	17.0–25.9°	n.r.	0.55	O/G; CA, BH	v. small/v. small	Oper.	3.6	n.r.
29	Yibei	1976 ON	Shahejie (Sha II, IV); Mesozoic (Jurassic ss)	S	25.7–33.0°	285	n.r.	O; FB	v. small	Oper.	8.3	n.r.
30	Yihezhuang	1977 ON	Shahejie (Sha I, II, III, IV); Guantao; Ordovician (Badou Fm., Majiagou Fm); Jurassic; Permian; Carbon-iferous	S	29.3–31.1°	255–410	0.74	O; BH	small	Oper.	24.7	n.r.
31	Yidong	1971 ON	Shahejie; Dongying; Guantao	S	27.5–31.1°	50–410	1.3	O/G; FB/s	small/v. small	Oper.	13.4	n.r.
32	Kenxi	1972 ON	Shahejie (Sha I); Dongying; Guantao	S	19.5–27.3°	n.r.	0.97–1.62 Guan; 0.18–1.12 Dong; 1.94 Sha	O/G; FB	medium/v. small	Oper.	32.5	n.r.

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33	Wuhaozhuang	1975 ON/OFF	Shahejie (Sha III)	S	33–37°	378–392	0.07–0.29	O/G; FB	large/small	Oper.	9.8	n.r.
34	Wangzhuang	1984 ON	Archean/Proterozoic rocks	S	57.2°	294	0.14	O; BH	small	Oper.	13.7	n.r.
35	Ninghai	1964 ON	Shahejie (Sha II); Dongying	S	30.4–33.4°	387	0.23–0.25	O; FB	medium	Oper.	33.8	n.r.
36	Pingfangwang	1966 ON	Shahejie (Sha II, IV); Cambrian	S	24.7–31.3°	250–600	0.2–0.5	O/G; FCA, BH	large/small	Oper.	70.1	n.r.
37	Binnan	1965 ON	Shahejie (Sha I, II, III, IV); Dongying	S	18.7–20.3°	175–500	0.22–1.26	O; FB, FA	large	Oper.	53.8	n.r.
38	Shinan	1975 ON	Shahejie	S	23.8–33°	150	0.11–0.71	O; FAN	medium	Oper.	29.7	n.r.
39	Xianhezhuang	1963 ON	Shahejie (Sha I, II, III)	S	14.1–33.2°	71–382	0.15–1.96	O; FAN	major	Oper.	75.5	n.r.
40	Zhuangxi	1985 ON	Shahejie; Ordovician; Cambrian	S	15.9–39.6°	n.r.	n.r.	O/G; AN, BH	small/small	Oper.	8.0	n.r.
41	Dawang-zhuang	1972 ON	Shahejie (Sha II)	S	16.8–32.1°	n.r.	n.r.	O; S	small	Oper.	4.1	n.r.
42	Xinlicun	1966 ON	Shahejie (Sha II, III); Dongying	S	n.r.	n.r.	n.r.	O; FB	v. small	Oper.	4.0	n.r.
43	Changti (Changdi)	1979 ON	Shahejie (Sha I, II, III); Mesozoic	S	21.3–43.8°	n.r.	n.r.	O/G	medium/small	Oper.	18.0	n.r.
44	Shaojia	1962 ON	Dongying; Guantao	S	n.r.	n.r.	n.r.	O/G; S	small/v. small	Oper.	4.1	n.r.
45	Xiaoying	1975 ON	Shahejie	S	33°	n.r.	n.r.	O; FB	v. small	Oper.	2.1	n.r.
46	Gaoqing	1978 ON	Shahejie (Sha III); Kongdian; Dong-ying; Mesozoic (Jurassic)	S	14.1–14.7°	n.r.	n.r.	O; FB	small	Oper.	2.5	n.r.

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47	Zhenglizhuang	1965 ON	Shahejie (Sha I, II, III)	S	22.5–32.8°	n.r.	n.r.	O/G; FB	small/v. small	Oper.	5.0	n.r.
48	Luojia (Cuojia)	1988 ON	Shahejie	S	17.1–26.6°	n.r.	n.r.	O; FB	v. small	Oper.	3.6	n.r.
49	Dawangbei	1984 ON	Shahejie (Sha II)	S	29.7–34°	n.r.	n.r.	O; FB	medium	Oper.	4.4	n.r.
50	Niuzhuang	1966 ON	Shahejie (Sha III)	S	21.0–32.8°	n.r.	n.r.	O	large	Oper.	5.6	n.r.
51	Chenjiazhuang	ON	Guantao	S	<10–11.9°	n.r.	n.r.	O/G; S/fc	v. small/v. small	Oper.	0.657	n.r.
52	Zhengjia	1980 ON	Shahejie (Sha III)	S	n.r.	n.r.	n.r.	O	n.r.	Appraising	n.r.	n.r.
53	Yangjiaogou	ON	Shahejie; Guantao	S	n.r.	n.r.	n.r.	O/G	n.r.	Appraising	n.r.	n.r.
54	Jinjia	ON	Shahejie (Sha I)	S	11.7–18.1°	n.r.	n.r.	O/G; FB	small/v. small	Oper.	6.5	n.r.
55	Boxing	ON	Shahejie (Sha IV); Ordovician	S	31.0–34.0°	n.r.	n.r.	O/G; FB, A	v. small	No prod.	n.r.	n.r.
56	Pingnan	ON	Shahejie (Sha IV); Ordovician	S	26.8–31.7°	n.r.	n.r.	O/G; BH	v. small	Appraising	n.r.	n.r.
57	Chendao (Chengdao)	OFF	Guantao; Dongying; Shahejie	S	15.9–33.2°	n.r.	n.r.	O	large	Oper.	n.r.	n.r.
58	Xintang (Xintan)	ON/OFF	Guantao; Shahejie	S	11.0–15.1°	n.r.	n.r.	O; S/fc	v. small	Appraising	n.r.	n.r.
59	Taiping	ON	Dongying; Guantao	S	<10–21.3°	n.r.	n.r.	O/G; FB	small/v. small	Appraising	n.r.	n.r.
60	Yuhuangmiao	ON	Shahejie; Dongying	S	21.5–34.6°	n.r.	n.r.	O/G	v. small/v. small	No prod.	n.r.	n.r.
63	Daluhu	ON	Shahejie	S	28.9–36.8°	n.r.	n.r.	O; S/fc	small	Oper.	1.3	n.r.
64	Feiyantan	ON	Guantao	S	18.2°	n.r.	n.r.	O/G; FB	v. small/v. small	Oper.	2.1	n.r.

Table 1. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jiyang subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). The cumulative oil and gas production values from this compilation are through about 1988, unless noted otherwise. For example, cumulative production of oil through 1994 is indicated by (94). Abbreviations: **Discovery date:** ON, onshore; OFF, offshore; **Reservoir, API Gravity,** and **Sulfur (percent):** Sha, Shahejie; Dong, Dongying; ss, sandstone; Fm, formation; **Source rock(s):** S, Shahejie Formation; **Gas-oil ratio (GOR):** ft^3 per bbl, cubic feet of gas per barrel of oil; ave., average; **Hydrocarbon type, trap:** O, oil; G, gas; O/G, oil and gas; A, anticline; AN, anticlinal nose; BH, buried hill; CA, compaction anticline; D, dome; FA, faulted anticline; FAN, faulted anticlinal nose; FCA, faulted compaction anticline; FB, fault block; FB/s, fault block/stratigraphic; S, stratigraphic; S/fc, stratigraphic/facies change; **Field status:** No prod., no production; Oper., operational. Other abbreviations: n.r., not recorded; v., very; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special reference: $^+$, Editorial Committee of Petroleum Geology of the Shengli Oil Field (1987)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
65	Yingxiongtan (Yingxiong-ztan)	OFF	Shahejie	S	25.6°	n.r.	n.r.	O; FB	small	Oper.	n.r.	n.r.
66	Dongfenggang	ON	n.r.	S	n.r.	n.r.	n.r.	O	n.r.	No prod.	n.r.	n.r.
67	Yanjia	ON	Shahejie	S	n.r.	n.r.	n.r.	G; FB	v. small	No prod.	n.r.	n.r.
68	Huagou	ON	Shahejie; Dongying; Guantao	S	n.r.	n.r.	n.r.	G; FB	v. small	No prod.	n.r.	n.r.

Table 2. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Liaohe subbasin, Bohaiwan basin (province 3127), China.

[Data are from an oil industry compilation (unpub. data, 1996), Li (1989), and Gustavson and Xin (1992). The cumulative oil and gas production values from the oil industry compilation are through about 1989. Abbreviations: **Discovery date:** ON, onshore; OFF, offshore; **Reservoir, API Gravity,** and **Sulfur (percent):** Sha, Shahejie; Fm, formation; Dong, Dongying; **Source rock(s):** S, Shahejie Formation; **Gas-oil ratio (GOR):** ft^3 per bbl, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; G, gas; O/G, oil and gas; BH, buried hill; CA, compaction anticline; FA, faulted anticline; FB, fault block; **Field status:** Oper., operational; No prod., no production. Other abbreviations: n.r., not recorded; v., very; negl., negligible; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special reference: $^+$, Ge and Editorial Committee of Petroleum Geology of the Liaohe Oil Fields (1989)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
1	Rehetai (part of Panshan complex)	1966 ON	Shahejie (volcanic rocks)	S	32.8–33.8°	412–490	0.15	O/G; FA	small/v. small	Oper.	7.1	4.2
2	Huangjindai	1964 ON	Shahejie (Sha Ia, Ib, II, III); Dongying	S	29.5–67.5° Sha Ia; 38.4–42.1° Sha Ib; 40–45.2° Sha II; 39.8–42.1° Sha III; 24–30.4° Dong	1,000	0.05–0.11 Sha Ia; 0.06–0.08 Sha Ib; 0.04–0.08 Sha II; 0.03–0.04 Sha III; 0.13–0.16 Dong	O/G; FA	small/small	Oper.	7.4	63.8
3	Yulou	1968 ON	Shahejie (Sha I lower, Sha I middle)	S	30.4–40.6°	n.r.	0.06–0.13	O/G; FA	small/v. small	Oper.	8.0	1.1
4	Xinglongtai (part of Panshan complex)	1969 ON	Shahejie (Sha I*, II*, III); Dongying; Archean rocks *major reservoir	S	38.4–46.5° 25.7–36.6° Sha I; 27.9–39.4° Sha II; 37.2–39.6° Sha III; 26.3–33.6° Dong	694	0.07–0.62	O/G; BH, FA	major/large	Oper.	163	352.3

Table 2. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Liaohe subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996), Li (1989), and Gustavson and Xin (1992). The cumulative oil and gas production values from the oil industry compilation are through about 1989. Abbreviations: **Discovery date:** ON, onshore; OFF, offshore; **Reservoir, API Gravity,** and **Sulfur (percent):** Sha, Shahejie; Fm, formation; Dong, Dongying; **Source rock(s):** S, Shahejie Formation; **Gas-oil ratio (GOR):** ft^3 per bbl, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; G, gas; O/G, oil and gas; BH, buried hill; CA, compaction anticline; FA, faulted anticline; FB, fault block; **Field status:** Oper., operational; No prod., no production. Other abbreviations: n.r., not recorded; v., very; negl., negligible; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special reference: +, Ge and Editorial Committee of Petroleum Geology of the Liaohe Oil Fields (1989)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
5	Shuguang (part of Panshan complex)	1975 ON	Archean rocks; Middle Proterozoic (Wumishan Fm); Shahejie (Sha I, II, III, IV)	S	33.6° Archean; 10–18.2° Sha I, II; 13.3–20.2° Sha III; 35.6° Sha IV	13–292	4.56–10.9	O/G; BH, FA	giant/small	Oper.	131.7 46.3 Archean; 24.4 Sha II; 61.0 Sha III, IV	6.6
6	Gaosheng (Gaoshen)+ (part of Panshan complex)	1975 ON	Shahejie; (Sha III lower, Sha IV upper)	S	15.9–37.0°	111–245	0.49–0.64	O/G; FA	major/medium	Oper.	69.7	48.7
7	Huanxiling (Huanxilin)+	1975 ON	Archean rocks; Shahejie (Sha I, II, III upper, III middle/lower, IV)	S	39.0° Archean; 10.0–17.9° Sha I; 12.2–31.3° Sha II; 35.0° Sha III upper; 14.5–43.6° Sha III middle/lower; 30.4–36.6° Sha IV	19–1,282	0.15–0.34 Sha I; 0.05–0.27 Sha II; 0.29 Sha III upper; 0.02–0.13 Sha III middle/lower	O/G; FB	giant/medium	Oper.	320.6	136.8

Table 2. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Liaohe subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996), Li (1989), and Gustavson and Xin (1992). The cumulative oil and gas production values from the oil industry compilation are through about 1989. Abbreviations: **Discovery date:** ON, onshore; OFF, offshore; **Reservoir, API Gravity,** and **Sulfur (percent):** Sha, Shahejie; Fm, formation; Dong, Dongying; **Source rock(s):** S, Shahejie Formation; **Gas-oil ratio (GOR):** ft^3 per bbl, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; G, gas; O/G, oil and gas; BH, buried hill; CA, compaction anticline; FA, faulted anticline; FB, fault block; **Field status:** Oper., operational; No prod., no production. Other abbreviations: n.r., not recorded; v., very; negl., negligible; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special reference: $^+$, Ge and Editorial Committee of Petroleum Geology of the Liaohe Oil Fields (1989)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
8	Shuangtaizi (part of Panshan complex)	1970 ON	Shahejie (Sha I, II, III); Dongying	S	35.2–79.7° Sha I, II; 43.8° Sha III; 43.8° Dong	1,110	0.06–0.24 Sha I, II; 0.11–0.15 Sha III	O/G; FA	medium/medium	Oper.	25.2	136.8
9	Niuju	1974 ON	Shahejie (Sha I upper, Sha I middle, Sha I lower, Sha II); Dongying	S	49.9–>86.2° Sha I upper; 46.5–>86.2° Sha I middle; 33.8–>86.2° Sha I lower; >86.2° Sha II; 49.7–>86.2° Dong	1,055	0.09 Sha I upper; 0.03–0.13 Sha I middle; 0.03 Sha I lower; 0.04 Sha II; 0.07–0.13 Dong	O/G; FA	medium/medium	Oper.	23.5	72.9
10	Qinglongtai	1980 ON	Shahejie (Sha I, Sha III upper, Sha III middle); Dongying	S	15.6° Sha I; 19.7° Sha III upper; 17.6–37.8° Sha III middle; 36.8° Dong	236	0.09–0.26	O/G; FA	small/small	Oper.	12.5	negl.
11	Qianjing-Damintun (part of Shenyang complex)	1965 ON	Shahejie (Sha I, Sha III, Sha III-IV)	S	19.0–39.0° 19.7° Sha III-IV	564–755	0.05–0.14	O/G; FA	large/small	Oper.	9.6	6.3

Table 2. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Liaohe subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996), Li (1989), and Gustavson and Xin (1992). The cumulative oil and gas production values from the oil industry compilation are through about 1989. Abbreviations: **Discovery date:** ON, onshore; OFF, offshore; **Reservoir, API Gravity,** and **Sulfur (percent):** Sha, Shahejie; Fm, formation; Dong, Dongying; **Source rock(s):** S, Shahejie Formation; **Gas-oil ratio (GOR):** ft^3 per bbl, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; G, gas; O/G, oil and gas; BH, buried hill; CA, compaction anticline; FA, faulted anticline; FB, fault block; **Field status:** Oper., operational; No prod., no production. Other abbreviations: n.r., not recorded; v., very; negl., negligible; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special reference: $^+$, Ge and Editorial Committee of Petroleum Geology of the Liaohe Oil Fields (1989)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
12	Fahaniu (part of Shenyang complex)	1974 ON	Shahejie (Sha III); Archean rocks	S	35.0–41.1°	703	<0.1	O/G; FA, BH	medium/v. small	Oper.	1.4	3.6
13	Jinganbu, Jinganpu, Jingbei (Jinganbao) (part of Shenyang complex)	1973 ON	Archean rocks; Middle Protero-zoic; Shahejie; Dongying	S	19.2–35°	n.r.	n.r.	O/G; FA, BH	giant/v. small	Oper.	97.7	0.140
14	Dawa	1987 ON	Dongying	S	20.7–37.0°	203–888	n.r.	O/G; FB	large/v. small	Oper.	7.6	1.7
15	Shuangnan (Shunag-nan) (part of Panshan complex)	ON	Shahejie	S	39.4°	n.r.	n.r.	G; FB	small	No prod.	n.r.	6.3
16	Niuxingtuo (part of Panshan complex)	ON	Shahejie	S	n.r.	n.r.	n.r.	O; FB	small	Oper.	5.4	n.r.
17	Haiwaihe	ON	Dongying	S	n.r.	n.r.	n.r.	O/G; FB	large/v. small	Oper.	13.2	3.2
18	Dapingfang	1965$^+$ ON	Shahejie; Dongying	S	n.r.	n.r.	n.r.	O/G; FB	v. small/v. small	Oper.	1.1	n.r.
19	Lejiapu (Lengjiapu) (part of Panshan complex)	ON	Shahejie	S	n.r.	n.r.	n.r.	O; FA	large	Oper.	0.798	negl.
20	Biantai (part of Shenyang complex)	ON	Archean rocks; Shahejie	S	36.0°	n.r.	n.r.	OG; FB	small/v. small	Oper.	6.4	0.490

Table 2. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Liaohe subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996), Li (1989), and Gustavson and Xin (1992). The cumulative oil and gas production values from the oil industry compilation are through about 1989. Abbreviations: **Discovery date:** ON, onshore; OFF, offshore; **Reservoir, API Gravity,** and **Sulfur (percent):** Sha, Shahejie; Fm, formation; Dong, Dongying; **Source rock(s):** S, Shahejie Formation; **Gas-oil ratio (GOR):** ft^3 per bbl, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; G, gas; O/G, oil and gas; BH, buried hill; CA, compaction anticline; FA, faulted anticline; FB, fault block; **Field status:** Oper., operational; No prod., no production. Other abbreviations: n.r., not recorded; v., very; negl., negligible; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special reference: $^+$, Ge and Editorial Committee of Petroleum Geology of the Liaohe Oil Fields (1989)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
21	Rongxingtun	ON	Shahejie; Dongying	S	n.r.	n.r.	n.r.	O/G; FA	small/small	Oper.	2.1	10.4
22	Xinxi (Xingxi) (part of Shenyang complex)	ON	Shahejie	S	n.r.	n.r.	n.r.	O; FB	v. small	Oper.	6.3	8.9
23	Ziyutou	ON	Shahejie	S	n.r.	n.r.	n.r.	O/G; FB	small/v. small	Oper.	n.r.	n.r.
24	Xiaowa	ON	n.r.	S	n.r.	n.r.	n.r.	O	small	Oper.	n.r.	n.r.
25	Taoyuan	ON	n.r.	S	n.r.	n.r.	n.r.	O	small	No prod.	n.r.	n.r.
26	Erlitouzi	ON	n.r.	S	n.r.	n.r.	n.r.	O	medium	No prod.	n.r.	n.r.
27	Taiyangdao	ON	n.r.	S	n.r.	n.r.	n.r.	O	v. small	No prod.	n.r.	n.r.
28	Suizhong 36-1	1987 OFF	Dongying	S	10–19°	low	n.r.	O; CA	major	n.r.	n.r.	n.r.

Table 3. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jizhong subbasin, Bohaiwan basin (province 3127), China.

[Data are from an oil industry compilation (unpub. data, 1996). The cumulative oil and gas production values from this compilation are through about 1992, unless noted otherwise. For example, cumulative production through 1984 is indicated by (84). Abbreviations: **Discovery date:** ON, onshore; **Source rock(s):** S, Shahejie Formation; C, Carboniferous strata; **Reservoir, API Gravity, Gas-oil ratio,** and **Sulfur (percent):** Fm, formation; Sha, Shahejie; Dong, Dongying; ft^3 per bbl, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; O/G, oil and gas; BH, buried hill; D, dome; FD, faulted dome; FA, faulted anticline; FB, fault block; FCA, faulted compaction anticline; A, anticline; S/fc, stratigraphic/facies change; **Field status:** No prod., no production; Oper., operational; Devel., being developed. Other abbreviations: n.r., not recorded; v., very; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special references: $^+$, Shi and Qin (1987); $^\#$, Zhao and others (1987); $^\Delta$, Qin and others (1987)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
1	Renqiu	1975 ON	Middle Proterozoic (Wumishan Fm);	S	27.9°	20	0.32	O; BH	giant	Oper.	629.8	n.r.
			Cambrian (Fujunshan Fm);		29.9°	23	0.2				7.7	n.r.
			Ordovician (Majiagou Fm)		28.9°	172	0.17					
2	Yongqing (includes Liuqiying)	1978 ON	Middle Proterozoic (Wumishan Fm); Ordovician (Majiagou and Fengfeng Fms)	S	51.8°	222	0.02	O/G; BH	v. small/v. small	Oper.	2.1	1.9
3	Longhuzhuang	1977 ON	Ordovician (Majiagou Fm)	S	36.4°	12	0.05	O; BH	small	Oper.	18.6	n.r.
4	Nanmeng	1976 ON	Cambrian (Fujunshan, Mentou, Changxia Fms); Ordovician (Majiagou Fm); Shahejie	S	39.8° Fujunshan; 40.4° Mentou; 46.0° Majiagou; 39.8° Sha	14 Fujunshan; 28 Mentou; 9 Majiagou; 28 Sha	0.08 Fujunshan; 0.06 Mentou; 0.06 Majiagou; 0.05 Sha	O; BH	v. small	Oper.	5.3	n.r.
5	Guxingzhuang (Guxinzhuang)	1979 ON	Ordovician (Majiagou and Fengfeng Fms);	S, C^+	46.0°	n.r.	n.r.	O/G; BH	v. small/v. small	Shut in	n.r.	1.5
6	Suqiao	1982$^\#$ ON	Ordovician (Majiagou Fm); Permian (Shihezi Fm)$^\Delta$	S, C^+	n.r.	n.r.	n.r.	O/G; BH	v. small/v. small	Oper.	n.r.	n.r.
7	Mozhou	1978 ON	Middle Proterozoic (Wumishan Fm); Shahejie	S	34.2°	39	0.07	O; BH	small	Oper.	21.8	n.r.
8	Yangling (Yanling)	1977 (1976) ON	Middle Proterozoic (Wumishan Fm)	S	26.8°	12	0.39	O; BH	medium	Oper.	33.5	n.r.

Table 3. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jizhong subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). The cumulative oil and gas production values from this compilation are through about 1992, unless noted otherwise. For example, cumulative production through 1984 is indicated by (84). Abbreviations: **Discovery date:** ON, onshore; **Source rock(s):** S, Shahejie Formation; C, Carboniferous strata; **Reservoir, API Gravity, Gas-oil ratio,** and **Sulfur (percent):** Fm, formation; Sha, Shahejie; Dong, Dongying; ft^3 per bbl, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; O/G, oil and gas; BH, buried hill; D, dome; FD, faulted dome; FA, faulted anticline; FB, fault block; FCA, faulted compaction anticline; A, anticline; S/fc, stratigraphic/facies change; **Field status:** No prod., no production; Oper., operational; Devel., being developed. Other abbreviations: n.r., not recorded; v., very; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special references: +, Shi and Qin (1987); #, Zhao and others (1987); Δ, Qin and others (1987)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
9	Balizhuang	1976 ON	Middle Proterozoic (Wumishan Fm)	S	31.1°	28	0.21	O; BH	small	Oper.	11.9	n.r.
10	Xuezhuang	1977 ON	Middle Proterozoic (Wumishan Fm); Dongying	S	 28.0° 27.5°	23	 0.21 0.40	O; FD, BH	small	Oper.	9.0	n.r.
11	Balizhuangxi	1978 ON	Middle Proterozoic (Wumishan Fm); Dongying; Guantao	S	32.1–34.0°	19–24	0.12–0.15	O; D, BH	small	Oper.	17.4	n.r.
12	Hejian	1977 ON	Middle Proterozoic (Gaoyuzhuang Fm); Dongying (primary reservoir ?)Δ	S	34.0° 32.1°	24 19	0.15	O; BH	small	Oper.	21.5	n.r.
13	Liubei (Liulubei North)	1976 ON	Middle Proterozoic (Wumishan Fm); Dongying; Shahejie; Guantao (primary reservoir ?)Δ	S	37.2° 29.3°	28	0.05 0.27	O; BH, FA	medium	Oper.	31.2	n.r.
14	Hezhuangxi	1982 ON	Ordovician (Fengfeng Fm)	S	43.4°	1,657–5,538	0.06	O; BH	v. small	Shut in	0.263	n.r.
15	Hezhuang	1979 ON	Ordovician (Fengfeng Fm)	S	36.6°	1,424–1,481	0.14	O; BH	v. small	Oper.	3.8	n.r.
16	Shenxi	1979 ON	Ordovician (Majiagou Fm)	S, C+	38.8°	814–1,111	0.11	O/G; BH	v. small	Oper.	n.r.	n.r.
17	Hexiwu	1966 ON	Shahejie	S	28.8–45.8°	759	0.04–0.15	O; FB	small	Oper.	3.4	n.r.
18	Liuquan	1978 ON	Shahejie	S	36.6–43.2°	564–810	0.06–0.16	O/G; FA	small/v. small	Oper.	3.6	0.259
19	Zhongchakou	1978 ON	Shahejie	S	27.5°	218	0.16	O; FB	v. small	Oper.	1.6	n.r.

Table 3. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jizhong subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). The cumulative oil and gas production values from this compilation are through about 1992, unless noted otherwise. For example, cumulative production through 1984 is indicated by (84). Abbreviations: **Discovery date:** ON, onshore; **Source rock(s):** S, Shahejie Formation; C, Carboniferous strata; **Reservoir, API Gravity, Gas-oil ratio,** and **Sulfur (percent):** Fm, formation; Sha, Shahejie; Dong, Dongying; ft^3 per bbl, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; O/G, oil and gas; BH, buried hill; D, dome; FD, faulted dome; FA, faulted anticline; FB, fault block; FCA, faulted compaction anticline; A, anticline; S/fc, stratigraphic/facies change; **Field status:** No prod., no production; Oper., operational; Devel., being developed. Other abbreviations: n.r., not recorded; v., very; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special references: [+], Shi and Qin (1987); [#], Zhao and others (1987); [Δ], Qin and others (1987)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
20	Bieguzhuang	1978 ON	Shahejie	S	33.2°	370	0.13	O/G; FB	medium/v. small	Oper.	26.0	0.830
21	Chaheji	1978[Δ] ON	Shahejie	S	34.8°	652	0.15	O; FCA	large	Oper.	45.4	n.r.
22	Liulizhuang	1977 ON	Kongdian	S	31.5°	125	0.23	O; FA	v. small	Oper.	4.9	n.r.
23	Nanmazhuang	1976 ON	Shahejie	S	29.3°	111	0.25	O; FA	small	Oper.	7.0	n.r.
24	Suning	1981 ON	Dongying	S	31.3°	250	0.16	O; FA	small	Oper.	59.2	n.r.
25	Dawang-zhuang	1979 ON	Shahejie; Dongying	S	28.2°	171	0.13–0.29	O; FA	medium	Oper.	18.0	n.r.
26	Liuxi	1980 ON	Shahejie	S	25.0°	153	0.47	O; FB	small	Oper.	7.3	n.r.
27	Shennan	1979 ON	Shahejie (Sha I); Dongying (Dong II, III)	S	29.1° Dong II; 20.8–28.8° Dong III	n.r.	0.09–0.67 Sha I; 0.13–0.22 Dong II; 0.07–0.82 Dong III	O; FA	v. small	Oper.	0.430	n.r.
28	Jinqiu (Jingqiu)	1982 ON	Shahejie	S	31.1°	366	0.31	O; FA	small	Oper.	16.5	n.r.
29	Wenan	ON	Dongying; Shahejie; Permian	S	76.3°	n.r.	n.r.	O/G; A	v. small/v. small	Oper.	0.578	0.802
30	Nanxiaochen	ON	Shahejie	S	n.r.	n.r.	n.r.	O; A	v. small	No prod.	n.r.	n.r.
31	Gaojiabu (Gaojiapu)	ON	Shahejie	S	25.0°	n.r.	n.r.	O	v. small	Shut in	0.560	n.r.
32	Fengheying	1964[#] ON	Shahejie	S	68.1°	n.r.	n.r.	O; S/fc	v. small	Oper.	0.445	n.r.
33	Xiliu	ON	Shahejie	S	22.3–31.3°	n.r.	n.r.	O; S/fc	v. small	Oper.	0.043	n.r.

Table 3. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jizhong subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). The cumulative oil and gas production values from this compilation are through about 1992, unless noted otherwise. For example, cumulative production through 1984 is indicated by (84). Abbreviations: **Discovery date:** ON, onshore; **Source rock(s):** S, Shahejie Formation; C, Carboniferous strata; **Reservoir, API Gravity, Gas-oil ratio,** and **Sulfur (percent):** Fm, formation; Sha, Shahejie; Dong, Dongying; ft^3 per bbl, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; O/G, oil and gas; BH, buried hill; D, dome; FD, faulted dome; FA, faulted anticline; FB, fault block; FCA, faulted compaction anticline; A, anticline; S/fc, stratigraphic/facies change; **Field status:** No prod., no production; Oper., operational; Devel., being developed. Other abbreviations: n.r., not recorded; v., very; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special references: $^+$, Shi and Qin (1987); $^\#$, Zhao and others (1987); $^\Delta$, Qin and others (1987)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
34	Taijiazhuang	ON	Shahejie	S	n.r.	n.r.	n.r.	O/G; S/fc	v. small/v. small	Oper.	0.480	1.7
35	Wuqiang	ON	Shahejie	S	n.r.	n.r.	n.r.	O; S/fc	v. small	Oper.	0.456	n.r.
36	Yukou	ON	Shahejie	S	n.r.	n.r.	n.r.	O; FB	v. small	Oper.	0.308	n.r.
37	Gaoyang	ON	Shahejie	S	33.0–34.4°	n.r.	n.r.	O; S/fc	v. small	Oper.	n.r.	n.r.
38	Liuzu	ON	n.r.	S	n.r	n.r.	n.r.	O	small	Devel.	n.r.	n.r.

Table 4. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Huanghua subbasin, Bohaiwan basin (province 3127), China.

[Data are from oil industry compilations (unpub. data, 1996) and Jin and McCabe (1998). The cumulative oil and gas production values from the oil industry compilations are through about 1986. Abbreviations: **Discovery date:** ON, onshore; OFF, offshore; **Reservoir, API Gravity, Gas-oil ratio (GOR)** and **Sulfur (percent):** Sha, Shahejie; Dong, Dongying; Guan, Guantao; Ming, Minghuazhen; cond., condensate; ft^3 per bbl, cubic feet of gas per barrel of oil; **Source rock(s):** S, Shahejie Formation; K, Kongdian Formation**; Hydrocarbon type, trap:** O, oil; G, gas; O/G, oil and gas; O/G/C, oil, gas, and condensate; FA, faulted anticline; FB, fault block; FAN, faulted anticlinal nose; D, dome; FD, faulted dome; S/fc, stratigraphic/facies change; BH, buried hill; **Field status:** Oper., operational; No prod., no production. Other abbreviations: n.r., not recorded; v., very; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special references: $^+$, Liang (1987a); $^\Delta$, Li (1987)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
1	Gangdong (Dagang complex)	1965 ON	Guantao; Minghuazhen	S	25.4°	267	0.15	O/G; FA	giant/medium	Oper.	290.2	n.r.
2	Gangxi (Dagang complex)	1965 ON	Guantao; Minghuazhen	S	22.0°	171	0.17	O; FA	large	Oper.	n.r.	n.r.
3	Gangzhong (Dagang complex)	1964 ON	Shahejie; Dongying	S	34.6°	606	0.08	O; FB	large	Oper.	n.r.	n.r.
4	Tangjiahe	1965 ON/OFF	Shahejie; Dongying; Guantao; Minghuazhen	S	35.8° Dong	763	0.07	O; FAN	medium	Oper.	n.r.	n.r.
5	Madong	1978 ON	Shahejie	S	35.4–37.4°	n.r.	0.04–0.08	O; FD	medium	Oper.	n.r.	n.r.
6	Maxi	1978$^\Delta$ ON	Shahejie	S	n.r.	n.r.	n.r.	O; D	small	Oper.	n.r.	n.r.
7	Liujianfang	1966$^\Delta$ ON	Shahejie	S	n.r.	n.r.	n.r.	O	small	Oper.	n.r.	n.r.
8	Banqiao	1973 ON	Shahejie (Sha I)	S	15.9–45.9° oil; 49.9–65.0° cond.	n.r.	0.05–0.2	O/G/C; FA	large/medium	Oper.	26.2	183.3
9	Zhouqingzhuang	1967 ON	Shahejie (Sha I, III)	S	34.6–38°	n.r.	n.r.	O; FB	small	Oper.	7.1	n.r.
10	Wangxuzhuang	1966 ON	Shahejie (Sha I, III)	S	35.8°	500	0.14	O; FD	medium	Oper.	30.4	n.r.
11	Yangerzhuang	1974 ON	Shahejie (Sha I, III); Guantao; Minghuazhen	S	29.3° Guan; 20.3° Ming	n.r.	0.19 Guan; 0.24 Ming	O; FA	large	Oper.	46.7	n.r.
12	Yangsanmu	1963, 1962$^\Delta$ ON	Guantao; Minghuazhen	S	14.4–19.0°	n.r.	n.r.	O; FD	small	Oper.	39.6	n.r.

Table 4. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Huanghua subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from oil industry compilations (unpub. data, 1996) and Jin and McCabe (1998). The cumulative oil and gas production values from the oil industry compilations are through about 1986. Abbreviations: **Discovery date:** ON, onshore; OFF, offshore; **Reservoir, API Gravity, Gas-oil ratio (GOR)** and **Sulfur (percent):** Sha, Shahejie; Dong, Dongying; Guan, Guantao; Ming, Minghuazhen; cond., condensate; ft^3 per bbl, cubic feet of gas per barrel of oil; **Source rock(s):** S, Shahejie Formation; K, Kongdian Formation**; Hydrocarbon type, trap:** O, oil; G, gas; O/G, oil and gas; O/G/C, oil, gas, and condensate; FA, faulted anticline; FB, fault block; FAN, faulted anticlinal nose; D, dome; FD, faulted dome; S/fc, stratigraphic/facies change; BH, buried hill; **Field status:** Oper., operational; No prod., no production. Other abbreviations: n.r., not recorded; v., very; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special references: $^+$, Liang (1987a); $^\Delta$, Li (1987)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
13	Kongdian	1972 ON	Guantao	S	12.6–15.6°	30	0.25–4.07	O/G; FA	small	Oper.	12.7	n.r.
14	Zaoyuan	1971 ON	Kongdian; Paleozoic limestone	S, K^+	21.1–27.5°	n.r.	0.14	O; FA	major	Oper.	19.2	n.r.
15	Wangguantun	1971 ON	Shahejie; Kongdian	S, K^+	15.9–30.6°	n.r.	0.11–0.23	O/G; FA	major/v. small	Oper.	29.6	n.r.
16	Xiaoji	1975 ON	Kongdian	S, K^+	22.8–30.0°	n.r.	0.06–0.17	O; FA	large	Oper.	22.1	n.r.
17	Qijiawu	ON	Shahejie	S	15.3°	n.r.	n.r.	O; FB	small	No prod.	n.r.	n.r.
18	Duanlubo (Duanliubo)	1983^Δ ON	Kongdian; Shahejie	S, K^+	30.8°	n.r.	n.r.	O; FB, S/fc	small	Oper.	2.4	n.r.
19	Shenusi	ON	Kongdian; Shahejie	S	27.7°	n.r.	n.r.	O; FB, S/fc	medium	No prod.	5.7	n.r.
20	Liuguan-zhuang	ON	Minghuazhen	S	19.2°	n.r.	n.r.	O; FB	v. small	No prod.	n.r.	n.r.
21	Koucun	ON	Guantao; Shahejie; Kongdian; Meso-zoic; Permian	S	25.4°	n.r.	n.r.	O; FB	v. small	Oper.	2.0	n.r.
22	Tanggu	ON	Shahejie	S	28.8°	n.r.	n.r.	O; FB	v. small	Oper.	n.r.	n.r.
23	Wumaying	ON	Kongdian	S	34.8°	n.r.	n.r.	O; FB	v. small	No prod.	n.r.	n.r.
24	Changlu	ON	Shahejie	S	31.3°	n.r.	n.r.	O; FB	small	No prod.	n.r.	n.r.
25	Gaochentou	ON	n.r.	S	n.r.	n.r.	n.r.	O	small	No prod.	n.r.	n.r.
26	Changjuhe	ON	Shahejie	S	33.6°	n.r.	n.r.	O; FB, S/fc	major	Oper.	n.r.	n.r.
27	Yuesanba	ON	Shahejie	S	31.0°	n.r.	n.r.	O; FB	small	No prod.	n.r.	n.r.
28	Dachangtou	ON	Shahejie	S	n.r.	n.r.	n.r.	G; S/fc	v. small	No prod.	n.r.	n.r.
29	Lianmeng	ON	n.r.	S	n.r.	n.r.	n.r.	O	small	No prod.	n.r.	n.r.
30	Zhaodong	ON	n.r.	S	n.r.	n.r.	n.r.	O	small	No prod.	n.r.	n.r.
31	Gaoshangbu (Gaoshang-bao)	1979 ON	Shahejie; Guantao	S	22.1–38.6°	n.r.	0.05–0.16	O/G; FA	major/small	Oper.	8.7	n.r.

Table 4. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Huanghua subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from oil industry compilations (unpub. data, 1996) and Jin and McCabe (1998). The cumulative oil and gas production values from the oil industry compilations are through about 1986. Abbreviations: **Discovery date:** ON, onshore; OFF, offshore; **Reservoir, API Gravity, Gas-oil ratio (GOR)** and **Sulfur (percent):** Sha, Shahejie; Dong, Dongying; Guan, Guantao; Ming, Minghuazhen; cond., condensate; ft^3 per bbl, cubic feet of gas per barrel of oil; **Source rock(s):** S, Shahejie Formation; K, Kongdian Formation**; Hydrocarbon type, trap:** O, oil; G, gas; O/G, oil and gas; O/G/C, oil, gas, and condensate; FA, faulted anticline; FB, fault block; FAN, faulted anticlinal nose; D, dome; FD, faulted dome; S/fc, stratigraphic/facies change; BH, buried hill; **Field status:** Oper., operational; No prod., no production. Other abbreviations: n.r., not recorded; v., very; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special references: $^+$, Liang (1987a); $^{\Delta}$, Li (1987)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
32	Liuzhan	1980^{Δ} ON	Shahejie; Guantao; Minghuazhen	S	29.7°	n.r.	n.r.	O; FB, S/fc	medium	Oper.	3.2	n.r.
33	Beipu (Beibao)	1980^{Δ} ON	Dongying; Guantao	S	43.2°	n.r.	n.r.	O	v. small	Oper.	0.078	n.r.
34	Laoyemiao	ON	Dongying; Minghuazhen	S	34.4°	n.r.	n.r.	O; FB, S/fc	v. small	Oper.	1.3	n.r.
35	Tanghai/ Duling (Tanghe)	ON	Shahejie; Mesozoic (Jurassic); Cambrian	S	22.3°	n.r.	n.r.	O; FB, BH, S/fc	v. small	Oper.	0.239	n.r.
36	Canshakou	ON	Shahejie	S	29.7°	n.r.	n.r.	O; FB	medium	Oper.	5.5	n.r.
37	Baigezhuang	≈1976^{Δ} ON	n.r.	S	n.r.	n.r.	n.r.	O	v. small	Oper.	n.r.	n.r.
38	Chengdao	1988 ON/OFF	Guantao and Minghuazhen	S	n.r.	n.r.	n.r.	O	giant	Oper.	n.r.	n.r.

Table 5. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Linqing/Dongpu subbasin, Bohaiwan basin (province 3127), China.

[Data are from an oil industry compilation (unpub. data, 1996). The cumulative oil and gas production values from this compilation are through about 1989. Abbreviations: **Discovery date:** ON, onshore; **Source rock(s):** S, Shahejie Formation; C, Carboniferous strata; **Gas-oil ratio (GOR):** ft^3 per barrel, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; G, gas; G/C, gas and condensate; O/G, oil and gas; FA, faulted anticline; FB, fault block; S/fc, stratigraphic/facies change; FAN, faulted anticlinal nose; **Field status:** Oper., operational; No prod., no production. Other abbreviations: n.r., not recorded; v., very; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special references: $^+$, Xu and Shen (1996); $^\#$, Zhu (1987); $^\Delta$, Dai and others (2004)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
1	Pucheng (Zhongyuan)	1979 (1975)$^\#$ ON	Shahejie	S	31.1–37.0°	389–949	0.19–0.56	O/G; FA	giant	Oper.	192.8	n.r.
2	Wenmingzhai	1979 ON	Shahejie	S	22.3–29.3°	240	1.37	O; FA	large	Oper.	33.3	n.r.
3	Weicheng	1977 ON	Shahejie	S	20.7–29.3°	444	0.06–1.9	O/G; FA	large/small	Oper.	26.1	n.r.
4	Guyunji	1980 ON	Shahejie	S	33.0–35.0°	n.r.	n.r.	O/G; FA	v. small/v. small	No prod.	n.r.	n.r.
5	Wendong	1978 ON	Shahejie	S	37.0–43.2°	n.r.	0.22–0.23	O/G; FA	major/small	Oper.	33.6	n.r.
6	Wennan	1978 ON	Shahejie	S	37.0–41.1°	740	0.1–0.8	O/G; FA	medium	Oper.	44.7	n.r.
7	Wenliu	1977 ON	Shahejie	S, C$^+$	33.8–39.4°	356–597	0.32–0.95	O/G; FA	giant/medium	Oper.	3.5	n.r.
8	Wen-23	1977 ON	Shahejie	S	n.r.	n.r.	n.r.	G/C; FA	major/medium	Oper.	17.0 (condensate)	2.1
9	Qiaokou	1977 ON	Shahejie	S	39.0–39.4°	296–477	n.r.	O; FA	small	Oper.	3.7	n.r.
10	Baimiao	1980 ON	Shahejie	S	n.r.	n.r.	n.r.	G; FB, S/fc	v. small	Oper.	n.r.	n.r.
11	Machang	1981 ON	Shahejie	S, C$^\Delta$	39.0°	419–663	n.r.	O/G; FB	v. small	Oper.	8.3	n.r.
12	Sanchunji	1987 ON	Shahejie	S	33.4–37.8°	n.r.	n.r.	O; FAN	v. small	No prod.	n.r.	n.r.
13	Mazhai	1988 ON	Shahejie	S	30.0°	60–111	n.r.	O; FA	v. small	Oper.	6.3	n.r.
14	Huzhuangji	1983 ON	Shahejie	S	17.1–38.0°	n.r.	0.54–0.70	O; FA, FB	large	Oper.	26.4	n.r.
15	Qingzuji	1986 ON	Shahejie	S	31.5–38.8°	126–316	0.21	O; FB	v. small	Oper.	1.7	n.r.
16	Liuzhuang	ON	Shahejie	S	26.6°	n.r.	n.r.	O; FB	v. small	No prod.	n.r.	n.r.

Table 5. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Linqing/Dongpu subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). The cumulative oil and gas production values from this compilation are through about 1989. Abbreviations: **Discovery date:** ON, onshore; **Source rock(s):** S, Shahejie Formation; C, Carboniferous strata; **Gas-oil ratio (GOR):** ft^3 per barrel, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; G, gas; G/C, gas and condensate; O/G, oil and gas; FA, faulted anticline; FB, fault block; S/fc, stratigraphic/facies change; FAN, faulted anticlinal nose; **Field status:** Oper., operational; No prod., no production. Other abbreviations: n.r., not recorded; v., very; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9). Special references: $^+$, Xu and Shen (1996); $^\#$, Zhu (1987); $^\Delta$, Dai and others (2004)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
17	Hupuzhai/Xueji	ON	n.r.	S	n.r.	n.r.	n.r.	G	v. small	Oper.	n.r.	n.r.
18	Xuji	ON	n.r.	S	n.r.	n.r.	n.r.	O	small	Oper.	n.r.	n.r.
19	Wenbei	ON	n.r.	S	n.r.	n.r.	n.r.	O	small	Oper.	n.r.	n.r.

Table 6. Size, cumulative production, and selected characteristics of oil and gas fields in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Bozhong subbasin, Bohaiwan basin (province 3127), China.

[Data are from Editorial Committee of Petroleum Geology of Oil- and Gas-Bearing Areas on the Continental Shelf and its Neighboring Regions (1987), Matsuzawa (1988), Lee (1989), Oil and Gas Journal (1997), Shirley (2000), and Hurst and others (2001). Abbreviations: **Discovery date:** OFF, offshore; **Reservoir:** Sha, Shahejie; **Source rock(s):** S, Shahejie Formation; **Gas-oil ratio (GOR):** ft^3 per barrel, cubic feet of gas per barrel of oil; **Hydrocarbon type, trap:** O, oil; O/G, oil and gas; BH, buried hill; CA, compaction anticline; FA, faulted anticline; FAN, faulted anticlinal nose; FB, fault block; **Field status:** Disc., discovery; Devel., being developed; Oper., operational; P&A, plugged and abandoned. Other abbreviations: n.r., not recorded; MMb, millions of barrels (bbl x 10^6); BCF, billions of cubic feet (ft^3 x 10^9)]

Field No.	Field name	Discovery date	Reservoir	Source rock(s)	API gravity	Gas-oil ratio (GOR; ft^3 per bbl)	Sulfur (percent)	Hydrocarbon type, trap	Field size Oil/Gas	Field status	Cumulative production of oil (MMb)	Cumulative production of gas (BCF)
1	Qinhuangdao 30-1	≈1975 OFF	Mesozoic (Jurassic)	S	n.r.	n.r.	n.r.	O; BH	n.r.	Disc.	n.r.	n.r.
2	Shijiutuo (Qinhuangdao 35-1, Bozhong 5)	1975 OFF	Mesozoic (Jurassic); Dongying; Guantao	S	27°	1,160	n.r.	O/G; CA, BH	n.r.	Devel.	n.r.	3,097
3	Bozhong 25-1-1	1981 OFF	Shahejie (Sha III); Mesozoic	S	33°	390	n.r.	O/G; FA	n.r.	n.r.	n.r.	n.r.
4	Bozhong 28-1	1981 OFF	Shahejie (Sha I); Cambrian; Ordovician	S	39°	970	0.2–0.17	O/G; BH	n.r.	n.r.	n.r.	n.r.
5	Bozhong 28-2-1	1983 OFF	Dongying	S	30.0°	760	0.24	O/G; FA	n.r.	Disc.	n.r.	n.r.
6	Bozhong 34-1-1	1984 OFF	Dongying; Guantao; Minghuazhen	S	39.5°	800	n.r.	O/G; FA	n.r.	Disc.	n.r.	n.r.
7	Bozhong 34-2	1983 OFF	Shahejie (Sha II, III); Dongying; Guantao	S	36°	520	0.11–0.21	O/G; FA	n.r.	Oper.	n.r.	n.r.
8	Bozhong 34-3	1984 OFF	Dongying; Guantao	S	36°	350–850	0.09	O/G; FAN	n.r.	n.r.	n.r.	n.r.
9	Bozhong 34-4	1985 OFF	Shahejie (Sha II, III)	S	n.r.	n.r.	n.r.	O/G; FA	n.r.	Oper.	n.r.	n.r.
10	Peng Lai 14-3-1	1997 OFF	Miocene sandstone	S	26–36°	n.r	n.r.	O; n.r.	n.r.	Disc.; P&A, 1999	n.r.	n.r.
11	Peng Lai 19-3-1	1999 OFF	Guantao; Minghuazhen	S	11–21°	50–300	n.r.	O/G; FB	n.r.	Disc.	n.r.	n.r.

Table 7. Selected geochemical properties of source rocks in Member 3 of the Shahejie Formation.

Subbasin	Total organic carbon (TOC) (weight percent)	Kerogen type	Hydrogen Index (HI) (milligrams of hydrocarbons per gram of organic carbon)	Reference
Jiyang	1–2	—	—	ECPG–Shengli (1987)[1]
	1.17–3.47	—	—	Jin (1991)
	—	—	150–400 (several values as high as 937 and 1,136)	Chen and others (1996)
Liaohe	1.5–2.0	I and II in western sag; II and III in eastern and Damitun sags	—	Ge and ECPG–Liaohe (1989)[2]
Jizhong	≥1.0 (Chaheji field)	—	—	Wu and Liang (1988)
	—	II (Renqiu field)	—	Liu and others (1988)
	—	—	200–579	Gao and others (1987)
Huanghua	0.75–2.22	II	—	Liang (1987a)
Linqing/Dongpu	0.3–3.2	II and III	394–623 (northern part) 113–315 (southern part)	Jin and McCabe (1998)
Bozhong	0.68–1.66	II	—	Gong and others (1998)

[1]Editorial Committee of Petroleum Geology of the Shengli Oil Field (1987).

[2]Ge and Editorial Committee of Petroleum Geology of the Liaohe Oil Fields (1989).

Table 8. Stratigraphic, geochemical, and thermal maturation data used to construct the burial history and hydrocarbon generation model (fig. 9) for the Jiyang subbasin, Bohaiwan basin, China.

[See figures 1 and 2 for location of the Jiyang subbasin and the burial history and hydrocarbon generation model. Asia Pacific region (03), China (31), Bohaiwan basin province (27), Jiyang subbasin (using geologic periods/epochs and other data assigned by Editorial Committee of Petroleum Geology of the Shengli Oil Field, 1987; Lee, 1989; and Hu and Krylov, 1996). Thicknesses of the sedimentary rocks used in the model are based on figure 2. Province geologist: R.T. Ryder; burial history and petroleum generation modeled by V.F. Nuccio, 1999. Present-day surface temperature = ~ 14°C; average geothermal gradient = 36°C/km. Abbreviations: **Formation:** undiff., undifferentiated; m, meter; Olig., Oligocene; Jur., Jurassic; Ord., Ordovician; Camb., Cambrian; mbr., member; **Lithology:** ss, sandstone; sls, siltstone; sh, shale; blk, black; evap, evaporite; ls, limestone; **Thermal indices** and **Geochem. indices**: $\%R_o$, vitrinite reflectance; pct., percent; TOC, total organic carbon]

Depth to top of unit (meters)	Formation	Lithology (percent)	Thermal indices	Geochem. indices	Period or epoch	Age (Ma)
Surface–1,400	Quaternary undiff. Minghuazhen Guantao	60 ss, 40 sls	$\%R_o < 0.5$		Neogene, Quaternary	23–0
	---unconformity--- (~300 m of Olig. strata removed)					24–23
(300 m)	Unnamed Olig. strata	50 ss, 50 sls			Oligocene (part)	28–24
1,400–2,000	Dongying	50 ss, 50 sls			Oligocene (part)	35–28
2,000–2,600	Shahejie (mbrs. 1, 2)	50 sh & blk sh, 30 ss, 20 sls			Oligocene (part), Eocene (part)	39–35
2,600–3,600	Shahejie (mbr. 3)	90 sh & blk sh, 10 sls		TOC = 2.0 weight percent 80 pct. type I kerogen, 20 pct. type II kerogen	Eocene (part)	49–39
3,600–7,100	Shahejie (mbr. 4) and Kongdian (mbrs. 1–3)	70 sh & blk sh, 10 evap & ls 10 ss, 10 sls			Eocene (part), Paleocene (part)	60–49
	---unconformity--- (~200 m of Jur. strata removed)					90–60
7,100–8,700	Mesozoic undiff.	80 sh, 20 ss			Jurassic (part), Cretaceous (part)	208–90
	---unconformity--- (~100 m of Permian strata removed)					245–208
8,700–9,900	Carboniferous-Permian undiff.	80 sh, 15 ss, 5 coal			Carboniferous, Permian	360–245
	---unconformity--- (~300 m of Ord.-Camb. strata removed)					438–360
9,900–10,400	Ordovician and Cambrian ---unconformity--- (~200 m of Archean rocks removed)	80 ls, 20 sh			Ordovician, Cambrian	570–438
10,400	Archean basement rocks	Igneous and metamorphic rocks			Archean	>2,500

Table 9. Stratigraphic, geochemical, and thermal maturation data used to construct the burial history and hydrocarbon generation model (fig. 10) for the Bozhong subbasin, Bohaiwan basin, China.

[See figures 1 and 3 for location of the Bozhong subbasin and the burial history and hydrocarbon generation model. Asia Pacific region (03), China (31), Bohaiwan basin province (27), Bozhong subbasin (using geologic periods/epochs and other data assigned by Editorial Committee of Petroleum Geology of Oil- and Gas-Bearing Areas on the Continental Shelf and its Neighboring Regions, 1987; Lee, 1989). Thicknesses of the sedimentary rocks used in the model are based on figure 3. Province geologist: R.T. Ryder; burial history and petroleum generation modeled by V.F. Nuccio, 1999. Present-day surface temperature = ~ 14°C; average geothermal gradient = 36°C/km. Abbreviations: **Formation:** undiff., undifferentiated; m, meter; Olig., Oligocene; mbr., member; Jur.-K, Jurassic and Cretaceous; Ord., Ordovician; Camb., Cambrian; **Lithology:** ss, sandstone; sls, siltstone; sh, shale; blk, black; evap, evaporite; ls, limestone; dolo, dolomite; **Thermal indices** and **Geochem. indices:** $\%R_o$, vitrinite reflectance; pct., percent; TOC, total organic carbon]

Depth to top of unit (meters)	Formation	Lithology (percent)	Thermal indices	Geochem. indices	Period or epoch	Age (Ma)
Surface–4,500	Quaternary undiff. Minghuazhen Guantao	60 ss, 40 sls	$\%R_o < 0.5$		Neogene, Quaternary	23–0
	---unconformity--- (~300 m of Olig. strata removed)					24–23
(300 m)	Unnamed Olig. strata	50 ss, 50 sls			Oligocene (part)	28–24
4,500–6,500	Dongying	50 ss, 50 sls			Oligocene (part)	35–28
6,500–7,500	Shahejie (mbrs. 1, 2)	50 sh & blk sh, 30 ss, 20 sls			Oligocene (part), Eocene (part)	39–35
7,500–8,500	Shahejie (mbr. 3)	90 sh & blk sh, 10 sls		TOC = 1.5 weight percent 50 pct. type I kerogen, 50 pct. type II kerogen	Eocene (part)	49–39
8,500–10,500	Shahejie (mbr. 4) and Kongdian (mbrs. 1–3)	70 sh & blk sh, 10 evap & ls, 10 ss, 10 sls			Eocene (part), Paleocene (part)	60–49
	---unconformity--- (~200 m of Jur.-K strata removed)					90–60
(200 m)	Mesozoic undiff.	80 sh, 20 ss			Jurassic (part), Cretaceous (part)	208–90
	---unconformity--- (~500 m of Ord.-Camb. strata removed)					438–208
(500 m)	Ord., Camb., Proterozoic undiff.	80 ls & dolo, 20 sh			Ordovician Cambrian, Proterozoic	570–438
	---unconformity--- (~200 m of Archean rocks removed)					
10,500	Archean basement rocks	Igneous and metamorphic rocks			Archean	>2,500

Table 10. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jiyang subbasin, Bohaiwan basin (province 3127), China.

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Guan, Guantao; ss, sandstone; Fm, formation; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; S/I, secondary intergranular porosity; V, vuggy porosity; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; ss, sandstone; sh, shale; slt, siltstone; marl, marlstone; ls, limestone; biols, bioclastic limestone; dolo. ls, dolomitic limestone; congl ss, conglomeratic sandstone; dolo, dolomite; congl, conglomerate; sdy ls, sandy limestone; argill. dolo, argillaceous dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average; max., maximum; min., minimum]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
1	Shentuo (Shengtuo)	Shahejie (Sha I, II, III); Dongying (Dong I, II, III); Guantao; Minghuazhen	26–34.8	P/I	1,000 ave., 20,600 max.	ss	n.r.	1,990	n.r.	970–2,960
		Sha I						<33.1#		
		Sha II						17.9#		
2	Guangli	Shahejie (Sha III, IV); Kongdian	23.1–25.8; ave. 25.0	P/I; S/f	229–1,795; ave. 356	0.124; f ss and sh	5–10	15.3–22.6#	35	2,500–2,650
3	Wangjiagang	Shahejie	25–30	P/I	600–3,200	0.15–0.33; f-m ss	n.r.	80–100; 40.4#	n.r.	1,700–2,460
4	Gudao	Shahejie (Sha I, II); Dongying; Guantao; Minghuazhen; Ordovician	32.7–35.1	P/I	510–3,118	ss	n.r.	19.3#	35	1,120–1,350
5	Chengdong	Guantao; Minghuazhen	21.8–37.4	P/I	643 min.–6,930 max.; ave. 1,000–1,500	f ss, slt	n.r.	11.0#	n.r.	1,060–1,360
6	Gudong	Shahejie; Guantao; Dongying; Minghuazhen		P/I		ss	3–5	19.3#	n.r.	1,000–2,500
		Sha	20–22		180–450					
		Guan upper	33.3							
		Guan lower	32.1		1,009					
7	Caoqiao (Le'an)	Kongdian; Shahejie (Sha I, II, III, IV); Guantao		P/I	50–100		n.r.	16.3#, east; 13.6#, west	n.r.	1,300, west; 1,000–1,200, east
		Sha I				slt, ss				
		Sha II				slt, ss				
		Sha III				slt, ss				
		Sha IV		S/f		slt, marl, ls, biols, dolo. ls				
		Guan				congl				

Table 10. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jiyang subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Guan, Guantao; ss, sandstone; Fm, formation; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; S/I, secondary intergranular porosity; V, vuggy porosity; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; ss, sandstone; sh, shale; slt, siltstone; marl, marlstone; ls, limestone; biols, bioclastic limestone; dolo. ls, dolomitic limestone; congl ss, conglomeratic sandstone; dolo, dolomite; congl, conglomerate; sdy ls, sandy limestone; argill. dolo, argillaceous dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average; max., maximum; min., minimum]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
8	Bamianhe	Shahejie		P/I		ss	n.r.	8.53#	n.r.	1,100–1,300
		(Sha III upper;	35.3		1,468					
		Sha III lower;	34.5		1,326					
		Sha IV);	31.0		575					
		Paleozoic								
9	Linfanjia	Dongying; Guantao	31	P/I	392	0.31; m arkosic ss, slt	n.r.	5.1#	n.r.	1,000–1,100
10	Bonan	Shahejie (Sha I, II, III); Dongying	18.4–24.1; 21.0 ave.	P/I, S/f	100–200	ss, congl ss	n.r.	15.1#	35.6	2,800–3,400
11	Shangdian	Shahejie (Sha II, III, Sha IV upper, Sha IV middle); Dongying; Guantao	23–31	P/I	44–1,000	ss	n.r.	7.3#, east; 4–6, central; 5.6–6.8, west	35	1,430–1,550, west; 1,390–1,470, central; 1,100–1,200, east
12	Shunhuazhen (Chun-huazhen)	Shahejie (Sha II, III, IV)	20	P/I, S/I, V	100, ss; <30, ls	ss, ls	n.r.	6.3#	n.r.	1,770–2,400
13	Qiaozhuang	Shahejie	15.3	P/I	151	ss	2–3	5.2–11#	n.r.	3,050–3,190
14	Gunan	Shahejie; Dongying; Guantao;	22–25	P/I	5–2,164; ave. >500	ss	n.r.	640; 25#	n.r.	2,100–2,740
		Mesozoic (Jurassic)				tuffaceous ss				
15	Shanghe	Shahejie (Sha I, II upper, II lower, III upper, III lower, IV); Dongying	16.2–22.4	P/I	11–151; ave. 30–50	ss	n.r.	12.6#	58.3	1,550–2,550
16	Dongxin	Shahejie (Sha I, II, III); Dongying; Guantao	25–31	P/I	2,350–4,500; usually 1,000	0.08–0.15; vf-f ss	n.r.	37.0#–173#	35	1,350–3,240
		Sha I						200		
		Sha II						400		
		Sha III						500		
		Dong						300		
		Guan						300		

Table 10. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jiyang subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Guan, Guantao; ss, sandstone; Fm, formation; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; S/I, secondary intergranular porosity; V, vuggy porosity; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; ss, sandstone; sh, shale; slt, siltstone; marl, marlstone; ls, limestone; biols, bioclastic limestone; dolo. ls, dolomitic limestone; congl ss, conglomeratic sandstone; dolo, dolomite; congl, conglomerate; sdy ls, sandy limestone; argill. dolo, argillaceous dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average; max., maximum; min., minimum]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
17	Yonganzhen	Shahejie (Sha II, III, IV)	23–32.6	P/I		ss	n.r.	14.6#	40	1,390–2,310
		Sha II			981–9,870					
		Sha III			7–16					
		Sha IV			7–16					
18	Haojia	Shahejie	25	P/I	707–2,740	ss	n.r.	4.9#	30–40	1,875–2,660
19	Linjin (Lijun)	Shahejie	24.7–29.6	P/I	260–1,770	0.09–0.21; vf-f ss	1–10	50–80; 12.6#	35	1,560–3,400
20	Kenli	Shahejie (Sha I, II); Mesozoic (Jurassic ss); Ordovician (Majiagou Fm)	40 max.; 28.6 ave.		2,486	ss	7–10		n.r.	1,810–1,944
		Sha I		P/I		ss		19.7#		
		Sha II		P/I		ss		16#		
		Jurassic ss		P/I		ss		12.1#		
		Majiagou	0.23	S/f, S/I, V	1,000	dolo		135#		
21	Hetang (Hetan)	Shahajie (Sha II, Sha II lower, Sha III; Mesozoic		P/I		ss	4–19.4	250	n.r.	2,050–2,300
		Sha II	34.3 max.; 29 ave.		10,600 max.; 3,280 ave.			13.6#		
		Sha II lower						20.1#		
		Sha III	31.1 max.; 28.5 ave.		5,424 max.; 1,353 ave.					
22	Liangjialao (Liangjialou)	Shahejie (Sha III)	18.8–22.8	P/I	514–4,118	congl, ss, slt	n.r.	50; 11.8# 70; 12#	31–50	2,000–2,860
23, 24	Hongliu-Kendong	Shahejie (Sha II, III); Guantao		P/I		0.18; f ss	n.r.	26.7#	n.r.	
		Sha	20.9		74.2	biols				2,200–2,300
		Sha II	20		363	slt; m congl ss				
		Sha III				slt				
		Guan	33.4		4,800	ss				1,250–1,450

Table 10. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jiyang subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Guan, Guantao; ss, sandstone; Fm, formation; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; S/I, secondary intergranular porosity; V, vuggy porosity; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; ss, sandstone; sh, shale; slt, siltstone; marl, marlstone; ls, limestone; biols, bioclastic limestone; dolo. ls, dolomitic limestone; congl ss, conglomeratic sandstone; dolo, dolomite; congl, conglomerate; sdy ls, sandy limestone; argill. dolo, argillaceous dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average; max., maximum; min., minimum]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
25	Laohekou	Guantao	33.9	P/I	557	0.1; vf biols	2.7–10, east; 2.3–9.1 west	6.4#	n.r.	1,340–1,700
26	Linpan	Shahejie; Dongying; Guantao	12–33.4	P/I		ss	n.r.	1,400; 12.4#	n.r.	1,360–3,360
		Sha			300–400					
		Guan			1,000					
27	Danjiashi	Shahejie; Dongying; Guantao	24–34	P/I	>5,000	congl, crs ss	n.r.		n.r.	1,000–1,200
		Dong						22#		
		Guan						62#		
28	Taoerhe (Guierhe)	Shahejie;	10–27	P/I	168	ss	n.r.		n.r.	1,600–1,670
		Ordovician;				dolo		3.6#–7.8#		
		Carboniferous						31.7#		
29	Yibei	Shahejie (Sha II, IV); Mesozoic (Jurassic)	13.9–18.7		9.6		n.r.	18.0#	n.r.	1,840–2,800
		Sha II				dolo and arkosic ss				
		Sha IV				ls and sdy ls				
		Jurassic		S/f		arkosic ss and volcaniclastics				
30	Yihezhuang	Shahejie (Sha I, II, III, IV); Guantao; Jurassic; Ordovician (Badou and Majiagou Fms); Carboniferous; Permian	n.r.				n.r.		n.r.	
		Badou		S/f, V	core: 4.5–14.2 matrix: 8.4	ls, dolo		30–50; 24.9#		1,830–2,280
		Majiagou		S/f, V	core: 2.5 matrix: 80–870	ls, dolo		30–50; 24.9#		1,830–2,280
31	Yidong	Shahejie; Dongying; Guantao	19.5	P/I	210–1,630	crs ss	n.r.	3#–54.8# 8.7#	n.r.	1,250–2,830

Table 10. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jiyang subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Guan, Guantao; ss, sandstone; Fm, formation; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; S/I, secondary intergranular porosity; V, vuggy porosity; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; ss, sandstone; sh, shale; slt, siltstone; marl, marlstone; ls, limestone; biols, bioclastic limestone; dolo. ls, dolomitic limestone; congl ss, conglomeratic sandstone; dolo, dolomite; congl, conglomerate; sdy ls, sandy limestone; argill. dolo, argillaceous dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average; max., maximum; min., minimum]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
32	Kenxi	Shahejie (Sha I); Dongying; Guantao		P/I		ss	n.r.	10.8#	n.r.	1,350–1,850
		Sha I			706	congl ss				
		Dong	28.8		1,360	ss				
		Guan	31.2		2,720	ss				
33	Wuhaozhuang	Shahejie (Sha III upper, Sha III lower)	18.3 upper; 12.5–16.2 lower	P/I	261 upper; 2.3–6.7 lower	congl ss, f ss, slt	n.r.	16.4#–21.4#	n.r.	3,200–3,800
34	Wangzhuang	Archean and Proterozoic rocks	5.6	S/f, V	493	granite	n.r.	200; 90#	n.r.	1,470–1,670
35	Ninghai	Shahejie; Dongying	19.0–28.2	P/I	300–1,800	ss	n.r.	14.7#–15.7#	n.r.	1,600–2,300
36	Pingfangwang	Shahejie (Sha II, IV); Cambrian	21–27	S/f, V	690		n.r.	17.9#	n.r.	1,510–1,580
		Sha				biols, oolitic ls, argill. dolo				
37	Binnan	Shahejie (Sha I, II, III, IV); Dongying	25	n.r.	45–897	ss	n.r.	12.4#	n.r.	1,700–3,020
		Sha I				ls				
		Sha II				ss				
		Sha III				ss				
		Sha IV				slt				
		Dong				ss				
38	Shinan	Shahejie	21.5	P/I	n.r.	ss	11–32	21.5#	n.r.	2,700–2,900
39	Xianhezhuang	Shahejie (Sha I, II, III)	25–30	P/I	702–2,200	f-m ss	n.r.	53.2#	n.r.	1,780–2,960
40	Zhuangxi	Shahejie; Orodovician, Cambrian	13–16	P/I; S/f, V	86.9	biols, ss, mudstone	n.r.	12#	43–48	3,000–3,100
41	Dawang-zhuang	Shahejie (Sha II)	15–26	n.r.	2,160–3,120	ss	n.r.	15#	n.r.	2,160–3,120
42	Xinlicun	Shahejie (Sha II, III); Dongying	n.r.	n.r.	n.r.	ss	n.r.	8.5#	n.r.	n.r.
43	Changti (Changdi)	Shahejie (Sha I, II, III); Mesozoic	17–32	P/I	11.6–1,001	ss	n.r.	10#	35–42	n.r.

Table 10. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jiyang subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Guan, Guantao; ss, sandstone; Fm, formation; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; S/I, secondary intergranular porosity; V, vuggy porosity; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; ss, sandstone; sh, shale; slt, siltstone; marl, marlstone; ls, limestone; biols, bioclastic limestone; dolo. ls, dolomitic limestone; congl ss, conglomeratic sandstone; dolo, dolomite; congl, conglomerate; sdy ls, sandy limestone; argill. dolo, argillaceous dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average; max., maximum; min., minimum]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
44	Shaojia	Dongying; Guantao Guan	n.r.	n.r.	n.r.	ss	n.r.	15#	n.r.	1,930–2,020
45	Xiaoying	Shahejie	13–17	P/I	2.8	ss, ls	n.r.	6.7#	4.3	1,900–3,040
46	Gaoqing	Dongying; Kongdian; Shahejie (Sha III); Mesozoic (Jurassic)	29	P/I	32	ss	n.r.	20#	33	n.r.
47	Zhenglizhuang	Shahejie (Sha I, II, III)	27	P/I	120–488	ss	n.r.	12.0#	45	1,400–1,650
48	Luojia	Shahejie	20–23	S/f, V	n.r.	ss, ls, volcanics	n.r.	n.r.	35–40	2,000–2,040
49	Dawangbei	Shahejie (Sha II)	16	P/I	32.8	ss	n.r.	7	43	2,850–3,500
50	Niuzhuang	Shahejie (Sha III)	17–20	P/I	1.5–29	ss	n.r.	10#	n.r.	n.r.
51	Chenjiazhuang	Guantao	28	P/I	800–2,000	ss	n.r.	6.5#	45	1,260–1,320
52	Zhengjia	Shahejie (Sha III)	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
53	Yangjiaogou	Shahejie; Guantao	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
54	Jinjia	Shahejie (Sha I)	32–34	P/I	1,056–1,653	ss	n.r.	14#	n.r.	800–900
55	Boxing	Shahejie (Sha IV)	14–17	P/I	3.7–23.3	ss	n.r.	43#	n.r.	2,600–2,820
56	Pingnan	Shahejie (Sha IV);		P/I			n.r.	n.r.	n.r.	
		Ordovician	2		2.36	dolo				2,260–2,600
57	Chendao (Chengdao)	Guantao; Dongying; Shahejie	20–34	P/I	516–2,045	ss	n.r.	n.r.	n.r.	1,250–2,730
58	Xintang (Xintan)	Guantao; Shahejie	35	P/I	2,914	ss	n.r.	n.r.	36	1,050–1,150
59	Taiping	Dongying; Guantao	23–28	P/I	1,464–2,088	ss	n.r.	n.r.	40–44	1,100–1,400
60	Yuhuangmiao	Shahejie; Dongying	22	S/f	240	volcanics	n.r.	n.r.	45	2,060–2,550
63	Daluhu	Shahejie	16	P/I	3–15	ss	n.r.	27.2#	n.r.	2,800–3,300
64	Feiyantan	Guantao	35	P/I	6,367	ss	n.r.	7.5#	32	1,200–1,340
65	Yingxiongtan	Shahejie	23	P/I	101.2	ss	n.r.	n.r.	44	2,000–2,100
66	Dongfenggang	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
67	Yanjia	Shahejie	27.7	P/I	95	ss	n.r.	n.r.	n.r.	n.r.

Table 10. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jiyang subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Guan, Guantao; ss, sandstone; Fm, formation; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; S/I, secondary intergranular porosity; V, vuggy porosity; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; ss, sandstone; sh, shale; slt, siltstone; marl, marlstone; ls, limestone; biols, bioclastic limestone; dolo. ls, dolomitic limestone; congl ss, conglomeratic sandstone; dolo, dolomite; congl, conglomerate; sdy ls, sandy limestone; argill. dolo, argillaceous dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average; max., maximum; min., minimum]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
68	Huagou	Shahejie; Dongying; Guantao	n.r.	P/I	n.r.	ss	n.r.	7.0#	n.r.	750–1,310

Table 11. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Liaohe subbasin, Bohaiwan basin (province 3127), China.

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Fm, formation; Prot, Proterozoic; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; V, vuggy porosity; Arch/Prot, Archean and Proterozoic; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; m-crs, medium to coarse grained; ss, sandstone; congl, conglomerate; congl ss, conglomeratic sandstone; dolo, dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
1	Rehetai	Shahejie (Sha I, II, III); volcanic rocks		P/I		1.52–1.77; m-crs ss	n.r.	7.9#	n.r.	1,950–2,675
		Sha I	25.9		1,172					
		Sha II	27.8		1,682					
		Sha III	22.3		595			33.1#		
		Sha I lower-Sha II				ss				
		Sha I middle				ss				
		Sha III lower				ss				
		volcanic rocks	20.3–24.9		1–16					
2	Huangjindai	Shahejie (Sha I, II, III); Dongying		P/I; S/f		0.1–0.44; vf-m ss	11–17	11.8#	n.r.	1,590–2,750
		Sha Ia	24.3		537					
		Sha Ib	20.1		322					
		Sha I						576–1,275		
		Sha II	16.3		213			184–293		
		Sha III	15.8		1.59			374		
		Dong	24.4		513			540–1,269		
3	Yulou	Shahejie (Sha I lower, Sha I middle)	19.6–22.0	P/I	204–2,824	0.286–0.316; m ss	0.3–2.3; 0.94 ave.	50–70, 10.8#	n.r.	1,880–2,790
4	Xinglongtai	Archean rocks; Shahejie (Sha I, II, III); Dong-ying		P/I		0.187–0.543; f-crs ss	n.r.	13.6#	n.r.	1,200–2,800
		Archean	1.3–11.6		<1					
		Sha I	26.0		4,410			100–250		
		Sha II	18.6		1,789			300–400		
		Sha III	15.7		26			200–400		
		Dong	25.7		209			400		

Table 11. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Liaohe subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Fm, formation; Prot, Proterozoic; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; V, vuggy porosity; Arch/Prot, Archean and Proterozoic; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; m-crs, medium to coarse grained; ss, sandstone; congl, conglomerate; congl ss, conglomeratic sandstone; dolo, dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
5	Shuguang	Archean/Proterozoic rocks; Middle Proterozoic (Wumishan Fm); Shahejie (Sha I, II, III, IV)		P/I, Sha; S/f, Arch/Prot			n.r.		n.r.	700–2,400
		Archean/Prot						173#		
		Sha						4#–33#		
		Sha I lower						50–250		
		Sha II	31.5		354	0.325; m ss		50–120		
		Sha III	25–30		336	0.512; crs ss		600		
		Sha IV	19.9–27.3		476–1,284	0.09–0.236; vf-f ss				
6	Gaosheng	Shahejie (Sha III, IV)	5.2–39.4; 20–25 ave.	P/I	1–20,675; 1,000–3,000 ave.	0.38–0.49; m ss	10–20	60–100; 67.6#	n.r.	1,300–1,700
7	Huanxiling	Archean rocks; Shahejie (Sha I, II, III, IV)		P/I		congl, congl ss, ss	n.r.	36.2#	n.r.	
		Archean	3.2	S/f, V	<1	granite				2,500–2,800
		Sha I						150–350		1,200
		Sha II	21.3–29.0		659–2,201	0.32; m ss		100–300		1,000–2,000
		Sha III						300–800		
		Sha III upper								1,700–2,500
		Sha III middle	19.2		302	0.305; m ss				1,400–2,700
		Sha III lower								2,000–2,200
		Sha IV	13.8		85	0.31; m ss		0–500		2,100–2,850
8	Shuangtaizi	Shahejie (Sha I, II, III); Dongying		P/I		0.349–0.40; m ss	n.r.	30.2#	n.r.	2,300–2,800
		Sha I lower-II								
		Sha II	4.0–28.1; 17.0 ave.		1–20,031; 282 ave.	congl ss and sandy congl		60–200		
		Sha III	3.4–20.8; 13.0 ave.		1–275; 15.4 ave.	ss and congl ss		1,000		

Table 11. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Liaohe subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Fm, formation; Prot, Proterozoic; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; V, vuggy porosity; Arch/Prot, Archean and Proterozoic; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; m-crs, medium to coarse grained; ss, sandstone; congl, conglomerate; congl ss, conglomeratic sandstone; dolo, dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
9	Niuju	Shahejie (Sha I, II); Dongying		P/I			2–5	33#	n.r.	945–3,266
		Sha I upper;	18.2		99	0.29; m ss		60		
		Sha I middle	18.8		246	0.34; m ss				
		Sha I lower	12.3		50	0.28; m ss				
		Sha II	13.3		37	0.43; m ss				
		Dong	22.5		1,501	0.37; m ss, congl ss		1,000		
10	Qinglongtai	Shahejie (Sha I, III); Dongying		P/I		0.2–0.8; f–crs ss; congl ss	20 oil; 3.2 gas	20#	n.r.	1,280–1,870
		Sha I	25.9		1,055			200		
		Sha III	19.8–23.5		1,092–4,191			250		
		Dong						650		
11	Qianjing-Damintun	Shahejie (Sha I, III, IV)		P/I		ss	4–46.5	21#	n.r.	1,773–2,158
		Sha I						360–650		
		Sha III						525–1,103		
		Sha III lower	14–20		100–1,000	0.3–0.7; m-crs ss				
		Sha III upper	18–23		100–650	0.1–0.35; vf-m ss				
		Sha IV						35–264		
12	Fahaniu	Archean rocks; Shahejie (Sha III)	7.6–22.3	P/I	10–890	0.07–0.84; vf-crs ss	0.6–6.8	17.3#	n.r.	1,420–2,708

Table 11. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Liaohe subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Fm, formation; Prot, Proterozoic; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; V, vuggy porosity; Arch/Prot, Archean and Proterozoic; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; m-crs, medium to coarse grained; ss, sandstone; congl, conglomerate; congl ss, conglomeratic sandstone; dolo, dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
13	Jinganbu (Jinganbao)	Archean/Proterozoic rocks; Middle Proterozoic rocks (Jinganbu Fm); Shahejie (Sha III); Dongying						n.r.	n.r.	
		Archean	3.8	S/f, V	26	amphibolite and granulite				
		Jinganbu	4.8	P/I	0.3	dolo and meta-argillite				2,450–3,450
		Sha				0.2–0.4; f-m ss	2–5			1,078–2,844
		Sha III	4.8–35.7; 16–22 ave.		1–27,998; 171–1,774 ave.					
		Dong								2,600
14	Dawa	Dongying	25	P/I	721	0.16; f ss	1.5–40	27.5#	n.r.	1,700–2,800
15	Shuangnan (Shunagnan)	Shahejie	12.8	n.r.	40	ss	n.r.	13.0#	35	3,150–3,380
16	Niuxingtuo	Shahejie	n.r.	n.r.	n.r.	ss	n.r.	20–60#	n.r.	1,500–2,200
17	Haiwaihe	Dongying	n.r.	n.r.	n.r.	ss	n.r.	20.6#	n.r.	1,600–2,400
18	Dapingfang	Shahejie; Dongying	30	P/I	29–4,582	ss	n.r.	15.4#	n.r.	1,300–2,350
19	Lejiapu (Lenjiapu)	Shahejie	n.r.	n.r.	n.r.	f ss	n.r.	20.1–40.7#, oil; 7.1#, gas	n.r.	1,300–2,800
20	Biantai	Archean rocks; Shahejie	6.8–21.1		91–761		n.r.	53.4#	n.r.	1,480–2,400
		Archean		S/f, V		metamorphic rocks				
		Shahejie		P/I		ss				
21	Rongxingtun	Shahejie; Dongying	22	n.r.	n.r.	ss	1.0–2.5	4.5#	n.r.	1,600–3,200
22	Xinxi (Xingxi)	Shahejie	n.r.	n.r.	n.r.	ss	n.r.	11.7#	n.r.	1,670–2,240
23	Ziyutou	Shahejie	n.r.	P/I, S/f	n.r.	ss	n.r.	11.7#	n.r.	1,670–2,240
24	Xiaowa	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
25	Taoyuan	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.

Table 11. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Liaohe subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Fm, formation; Prot, Proterozoic; **Porosity type:** P/I, primary intergranular porosity; S/f, fracture porosity; V, vuggy porosity; Arch/Prot, Archean and Proterozoic; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; m-crs, medium to coarse grained; ss, sandstone; congl, conglomerate; congl ss, conglomeratic sandstone; dolo, dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
26	Erlitouzi	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
27	Taiyangdao	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
28	Suizhong 36–1	Dongying	28–35	P/I	0.01–5,000	ss	n.r.	n.r.	n.r.	n.r.

Table 12. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jizhong subbasin, Bohaiwan basin (province 3127), China.

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Dong, Dongying; Guan, Guantao; Sha, Shahejie; Fm, formation; **Porosity type:** S/IC, secondary intercrystalline porosity; S/f, fracture porosity; V, vuggy porosity; P/I, primary intergranular porosity; P/IC, primary intercrystalline porosity; **Mean grain size and primary lithology:** f, fine grained; vf, very fine grained; dolo, dolomite; ls, limestone; calc. dolo, calcareous dolomite; dolo. ls, dolomitic limestone; ss, sandstone; congl, conglomerate. Other abbreviations: md, millidarcy; mm, millimeter; cm, centimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
1	Renqiu	Middle Proterozoic (Wumishan Fm); Cambrian (Fujunshan Fm); Ordovician (Majiagou Fm)							n.r.	
		Wumishan	6	S/IC; S/f; V	1,253	algal dolo	2,341	270#		3,250
		Fujunshan	4.3	S/IC; S/f; V	1,288	dolo	41–56	30#		3,227
		Majiagou	5	S/IC; S/f; V	296	ls and dolo		32.2#		3,440
2	Yongqing	Middle Proterozoic (Wumishan Fm); Ordovician (Fengfeng and Majiagou Fms)	0.09–5.7	P/I	0.85 ave.	dolo and ls	n.r.	24.9#	n.r.	2,000–2,080
3	Longhuzhuang	Ordovician (Majiagou Fm)	1.87–4.06	P/I; S/f; V	0.88–20	dolo and ls	n.r.		n.r.	1,966–2,275
4	Nanmeng	Cambrian (Fujunshan, Mentou and Changxia Fms); Ordovician (Majiagou Fm); Shahejie		P/I			n.r.	42–49.3#	n.r.	1,842–2,036
		Fujunshan			223	dolo				
		Mentou				oolitic ls				
		Changxia				dolo. ls, calc. dolo				
		Majiagou			1,087	dolo				
		Shahejie	17.1		110	f ss				
5	Guxingzhuang (Guxinzhuang)	Ordovician (Fengfeng and Majiagou Fms)	n.r.	S/f	n.r.	dolo and ls	n.r.	15.8#	n.r.	3,300–3,500
6	Suqiao	Ordovician (Majiagou Fm)	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
7	Mozhou	Middle Proterozoic (Wumishan Fm); Shahejie		P/I				128.9#	n.r.	4,060–4,410
		Wumishan	2.8–3.1		5.1–9.3	dolo				
		Shahejie	16			ss	2.3			
8	Yangling (Yanling)	Middle Proterozoic (Wumishan Fm)	1.16–1.55	P/I; P/IC; S/f; V	1.5–90	dolo	n.r.	86.0#	n.r.	2,840–3,090
9	Balizhuang	Middle Proterozoic (Wumishan Fm)	6	P/I; S/f; V	138	dolo	n.r.	81.0#	n.r.	2,580–2,750

Table 12. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jizhong subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Dong, Dongying; Guan, Guantao; Sha, Shahejie; Fm, formation; **Porosity type:** S/IC, secondary intercrystalline porosity; S/f, fracture porosity; V, vuggy porosity; P/I, primary intergranular porosity; P/IC, primary intercrystalline porosity; **Mean grain size and primary lithology:** f, fine grained; vf, very fine grained; dolo, dolomite; ls, limestone; calc. dolo, calcareous dolomite; dolo. ls, dolomitic limestone; ss, sandstone; congl, conglomerate. Other abbreviations: md, millidarcy; mm, millimeter; cm, centimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
10	Xuezhuang	Middle Proterozoic (Wumishan Fm); Dongying		P/I; S/f; V			n.r.	79#	n.r.	2,820–3,000
		Wumishan	6		129	dolo				
		Dong	23		59–250	ss				
11	Balizhuangxi	Middle Proterozoic (Wumishan Fm); Dongying; Guantao		P/I; S/f; V			n.r.	126.0#	n.r.	3,760–4,050
		Wumishan				dolo				
		Dong	21		190					
		Guan	8.4–24.5		8.9–4,900					
12	Hejian	Middle Proterozoic (Gaoyuzhuang Fm); Dongying		P/I; S/f; V			n.r.	150–180	n.r.	
		Gaoyuzhuang	8.4–24.5		8.9–4,900	dolo and quartzite		49#		2,290–2,450
		Dong	21		190	ss		13.4#		2,000–2,400
13	Liubei (Liulubei North)	Middle Proterozoic (Wumishan Fm); Shahejie; Dongying; Guantao;		P/I; S/f; V			n.r.		n.r.	
		Wumishan	2.3–4.8		156, core; 10–30, matrix	dolo		116#		3,220–3,450
		Sha	29							
		Dong								
		Guan			294–8,330, core	ss		5.1#		2,120
14	Hezhuangxi	Ordovician (Fengfeng Fm)	6	P/I; S/f; V	8.5	ls and dolo	n.r.	160; 20.2#	n.r.	3,540–3,770
15	Hezhuang	Ordovician (Fengfeng Fm)	6–9	P/I; S/f; V	50	dolo and ls	n.r.	429–14.0#	n.r.	3,200–3,300
16	Shenxi	Ordovician (Majiagou Fm)	5	P/I; S/f; V	65	dolo and ls	n.r.	44.9#	n.r.	3,750–4,100
17	Hexiwu	Shahejie (Sha II, III)		P/I		ss (lithic arenite)	n.r.	220–1,374; 6#	n.r.	2,600–3,200
		Sha II	18.6–20.3		30–90					
		Sha III lower	22.1		25					
		Sha III upper	24.6–28.9		160–190					
18	Liuquan	Shahejie	17–27.2	P/I	9–280	0.079; vf ss (lithic arkose)	0.6–10.8; 2–4 ave.	1,000; 9#	n.r.	1,000–3,200

Table 12. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jizhong subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Dong, Dongying; Guan, Guantao; Sha, Shahejie; Fm, formation; **Porosity type:** S/IC, secondary intercrystalline porosity; S/f, fracture porosity; V, vuggy porosity; P/I, primary intergranular porosity; P/IC, primary intercrystalline porosity; **Mean grain size and primary lithology:** f, fine grained; vf, very fine grained; dolo, dolomite; ls, limestone; calc. dolo, calcareous dolomite; dolo. ls, dolomitic limestone; ss, sandstone; congl, conglomerate. Other abbreviations: md, millidarcy; mm, millimeter; cm, centimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
19	Zhongchakou	Shahejie	14.0	P/I	n.r.	ss	n.r.	7.2#	n.r.	1,320–1,720
20	Bieguzhuang	Shahejie	28	P/I	165, core; 42, matrix	<0.1; vf ss	15–35, flank; 40–70, top	103; 36#	n.r.	1,200–1,600
21	Chaheji	Shahejie	n.r.	P/I	n.r.	ss	0.6–9.8; 2.6 ave.	200–400; 6.9–16.2#	n.r.	2,700
22	Liulizhuang	Kongdian	10	P/I	417	0.5–10 cm; 2–3 cm ave.; pebble congl/congl	n.r.	8.0#	n.r.	2,660–2,860
23	Nanmazhuang	Shahejie	21.6	P/I	113	0.105; vf ss (arkose)	2–3	6.3#	n.r.	1,830–2,220
24	Suning	Dongying	17–20	P/I	14–170	0.095; vf ss	4–6	600; 6.9#	n.r.	2,800–3,400
25	Dawang-zhuang	Shahejie; Dongying		P/I		ss		16.7#	n.r.	3,200
		Sha	11.1–21.6		30–67; 49 ave.		0.5–2.95			
		Dong	8.7–23.2		1.4–370		0.8–2.25			
26	Liuxi	Shahejie	16–18	P/I	60–70	0.13; vf ss (arkose)	4	25.0#	n.r.	3,080
27	Shennan	Shahejie; Dongying Dong	14.7–26.1	P/I	42–710	ss	8.3	44.6# 271	25–41	2,400–3,000
28	Jinqiu	Shahejie	13.9–18.2	P/I	1.6–110	0.088–0.100; vf ss	4.12	200; 30#	30–57	3,150
29	Wenan	Dongying; Shahejie; Permian	20	P/I; S/f	499	ss	n.r.	5.7#	n.r.	1,940–2,700
30	Nanxiaochen	Shahejie	n.r.	n.r.	n.r.	ss	n.r.	n.r.	n.r.	n.r.
31	Gaojiabu (Gaojiapu)	Shahejie	15	n.r.	49	ss	n.r.	6.0#	40	1,650–1,700
32	Fengheying	Shahejie	14–20	P/I	21–49	ss	n.r.	8.5#	35–40	1,400–2,780
33	Xiliu	Shahejie	10–18	P/I	3,130–3,366	ss	n.r.	10–14.9#	40	3,180–3,340
34	Taijiazhuang	Shahejie	n.r.	n.r.	n.r.	ss	n.r.	9.5#	50	2,960–3,050
35	Wuqiang	Shahejie	n.r.	n.r.	n.r.	ss	n.r.	15.0#	n.r.	2,800–3,390
36	Yukou	Shahejie	n.r.	n.r.	n.r.	ss	n.r.	15#	n.r.	2,250–2,900
37	Gaoyang	Shahejie	15–20	P/I	23–143	ss	n.r.	8.9#	49	2,510–2,760

Table 12. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Jizhong subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Dong, Dongying; Guan, Guantao; Sha, Shahejie; Fm, formation; **Porosity type:** S/IC, secondary intercrystalline porosity; S/f, fracture porosity; V, vuggy porosity; P/I, primary intergranular porosity; P/IC, primary intercrystalline porosity; **Mean grain size and primary lithology:** f, fine grained; vf, very fine grained; dolo, dolomite; ls, limestone; calc. dolo, calcareous dolomite; dolo. ls, dolomitic limestone; ss, sandstone; congl, conglomerate. Other abbreviations: md, millidarcy; mm, millimeter; cm, centimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
38	Liuzu	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.

Table 13. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Huanghua subbasin, Bohaiwan basin (province 3127), China.

[Data are from oil industry compilations (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Guan, Guantao; Ming, Minghuazhen; Kong, Kongdian; **Porosity type:** P/I, primary intergranular porosity; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; vf-f, very fine to fine grained; ss, sandstone; slt, siltstone; biols, bioclastic limestone; ls, limestone. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
1	Gangdong	Guantao; Minghuazhen	32	P/I	4.4–17.6	0.17; f ss	15	1,000; 15#	35	2,600
2	Gangxi	Guantao; Minghuazhen	31	P/I	834	0.11; vf ss	n.r.	1,000; 14.5#	40	602–1,673
3	Gangzhong	Shahejie; Dongying	21	P/I	2–1,194; 67 ave.	0.081; vf ss	n.r.	200–400; 8.8#	40	1,900–3,050
4	Tangjiahe	Shahejie; Guantao; Dongying; Minghuazhen	27	P/I	306	0.05–0.32; slt, m ss	n.r.	19.5#	n.r.	1,690–3,260
5	Madong	Shahejie	9.0–19.7	P/I	49–523	0.117–0.158; vf-f ss	13–16	220–240; 33.4#	n.r.	3,788–4,015
6	Maxi	Shahejie	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
7	Liujianfang	Shahejie	n.r.	n.r.	n.r.	ss	n.r.	n.r.	n.r.	n.r.
8	Banqiao	Shahejie (Sha I)	21	P/I	99	ss	n.r.	1,656; 8.3#	n.r.	2,436–4,092
		Sha I				ss				
9	Zhouqing-zhuang	Shahejie (Sha I, III)	13.5	P/I	6	0.1–0.7; vf-crs ss	5–8	7.6#	n.r.	2,500–3,100
		Sha I				oolitic ss		60–160		
		Sha III				ss		150–450		
10	Wangxu-zhuang	Shahejie (Sha I, III)		P/I			4–6	8.4#	n.r.	2,030–2,540
		Sha I	25		204	biols				
		Sha III	26		994	ss				
11	Yangerzhuang	Shahejie (Sha I, III); Guantao; Minghuazhen		P/I		ss	n.r.	25.2#	n.r.	1,110–2,030
		Guan	4.8–10.4		841–2,714					
		Ming	10.3–17.6		1,246–4,836					
12	Yansangmu	Guantao; Minghuazhen	31	P/I	1,475	0.159; f ss	5–8	19.4#	n.r.	1,180–1,460
13	Kongdian	Guantao	33	P/I	1,878	ss	n.r.	250; 11.8#	n.r.	1,200–1,440
14	Zaoyuan	Kongdian;	21.9–26.7	P/I	165–1,543	0.092–0.211; vf-f ss	20–61.5	400; 19.4#	n.r.	1,640–2,280
		Paleozoic				ls				
15	Wangguantun	Shahejie; Kongdian	19–29	P/I	27–626				n.r.	1,800
		Sha				slt	3–9	13.9#		
		Kong				biols	14			
16	Xiaoji	Kongdian	15–17	P/I	128–197	f ss	n.r.	200; 41.2–67.2#	n.r.	2,700–3,100
17	Qijiawu	Shahejie	19	P/I	n.r.	ss	n.r.	3.5#	40	1,920–2,600

Table 13. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Huanghua subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from oil industry compilations (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Guan, Guantao; Ming, Minghuazhen; Kong, Kongdian; **Porosity type:** P/I, primary intergranular porosity; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; vf-f, very fine to fine grained; ss, sandstone; slt, siltstone; biols, bioclastic limestone; ls, limestone. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
18	Duanlubo (Duanliubo) (Duabkiubo)	Kongdian; Shahejie	15.1	P/I	29	ss	n.r.	40.1#	30	2,880–3,570
19	Shenusi	Kongdian; Shahejie	25	P/I	304	ss	n.r.	18.0#	37	1,360–3,050
20	Liuguanzhuang	Minghuazhen	32	P/I	352	ss	n.r.	1.8#	45	1,300–1,500
21	Koucun	Guantao; Shahejie; Kongdian; Mesozoic; Permian	26.9	P/I	230	ss	n.r.	14.0#	33	1,360–1,790
22	Tanggu	Shahejie	22	P/I	10	ss	n.r.	8.6#	40	2,120–2,600
23	Wumaying	Kongdian	18.6	P/I	293	ss	n.r.	7.46#	36	2,460–3,510
24	Changlu	Shahejie	20	P/I	30–100	ss	n.r.	15.9#	40	3,750–3,850
25	Gaochentou	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
26	Changjuhe	Shahejie	20	P/I	44	ss	n.r.	11.7#	40	2,610–3,700
27	Yuesanba	Shahejie	16.4	n.r.	50	ss	n.r.	10.8#	40	2,160–3,470
28	Dachangtou	Shahejie	20	P/I	80	ss	n.r.	5.5#	32	2,550–2,750
29	Lianmeng	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
30	Zhaodong (includes Zhao Dong C-1 and Zhao Dong D-1)?	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
31	Gaoshangbu (Gaoshangbao)	Shahejie; Guantao;		P/I		ss	n.r.	50#	n.r.	3,000
		Sha	13.5–19.1		5–354					
		Guan	28.9–30.9		949–1,446					
32	Liuzhan	Shahejie; Guantao; Minghuazhen	21.5	P/I	n.r.	ss	n.r.	10#	40	1,500–3,640
33	Beipu	Dongying; Guantao	22	P/I	n.r.	ss	n.r.	10.8#	40	1,920–4,000
34	Laoyemaio	Dongying; Minghuazhen	24.5	P/I	n.r.	ss	n.r.	8.0#	38	1,860–3,080

Table 13. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Huanghua subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from oil industry compilations (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; Guan, Guantao; Ming, Minghuazhen; Kong, Kongdian; **Porosity type:** P/I, primary intergranular porosity; **Mean grain size and primary lithology:** crs, coarse grained; m, medium grained; f, fine grained; vf, very fine grained; vf-f, very fine to fine grained; ss, sandstone; slt, siltstone; biols, bioclastic limestone; ls, limestone. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
35	Tanghai/ Duling (Tanghe)	Shahejie; Mesozoic (Jurassic); Cambrian	5	P/I	n.r.	ss	n.r.	6.7#	35	1,710–1,800
36	Canshakou	Shahejie	21.5	P/I	n.r.	ss	n.r.	93.3#	40	1,500–3,600
37	Baigezhuang	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.

Table 14. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Linqing/Dongpu subbasin, Bohaiwan basin (province 3127), China.

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; **Porosity type:** P/I, primary intergranular porosity; **Mean grain size and primary lithology:** f, fine grained; vf, very fine grained; slt, siltstone; ss, sandstone. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average; max, maximum]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
1	Pucheng	Shahejie (Sha I, II, III, IV)		P/I		f ss (arkose)	n.r.	30#	n.r.	2,200–3,800
		Sha I	27.7		548	ss				
		Sha II upper	23.4		165	ss				
		Sha II lower	10.6–23.5		37.1–241.6	ss				
		Sha II				ss				
		Sha III				ss				
		Sha III and IV				ss				
2	Wenmingzhai	Shahejie (Sha I, II, III)	24–28	P/I	300–700	f ss	n.r.	26.2#	n.r.	1,360–2,320
3	Weicheng	Shahejie	14–20	P/I	2–100	ss	n.r.	1,000; 18.5#	n.r.	1,700–2,900
4	Guyunji	Shahejie	16–19	P/I	n.r.	f ss	n.r.	n.r.	n.r.	n.r.
5	Wendong	Shahejie (Sha II, III, IV)		P/I		slt, ss	1–3	n.r.	n.r.	3,100–3,350
		Sha II	21.4		210					
		Sha III	11.7–21.5		2.8–131					
6	Wennan	Shahejie (Sha II, III)	15–20	P/I	20–110	slt	1–2	850; 19.7#	n.r.	2,500–3,750
7	Wenliu	Shahejie (Sha II, III)		P/I		ss	n.r.	17.2–22.8#	n.r.	1,900–2,600
		Sha II	21.2–24.7		53.7–245					
		Sha III	23.2–23.7		163–236					
8	Wen-23	Shahejie		P/I		0.032–0.092, slt, vf ss	n.r.	400	n.r.	2,670–3,110
		Sha lower	11.4–12.4		3.6–3.7			69.5#		
		Sha middle	11.6–13.9		12.3–17.1			44.4#		
		Sha upper	8.8–10.3		0.2–1.77			12.4#		
9	Qiaokou	Shahejie (Sha II, III)		P/I		slt	n.r.	n.r.	n.r.	2,450–2,950
		Sha II	19.5		140					
		Sha III	15–27		11					
10	Baimiao	Shahejie	7.6	P/I	1.36–1.88	n.r.	n.r.	n.r.	n.r.	n.r.
11	Machang	Shahejie	19.5	P/I	101	ss	2–4	50	n.r.	2,500–3,000
12	Sanchunji	Shahejie	11.1–21.6	P/I	0.6–333	slt	2–4	n.r.	n.r.	3,030–3,200
13	Mazhai	Shahejie	15–27; 22.1 ave.	P/I	4–200	ss (lithic arkose)	n.r.	62.6#	n.r.	1,860–1,950
14	Huzhuangji	Shahejie	20–23	P/I	202–248	0.04–0.3; slt, ss	2–4	n.r.	n.r.	1,700–2,500
15	Qingzuji	Shahejie	16–20; 18 ave.	P/I	30; 726 max.	slt	2–3	n.r.	n.r.	1,900–2,040
16	Liuzhuang	Shahejie	5	P/I	120	ss	n.r.	3.2#	40	2,890–3,050

Table 14. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Linqing/Dongpu subbasin, Bohaiwan basin (province 3127), China.—Continued

[Data are from an oil industry compilation (unpub. data, 1996). Abbreviations: **Reservoir:** Sha, Shahejie; **Porosity type:** P/I, primary intergranular porosity; **Mean grain size and primary lithology:** f, fine grained; vf, very fine grained; slt, siltstone; ss, sandstone. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded; ave., average; max, maximum]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
17	Hupuzhai/ Xueji	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
18	Xuji	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
19	Wenbei	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.

Table 15. Selected properties of major reservoirs in the Shahejie–Shahejie/Guantao/Wumishan Total Petroleum System in the Bozhong subbasin, Bohaiwan basin (province 3127), China.

[Data are from Editorial Committee of Petroleum Geology of Oil- and Gas-Bearing Areas on the Continental Shelf and its Neighboring Regions (1987), Lee (1989), and Hurst and others (2001). Abbreviations: **Reservoir:** Sha, Shahejie; Dong, Dongying; Guan, Guantao; L., lower; U., upper; ss, sandstone; **Mean grain size and primary lithology:** ss, sandstone; dolo, dolomite. Other abbreviations: md, millidarcy; mm, millimeter; m, meter; Sw, water saturation; n.r., not recorded]

Field No.	Field name	Reservoir	Porosity (percent)	Porosity type	Permeability (md)	Mean grain size (mm) and primary lithology	Average individual pay thickness (m)	Gross reservoir interval thickness (m); # Total net pay thickness (m)	Average Sw (percent)	Average burial depth (m)
1	Qinhuangdao 30-1	Mesozoic (Jurassic)	22.8	n.r.	16.7	andesite	n.r.	30#	n.r.	3,000
2	Shijiutuo	Dongying; Guantao; Mesozoic	n.r.	n.r.	n.r.	ss basalt	n.r.	30#	n.r.	n.r.
3	Bozhong 25-1-1	Shahejie (Sha III); Mesozoic	8–12	n.r.	6.51–61.19	ss	n.r.	4	n.r.	3,355
4	Bozhong 28-1	Shahejie (Sha I); Ordovician; Cambrian		n.r.			n.r.	323	n.r.	2,975
		Sha I	5.2–8.5		2–14.2	ss		n.r.		2,990
		L. Ordovician-U. Cambrian	2.24		1.8	dolo		n.r.		3,200
5	Bozhong 28-2-1	Dongying (Dong lower)	6–16	n.r.	0.29–3.45	ss	n.r.	20.5	n.r.	3,067
6	Bozhong 34-1-1	Dongying; Guantao; Minghuazhen	13.9–23.5 25.9	n.r.	several >987 520.3	ss ss ss	n.r.	2.5–8 4#	n.r.	2,244
7	Bozhong 34-2	Shahejie (Sha II, III); Dongying; Guantao		n.r.			n.r.		n.r.	3,344
		Sha II, III	8–17		0.29–977.13	ss		1,162; 83#		
		Dong lower	23.5		987	ss		8#		
		Dong	16.8		160	ss		26		
		Guan	25.9		520.3	ss				
8	Bozhong 34-3	Dongying; Guantao		n.r.			n.r.		n.r.	
		Dong lower	23.5		987	ss		8#		3,000
		Guan	25.9		520.3	ss		200		3,300
9	Bozhong 34-4	Shahejie (Sha II, III)	12.34	n.r.	3.33	ss	n.r.	n.r.	n.r.	3,400
10	Peng Lai 14-3-1	Miocene ss	n.r.	n.r.	n.r.	ss	n.r.	n.r.	n.r.	2,372
11	Peng Lai 19-3-1	Guantao; Minghuazhen	n.r.	n.r.	100–1,000	ss	n.r.	160# in Guantao	n.r.	1,200

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