
Abstract

Crude oil and natural gas deposits are considered to be stratabound ore deposits, because of similar mechanisms of formation. The necessary geological conditions for the formation of oil and gas deposits are petroleum source rock, reservoir rock, caprock, and trap, all of which require a favorable time and space association. Details about these geological conditions, tectonic factors, and locations of oil fields are delineated for the inland petroliferous basins of west China, such as the Tarim, Junggar, Turpan, Qaidam, and West Jiuquan basins, and the coastal shelf petroliferous basins in the East and South China Seas, such as the Liaohe, Beibu Gulf, and Zhujiang Mouth Basins.

Keywords

Stratigraphy and lithofacies • Tectonic units • Potential petroleum source rock series • Oil–gas fields

2.1 Introduction

The geological background to understand why the inland and coastal shelf basins of China are so rich in hydrocarbons is quite complex. It requires analysis of three essential parts. The first is a clear description of the source rocks, reservoirs, and caprocks. The second is an explanation of the generation, migration, and accumulation of oil and gas. Finally, the geological processes that created and still act in the inland and coastal shelf basins must be explained.

2.2 Geological Conditions for Oil–Gas Field Formation

2.2.1 Complex of Source Rock, Reservoir Rock, and Seal Rock

The formation of oil and gas fields in general has essential conditions including oil source rocks (generating rocks), reservoir rocks, seal rocks, and traps, while at the same time having favorable configurations for these numerous factors in

time and space. Among sedimentary rocks, carbonates and dark argillaceous rocks form the most productive hydrocarbon source rocks. Carbonate rocks that have developed holes and sandstones having well-developed pore structures are ideal reservoir rocks. Mudstone, shale, and halite layers as well as carbonate rock layers can form caprocks. In addition, igneous and metamorphic rocks with developed fissure structures can also be regarded as oil and gas reservoir rocks. Crustal movements and climate change participate in the process with regression and transgression of sea levels; such kinds of tectonic movements and regression–transgression may result in different types of hydrocarbon associations, as well as traps for source rocks, reservoir rocks, and caprocks.

In general, reservoir rocks are typically underlain by source rocks and overlain by caprocks. When source rocks and reservoir rocks are formed in the same period without depositional breaks, then in situ generation and in situ deposit formation are created. When source rocks and reservoir rocks are formed in different periods separated by depositional breaks, then the new complexes of source rock, reservoir rock, and seal rock are formed. Complexes including igneous or metamorphic reservoir rocks associated with sedimentary Mesozoic and Cenozoic petroleum source rocks have been found.

2.2.2 Generation, Migration, and Accumulation of Petroleum

Oil and gas are both fluids. They change their motion from a dispersed state in the source rocks to aggregation in reservoir rock traps, during which a migration process is also necessary. Oil and gas generation, migration, and accumulation represent a continuous evolution process. When buried organic materials are introduced into the threshold of oil generation and begin forming petroleum in the source rocks, the oil–gas generated from this source bed may begin to migrate through the carrier bed or the reservoir bed.

Hydrocarbon generation is an important cause of the abnormal high pressure and formation of microfissures. Microfissures are important channels for primary migration of oil and gas. Thus, hydrocarbon generation and hydrocarbon expulsion participate in a continuous process. The power that drives oil and gas migration includes abnormal stratigraphic pressure, tectonic stress, compaction water power, gravity, buoyancy, molecular diffusion forces, and molecular penetration (Li 2004).

Tectonic forces produce two essential structural features important in producing large oil and gas fields. One is the formation of depressions into which sediment can accumulate and the second is uplift. Therefore, depressions of hereditary nature are favorable for oil and gas generation, and uplift is the target of oil and gas migration. However, oil and gas loss in the course of oil and gas migration is absolute, while the accumulation of oil and gas that occurs in the process of migration is relative and conditional.

Trap and caprocks are basic conditions for oil and gas accumulation and preservation. The trap represents the boundary space that prevents oil and gas from escaping, resulting in the accumulation of oil and gas in reservoir beds. Trap formation mainly depends on structural factors; anticline trap and fault trap are common structural trap types. In addition, stratigraphic overlap, stratigraphic unconformity between strata, as well as lithologic pinch out and lenticular beds are also important factors for trap formation. The caprock bed is a relatively impermeable bed that can prevent upward or up direction motion of hydrocarbon migration and leakage. Whether the oil–gas gathered in such traps can be preserved largely depends on the sealing capacity of the trap and the sealing ability of the caprocks.

Common caprocks include dense shale, shale in general, salt deposits, and carbonate rocks; both the lithology and thickness of the caprock determine caprock capability. The ideal caprocks are anhydrite, gypsum, rock salt, and compacted mudstone. Such caprocks do not require great thickness in order to prevent leakage of oil and gas.

2.2.3 Petroleum Deposit and Its Classification

A petroleum deposit (petroleum pool) is the volume of oil and gas accumulated in a trap that encloses a single reservoir bed. The petroleum deposit is the smallest unit of oil–gas accumulation in a petroliferous basin. Oil and gas fields occur where a trap encloses two or several reservoir beds. According to the causes of trap formation, petroleum deposits can be divided into the following types: structural trap petroleum deposits, including anticline trap and fault trap; stratigraphic–lithologic trap petroleum deposits, including stratigraphic trap and lithologic trap; and complex trap petroleum deposits, including lithology–anticline trap and strata–structural trap. According to the phases of the hydrocarbon, petroleum deposits can be divided into four categories, including gas deposit, boundary state deposit, oil deposit, and asphaltic oil deposit (Li 2004).

2.3 Inland Petroliferous Basins

There are many inland oil- and gas-bearing basins in China. In this chapter, we highlight and discuss the most important basins in great detail because of their significance to the thesis that palynology plays a major role both in understanding the hydrocarbon potential of such basins and in providing information about other exploration targets. They include the Tarim, Junggar, Turpan-Hami, Qaidam, and West Jiuquan basins.

2.3.1 The Tarim Basin

The Tarim Basin is located in between the Tianshan, Kunlun, and Aljin mountains, with a cover area of 560,000 km². The basin depth is as much as 13,000–15,000 m. It is a large-sized cratonic, superimposed, composite basin.

The geological development history of the basin is divided into three stages, namely the Proterozoic geosynclinal stage, the Paleozoic platform developmental stage, and the Cenozoic

platform fault block developmental stage. The Jinning Orogeny is equivalent in time to the Tarim Orogeny participated in the Proterozoic geosynclinal folding, thus resulting in the creation of the ancient Tarim platform and its crystalline basement. During the Paleozoic, the basin sank and was subject to five transgressions and a huge thickness of marine carbonate sediments. These sediments constitute the bottom cover of the platform. Late Hercynian movements included folding which also affected the peripheral Tianshan Mountains and Kunlun geosyncline. Within the platform, the sediments were subject to relatively uneven subsidence, and in the mountain front depression and sag regions, continental clastic sediments were deposited during the Mesozoic. The Himalayan Orogeny created sharply rising peripheral mountains, and finally, today's Tarim Basin was formed. A great thickness of Cenozoic continental sediments was next deposited. The Mesozoic and Cenozoic deposits form the upper caprock of the platform. The Tarim Basin is thus a Mesozoic and Cenozoic fault depression basin formed above Pre-Sinian crystalline basement and the Paleozoic stable platform. Therefore, it represents a typical cratonic, superimposed, composite basin.

2.3.1.1 Stratigraphy and Lithofacies (Table 2.1)

The Sinian System: In the northwest margin of the Tarim Basin, there is a set of continuous transgressive deposits in the Keping area. These are about 1940 m in total thickness and composed of conglomeratic sandstones, sandstones, and sandy shales that gradually transition to carbonates. The lower part of the Sinian System in the Keping area is represented by the Yourmeilake Formation, which is composed of conglomerates, conglomeratic mudstones, with intercalations of mudstones. The middle part is the Sugeitblake Formation which is mainly composed of shallow marine and coastal clastic rocks of terrestrial origin; it also contains a basalt in the lower stratigraphic member, as well as muddy limestone, dolomitic limestone, and dolomite in the upper stratigraphic member. The upper part of the Sinian System in the Keping

Table 2.1 Potential petroleum source rock series of the Tarim Basin

Geological age	Stratigraphic formation	Code	Lithology	Facies
Late Cretaceous	Yingjisha Group	K _{2y}	Gray limestone, dolomite, and sandy mudstone	Shallow sea facies
Middle Jurassic	Qiakemake (Taergan) Formation	J _{2q}	Gray sandstone, siltstone, and mudstone	Lacustrine
	Kezilenuer (Yangye) Formation	J _{2k}	Gray sandstone, mudstone, carbonaceous shale, coal beds	Lacustrine to swamp facies
Early Jurassic	Yangxia (Kansu) Formation	J _{1y}	Gray mudstone, sandstone, and carbonaceous shale with coal beds	Lacustrine to swamp facies
	Ahe formation	J _{1a}	Gray sandstone, conglomerates with intercalations of mudstone	Fluvial–lacustrine facies
Late Triassic	Taqilike Formation	T _{3t}	Gray mudstone, sandstone and carbonaceous shale, coal beds	Lacustrine to swamp facies
	Huangshanjie Formation	T _{3h}	Gray mudstone, sandstone and carbonaceous shale, coal beds	Lacustrine to swamp facies
Middle Triassic	Karamay Formation	T _{2k}	Gray mudstone, sandstone, carbonaceous shale	Lacustrine to swamp facies
Early Triassic	Ehuobulake Formation	T _{1e}	Conglomeratic sandstones alternated with mudstone	Fluvial–lacustrine facies
Carboniferous-Permian	Muziduke Group	C-P	Biologic reef limestone, black shale	Shallow sea facies
Late Carboniferous	Bijingtawu Formation	C _{2b}	Limestone, sandstone, black shale	Shallow sea facies
Middle Ordovician	Yinggan Formation	O _{2y}	Black shale, mudstone, containing graptolites	Littoral facies
	Saergan Formation	O _{2s}	Black shale, rich in graptolites	Littoral facies
Early Ordovician	Qilutige Group	O _{1q}	Limestone, dolomite, geode seepage	Shallow sea facies
Early Cambrian	Wusongge'er Formation	Є _{1w}	Limestone, dolomite	Marine facies
	Xiaerbulake Formation	Є _{1s}	Limestone, dolomite; contains trilobites	Marine facies

area of the Tarim Basin is represented by the Qigebulake Formation, which is mainly composed of gray algal dolomite carbonate deposits, with well-developed algal laminations and a few columnar laminated beds.

In the Kuluketage region, which is at the margin at the northeast of the Tarim Basin, there is a set of massive, thick deposits of coastal to shallow marine clastic, volcanic, and pyroclastic

rocks, as well as tillite and sandy limestone deposits. These deposits are as much as 5750 m in total thickness. In the Kuluketage region, the Qigebulake Formation is unconformably underlain by Pre-Sinian System.

The Cambrian System: The Cambrian System in the Keping region of the Tarim Basin is represented by a series of shallow marine platform carbonate deposits, about 600 m in

thickness. The lower part of the Lower Cambrian is dominated by dark gray, phosphatic lenticular siliceous rocks and phosphates with intercalations of dolomitic limestones. The middle part is characterized by black carbonaceous shales, gray green, and purple shales with intercalations of dolomites. And the upper part is a gray white, thin-layered dolomitic, and knotty dolomitic shales, about 8–35 m in thickness. The middle part of the Lower Cambrian is represented by the Xiaerbulake Formation which consists mainly of limestone and dolomite, yielding fossil trilobites and brachiopods, about 150 m in thickness. The upper part is defined as the Wusongger Formation, which is composed of dolomitic limestone, nodular limestone, as well as limy dolomite with cherts, about 150 m in thickness. Of Middle Cambrian age, the lower part of the Shayilike Formation is dominated by biolimestone, leopard skin limestone, bamboo-like limestone, and conglomeratic limestone; the upper part of this formation is characterized by thin chert strip limestone with muddy dolomite, about 90 m in thickness. The Awatage Group of the Middle to Upper Cambrian is dominated by a series of gray and brick red gypsum, muddy dolomite with chert strips, and algal dolomite deposits representing a shallow marine lagoon facies, about 200 m in thickness.

In the Kuluketage region, the lower part of the Lower Cambrian is characterized by the Xishanbulake Formation, which at its base is composed of black siliceous and phosphatic rocks; the middle section is volcanic rocks; and the upper part is black siliceous rocks, and the entire formation is 37–130 m in thickness. The upper part of the Lower Cambrian is represented by the Xidashan Formation which is composed of gray black mudstone, sandy limestone with intercalations of cherty limestone, nodular limestone, and purple shale; it contains fossil trilobites and brachiopods and is 13–88 m in thickness. The Middle Cambrian is defined as the Mohe'er Group, which consists of dark gray and gray black sandy and muddy limestones with intercalations of cherty limestone, leopard skin limestone, and marls and shales; the formation is 120–300 m in thickness. The Upper Cambrian in

the Kuluketage region is represented by the Tuershaketage Group, which mainly consists of dark gray, thick limestones with intercalations of thin limestones and has a thickness of over 250 m.

The Ordovician System: The Ordovician of the Tarim Basin is mainly dominated by shallow marine carbonate deposits; in the Keping area, it is about 1400 m in thickness, and in the Kuluketage area, the thickness varies from 2600 to 2800 m. In the Keping area, the Lower Ordovician Qiuliketage Group is a gray to dark gray dolomite and limestone with cherty masses or thin beds; it contains fossil trilobites and brachiopods and has a thickness of 178–1300 m. The Middle Ordovician Saergan Formation consists of black, gray black, and gray green shales with intercalations of thin layers or nodular muddy limestones; it contains fossil graptolites, trilobites, and conodonts and has a thickness of 16 m in the Dalanggou Section. The Kanling Formation of the lower part of the Middle Ordovician is composed of purple calcilutite limestone, with intercalations of gray green silty sandstone; it contains fossil conodonts, cephalopods, and trilobites and has a thickness of 17–36 m. The Qilang Formation of the middle part of the Middle Ordovician consists of gray, thin-layered calcilutite limestone interbedded with gray green siltstone, mudstone, and muddy limestones; it contains fossil graptolites, trilobites, and cephalopods and ranges in thickness from 158 to 177 m. The upper part of the Middle Ordovician is represented by the Ying'an Formation which consists of black and dark gray carbonaceous shale and mudstones with intercalations of calcilutite limestone; it contains fossil graptolites, trilobites, and brachiopods and has a thickness of 35 m. The Late Ordovician is missing because the platform was uplifted during the latest Middle Ordovician.

The Silurian System: In the Keping area of the Tarim Basin, the Silurian System is characterized by clastic rocks deposited in a littoral facies; a disconformity separates it from the underlying Ordovician. The Lower Silurian Kepingtage Formation is composed of gray green sandstone, siltstone, and mudstone; it contains

fossil graptolites, trilobites, and plants and has a thickness of 390–445 m. The Middle and Upper Silurian Tataertage Formation consists of purple and gray green sandstones, siltstones, and silty shales; it varies from 160 to 270 m in thickness. In the Kuluketage area, only the Lower Silurian Series is exposed, and is represented by the Tushibulake Formation, which consists of gray green sandstones, siltstones, dark gray to black shales, marls, and limestones, with a thickness of 720–2271 m. It lies disconformably above rocks of the Ordovician System.

The Devonian System: In the Keping area of the Tarim Basin, the Devonian is of littoral to continental facies origin; the rocks are red clastics which grade conformably into underlying Silurian rocks. The Lower Devonian Yimugantawu Formation consists of purple sandstones and siltstones, including gray white greywacke; the formation varies from 450 to 500 m in thickness. The Middle to Upper Devonian Keziertage Formation consists of brick red sandstones, fine sandstones, and siltstones, with a thickness of 920–1200 m. In the Kuluketage area, the Lower Devonian Shugouzi Formation is composed of gray green and interbedded red sandstones; the sandstones of the upper part are red. The unit disconformably overlies the Silurian and varies from 300 to 400 m in thickness. The Middle to Upper Devonian Series is represented by the Aertemeishibulake Formation which consists of purple, coarse sandstones, and gray white sandstones in the lower part; and red conglomerates and coarse sandstones in the upper part, and the formation has a thickness of 1200–1300 m.

The Carboniferous System: During the Carboniferous period, a shallow sea and lagoon facies developed in the Tarim Basin. Carboniferous strata are widely exposed and disconformably cover Devonian rocks. In the Tiekelike area at the southwestern margin of the basin, the basal part of the Lower Carboniferous, the Kelitage Formation, consists mainly of dark gray limestone with intercalations of gray dolomite and a few gray green sandstone and siltstone beds, with a thickness of 190–380 m. The upper part of the Lower Carboniferous Heshilapu

Formation consists of the conglomerate, sandstone, siltstone, biolimestone, and carbonaceous shale with coal seams, about 818–1900 m in thickness. The lower part of the Upper Carboniferous, the Kalawuyi Formation, consists mainly of gray green and gray black mudstone, and light gray sandstone alternating with dark gray limestone; the formation has locally developed coal seams and contains fusulinids, brachiopods, and plant fossils, about 140–190 m in thickness. The middle part is represented by the Azigan Formation, consisting of gray limestone with intercalations of a minor sandstone and gray green mudstone; it contains fossil fusulinids, brachiopods, and corals and is 170–445 m in thickness. The upper part is defined by the Tahaqi Formation, which is composed of gray limestone with intercalations of minor purple silty mudstone and dark gray mudstone; it contains fusulinid and brachiopod fossils and is about 130–175 m in thickness.

In the northwestern margin of the Tarim Basin, in the Keping area, the Lower Carboniferous Series Kongtaikenggou Formation consists of gray conglomerate, sandstone, and siltstone with intercalations of gray limestone, marl, and purple mudstone and siltstone; total thickness is 346 m. The lower part of the Upper Carboniferous Bijingtawu Formation consists mainly of dark gray limestones alternating with sandstones and siltstones; the middle part of the series is represented by biolimestone, and sandstone alternating with black shales and coal seams. The upper part is sandstone having intercalations of black shales and limestone; fossils include brachiopods and corals, and the total thickness of the Bijingtawu Formation is 1660 m at the southern end of the Wushi area. The upper part of the Upper Carboniferous Kangkelin Formation consists of black shales, grayish brown sandstones, and gray siltstones intercalated with dark gray limestones; the upper part contains limestones yielding fossil fusulinids, brachiopods, and corals. The total thickness of the Kangkelin Formation varies from 86 to 663 m (Ma and Wen 1991).

In the western margin of the Tarim Basin where the Yanguan Series is absent, the Lower

Carboniferous is mainly dominated by carbonate deposits. At the southern margin, the Lower Carboniferous Datang Series and the Upper Carboniferous deposits consist mainly of clastic rocks deposited in a shallow sea along with carbonates; volcanoclastic rocks are also present. At the eastern margin of the basin, in addition to the shallow sea clastics and carbonates, there are a large number of volcanic intrusive and eruptive rocks in the Carboniferous. The entire Carboniferous has a maximum thickness of more than 5000 m (Zhou and Chen 1990).

The Permian System: The Permian System is mainly distributed in the northwest and southwest margin of the Tarim Basin, conformably covering the Carboniferous System. In the Keping area at the northwestern basin margin, the Lower Permian is bounded by the Yinggan Shan Mountain Range. The western part is of marine origin, whereas the eastern side is a terrestrial deposit. In western part of the Yinggan Mountain Range, the basal part of the Lower Permian Balikeli Formation is a marine deposit, consisting of dark gray and black limestone, and shelly limestone with intercalations of carbonaceous shale; the formation contains brachiopods, bivalves, and fusulinid fossils and is 340 m in thickness. The upper part of the Lower Permian, the Kalundaer Formation, is of terrestrial facies origin and is composed of variegated sandstone and mudstone as well as carbonaceous mudstone and siltstones, yielding fossil spores and pollen grains, and is 22–340 m thick. In the eastern Yinggan Mountain Ranges, the basal Lower Permian is the Kupukuziman Formation which consists of a series of variegated sandstone, siltstone, and mudstone with intercalations of volcanic tuff. The upper part of this formation is composed of basalt with intercalations of grayish green and grayish purple silty mudstone, tuffaceous sandstone, volcanic breccia, with a thin coal seam at the top of the formation yielding plant fossils; the entire formation is 451–470 m thick. The upper part of the Lower Permian Series is represented by the Kaipazileike Formation. In this formation, the lower part is characterized by variegated sandstone and dark mudstone with coal seams, and the upper part

consists of basalt with variegated sandstone, siltstone, mudstone, and coal seams. The formation contains plant and sporo-pollen fossils, and the entire formation is 580–660 m thick. For the Upper Permian Series, the Shajingzi Formation is of terrestrial origin, and consists of variegated sandstone, siltstone, carbonaceous mudstone with thin coal seams, about 700 m in thickness.

In the southwestern margin of the Tarim Basin, which is the western part of the Pishan River region, the Lower Permian Qipan Formation is a marine deposit, and consists of gray and grayish black calcareous mudstone, carbonaceous mudstone, grayish green as well as mousy gray sandstone and siltstone with intercalations of biolimestone and shelly limestone, yielding fossil brachiopods and lamellibranchs, as well as bryozoans and spores and pollen; the formation is 476 m thick. The Upper Permian Daliyue'er Formation is a continental facies, consisting of purple, maroon, and grayish green sandstone, siltstone, and mudstone; it contains plant (*Calamites*) and ostracode fossils and is 191 m thick. In the eastern part of the Pishan River region, the Lower Permian Pusige Formation is a continental facies, consisting of brownish red, maroon, and grayish green sandstone, sandy mudstone, siltstone with thin-layered limestone, and containing plant fossils; it is about 1791 m in thickness. The Upper Permian Duwa Formation is a continental facies, consisting of maroon and taupe conglomerates, coarse sandstone, and siltstone, with grayish green mudstone and a thin-layered limestone at the top of the formation, bearing lamellibranch and conchostracan fossils; the thickness varies from 418 to 1268 m.

In addition, the Upper Permian Biyoulebaoguzi Group in the Kuqa area consists of purple and brownish red conglomerate, sandstone, and dark sandy mudstone with intercalations of grayish green sandstone and carbonaceous shale. The unit disconformably covers Carboniferous rocks and has a thickness of 286 m.

The Triassic System: The Triassic System is mainly exposed in the northern portion of the Tarim Basin and contains terrestrial sediments. In the Kuqa–Baicheng region, the Lower Triassic

Ehuobulake Formation disconformably covers the Lower Permian Biyoulebaoguzi Group. The unit is dominated by purple, sandy conglomerates that alternate with grayish green sandy mudstone and is underlain by a basal conglomerate. The fossils in the formation are plants, conchostracans, charophytes, and ostracodes; the thickness varies from 191 to 592 m. The Middle Triassic “Karamay Formation” consists of grayish green and beige conglomerates, sandstone intercalated with purple sandy mudstone, and siltstone; it also contains black carbonaceous shale at the top of the formation with fossil plants, spores, pollen, and conchostracans. Total thickness of the formation is 572–885 m.

The lower Upper Triassic Huangshanjie Formation consists of grayish green sandstones and siltstones intercalated with dark gray mudstone, carbonaceous mudstone, and coal beds; it contains various fossils including plants, spores and pollen, charophytes, and conchostracans, with a thickness varying between 168 and 279 m. The uppermost Triassic Taliqike Formation includes gray conglomerates, sandstones, grayish green siltstone, sandy shale, as well as black carbonaceous shale and coal beds, yielding plants, spores and pollen, and conchostracans, with a thickness of 544–837 m.

In the Avati region, Triassic strata are encountered in the drilled boreholes including Yuecan #1, Shacan #1, and Acan #1. The Triassic Manjiaer Group in the drill samples is composed of basal grayish green, beige mudstones, siltstone, and fine sandstone alternating with fine conglomerate and thin-layered limestone, with a thickness of 239 m. The middle part consists of grayish green and beige mudstones, and siltstone with intercalations of dark gray carbonaceous mudstone and coal beds, with a thickness of 241 m. The upper part is composed of gray, beige, and reddish brown mudstones, siltstone with intercalations of black carbonaceous shale and thin coal beds, and the lower part with variegated conglomerate with a thickness of 190 m (Ma and Wen 1991).

The Jurassic System: Jurassic strata are mainly distributed in the Kuqa–Baicheng and Kashi areas in the northern Tarim Basin and

Tiekelike area in the southwestern Tarim Basin. The sediments are mainly of a lacustrine and swamp facies with coal-bearing clastic deposits. The Jurassic lies disconformably or unconformably in contact with the underlying strata. In the Kuqa–Baicheng area, the lower part of the Lower Jurassic, the Ahe Formation, disconformably lies above the underlying Triassic Series; consists of grayish white, yellowish gray conglomerates and sandy conglomerates, and sandstones with some thin dark gray mudstone layers; and is 300–500 m thick. The upper part of the Lower Jurassic is represented by the Yangxia Formation, which consists of gray and yellowish gray coarse sandstones, siltstones, grayish black mudstones, and black carbonaceous shale with coal beds, including fossil plants, pollen, and bivalves; total formation thickness is 200–400 m. The Middle Jurassic Kezilenuer (Yangye) and Qiakemake (Taerga) formations include gray sandstones, dark gray and greenish gray mudstones, black carbonaceous mudstones, coal beds, and oil shales, containing miospores, megaspores, estherids, ostracodes, and bivalves; formation thickness ranges from 872 to 1245 m. The Upper Jurassic Qigu Formation consists of brown and brownish red mudstones intercalated with sandstones, and the thickness is 256 m; fossils include charophytes, ostracodes, and bivalves.

In the Kashi area, the lower part of the Lower Jurassic Series is represented by the Shaliquke Formation, which unconformably overlies Permian strata, and is composed of grayish green conglomerates and sandstones, siltstones, and black carbonaceous shales, containing plants and spore-pollen fossils, with a thickness of 1314 m. The upper part of the series is the Kansu Formation, consisting of grayish green sandstones and sandy conglomerates with alternating dark gray mudstones, black carbonaceous mudstones, and coal beds, yielding plants, pollen, and bivalves; the thickness is 1160 m. For the Middle Jurassic Series, the lower part is the Yangye Formation which consists of gray, grayish black mudstones, with intercalations of sandstones, shale, and marl, yielding fossil spores and pollen, ostracodes, and bivalves, with a thickness of

1030 m. The upper part of the Middle Jurassic, the Taergan Formation, consists of variegated clastic rocks dominated by grayish green mudstone, yielding spores and pollen, ostracodes, bivalves, and conchostracans; and is 215 m thick. The Upper Jurassic Kuzigongsu Formation is composed of red conglomerates with intercalations of sandstone and mudstone, and 423 m in thickness.

In the Tiekelike area, the basal part of the Lower Jurassic, the Shalitashi Formation, consists of conglomerates, whereas the upper part of the Lower Jurassic Formation, the Kansu Formation consists of grayish green and grayish yellow sandstones with black carbonaceous shales. The basal part of the Middle Jurassic Yangye Formation consists of grayish green and yellowish green mudstones with intercalations of sandstones, conglomerates, and coal beds. The upper part of the Middle Jurassic, the Taerga Formation, consists of purple mudstones and siltstones. The Lower to Middle Jurassic Ye'erqiang Group has a total thickness of 850–2759 m and lies disconformably over the underlying Permian strata. The Upper Jurassic strata are missing in this region (Zhou and Chen 1990; Ma and Wen 1991; Zhou 2001).

The Cretaceous System: The Cretaceous System is of terrestrial origin, a clastic facies in most of the Tarim Basin, except in the southwestern part, where the Upper Cretaceous is a marine facies. In the Kuqa–Baicheng area, the Lower Cretaceous Kapushaliang Group lies unconformably above the Upper Jurassic Qigu Formation. The basal part of the Lower Cretaceous, the Yageliemu Formation, consists largely of grayish purple conglomerates, conglomeratic sandstones, and sandstones, about 120–290 m thick. The middle part Shushanhe Formation consists of brownish red, reddish brown, and blue gray mudstones with intercalations of yellowish green fine sandstones and siltstones, yielding fossils of sporo-pollen and ostracodes, with a thickness of 141–1099 m. The upper part of the Lower Cretaceous, the Baxigai Formation, consists of beige and red brown conglomerates and sandstones, with mudstones and siltstones, yielding fossil sporo-pollen, ostracodes, and

conchostracans; the formation is 240–400 m thick. The Upper Cretaceous Bashijiqike Formation consists of purple red conglomerates and sandstones and lies disconformably over the Lower Cretaceous; it is about 115–200 m in thickness.

In the Shache–Kashgar area, the Lower Cretaceous Kezlesu Formation lies unconformably or disconformably over Lower Jurassic strata and consists of brownish red and grayish green sandstones and conglomerates intercalated with mudstones and siltstones; it yields fossil spores and pollen, and ostracodes and has a thickness of 500–1300 m. The Upper Cretaceous Yingjisha Group is marine facies that is divided into Kukebai, Wuyitage, Yigeziya, and Tuyiluke formations in ascending order; the group lies conformably over the Kezilesu Group. The lower part of the Kukebai Formation consists of reddish brown and grayish green mudstones having intercalations of dolomite and thin-layered gypsum; the base of this formation consists of white sandy dolomicrites, and the top consists of micrites and aphanitic limestones, yielding foraminifera and bivalve fossils, about 62 m thick. The middle part of this formation consists of dark gray and grayish green mudstones with oyster-shell limestones and aphanitic limestones, yielding fossil foraminifera and bivalves, about 69 m thick. The upper part of this formation consists of gray mudstones with limestones, yielding bivalves and ostracode fossils, about 26 m thick. The Wuyitage Formation consists of grayish green and dark purple mudstones and siltstones with intercalations of white gypsum layers, about 87 m in thickness. The Yigeziya Formation is composed of grayish green, gray, and purple dolomite and limestone with mudstones in the upper part, yielding fossil bivalves, echinoderms, foraminifera, bryozoans, and other fossils, about 162 m thick. The Tuyiluke Formation is composed of brownish red mudstone and gypsum-bearing mudstone and is about 67 m in thickness.

In addition, in the Jianggeshayi Section of Qiemo County, southwestern Tarim Basin, the Lower Cretaceous Kezlesu Group consists of brownish red sandstones, siltstones, and

mudstones with intercalations of green sandstones and mudstones, and the base of the formation is composed of light gray, fine conglomerates that lay disconformably over the Upper Jurassic Kuzigongsu Formation; the Keszlesu Group has a thickness of 498 m.

The Tertiary System: In the southwest Tarim Basin, the Lower Tertiary (Paleogene) is a marine facies; in other places, the Lower Tertiary deposits are terrestrial facies, lying disconformably or unconformably above the underlying strata. In the Shache–Hetian area, the Paleocene Alta Formation is marine in the upper part, consisting of white, massive gypsum, about 214–450 m thick. The Paleocene to Eocene Series Qimugen Formation consists of marine limestones and grayish green mudstones in the lower part, and of a lagoon facies in the upper part with red mudstones, gypsum-bearing mudstone, and gypsum, all about 86–194 m in thickness. The middle part of the Eocene Kalataer Formation consists of red gypsum-bearing mudstone, gypsum, and limestones in the lower member, and marine limestones in the upper member, all about 78–98 m in thickness. The Upper Eocene Series Wulagen Formation is a shallow marine and littoral facies; the middle to lower parts are composed of grayish green mudstone with limestone, whereas the upper part is red mudstones with intercalations of grayish green sandstones, mudstones, and a thin shell layer, all about 98–130 m thick. The Oligocene Bashibulake Formation is a lagoon facies, consisting mainly of brownish red mudstones, grayish red siltstones, and fine sandstones with intercalations of grayish green mudstones, siltstones, sandstones, shell layers, and white gypsum, all with a thickness of 315–800 m. The lower part of the Miocene Keziluoyi Formation consists of brownish red mudstones with grayish beige siltstones and sandstones, with a basal layer of gypsum and gypsum-bearing mudstone, lying conformably over the Paleogene; the formation is about 422–450 m in thickness. The Middle Miocene Anju'an Formation consists of gray and grayish green mudstones, siltstones, sandstones, and a gypsum layer, all about 486–668 m in thickness. The Upper Miocene Pakabulake Formation

consists largely of brown, sandy mudstones, with alternations of siltstones and sandstones, about 1100–2168 m thick. The lower part of the Pliocene Atushi Formation consists of gray and brown sandstones and conglomerates with intercalations of yellow, sandy shale, and siltstone, all of which is 1750–3497 m thick. The Pliocene Xiyu Formation consists of dark gray conglomerates; the thickness varies from 100 to 3000 m.

In the Kuqa–Baicheng area, the Lower Tertiary Kumugeliemu Group is a tidal flat and lagoon facies composed of gypsum-bearing mudstones. The Paleocene to Eocene Talake Formation consists of variegated clastic rocks and dolomites with a basal conglomerate, whereas the upper part is gypsum-bearing mudstone and siltstone containing ostracode and bivalve fossils, all with a thickness of 150–210 m. The middle part of the Eocene Xiaokuzibai Formation consists of brick red and purple sandy mudstone, siltstone with a thin layer of gypsum and halite, and yields ostracode and foraminifera fossils; this sequence is 230–500 m thick. The Upper Eocene Awate Formation is composed of purple and brown mudstone, and sandy mudstone with intercalations of grayish green siltstone and halite; the formation varies from 259 to 500 m in thickness.

The Neogene System is mainly a terrestrial deposit which lies disconformably over the underlying strata. The basal Miocene Suweiyi Formation consists of maroon conglomerate, sandstone, siltstone, and mudstone with gypsum and halite, all about 200–400 m in thickness. The Middle Miocene Jidike Formation consists of red and maroon conglomerate, sandstone and conglomeratic sandstone, and mudstone with gypsum-bearing mudstone, varying from 600 to 800 m in thickness. The Upper Miocene Kangcun Formation is composed of gray sandstone alternating with brown mudstone that includes a banded, grayish green siltstone; total thickness is 300–800 m. The lower part of the Oligocene Kuqa Formation is composed of beige conglomerate that changes to the south into gray to brownish gray sandstone and siltstone alternating with conglomerate, all of which is about 300–

700 m in thickness. The Upper Oligocene Xiyu Formation consists of dark gray conglomerate with intercalations of beige sandy mudstone and conglomeratic sandstone; the thickness is 50–600 m in general, with the maximum thickness of 1366 m in the Tarim Basin.

2.3.1.2 Tectonic Characteristics and Tectonic Units

Tectonically, the Tarim Basin (Fig. 2.1) is located in the Tarim platform area. The basin is bounded to the north by the Tianshan Mountain Range, to the southwest by the Kunlun Mountain Range, and to the southeast by the Altun Mountain Range. The Tarim Basin has experienced seven tectonic movements and is characterized by six unconformity surfaces. The Tarim Orogeny is equivalent to the Jinning Orogeny that inverted folds in the Paleozoic geosyncline and formed crystalline basement. The Sinian System forms caprocks that lie unconformably over the Pre-Sinian System. Middle Ordovician Caledonian Orogeny resulted in uplifting the platform and creating exposed land. Erosion of the Upper Ordovician sediments thus formed an

unconformity surface between the Silurian and Ordovician systems. Early Hercynian Orogeny during the latest Devonian sank the platform, thereby forming an unconformity surface between the Carboniferous and Devonian systems. Late Hercynian Orogeny formed an unconformity surface between the Lower and Upper Permian Series. The Indosinian Orogeny at the end of the Triassic produced an unconformity surface between the Jurassic and Triassic. At the end of the Cretaceous period, the Late Yanshanian Orogeny produced an unconformity surface between the Tertiary and the Cretaceous. The Himalayan Orogeny formed the basic pattern seen in the modern basin. In addition to stratigraphic unconformities produced in different periods, all previous tectonic movements determine the shape, structure, and tectonic characteristics of the basin. The rigid crystalline basement of the Pre-Sinian System is cut by the two deep faults bearing west-northwest and east-northeast, thus forming rhombohedral blocks. These two set of deep faults control the basic tectonic framework of the basement and cover, thereby forming three upheavals, four

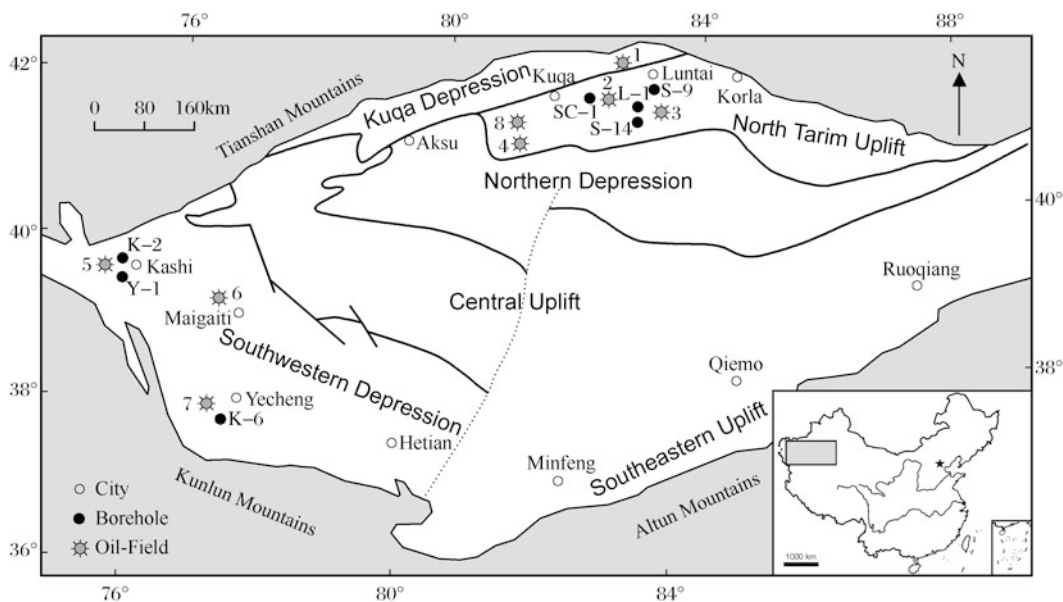


Fig. 2.1 Sketch map showing tectonic subdivisions and locations of oil fields and boreholes in the Tarim Basin. 1 Yiqikelike oil field. 2 Yakala oil field. 3 Lunnan oil field.

4 Yingmaili oil field. 5 Kelatu oil field. 6 Maigaiti oil field. 7 Kekeya oil field. 8 Donghetang oil field

depressions, and various types of folds and faults. Inside the Tarim Basin, seven tectonic units are recognized, including Central Upheaval, North Depression, North (Tarim) Upheaval, Southeast Upheaval, Kuqa Depression, Southwest (Tarim) Depression, and the Southeast Depression. The North Depression can be further subdivided into four secondary tectonic units, such as the Avati Sag, Manjiaer Sag, Yingjisu Sag, and the Kongque River Slope. The Southwest (Tarim) Depression can be subdivided into five secondary tectonic units, including the Kashi Sag, Yecheng Sag, Tanggu Ancient Sag, and Meigaiti Slope (Zhou and Zheng 1990) (Fig. 2.1). Fault activity plays an important role in the formation of the Tarim Basin tectonic framework and petroleum reservoir formation; all of the above tectonic units demonstrate block fault features. The formation and evolution of each block are controlled by deep fault activity that formed basin basement fault blocks in the west-northwest and east-northeast directions. Thus, the tectonic axis and fracture direction are mostly in the west-northwest and east-northeast directions.

2.3.1.3 Potential Petroleum Source Rock Series and Oil–Gas-Bearing Prospects

The massive, thick sedimentary sequence in the Tarim Basin contains many sets of carbonates and dark mudstones; these are potential hydrocarbon source rocks in a variety of geological periods (Table 2.1). The grayish black carbonate rocks are well developed in the Lower Cambrian Xiaerbulake and Wusongger formations, which are fossiliferous and exhibit good potential for oil and gas generation. The Lower Ordovician Qiulitage Group contains neritic facies limestone and dolomite, and liquid crude oil is found in the geodes of the miarolitic limestones, showing that these carbonate rocks should be a good oil source rocks. The black shales and mudstones in the Middle Ordovician Saergan and Yinggan formations are rich in fossil graptolites and pyrites nodules, representing a deoxygenated environment of stagnant conditions and anoxic sediment. These are favorable for enrichment and preservation of organic matter and thus are also a

potential oil source rock series. In the Carboniferous and the Lower Permian, black and carbonaceous shales with intercalations of minor sandstone, siltstone, and limestone should also be ideal hydrocarbon rock series. In the Keping–Aheqi area, the organic reef facies limestone of the Upper Carboniferous to Lower Permian Muziduke Group contains abundant reef-forming organisms, such as fusulinids, corals, brachiopods, bryozoans, algae, and sponges; these thrived in the warm water environment of the platform edge. Such reef facies are often hydrocarbon source rocks. The Middle Triassic “Karamay Formation” and the Upper Triassic Huangshanjie and Taliqike formations are deposits of inland lake and swamp deposits, consisting of dark mudstones with intercalations of thin layers of siderite and coal beds; these units are rich in organic matter and thus are ideal continental hydrocarbon source rocks. The Lower Jurassic Yangxia (Kangsu) Formation and Middle Jurassic Kezilluener (Yangye) Formation are a coal-bearing series, containing rich organic matter deposited in lacustrine and swamp facies. The Middle Jurassic Qiakemake (Taergan) Formation is another lacustrine deposit (Zhong et al. 2003) and is also an ideal continental hydrocarbon source rock. The Upper Cretaceous Yingjisha Group contains marine sediments, yielding ostracodes, sea urchins, foraminifera, dinoflagellates, and algal fossils, reflecting a shallow bay or lagoon environment that is favorable for the formation of hydrocarbon source rocks.

Apart from the above potential hydrocarbon source rock series, there is no lack of reservoir rocks and caprocks in the Tarim Basin. Cambrian–Ordovician carbonate rocks were exposed to the sea surface in the Late Ordovician and then eroded; the holes and cracks formed during long-term dissolution provided space to create oil and gas reservoirs, and to form carbonate reservoir rocks such as the Qiulitage Group in the Yakela oil field. The sandstones with well-developed pores from a variety of horizons in the Upper Paleozoic and Mesozoic–Cenozoic strata are also ideal oil and gas reservoir rocks. Additionally, the Ordovician and Permian all

have mudstones and shales that can serve as caprocks; finally, the compact mudstone, gypsum-bearing mudstone, and gypsum in the Mesozoic to Cenozoic strata also provide good caprock potential for oil and gas preservation.

Depressions in basins are favorable zones for organic matter accumulation and preservation; multiple superimposed tectonic events resulted in superimposed composite depressions that are particularly favorable for organic matter accumulation and preservation. The four depressions of such a hereditary nature, the Kuqa, North, Southwest, and Southeast depressions, occur in the Tarim Basin. Oil and gas fields are already known in some of these basins. The North Tarim Upheaval is bounded to the north by the Kuqa Depression and to the south by the North Depression. Being surrounded by depressions, there is a potentially rich oil source supply. Indeed, it has the most favorable conditions to form large oil and gas fields. The discovery of the Yakela and Lunnan oil fields, as well as other rich oil and gas fields, demonstrates that the Tarim Basin is a petroliferous basin having great prospective potential.

2.3.2 The Junggar Basin

The Junggar Basin, which is located in the intersection of the Kazakhstan, Siberian, and Tarim plates, is a continental intraplate bounded on three sides by Paleozoic sutures. Its western part is the Hercynian fold belt that is the leading edge of the NE–NEE Kazakhstan Plate, composed of the West Junggar anticlinorium belt. At the northeastern and eastern margins of the Junggar Basin, the Altai and East Junggar fold belts were created by motion at the southern edge of the Siberian Plate. At the southern end of the Junggar Basin, the Tianshan fold belt formed at the northern edge of the Tarim Plate.

According to aeromagnetic and seismic data, the Junggar Basin has a rigid Precambrian crystalline basement, where the general trend of its basement relief is such that the central western region is higher, surrounded by a deep depression. The formation of the Junggar Basin was

greatly influenced by the Hercynian Orogeny, and the basin is a fault depression basin within the plate developed in the Late Hercynian. The basin was initially formed in the Permian period. The Mesozoic was a period that involved integrated development of the basin, and thus, the continental sedimentary sequence was formed by the combination and transformation of both uplift and depression. By Cenozoic time, most orogeny had ceased except along the southern edge of the basin where thick continental sediments were deposited.

The Junggar Basin is a large-sized superimposed composite basin with an overlapping area about 145,000 km² and a superimposed sedimentary thickness of 12,000–15,000 m. The basin contains six petroliferous strata from Carboniferous to Tertiary in age.

2.3.2.1 Stratigraphy and Lithofacies (Table 2.2)

The Carboniferous System: The lower part of the Lower Carboniferous in the East Junggar subarea is characterized by the Tamugang Formation, which is mainly composed of gray and black argillaceous siltstone, gray conglomerate, and carbonaceous shale, with a thickness of 1550 m. The upper part of the Lower Carboniferous is the Dishuiquan Formation, which unconformably overlies the underlying strata. The Dishuiquan Formation is grayish green and taupe conglomerate, sandstone, and siltstone tuff, with a thickness of about 1600 m. The lower part of the Upper Carboniferous is the Batamayineishan Formation (=Liushugou Formation), which is composed of variegated volcanic and pyroclastic rocks, tuff and tuff breccia, with a thickness of 176–1011 m, in angular unconformity with the underlying Dishuiquan Formation. The middle part of the Upper Carboniferous, the Shiqiantan Formation, is grayish yellow siltstone, mudstone, and limestone with conglomerate, and about 480 m in thickness. The upper part of the Upper Carboniferous is the Liukeshu Formation (=Ao'ertu Formation), consisting of grayish green and gray siltstone, shale with intercalations of limestone, and siltstone glutenite, about 268–380 m in thickness. In the Carboniferous, tectonic

Table 2.2 Potential petroleum source rock series of the Junggar Basin

Geologic age	Lithostratigraphic units	Code	Lithology	Lithofacies
Oligocene	Anjihaihe Formation	E _{3a}	Gray, gray green sandstone, and mudstone	Lacustrine facies
Middle Jurassic	Toutunhe Formation	J _{2t}	Variegated mudstone alternating with sandstone, interbedded with carbonaceous shale and coal beds	Lacustrine–swamp facies
	Xishanyao Formation	J _{2x}	Gray conglomerate, sandstone, interbedded with clay and coal seams	Fluvial–swamp facies
Early Jurassic	Sangonghe Formation	J _{1s}	Gray green sandstone, mudstone, and siltstone	Lacustrine facies
	Badaowan Formation	J _{1b}	Gray mudstone, sandstone, interbedded with conglomerate and coal seams	Fluvial–swamp facies
Late Triassic	Haojiahe Formation	T _{3ha}	Gray sandstone and mudstone, interbedded with coal seams and siderites	Lacustrine–swamp facies
	Huangshanjie Formation	T _{3h}	Gray mudstone, shale, and black carbonaceous shale	Lacustrine–swamp facies
Middle Triassic	Kelamayi Formation	T _{2k}	Gray green mudstone, sandstone, and carbonaceous shale seams	Lacustrine–swamp facies
Early Triassic	Shaofanggou Formation	T _{1s}	Purple sandstone and mudstone, interbedded with gray mudstone and siltstone	Lacustrine facies
	Jiucuiyuan Formation	T _{1j}	Sandstone alternating with mudstone, interbedded with dark mudstone, siltstone	Lacustrine facies
Late Permian	Wutonggou Formation	P _{2w}	Gray glutenite alternating with mudstone, with intercalation of carbonaceous shale and coal seams	Lacustrine–swamp facies
Middle Permian	Quanzijie Formation	P _{2q}	Lower part with conglomerate, the upper part of mudstone, carbonaceous shale, and coal seams	Fluvial–swamp facies
	Hongyanchi Formation	P _{2h}	Gray, gray green mudstone, sandstone, interbedded with marl	Lacustrine facies
	Lucaogou Formation	P _{2l}	Gray black mudstone, oil shale, sandstone, siltstone, interbedded with dolomite	Lacustrine facies
Late Carboniferous	Ao'ertu Formation	C _{2a}	Gray green, dark gray siltstone, interbedded with glutenite	Continental facies
	Batamayineishan Formation	C _{2b}	Andesitic porphyry, basalt porphyry, tuffaceous sandstone	Continental facies
Early Carboniferous	Dishuiquan Formation	C _{1d}	Gray clastic interbedded with tuff	Marine facies
	Tamugang Formation	C _{1t}	Gray siltstone and mudstone, carbonaceous shale, glutenite	Marine and terrestrial alternating facies

and volcanic activities were intense with frequent marine transgressions and regressions, so the sedimentary combination of marine and continental facies as marine–terrestrial alternating

deposits was coeval. In the Kelameily region, volcanic and pyroclastic rocks are well developed.

The Permian System: The Permian System is well developed in the Bogda foreland area of the

Junggar Basin. The Lower Permian Xiajijicao Group, which lies unconformably or disconformably over the underlying strata, is composed of littoral or paralic dark clastic sediments in the Manas–Jimusaer region. The lower part of the Xiajijicao Group is the Shirenzigou Formation, and the upper part is the Tashikula Formation. The former is grayish green tuffaceous conglomerate, sandstone, siltstone, and sandy mudstone with tuff layers, containing brachiopods, bivalves, plants, spores and pollen, and other fossils, about 205–770 m in thickness. The latter formation is gray to grayish green fine-grained sandstone, siltstone, silty mudstone, limestone, and black shale, including bivalves, plants, pollen, and other fossils, about 1102–2593 m in thickness. The Upper Permian Shangjijicao and Xiacangfanggou groups consist of continental sediments, conformably overlying the underlying strata. The Shangjijicao Group has been subdivided into Wulabo, Jingjingzigou, Lucaogou, and Hongyanchi formations, in ascending order. The Xiacangfanggou Group is subdivided into Quanzijie, Wutonggou, and Guodikeng formations, in ascending order. The Wulabo Formation is as much as 1065–2543 m thick, consisting of gray and grayish green sandstone, siltstone, and silty mudstone, yielding bivalves, plant, spores and pollen, and other fossils. The Jingjingzigou Formation is composed of blue gray tuff, gray sandstone, siltstone, and mudstone, yielding ostracodes, plants, spores and pollen, and other fossils, about 319–1654 m thick. The Lucaogou Formation is composed of grayish black mudstone, shale, oil shale, sandstone, and siltstone with intercalations of dolomite and dolomitic limestone, yielding fossils of bivalves, ostracodes, fish, plants, spores, and pollen, with a thickness of 1100–1300 m. The Hongyanchi Formation is as much as 735 m thick and is composed of gray to grayish green mudstone, shale, and sandstone with intercalations of marl, yielding fossils of bivalves, ostracodes, plants, as well as spores and pollen. The Quanzijie Formation is 196–273 m in thickness; its lower part consists of brownish red conglomerate sandstone and mudstone, and the upper part consists of gray and dark gray mudstone, and carbonaceous shale

interbedded with coal beds, yielding bivalves, ostracodes, plants, pollen, and other fossils. The Wutonggou Formation is 87–286 m thick, consisting of grayish green glutenite and mudstone interbedded with grayish black carbonaceous shale and thin coal beds, yielding fossil bivalves, ostracodes, and spores and pollen. The Guodikeng Formation consists of dark red and grayish green mudstone, and sandy mudstone intercalated with fine sandstone and carbonaceous mudstone, yielding bivalves, ostracodes, conchostracans, pollen, and other fossils; formation thickness is 68–128 m (Hu et al. 1991; Ouyang et al. 2003).

The Triassic System: The Triassic deposits crop out around the Junggar Basin. These are well developed in the Bogda piedmont sag, which is represented by inland fluvial and lacustrine facies. The Triassic mostly lies conformably over the underlying Permian strata; however, there are also unconformity or disconformity contacts. The Lower Triassic Shangcangfanggou Group is red clastic sediments, the lower part of which is the Jiucaiyuanzi Formation, composed of grayish green and dark red sandstone, mudstone interbedded with gray and grayish green mudstone, silty mudstone, and muddy siltstone, yielding fossils of reptiles, and spores and pollen, about 237–376 m thick. The upper part of the Shangcangfanggou Group is the Shaofanggou Formation, which consists of light purple and grayish green sandstones and red mudstones intercalated with gray mudstones and pelitic siltstones, yielding fossils of ostracodes, and spores and pollen, and having a total thickness of about 258–352 m. The Middle Triassic Karamay Formation is composed of grayish green to reddish brown and grayish black mudstones and grayish green sandstones intercalated with carbonaceous shales and thin coal beds, yielding fossils of plants and spores and pollen; the total thickness is about 465 m. The Lower–Upper Triassic Huangshanjie Formation consists of dark gray and yellowish gray mudstones and shales with black carbonaceous shales at the base, yielding plants, and spores and pollen fossils, about 225–450 m thick. The upper part of the Upper Triassic is the Haojiagou Formation,

which consists of gray and grayish yellow sandstones and mudstones intercalated with thin coal and siderite beds, yielding fossils of plants, and spores and pollen, and a total thickness of 184–380 m.

The Jurassic System: Jurassic outcrops are exposed along the Junggar Basin margins and in mountain depressions and are well developed at the southern edge of the basin and the Bogda piedmont depression. Jurassic deposits are 976–1237 m thick, consisting of fluvial, lacustrine, and swamp facies. The Lower and Middle Jurassic are represented by coal-bearing strata. The Lower Jurassic is divided into the Badaowan Formation at the base and the Sangonghe Formation above it. The Badaowan Formation contains coal and clastic sediments of fluvial, lacustrine, and swamp facies, consisting of gray, grayish green, and yellowish green mudstone, and sandstone with intercalations of coal and conglomerate; and includes fossils of bivalves, plants, and spores and pollen; the thickness is 300–670 m. The Sangonghe Formation is composed of yellowish green and dark red sandy mudstone interbedded with sandstone, conglomerate, carbonaceous, and siderite lenticular bodies, yielding plant fossils; total thickness is about 234 m. The Lower–Middle Jurassic Xishanyao Formation consists of gray conglomerate, and sandstone intercalated with clay and coal beds; the Upper and Middle Jurassic Toutunhe Formation is grayish green and purple mudstone and sandstone intercalated with carbonaceous shale and coal beds. The total thickness of the Middle Jurassic in the basin is as much as 377 m. The Upper Jurassic Qigu Formation is brownish red mudstone intercalated with grayish green and grayish brown sandstone and conglomerate, about 168–352 m thick.

The Cretaceous System: The sedimentary deposits of Cretaceous age in the Junggar Basin are mainly fluvial and lacustrine facies; these lay unconformably or disconformably on the underlying strata. The Lower Cretaceous Tugulu Formation consists of red sandstone and mudstone, with a basal conglomerate, and includes fossils of fish, ostracodes, conchostracans, and charophytes, about 100–260 m thick. The Upper

Cretaceous Donggou Formation (Honglishan Formation–Wulungu Formation) is composed of red coarse clastic sediments, mainly consisting of conglomerate including ostracodes, charophytes, and vertebrate fossils; the unit lies unconformably on the underlying Tugulu Group.

The Tertiary System: Tertiary strata are well developed at the southern edge of the Junggar Basin and unconformably cover the underlying Upper Cretaceous Donggou Formation. The Paleocene–Eocene Ziniqianzi Formation crops out in foothills where it is a fluvial facies, consisting of red sandstone and conglomerate intercalated with sandy mudstone; it contains charophytes and ostracodes and is about 13–854 m thick. The Oligocene Anjihai Formation is a lacustrine sediment and consists of gray and grayish green sandstone and mudstone, yielding bivalves, ostracodes, spores and pollen, and other fossils, with a thickness of about 167–763 m. The Miocene Taxihe Formation consists of gray, gray brown, and grayish green sandstone, mudstone, and conglomerate, yielding fossils of bivalves, ostracodes, and charophytes; the total thickness is 500–2300 m. The Pliocene Dushanzi Formation contains fossil teeth of the three-toed horse *Hipparion* and is equivalent to the “three-toed horse laterite” horizons in North China.

The potential oil source rock series in the Junggar Basin are shown in Table 2.2.

2.3.2.2 Tectonic Units

The Junggar Basin (Fig. 2.2) can be subdivided into five tectonic units, including the Manashu Depression, the Wulungu Depression, the Luliang Uplift, and the East and South Junggar depressions. In addition, two units can be distinguished in the basin subsurface using magnetic data that show two structures named the Mosuowan Uplift and the Moqu Depression (Division of Earth Science of Academia Sinica and Xinjiang Petroleum Administration 1989) (Fig. 2.2).

The Manashu Depression is located in the northwestern edge of the basin, about 250 km in length and 40 km in width, extending in a northeast direction. It is the locality of the Karamay–Urho oil field region. The northwestern margin of the basin was subject to a break in subsidence during

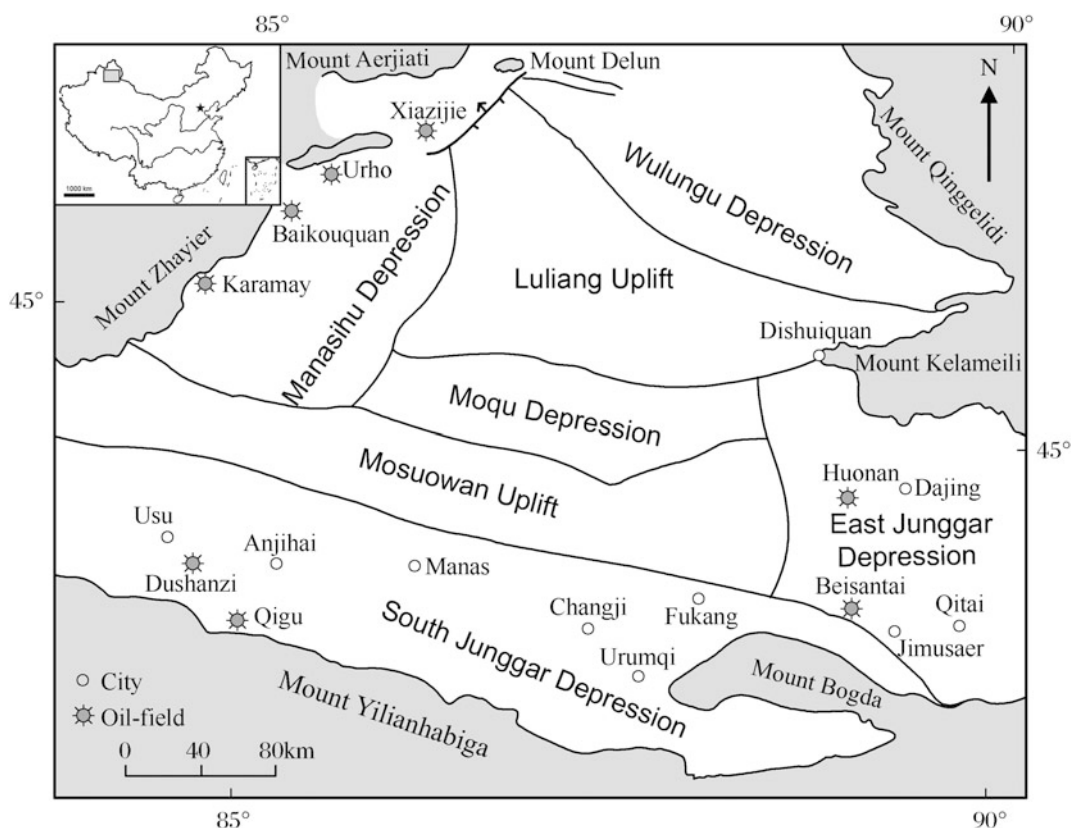


Fig. 2.2 Sketch map showing tectonic subdivisions and locations of oil fields in the Junggar Basin

the Permian, thereby forming two deposition centers: the larger one of which is in the Manas area, which has sediments about 3000 m thick; and the smaller depo-center is in the Urho region, having sediments about 2900 m thick. After the Triassic period, the depression continued to sink rapidly, and the total thickness of sedimentary rocks in the depression is as much as 8000 m. So far, about 13 anticline structures and nose-shaped folds have been discovered in the basin.

The Wulungu Depression is located in the northeast edge of the basin, about 235 km in length and 40–60 km in width; it strikes NWW, the eastern end of which converges and narrows to the north of Kelameili Mountain. The depression is inherited from the Permian and continued sinking into the Triassic. So while the thickness of Permian sediments is about 1500 m, the thickness of Triassic sediments is as much as 4500 m. The total thickness of sedimentary rock in the depression is therefore about 6000 m.

The Luliang Uplift is located in the north-central part of the Junggar Basin, and is bounded at the NW by the Luliang fracture, at the north by the Wulungu Depression, at the west by the Manas Depression, and at the south by the Moqu Depression. The uplift extends NW, and it about 120 km long and 80 km wide, with an area of approximately 9000 km². The uplift is composed of Permian, Triassic, Jurassic, and Cretaceous sequences. Drilling and seismic data show two unconformities between the Permian and Triassic, and the Jurassic and Cretaceous in this area.

The East Junggar Depression of the Junggar Basin is located in the Kelameili piedmont and the east–west “Corridor” of the north Jimusaer–Qitai areas, with an area of about 3500 km². The depression was formed by intense sinking in the Late Permian, followed by further sinking in the Triassic, and the sedimentary thickness is about 6000 m. The East Junggar Depression is complex and is divided into a series of sags and uplifts

named the Wucuiwan Fault Sag, the Shaqiu Fault Uplift, the Huoshaoshan Fault Sag, the Zhangpenggou Fault Uplift, the Dajing Fault Sag, the Beisantai–Shaqiu Fault Uplift, the Jimusaer Fault Sag, and the Qitai Fault Sag. The Huoshaogou Fault Sag is mainly Permian in age and contains the Huonan oil field. At the north end of the Beisantai–Shaqiu Fault Sag, the Wucuiwan, Huoshaoshan, and Dajing fault sags lay at the north, whereas the Jimusaer Fault Sag lays to the south, where it represents an inherited fault uplift of the east sag. The Beisantai–Shaqiu Fault Sag contains direct evidence for oil and gas migration and accumulation into its Beisantai oil field.

The South Junggar Depression (Changji Depression) of the Junggar Basin is located in the Mesozoic fold belt of the piedmont of Changji–Fukang and Mount Bogda and in the piedmont of Mount Yilianhabiga. This is a large depression that began sinking in the Permian where total thickness of the enclosed sediments is as much as 16,000 m. There are two depo-centers in the South Junggar Depression: one in the piedmont of the Mount Bogda, with sediment thickness of about 4000 m, and the other near the Changji area, where sediment thickness is about 3000 m. During the Mesozoic era, the depositional center moved westward; the Jurassic and Cretaceous depositional center is in the Changji to Manas areas. The Tertiary depositional center shifted westward to the Anjihai area. Seismic data show a significant unconformity between Jurassic and Cretaceous strata. The Jurassic Qigu oil field and

the Tertiary Dushanzi oil field are both located in the west part of the South Junggar Depression.

2.3.3 The Turpan-Hami Basin

The Turpan-Hami Basin (Fig. 2.3) is an intermontane basin in the Northern Tianshan Eugeosynclinal fold belt. It is bounded to the south by the Aqikuduke break and adjacent to the uplift belt of the central Tianshan Mountains. The basin is bounded to the north by buried deep faults and is adjacent to the Bogda–Kaerlike fold belt. Surrounded by mountains, the basin is bounded on the north by Mount Bogda, Mount Balikun, and Mount Karlike where it is adjacent to the Junggar Basin. It is bounded on the south by Mount Jueluotage and adjacent to the Tarim Basin.

The Turpan-Hami Basin has its long axis in an east–west direction; its structure is that of an extensional basin. Its area is approximately 50,000 km² with the maximum thickness of sedimentary rocks as much as to 8600 m. The basement of the basin belongs to the easternmost part of the Kazakhstan Plate, so it should be composed of Precambrian crystalline rocks. Collision of the Kazakhstan and Tarim plates caused Jueluotage and Bogda–Kaerlike Orogeny activities, which is the main factor affecting the development and evolution of the basin's structure. The Turpan-Hami Basin is one of the three major oil and gas basins in Xinjiang, where the

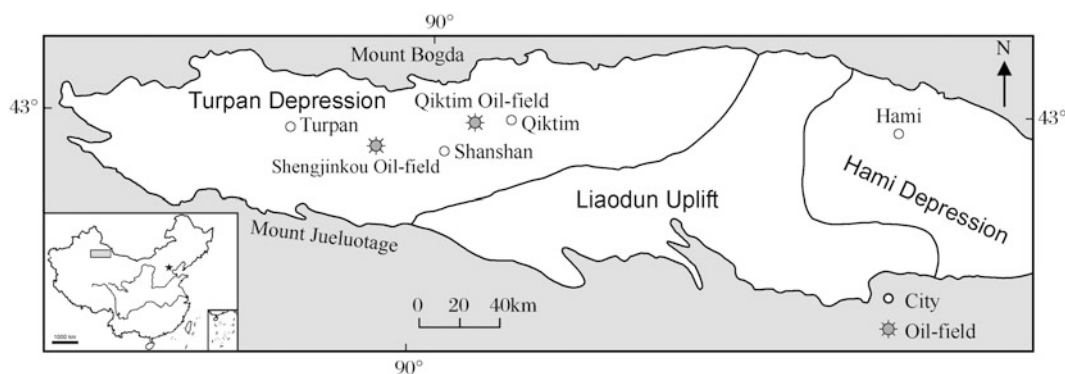


Fig. 2.3 Sketch map showing tectonic subdivisions and locations of oil fields in the Turpan-Hami Basin

Shengjinkou, Qiketai, and Shanshan oil and gas fields were discovered. Moreover, the basin has large-scale oil and gas deposits, enhanced by Jurassic coal seams, and thus, additional gas prospects can be predicted (Hu et al. 1991; Wang et al. 1993).

2.3.3.1 Stratigraphy and Lithofacies (Table 2.3)

The Permian System: The Lower Permian is lacking in the western part of the Turpan-Hami Basin. The lower part of the Upper Permian is the Taodonggou Group, which is quite similar to the Shangjijicao Group in Junggar Basin. The upper part is the Xiayangfanggou Group and has lithofacies that can be correlated with that of the Xiayangfanggou Group in the Junggar Basin. The Daheyan Formation in the Lower Taodonggou Group consists of purple conglomerate, pebbly coarse sandstone, sandstone interbedded with minor siltstone, tuff, and limestone lenses, with a thickness of 163 m; these sediments are in angular unconformity with the underlying strata. The Tarlang Formation in the Upper Taodonggou Group consists of variegated mudstone, marl, siltstone, sandstone, and fine-grained conglomerates, containing fish, ostracodes, and plant fossils and having a thickness of 352 m. The Upper Permian in the eastern

basin is composed of alternating coastal marine and terrestrial facies and is composed of variegated clastic sediments. The Upper Permian can be divided into Daheyan, the Tarlang, and the Wutonggou Formations, in ascending order. The Daheyan Formation consists of purple and gray fine conglomerate, sandstone, siltstone, and mudstone, with a thickness of 165 m; the formation lays unconformably above the underlying Lower Permian strata. The Tarlang Formation is composed of variegated mudstone, silty mudstone, siltstone, and sandstone, with a thickness of 520 m. The Wutonggou Formation consists of grayish green and pale yellow coarse sandstone and conglomerate, interbedded with purple fine silty mudstone and mudstone, with a thickness of 205 m; it lays unconformably above the underlying Tarlang Formation. The Late Permian deposits of the basin in mountain foothills are fluvial-lacustrine sediments.

The Triassic System: Triassic rocks are mainly exposed in the western part of the basin adjacent to the Junggar Basin where they are inland fluvial-lacustrine deposits. The Shangyangfanggou Group in the Lower Triassic is mainly red clastic sediment. The lower part of this group is the Jiucayuan Formation and consists of red sandstone, conglomerate, and mudstone marl lenses. The total thickness of this

Table 2.3 Potential petroleum source rock series of the Turpan-Hami Basin

Geological age	Lithostratigraphic units	Code	Lithology	Lithofacies
Middle Jurassic	Toutunhe Formation	J _{2t}	Sandstone, siltstone, mudstone, intercalated with coal seams	Lacustrine-swamp facies
	Xishanyao Formation	J _{2x}	Siltstone, mudstone, carbonaceous mudstone, intercalated with coal beds	Lacustrine-swamp facies
Early Jurassic	Sangonghe Formation	J _{1s}	Sandstone, mudstone intercalated with coal beds	Lacustrine-swamp facies
	Badaowan Formation	J _{1b}	Mudstone, carbonaceous mudstone, sandstone, intercalated with coal beds	Lacustrine-swamp facies
Late Triassic	Haojiagou Formation	T _{3ha}	Sandstone alternated with mudstone, with intercalations of coal beds and siderite	Lacustrine-swamp facies
	Huangshanjie Formation	T _{3h}	Mudstone, shale, carbonaceous shale, containing siderite nodules	Lacustrine facies
Late Permian	Tarlang Formation	P _{2t}	Variegated mudstone, siltstone, fine sandstone, and conglomerate	Lacustrine facies

formation is 128–235 m. The upper part of the Shangcangfanggou Group is the Shaofanggou Formation, which is composed of red and green sandstone with alternations of mudstone; the thickness is 83–169 m. The Middle Triassic Karamay Formation consists of gray green sandstone, sandy mudstone, and red mudstone; the basal part is a yellow green thick conglomerate. The fossils include reptiles, amphibians, ostracodes, and plants, and the thickness is about 300 m. The lower part of the Upper Triassic is represented by the Huangshanjie Formation, consisting of dark gray, gray, yellow green mudstone, and sandstone interbedded with coal beds that also include siderite nodules, as well as fossils of plants and bivalves, with a thickness of 193–289 m. The upper part of the Upper Triassic is Haojiagou Formation, which consists of grayish yellow glutenite and dark gray mudstone, and carbonaceous mudstone with coal beds that bear siderite nodules and plant fossils; formation thickness is 92–157 m.

The Jurassic System: The Jurassic System is mainly exposed in the west part of the basin and is represented by inland fluvial, lacustrine, and swamp facies deposits having a thickness of 1340–2178 m. The lower and middle parts of the Jurassic are coal-bearing strata, while the middle part also contains hydrocarbon-bearing strata. The lower part of the Lower Jurassic is the Badaowan Formation, consisting of grayish black mudstone, carbonaceous mudstone, and yellowish green sandstone interbedded with thin coal seams; the basal part of the formation is conglomerate. The formation also has siderite nodules and fossil plants and pollen and spores, with a thickness of 43–540 m. The upper part of the Lower Jurassic, the Sangonghe Formation, consists of gray sandstone with conglomerate and gray mudstone, and silty mudstone with coal beds, yielding plant and pollen fossils; the thickness is 18–246 m. The lower part of the Middle Jurassic is represented by the Xishanyao Formation, consisting of gray and grayish yellow siltstone and black mudstone with coal beds and siderite nodules, yielding plant and pollen fossils; the thickness is 412 m. The upper part of the

Middle Jurassic, the Toutunhe Formation, consists of grayish green and brownish red sandstone, siltstone, and silty mudstone with coal beds; the thickness is 455 m. The Upper Jurassic is represented by the Qigu Formation, which consists of purple and grayish green sandstone and mudstone with intercalations of conglomerate, yielding fossil ostracodes, with a thickness of 24–295 m.

The Cretaceous System: The Cretaceous is represented mainly by alternative clastic and lacustrine sediments deposited in inland fluvial, lacustrine, and fluvial–lacustrine environments. The Lower Cretaceous Tugulu Group is divided into Sanshilidadun, the Shengjinkou, and the Lianmuqin formations, in ascending order. The Upper Cretaceous is divided into the Kumtag Formation and the Subashi Formation. The Sanshilidadun Formation consists of red sandstone and sandy mudstone, with a basal fine-grained gravel; these lie unconformably or disconformably over the underlying strata, and the thickness is 768 m. The Shengjinkou Formation consists of grayish green mudstone, sandy mudstone, and siltstone with the fish fossils *Turfanichthys* sp. and *Hunyshania* sp., and the thickness is 49–62 m. The Lianmuqin Formation consists of brownish red sandy mudstone and grayish green and taupe fine sandstone, yielding fossil ostracodes, with a thickness of 213–307 m. The Kumtag and Subashi formations consist of hyacinth and orange fine-grained sandstone containing ostracodes and vertebrate fossils, with a thickness of 57–120 m.

The Tertiary System: Tertiary rocks were deposited in an oxygenated environment that left numerous inland lacustrine ostracode fossils. The Paleogene consists of orange, yellow, and green mudstone and sandstone; it has a basal conglomerate, yields ostracodes and vertebrate fossils, and has a thickness of 170–701 m. The Neogene consists of purple and pale yellow mudstone, siltstone, and conglomerate bearing a gypsum layer; fossils are ostracodes and vertebrates, and the thickness is 57–120 m.

The potential petroleum source rock system in the Turpan-Hami Basin is shown in Table 2.3.

2.3.3.2 Tectonic Units

The Turpan-Hami Basin (Fig. 2.3) can be subdivided into three tectonic units, including the Turpan Depression, the Liaodun Uplift, and the Hami Depression. Bordered by the Central Flaming Hill Fault, the Turpan Depression is bounded to the north by the Taibei Sag and to the south by the Aidinghu Slope and the Tuokexun Sag. There are seven anticline belts in the Taibei Sag, including the Taoshuyuan, the Kekeya, the Tudunzi, the Kushuijing, the Gedatai, the Flaming Hill, and the Yanmuxi anticline belts. The Shengjinkou and Qiktim oil fields are located in the west and east part of the Flaming Hill Anticline Belt, respectively (Hu et al. 1991) (Fig. 2.3).

2.3.4 The Qaidam Basin

The Qaidam Basin (Fig. 2.4) is located in the northeastern Qinghai-Tibetan plateaus. It is bounded at the northwest by the Altun Mountains, at the northeast by the Qilian Mountains, and at the south by the Kunlun Mountains. It is a Mesozoic-Cenozoic intermontane basin having an area of 120,000 km² and was formed after the Indosinian Orogeny. The basement of the basin consists of Pre-Sinian crystalline rocks and the

Caledonian fold belt. The Qaidam Basin has a Mesozoic-Cenozoic continental sedimentary thickness of more than 10,000 m.

The Qaidam Basin is a large inland petroliferous basin located in western China, where more than 100 oil-bearing structures, excellent trap conditions, 17 oil fields, and 5 gas fields have been found so far. Boreholes reveal a thickness greater than 4000 m in the Lower-Middle Jurassic petroliferous rock series in the Lenghu area; total thickness of the Tertiary potential petroleum source rock series is probably 3600 m (Research Institute of Exploration and Development, Qinghai Petroleum Administration, Nanjing Institute of Geology and Palaeontology, Academia Sinica, 1985; Huang et al. 1993). Zhu (1986) pointed out that, in a comparatively broader tilted fault depression, especially in a semi-graben, because of the constraint of geological factors, coarse clastic rocks should be deposited on one side of the fault, while variegated sandstone and shale intercalated with dark pelites should be developed on the slope side. The transition zone between these two kinds of deposits can be regarded as of great significance for both generation and the accumulation of oil and gas. The Qaidam Basin is mainly controlled by fault depression even as it

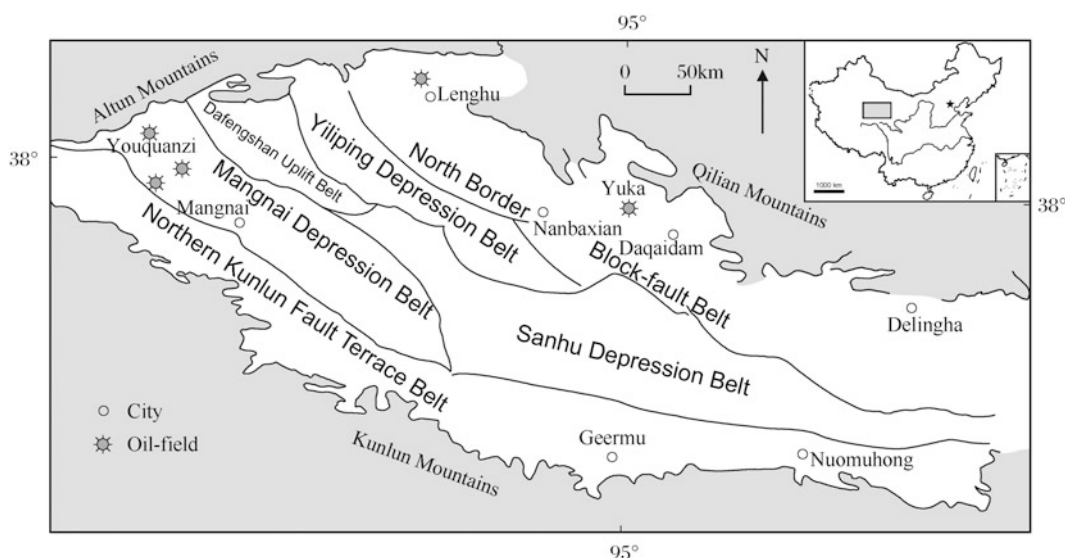


Fig. 2.4 Sketch map showing tectonic subdivisions and locations of oil fields in the Qaidam Basin

also possesses a combination of fault depression and depression. Near the Qilian Mountains and Altun Mountains, Tertiary coarse clastic rocks developed, while fine-grained clastic rocks represented by dark pelites alternate with sandstones that are well developed in the center of basin. Dark pelites favor oil generation, and alternations of sandstones and shales provide oil–gas accumulation and preservation conditions.

2.3.4.1 Stratigraphy and Lithofacies (Table 2.4)

The Jurassic System: The Jurassic System in the Qaidam Basin is composed of fluvial, lacustrine, and swamp facies which are mainly distributed in the piedmont fault depression of the Altun and Qilian mountains at the northern margin of the basin. Most of the strata are well exposed in the Dameigou and Xiaomeigou areas in the south-eastern Daqaidam area and have a thickness of 1260 m. The Lower Jurassic Xiaomeigou Formation consists of grayish yellow and grayish green conglomerates and sandstones interbedded with dark gray mudstones and black carbonaceous shales; these are also intercalated with coal beds and yield siderite concretions as well as fossil plants, and spores and pollen. The thickness is 141 m in the Xiaomeigou Section. Grain size of borehole sediments becomes finer in the Lenghu area, where thickness is more than 1000 m. The Middle Jurassic Dameigou Formation consists of grayish green and grayish yellow sandstones, conglomerates, and grayish black carbonaceous shales intercalated with coal and siderite beds; contains fossils of conchostracans, plants, and pollen; and has a thickness of 1029 m at the Dameigou Section, and in the Lenghu area, the grain size of borehole sediments also becomes finer, where thickness is more than 3000 m. The Upper Jurassic Caishiling Formation is composed of purple mudstones intercalated with sandstones and gypsum and has a thickness of 90 m. Lower–Middle Jurassic dark pelites are the main source rocks in the northern Qaidam Basin.

The Cretaceous System: The Cretaceous Quanyagou Group in the Qaidam Basin is a red clastic deposit that consists of purple, brownish red, and grayish brown sandstones and

mudstones, yielding fossils of ostracodes, conchostracans, and charophytes; the thickness is 300–2100 m.

The Tertiary System: The Tertiary is widely distributed in the Qaidam Basin, where the depositional environments left inland fluvial and lacustrine facies. Sedimentary thickness of the Tertiary is 7000 m in the Mangnai Depression of the western basin, and as much as 13,000 m in the Yiliping Depression of the central basin. The Paleocene–Eocene Lulehe Formation is mainly composed of fluvial deposits and consists primarily of dark brown and brownish red conglomerates and pschitic sandstones intercalated with brownish red and yellowish green sandstones, mudstones, and siltstones; total thickness is 200–1000 m. The Oligocene Xiaganchaigou Formation in the interior basin is a lacustrine facies that consists mainly of gray and dark gray pelites intercalated with siltstones; the thickness is 300–2800 m. The Lower Miocene Shangganchaigou Formation in the central basin is composed mainly of a lacustrine facies, consisting of gray mudstones intercalated with grayish green sandstones and siltstones; the thickness is 300–1200 m. The Upper Miocene Xiayoushashan Formation in the central basin is mainly a shallow lacustrine facies that is primarily composed of grayish green, greenish gray, and brownish red sandstones interbedded with mudstones that intercalate with light gray marlites and variegated mudstones; the thickness is 300–2000 m. The Lower Pliocene Shangyoushashan Formation at the margin of the basin is a fluvial facies; in the central basin, it forms shallow lacustrine deposits with gypsum, consisting mainly of dark brown and yellowish green sandy mudstones intercalated with grayish green sandstones, siltstones, gray marlites, and thin-bedded gypsum. Formation thickness is 150–1800 m. The Upper Pliocene Shizigou Formation is a fluvial facies, mainly composed of yellowish gray sandy mudstones intercalated with sandstones, conglomerates, and siltstones; the thickness varies from 300 to 2000 m. The thickness of the Oligocene and Miocene dark mudstones in the Mangnai Depression is over 2000 m, and the dark mudstones are the main source rocks in the basin.

Table 2.4 Potential petroleum source rock series of the Qaidam Basin

Geologic Age	Lithostratigraphic units	Code	Lithology	Lithofacies
Pliocene	Shangyoushashan Formation	N ₂ ¹	Sandy mudstones intercalated with sandstones, siltstones, and gypsum	Fluvial and lacustrine facies
Miocene	Xiayoushashan Formation	N ₁ ²	Sandstones interbedded with mudstones, intercalated with marlites	Shallow lacustrine facies
	Shanganchaigou Formation	N ₁ ¹	Gray mudstones intercalated with sandstone and siltstones	Lacustrine facies
Oligocene	Xiaganchaigou Formation	E ₃	Dark gray mudstones and siltstones	Lacustrine facies
Middle Jurassic	Dameigou formation	J _{2d}	Sandstones, conglomerates, carbonaceous shales intercalated with coal beds and siderite	Lacustrine–swamp facies
Early Jurassic	Xiaomeigou formation	J _{1x}	Sandstones, conglomerates, mudstones, carbonaceous shales intercalated with coal beds	Lacustrine–swamp facies

Note The dark pelites in the Paleo-Eocene Lulehe formation (E₁₋₂) have oil generation potential

The potential petroleum source rock series of the Qaidam Basin are shown in the Table 2.4.

2.3.4.2 Tectonic Units

The Qaidam Basin (Fig. 2.4) can be subdivided into six tectonic units, i.e., the North Border Block-fault Belt, the Mangnai Depression Belt, the Dafengshan Uplift Belt, the Yiliping Depression Belt, the Northern Kunlun Fault Terrace Belt, and the Sanhu Depression Belt. The North Border Block-fault Belt formed in the Jurassic and can be subdivided, from the west to the east, into four secondary tectonic units, i.e., the Lenghu Tectonic Fault Zone, the Mahanbaxian Anticlinal Zone, the Yuka Sag, and the Delingha Sag. The Lenghu oil field is located in the Lenghu Tectonic Fault Zone and the Yuka oil field is located in the Yuka Sag. The Mangnai Depression subsided during the Tertiary from the Oligocene to the Pliocene and is the main oil-bearing area in the basin. The Youquanzi and the Xianshuiquan oil fields were discovered in this depression. The Dafengshan Uplift Belt consists of the Jianshan, the Jiandingshan, and the Dafengshan Anticlinal Zones, and the Dafengshan oil field is located in the Dafengshan Anticlinal Zone. The Yiliping Depression Belt possesses the thickest Mesozoic–Cenozoic deposits, where the thickness is as much as 15,500 m. The Sanhu Depression Belt subsided

during the Quaternary and is thus the Quaternary gas-bearing area in the basin. The Sebei#1 and Sebei#2 gas fields were discovered there (Huang et al. 1993) (Fig. 2.4).

2.3.5 The West Jiuquan Basin

The West Jiuquan Basin (Fig. 2.5) is located in the western piedmont depression of the Qilian Mountains. It is a Mesozoic–Cenozoic continental petroliferous basin having an area of 2700 km² and a sedimentary thickness of 7000 m. Tectonically, the Qilian Caledonian fold belt is located between the Alxa Block and the Qaidam Block. The Qilian Mountains are developed on Caledonian fold basement rocks. In the northern piedmont depression of the Qilian Mountains, Carboniferous to Mesozoic–Cenozoic rocks are exposed. The Jiuquan Basin in the western part of the depression contains valuable oil and gas resources. The Carboniferous deposition was in shallow seas where marine and terrestrial rocks alternate and are only exposed in the southern part of the Jiuquan Basin. The grayish green and red clastic sediments of the Permian and the Triassic are not developed in the Jiuquan Basin, and the Upper Triassic is lacking. Due to the influence of the Indosinian and Yanshan orogenies, the depression was tilted so that the rocks are uplifted

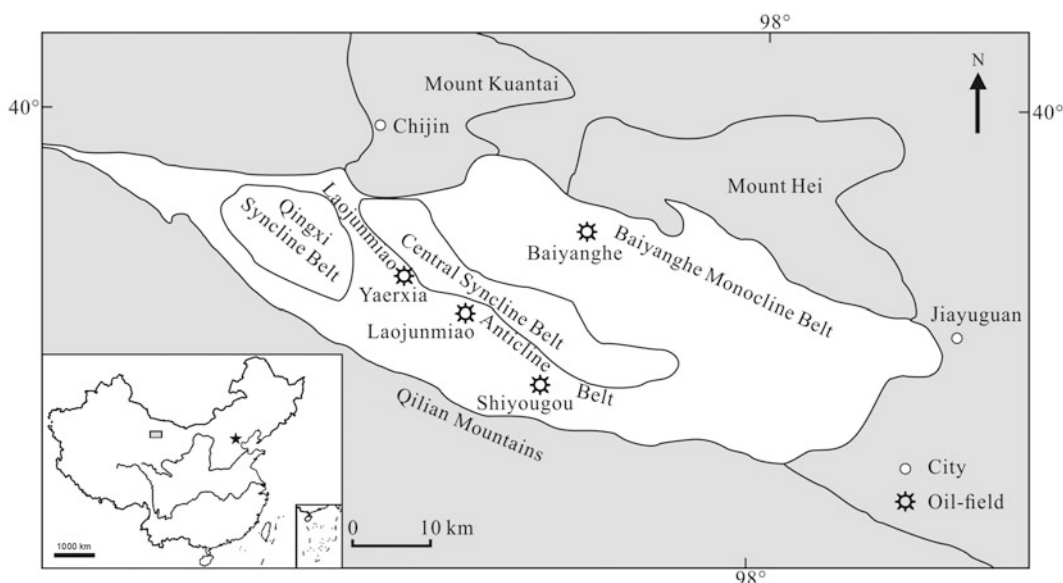


Fig. 2.5 Sketch map showing tectonic subdivisions and locations of oil fields in the West Jiuquan Basin

in the east and down dropped in the west. Jurassic and Cretaceous sediments in the basin have a total thickness of about 3600 m. The Himalayan Orogeny influenced deposition in the basin where Paleocene to Eocene rocks are thin because of regional uplift, but Late Cenozoic deposits are thick due to strong subsidence. Red clastic sediments of Cenozoic age in the basin are about 2500 m in total thickness.

2.3.5.1 Stratigraphy and Lithofacies

The Jurassic System: The Jurassic of the Western Jiuquan Basin is represented by fluvial and swamp facies, which lay disconformably over the underlying strata. The southern part of the basin contains the Longfengshan Group, which is about 1350 m in thickness, and composed of grayish green and purple sandy shale, and sandstone intercalated with conglomerate, with coal beds at the base containing plant fossils. In the northern part of the basin, the Jurassic is represented by the Chijinbao Group, which consists of grayish green and purple brecciated sandstone, and sandstone with alternations of black shale; it yields fossil plants, conchostracans, ostracodes, and bivalves and has a thickness of about 250–1440 m.

The Cretaceous System: The Cretaceous System is widely distributed in the West Jiuquan Basin, where it crops out in the Hongliuxia and Hanxia areas. The Lower Cretaceous is represented by lacustrine sediments having a total thickness as much as 1400 m, and the Upper Cretaceous is represented by a fluvial facies having a thickness of 100–1100 m. The Lower Cretaceous and Lower Huihuibao groups (Lower Xinminpu Formation) are composed of grayish black shales intercalated with grayish green sandstones and gray marl; the base of the formation is conglomerate. The formation has pyrite nodules and fossil plants, spores and pollen, conchostracans, bivalves, ostracodes, and fish and has a thickness of 300–1140 m. The Lower Xinminpu Formation lays unconformably over Precambrian or Paleozoic metamorphic rocks at the edge of the basin, but disconformably over the underlying Jurassic Chijinbao Formation in the central part of the basin. Lower Cretaceous organic-rich strata are the potential petroleum source rock series in this basin. The lithology of the Upper Cretaceous and Upper Huihuibao groups are red, gray, yellow, and green conglomerate, sandstone, and shale, with the

thickness of about 100–1100 m; it lies unconformably over the underlying Lower Huihuibao Group.

The Tertiary System: The Paleogene Huoshaogou Formation is distributed in the northern part of the West Jiuquan Basin, where it is a red clastic, fluvial facies, composed of brownish red conglomerate intercalated with gray sandstone and red sandy mudstone, about 930 m thick. The Huoshaogou Formation lies unconformably over the underlying Cretaceous strata. According to the spore–pollen assemblage, the geological age of the formation is Oligocene (Sung 1958). The Neogene, laying unconformably in contact with the underlying Huoshaogou Formation, is widely distributed in the southern and northern parts of the basin. The Miocene Baiyanghe Formation is a fluvial facies composed of red quartz sandstone and dark red mudstone intercalated with a gypsum layer, and the formation thickness is 410–470 m. The sandstone of the Baiyanghe Formation is well sorted and loosely packed and has high porosity; it is a reasonable reservoir rock, with the gypsum layer that could form a cover rock. The Pliocene Shulehe Formation is khaki sandstone and brownish yellow sandy mudstone, about 1410 m thick.

2.3.5.2 Tectonic Units

The West Jiuquan Basin (Fig. 2.5) can be divided into four tectonic units: the Laojunmiao Anticline Belt, the Central Syncline Belt, the Baiyanghe Monoclinical Belt, and the Qingxi Syncline Belt. The Laojunmiao Anticline Belt has eight anticlinal structures, including the Qingcaowan, the Yaerxia, the Laojunmiao, the Shiyougou, and the Dahongjuan structures. The Laojunmiao Anticline Belt is a relative uplift in the depression, and therefore a prospective target for petroleum migration. The anticline belt, therefore, is favorable for the accumulation of petroleum and creation of oil and gas fields. In fact, the Laojunmiao, Yaerxia, and Shiyougou oil fields have all been found in this anticline belt. The Central Syncline Belt is located in the northeast side of the Laojunmiao Anticline Belt and is the center of piedmont depression, where depth of basement is 3500–4000 m, and it contains three

buried structures. The Baiyanghe Monoclinical Belt is located in the northern part of the piedmont depression. The basement and covering strata of the Baiyanghe Monoclinical Belt are both gently south-dipping with dip angles of 3°–5°; however, the dip steepens greatly in the Central Syncline Belt, where dip angles are as much as 30°–50°. The change in dip reflects the bedrock fault. The Baiyanghe Monoclinical Belt includes the Baiyanghe, Huihuibao, and Nanshan Brachyanticlines; the Baiyanghe oil field is located in the middle part of the Baiyanghe Monoclinical Belt. The Qingxi Syncline Belt is located in the west of the Qingcaowan area, between the Hongliuxia, Hanxia, and Dongdakou areas; the depth of basement is about 4000 m (Lanzhou Institute of Geology, Academia Sinica 1960).

2.4 Coastal Shelf Petroliferous Basins

China has several coastal shelf petroliferous basins, three of which will be discussed here in detail. They are useful because of their significance to explaining the role that palynology plays both in understanding the hydrocarbon potential of such basins and in providing information about other exploration targets. These basins are the Liaohe, the Beibu Gulf, and the Zhujiang Mouth Basins.

2.4.1 The Liaohe Basin

The Liaohe Basin (Fig. 2.6) is a Cenozoic petroliferous basin in the northern Bohai Gulf area of eastern China. The land area of the basin is about 12,400 km² and the sedimentary thickness is over 8000 m. The Liaohe Basin was formed by extensional forces caused by complex motion between the Pacific and China plates following onset of the Himalayan Orogeny at the end of the Cretaceous. Complex motion included reverse torsional pressure or pressure torsion stress that twisted the China Plate on which the Liaohe Basin sits. In eastern China, the development of this twist extension formed several basins,

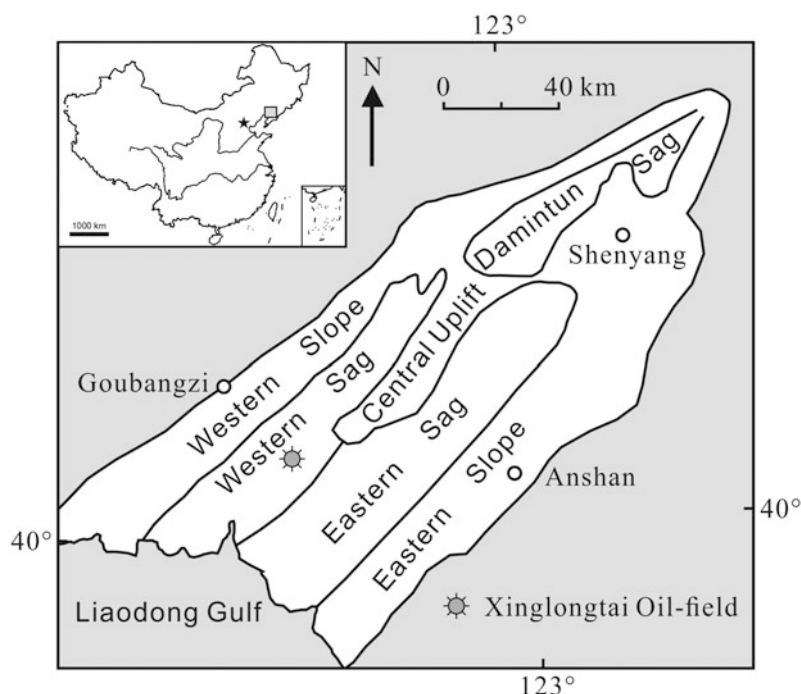


Fig. 2.6 Sketch map showing tectonic subdivisions and location of oil field in the Liaohé Basin

including the Liaohé Basin, Cenozoic sedimentary basins in north China, the Bohai Sea, and the eastern China continental shelf. Indeed, Zhu (1986) argued that interactions between the Pacific and China plates created basins on the China Plate. The location of the Liaohé Basin is close to the eastern “frontline” of the intersection of the Pacific Plate with the China Plate and is thus a Cenozoic rift-depression transformation-type basin.

The basement of the Liaohé Basin is pre-Tertiary in age. While the central parts of the basin were uplifted and the sediment stripped, downwarped edges filled with Tertiary deposits. Within the basin, the maximum thickness of Cenozoic sedimentary rocks is over 8000 m, most of which are Lower Tertiary in age.

2.4.1.1 Stratigraphy and Lithofacies

The Lower Tertiary in the coastal region of the Bohai Sea is dominated by lacustrine deposits. About ten members of three formations are recognized and have been divided in ascending order:

The Eocene Kongdian Formation is composed of three sets of red and gray coarse clastic rocks, divided into three members:

The 3rd Member of the Kongdian Formation is a red sandstone alternating with mudstones, over a basal conglomerate; it lays unconformably over pre-Cenozoic strata, with a thickness of 300–500 m.

The 2nd Member of the Kongdian Formation is a gray and dark gray mudstone with intercalations of carbonaceous shale, oil shale, coal beds, and sandstone, about 500–600 m thick.

The 1st Member of the Kongdian Formation is a red mudstone alternating with sandstone, 300–500 m thick.

The Oligocene Shahejie Formation consists mainly of gray and dark gray mudstones with four members as follows:

The 4th Member of the Shahejie Formation in the lower part is composed of red mudstone with minor thin sandstones, 150–500 m thick. The middle part is composed of bluish gray mudstone with gypsum, 100–300 m thick. The upper part is

composed of grey mudstone intercalated with carbonates and oil shale, 100–150 m thick.

The 3rd Member of the Shahejie Formation mainly consists of massive sets of gray mudstones, 500–1000 m thick, and as much as 1600 m in the Xinmin area of Liaoning Province. The lower part is composed of gray mudstone with intercalations of sandstone; the sandstone is mostly concentrated at the base, about 100–150 m thick. The middle part is composed of gray and dark gray mudstone and shale intercalated with lenticular sandy conglomerate, about 400–600 m thick. The upper part consists of gray mudstone alternating with siltstone and fine sandstone, 300–400 m thick.

The 2nd Member of the Shahejie Formation consists mainly of the sandstone with grayish green mudstone and carbonaceous shale in the lower part; the upper part is a grayish green and red mudstone, 100–250 m thick.

The 1st Member of the Shahejie Formation consists mainly of mudstone, with intercalations of shale and carbonates. The lower part is composed of gray mudstone intercalated with shale, shale, limestone, and dolomite, 100–200 m thick. The upper part is composed of gray and dark gray mudstone with a small amount of sandstone, 100–200 m thick.

The Oligocene Dongying Formation is composed of gray and dark gray mudstones intercalated with sandstones; deposition was greatest in the Eastern Hebei Plain where the sediment is 1000–1500 m thick. Away from there, it gradually becomes courser and thinner. Three members are divided as follows:

The 3rd Member of the Dongying Formation consists of gray mudstone with carbonaceous shale and sandstone, and the thickness is as much as 800 m in Eastern Hebei Plain. In the lower distributary of Liaohe River area, the unit is more sandy and thinner.

The 2nd Member of the Dongying Formation is gray mudstone with sandstone, about 300–500 m thick.

The 1st Member of the Dongying Formation is brownish red and grayish green mudstone with intercalations of sandstone, 0–300 m in thickness. It lays unconformably below the overlying Guantao Formation of Neogene age.

Based on investigations on fossil algae, and spore and pollen assemblages, the upper part of the 4th Member of the Shahejie Formation is equivalent to the marine facies in the Kenli, Boxing, and Bingxian areas of Shandong Province; the 3rd Member of the Shahejie Formation is a brackish water facies; the 2nd Member of the Shahejie Formation is a freshwater lacustrine facies; the lower part of the 1st Member of the Shahejie Formation is a semi-brackish water facies, while the upper part of this member is a fresh water facies; the 3rd and 2nd members of the Dongying Formation represent semi-brackish to littoral facies; and the 1st Member of this formation is a continental freshwater facies (Research Institute of Petroleum Exploration and Development, Ministry of Petroleum Chemistry Industry, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences 1978b).

2.4.1.2 Tectonic Units and Oil-Gas Reservoirs

In the Liaohe Basin (Fig. 2.6), six tectonic units can be subdivided, including Damintun Sag, Eastern Sag, Western Sag, Central Uplift, West Slope, and Eastern Slope. In the Western Sag, the 3rd Member of the Shahejie Formation is a deep lake facies, consisting of dark mudstone with turbidite rock, thereby being an excellent example of a reservoir and seal complex favorable for the formation of oil and gas reservoirs. Founded in 1972, the Xinglongtai oil field has a turbidite reservoir that is located in the Western Sag. The Xinglongtai oil field is dominated by oil, with an association to an oil-type gas reservoir. The lacustrine mudstone in the Shahejie and Dongying formations is the ideal gas source rock, and indeed, the gas output is greater than the oil output. The natural gas production in the Liaohe Basin ranks second in China (Xu et al. 1994, 2000).

2.4.2 The Beibu Gulf Basin

The South China Sea is the largest marginal sea of the northwest Pacific Ocean, bearing remarkable oil and gas resources. Along the northern

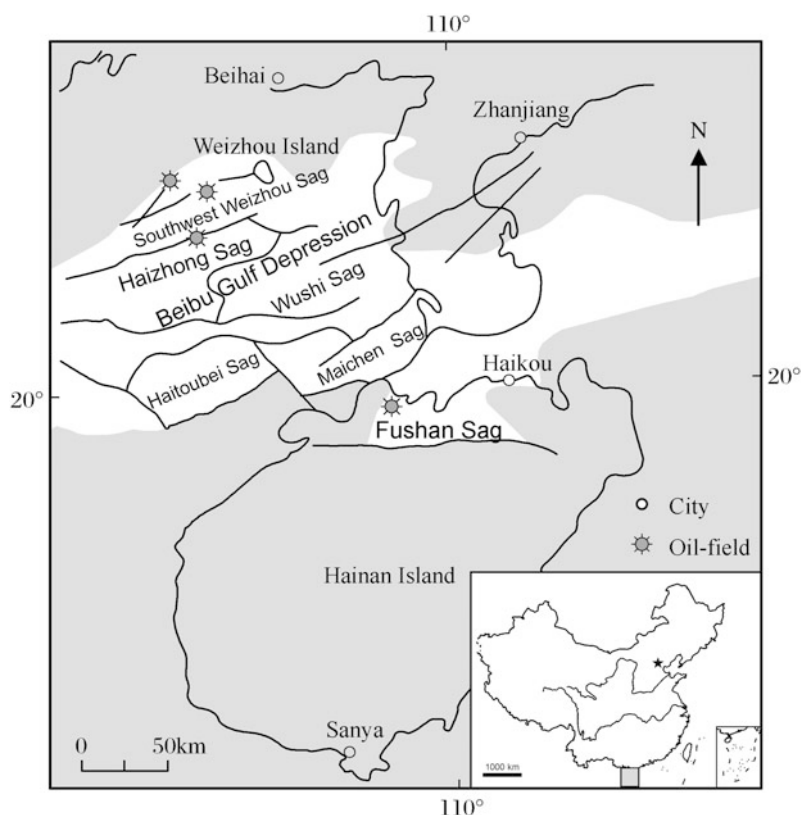


Fig. 2.7 Sketch map showing tectonic subdivisions and locations of oil fields in the Beibu Gulf Basin

continental shelf of South Sea, there are three large Cenozoic petroliferous basins, including the Beibu Gulf Basin, the Yinggehai Basin, and the Zhujiang Mouth Basin.

The Beibu Gulf Basin (Fig. 2.7) lies in the Beibu Gulf Depression of the western North Shelf of South China Sea. It is located east of longitude 108°, offshore of the Leizhou Peninsula, and north of latitude 35°19' to Qinzhou area of Guangxi Autonomous Region and covers an area of about 40,000 km². The basin is a Cenozoic petroliferous basin, and is developed on Paleozoic basement and Yanshanian granite to form a large fault depression to depression-type basin, with a sedimentary thickness of 7000 m. The embryonic basin was formed in the Late Cretaceous, and the fault tectonic framework

formed during Late Yanshanian Orogeny and was inherited and transformed in the Tertiary Himalayan Orogeny, thereby creating the Beibu Gulf Basin in the Tertiary. The Beibu Gulf Basin predominantly filled in the Paleogene when a set of lacustrine facies sediments were deposited, consisting of the Changliu, Liushagang, and Weizhou formations in ascending order, with a total thickness of as much as 6000 m. During the Neogene period, new oceanic crust was formed and further expanded in the South China Sea. As sea level began to rise, coastal and shallow marine facies clastic sediments were deposited in the Beibu Gulf Basin. Deposition in the basin, in ascending order, included the Xiayang, Jiaowei, Dengloulujiao, and the Wangloulou formations, with a total thickness of 1200–2000 m.

2.4.2.1 Stratigraphy and Lithofacies

The Paleocene Changliu Formation is characterized by pluvial to alluvial facies deposits, consisting of brownish gray mudstones with alternations of gravel layers, about 40–840 m thick.

The Eocene–Oligocene Liushagang Formation represents a littoral lacustrine deposit, consisting of grayish black and dark gray mudstone, beige shale, and oil shale. The lower part bears an oil-bearing coarse-grained sandstone, and the upper part is a grayish white fine-grained sandstone; formation thickness is as much as 4400 m. The solitary dark argillaceous rock layer in the Liushagang Formation is 500 m thick, where its depositional environment was a deep anoxic basin, and it is the major oil source rock series in the Beibu Gulf Basin. The dark mudstone with intercalations of sandstone may represent turbidites of the deep lake facies and is a potential target layer for oil exploration.

The Middle Oligocene Weizhou Formation represents alternation of marine and terrestrial facies, consisting of variegated mudstone and silty mudstone with alternations of sandstone and gravel; the middle part is composed of dark gray mudstone. The maximum thickness is as much as 2000 m, with 766.5 m in the Wan #2 Well.

The Lower Miocene Xiayang Formation is a coastal shoal facies. The lithology consists of greenish gray gravels, coarse sandstone with intercalations of gray mudstone, and sandy dolomite; the thickness is 235 m in the Wan #2 Well.

The Middle Miocene Jiaowei Formation is a shallow marine facies; the lower part consists of grayish green fine sandstone alternating with mudstone; the upper part is composed of a gray thick mudstone. Formation thickness is 264.5 m in the Wan #2 Well.

The Upper Miocene Denglougiao Formation is a shallow marine facies. The lower part consists of grayish yellow sandy gravels; the middle part is dominated by gray mudstone with intercalations of muddy gravels. The upper part is marked by grayish yellow coarse-grained sandstone and conglomerates with gray mudstone. Formation thickness is 383 m in the Wan #2 Well.

The Upper Miocene Wanglougang Formation is a littoral facies. The lower part consists of gray mudstone with intercalations of grayish yellow sandstone; the middle part is grayish yellow sandstones with alternations of mudstones. The upper part is grayish yellow, sandy conglomerates. Formation thickness is 282.5 m in Wan #2 Well.

The dark mudstone in the Liushagang Formation is rich in organic matter that creates a thick sedimentary unit that could be the major hydrocarbon source rock in the basin. The 3rd Member of the Liushagang Formation contains massive thick dark mudstone intercalated with sandstone, indicating a good reservoir potential. In addition, in the Weizhou, Xiayang, and Jiaowei formations contain sandstones that could be productive oil reservoirs (Zeng and Guo 1981).

2.4.2.2 Tectonic Units and Oil–Gas Reservoirs

There are six sags in the Beibu Gulf Depression (Fig. 2.7), including the Southwest Weizhou, Haizhong, Wushi, Haitoubai, Maichen, and Fushan Sags. Abundant oil has been extracted by industry from the Southwest Weizhou, Wushi, and Fushan sags since exploration began in the 1970s. For example, the Wan #2 Well in the Southwest Weizhou Sag has produced oil in the sandstones of the 3rd Member of the Liushagang Formation; the Wan #5 Well has produced oil in the sandstone reservoir of the Xiayangjiao and Jiaowei formations; the Wan #11 Well in the Wushi Sag has produced oil in the 1st sandstone reservoir of the Liushagang Formation; and the Fu #23, Fu #28, and Fu #29 wells in the Fushan Sag have produced oil in the sandstone reservoirs of the Weizhou Formation (Zeng and Guo 1981).

2.4.3 The Zhujiang Mouth Basin

The Zhujiang Mouth Basin (Fig. 2.8) is one of three Cenozoic basins on the northern continental shelf of the South China Sea. The basin is bounded at the north by Guangdong Province, at the south by the Xisha Islands, at the west by

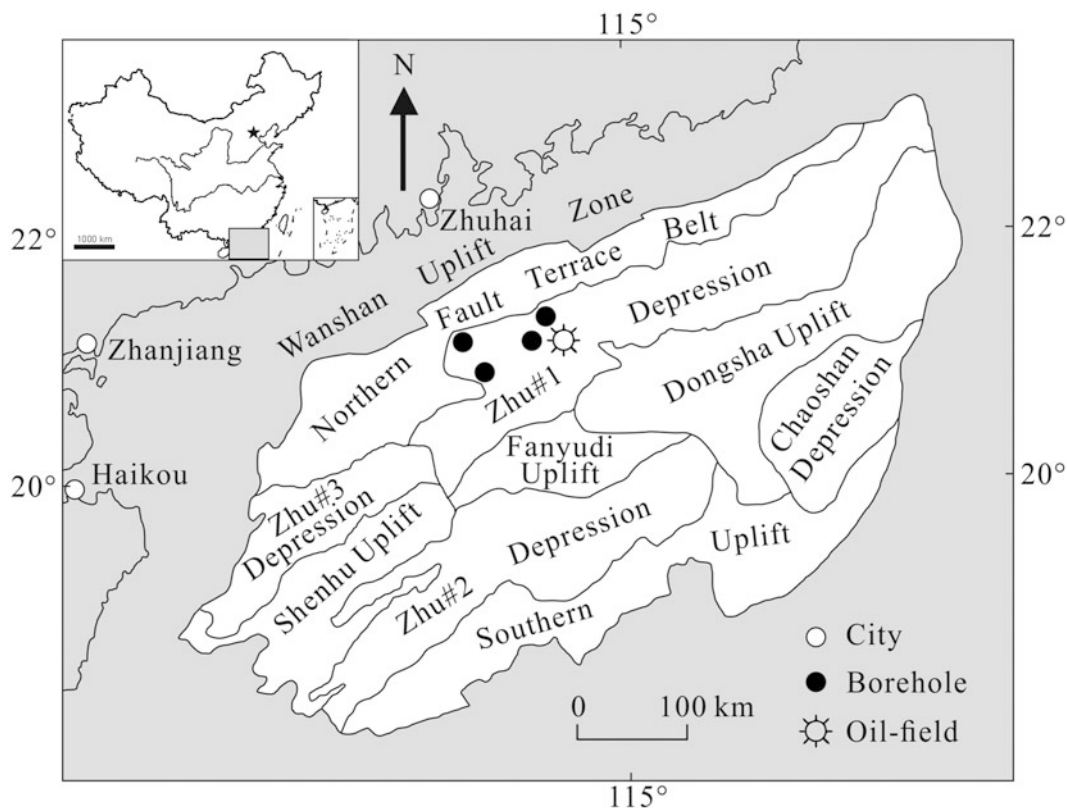


Fig. 2.8 Sketch map showing tectonic subdivisions and locations of oil fields and boreholes in the Zhujiang Mouth Basin

Hainan Island, and adjacent to the Dongsha Islands at the east. It is located in between longitude 110°–117°E and latitude 19°–22°N and covers an area of 150,000 km².

Tectonically, the basin lies in the Zhujiang Mouth Depression of the eastern North Shelf of the South China Sea. It is bounded at the north by the Wanshan Uplift Zone, at the south by the North Xisha Fault Belt, at the west by the Hainan Uplift Zone, and at the east by the Dongsha Uplift. This basin developed on Caledonian, Hercynian, and Yanshanian fold basement; sedimentary thickness is about 8000–10,000 m. The basin was formed in the Middle Eocene due to the influence of Himalayan Orogeny. At that time, a series of graben fault depressions were formed in the south Wanshan Uplift area; they

filled with lacustrine facies deposits that are Eocene to Oligocene in age. In the Early Miocene, north–south differences in uplift and the activity of a NE fault resulted in creating land to the north of the Wanshan Uplift; to the south, downdropping laid a foundation for unification of the individual basins creating the Zhujiang Mouth Basin following the Miocene when there was large-scale marine transgression.

The maximum thickness of the Tertiary in wells in the Zhujiang Mouth Basin is as much as 4620 m. Paleogene deposition was mainly terrestrial, consisting of the Shenhu, Wenchang, Enping, and Zhuhai formations, in ascending order. Neogene deposition was marine, consisting of the Zhujiang, Hanjiang, Yuehai, and Wanshan formations, in ascending order.

2.4.3.1 Stratigraphy and Lithofacies

The Paleocene to Lower Eocene Shenhu Formation is a fluvial facies, consisting mainly of grayish white and brownish red sandstone with alternations of mudstone, with a maximum thickness of 95 m.

The Middle Eocene Wenchang Formation is a lacustrine facies deposit, consisting mainly of dark gray and grayish black mudstone and shale, with grayish white sandstone. The maximum drilled thickness is 1110 m.

The Upper Eocene to Middle Oligocene Enping Formation is a lacustrine and swamp facies, consisting mainly of light gray sandstone with alternations of gray and dark gray mudstone and siltstone with thin coal beds. The maximum drilled thickness is 2055 m.

The Upper Oligocene Zhuhai Formation is a lacustrine and littoral facies, consisting mainly of light gray and gray white fine conglomerates, argillaceous sandstone, dolomitic fine sandstone, argillaceous siltstone, and dark gray silty mudstone with intercalations of multilayers of fine sandstone, oil sands, oil shale, bituminous shale and lignite, and occasional glauconite. The drilled thickness is 730–817 m.

The Lower Miocene Zhujiang Formation is a littoral and shallow marine facies, consisting mainly of light gray sandstone, siltstone with intercalations of dark gray mudstone, bituminous shale and oil shale, and containing minor glauconite. The drilled thickness is 210–1180 m.

The Middle Miocene Hanjiang Formation is a littoral and shallow marine facies; the lower part consists of light gray and grayish green sandstone and mudstone with alternations of mudstone and limestone; the upper part is composed of dark gray silty mudstone with intercalations of asphalt-bearing shale and sandstone. Southward in the Shenhua Uplift area, the formation becomes a fossiliferous reef limestone, containing glauconite and foraminifera. The drilled thickness is 90–709 m.

The Upper Miocene Yuehai Formation is a shallow sea facies, consisting mainly of light gray and gray silty mudstone, and argillaceous siltstone with alternations of different thicknesses of gray fine-grained conglomerates with gray

sandstone and thin layers of limestone. The drilled thickness is 51–382 m.

The Pliocene Wanshan Formation is a set of shallow marine facies composed of nonconsolidated sediment. It consists of gray clay and silty clay with light gray sand layers and contains glauconite, fossil foraminifera, and bioclastics. The drilled thickness is 208–644 m.

2.4.3.2 Tectonic Units and Oil Fields

The tectonic framework of the Zhujiang Mouth Basin (Fig. 2.8) is that of north–south zonation and east–west block faulting. The basin is arranged from north to south as a series of E–N–E trending uplifts and depressions. A series of graben faults that formed during the Middle Yanshan Orogeny trends in a west to east direction. Within the basin, about eight tectonic units are subdivided, including the Northern Fault Terrace Belt, Zhu#1 Depression, Zhu#2 Depression, Zhu#3 Depression, Central fold belt, Weitan Uplift, Shenhua Uplift, and the South Slope. The Zhu#5 Well in the western part of the Zhu#2 Depression of the northeastern basin began oil production in August 1979, thereby becoming an important prospect for further oil and gas exploration and development of this basin (Zeng and Guo 1981; Jiang et al. 1994).

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