Reservoir and seal rock distribution and controlling factors in hydrocarbon-bearing rift basins of China

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Abstract: Hydrocarbon-bearing rift basins of China are mostly found in the Mesozoic and Cenozoic of eastern China. It can be divided into two types, namely the continental margin type represented by the Pearl River Mouth basin and East China Sea basin and the intercontinental type, examples being Songliao basin, Bohai Bay basin and South Huabei basin. Except for some rift basins of the continental margin type which show marine influence during the rift period, the majority of the basins are rift lakes. They give rise to the unique characteristics of terrestrial petroliferous basins of China.

Exploration of rift basins proved that reservoirs in them are mainly of fluvial-delta, fan delta, bar and turbidite sand bodies formed at the rift stage and post-rift stage. Seals are mainly of lacustrine mudstone of rift stage and lacustrine mudstone or shallow marine mudstone of post-rift stage. Factors which controlled the distribution of reservoir and seal rock include a) faulting activities, b) rift basin evolution, c) ancient river, d) palaeotopography and old source region, e) palaeoclimate, and f) change of lake level, are discussed in detail.

INTRODUCTION

The Chinese hydrocarbon-bearing rift basins mostly developed during the Mesozoic and Cenozoic and are presented in the eastern part of the continent and offshore (Fig. 1). In China, 90% of the discovered reserves up to present are from these basins. The study of their development of the rift basins as well as the occurrence of reservoir and seal during the evolution process directly affected the planning of hydrocarbon exploration, and is helpful for increasing the exploration success ratio. It is obvious that the study on the occurrence of reservoir and seal as well as their controlling factors in the Chinese rift basins is of great significance.

TYPE AND CHARACTERISTICS OF CHINESE HYDROCARBON-BEARING RIFT BASINS

The formation of rift basins is generally related extension in the crust of the earth. During the end of Mesozoic and early Cenozoic, seafloor spreading of the Pacific Ocean plate and the subduction of the Pacific-Kula plate caused the elevation of hot mantle, spreading of flexible flow, cracking of crust and rifting of continental segments. Finally, a series of rift basins in the eastern part of the continent and offshore China were formed.

Type of rift basins

Summarizing the research achievements (Li Desheng, 1980, 1983; Zhu Xia *et al.*, 1982), the hydrocarbon-bearing rift basins in eastern and offshore China can be divided into 2 types.

1. Rift basins in the continental margin (including rift basins developed both on passive and active continental margins). Because basins of this type mostly developed in the transitional zone of marine and continent, sea water encroach into the basin during the basin developing process. The basins are usually characterized by isolated rift-subsidence lakes in the early stages, and successively reach the depression development stage which is marked by bay and lagoon deposition with increasing marine influences (Fig. 2). Some typical basins of this kind are Pearl River Mouth, Qiongdongnan, Yinggehai and East China Sea basins, etc. (Table 1).
2. Intracontinental rift basins. They developed within the continental plate or platform. During the development process, there is only little marine influences. Because the rift basins within the eastern China continental platform are near to the continental margin, momentary marine transgression occasionally took place during the developing stage. The entire development process of these rift basins is

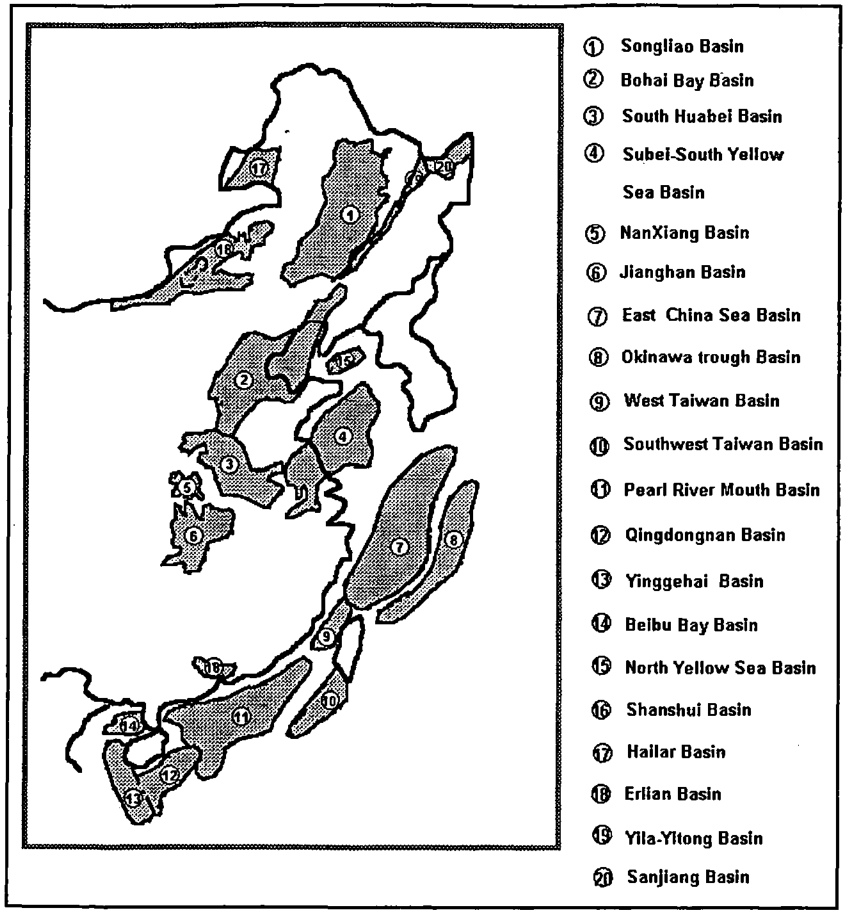


Figure 1. Distribution of hydrocarbon-bearing rift basins in eastern onshore and offshore China.

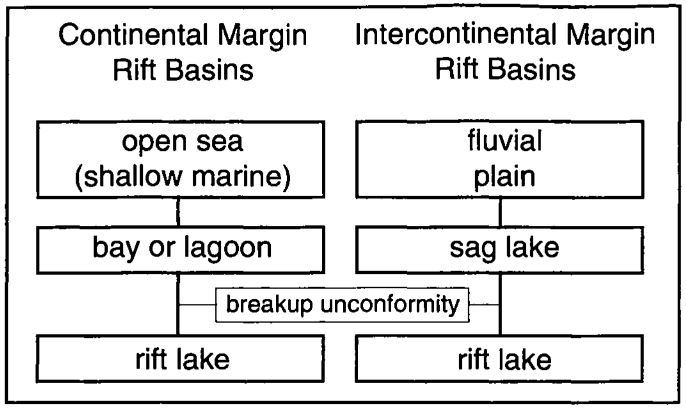


Figure 2. Evolution route of rift basins of China. Different evolution route can be seen between rift basins of continental margin type and intercontinental type after breakup unconformity.

Table 1. Classification of hydrocarbon-bearing rift basins of China.

Basin Type	Continental Margin Rift Basin	Inter-Continental Rift Basin
BASINS	Pearl River Mouth Qiongdongnan basin Yinggehai basin Beibu Bay basin East China Sea basin Subei-South Yellow Sea basin North yellow Sea basin Southwest Taiwan basin West Taiwan basin	Songliao basin Southern huabei basin Erlian basin Hailar basin Yila Yitong basin Sanjiang basin Nanxiang basin Jianghan basin Sanshui basin Northern Huabei basin Bohai Bay basin

therefore in the continental lacustrine environment (Fig. 2). This kind of basin is represented by Songliao, Jianghan, south Huabei and Nanxian basins (Table 1).

Characteristics of the rift basins

The hydrocarbon-bearing rift basins in the eastern China and offshore have inherited particular features themselves that characterise the Chinese petroliferous basins.

1. Features in general

a. Most of the rift basins are stretched in the NNE or NE direction, which is basically identical with the regional strike of the crystalline basement in eastern China (Fig. 1).
b. Represented by negative Bouguer anomaly, the thickness of the continental crust beneath the rift basins is thinner than the surrounding crust as a mirror response, such as Songliao.
c. The basins have high heat flow values and high geothermal gradient of 3–4.5°C/100 m in general (Table 2).
d. Frequent volcanic activities took place, especially at the early development stage of the rift basins.

Table 2. Mean geothermal gradient comparison between some rift-basins and compressional basins.

Type	Basins	Mean Geothermal Gradient (°C/100 m)
RIFT BASINS	Songliao Basin	3.9
	Bohai Bay Basin	3.6
	Nanxiang Basin	4.1
	East China Sea Basin	3.5
	Beibu Bay Basin	3.0
	Qiongdongnan Basin	4.0
	Yinggehai Basin	4.5
	Pearl River Mouth Basin	4.0
	Erlian Basin	3.8
COMPRESSIONAL BASINS	Sichuan Basin	2.4
	Tarim Basin	2.2
	Shan Gan Ning Basin	2.9
	Tuha Basin	2.4
	Junggar Basin	2.2
	Qaidam Basin	2.8

2. Evolution characteristics

a. The basin mainly experienced 2 evolution stages, i.e., rift and post-rift stages. The rift stage can be further divided into early rift stage, deep-downwarping stage and late rift stage. The basin evolution represented by slow-fast-slow sedimentary rate, corresponding to the complete cycle of coarse-fine-coarse deposits (Table 3).
b. The sedimentary fill of rift basin is of a double-layered structure which corresponds to the development and evolution stages of the rift basin. Most of the rift basins possess characteristics of multi-cycles complex. During the developing process of rift and post-rift stages, compressive fold structures often formed in the late stage due to influences of one or more episodes of tectonic movements which are represented by uplifting, compression and folding.
c. The rift basins in the early stage are featured by half-grabens and a few grabens. The half-graben consists of a growth fault at one edge and one oblique fault at another edge which is the top surface of the Pre-Tertiary (or older basement) developed with second order basement faults. This constituted the buried-hill zone (Fig. 3). Many of the Chinese rift basins have these features and form big oil and gas fields, typified by Renqiu oil field (Liang Shengzheng *et al.*, 1991) at Bohai Bay basin (Fig. 4).
d. The development of the basins is earlier in the North than in the South. The rift stage of the basins in the North, bounded by the Inner Mongolia earth axis, such as the Songliao, Erlian and Hailaer basins, was in Jurassic.

Table 3. Evolution characteristics of rift basins of China.

Evolution Stage		Subsidence Rate	Deposition Rate	Grain Size Size	Deposits Colour	Deposition Feature	Deposition Rate
Post-rift Stage	late (II_2)	slow	slow	coarse	light	compensated	< 200 m/Ma
	early (II_1)	fast	relatively fast	fine	light to dark	starved	200–300 m/Ma
Rift-Stage	late (I_3)	slow	relatively fast	relatively coarse	light to dark	compensated	200 m/Ma
	deep-downwarping (I_2)	fast	fast	fine	dark	starved	200–400 m/Ma
	early (I_1)	slow	slow	coarse	variegated	filling deposition	< 200 m/Ma

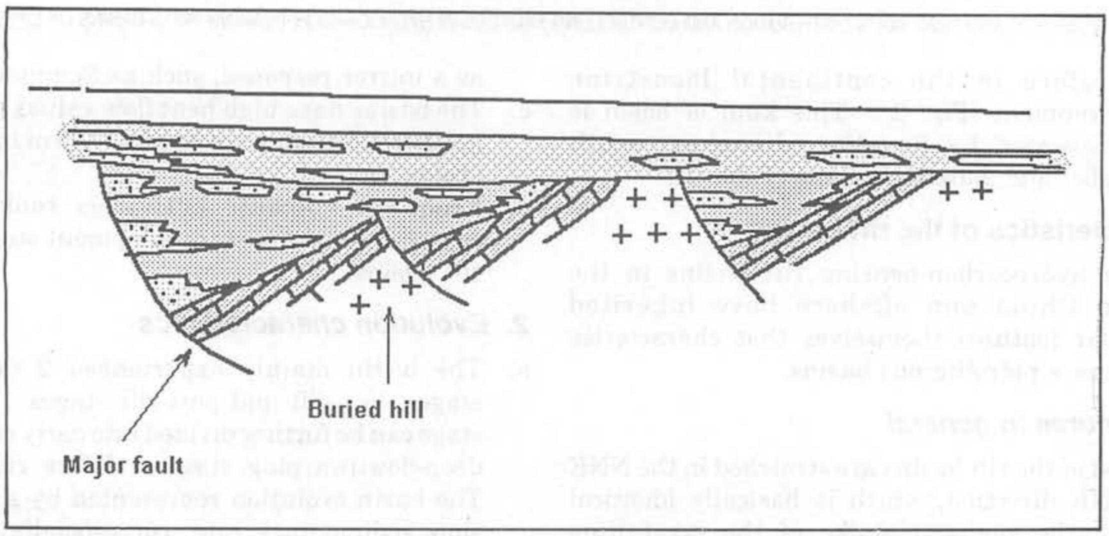


Figure 3. Schematic map showing the internal structure in half-graben and tilted fault block.

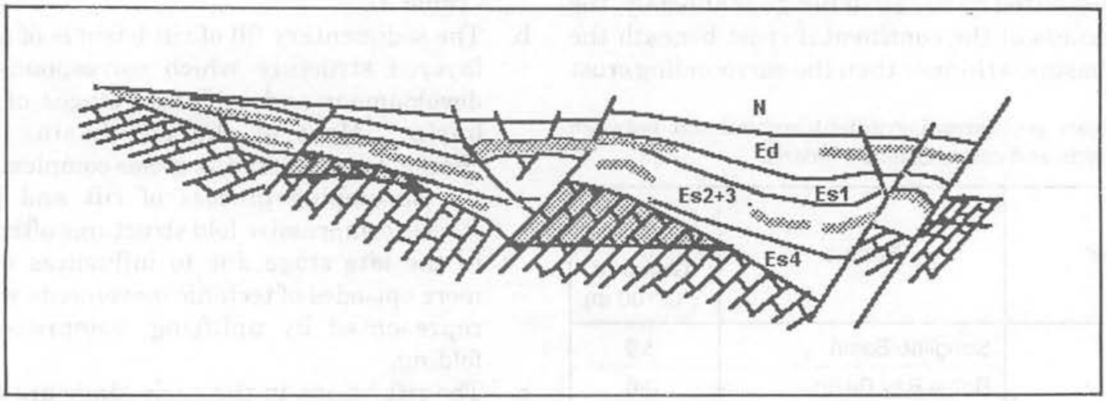


Figure 4. Renqiu oil field, Jizhong depression representing the buried hill oil reservoir in the Bohai Bay basin (Based on Liang Shengzheng *et al.*, 1991).

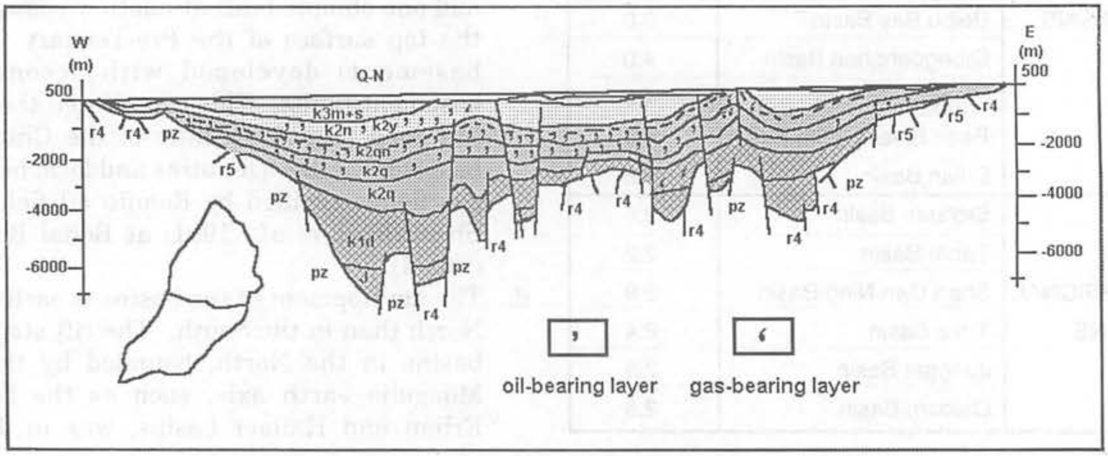


Figure 5. Cross-section of the Songliao basin (Modified from Yang Jiliang, 1990).

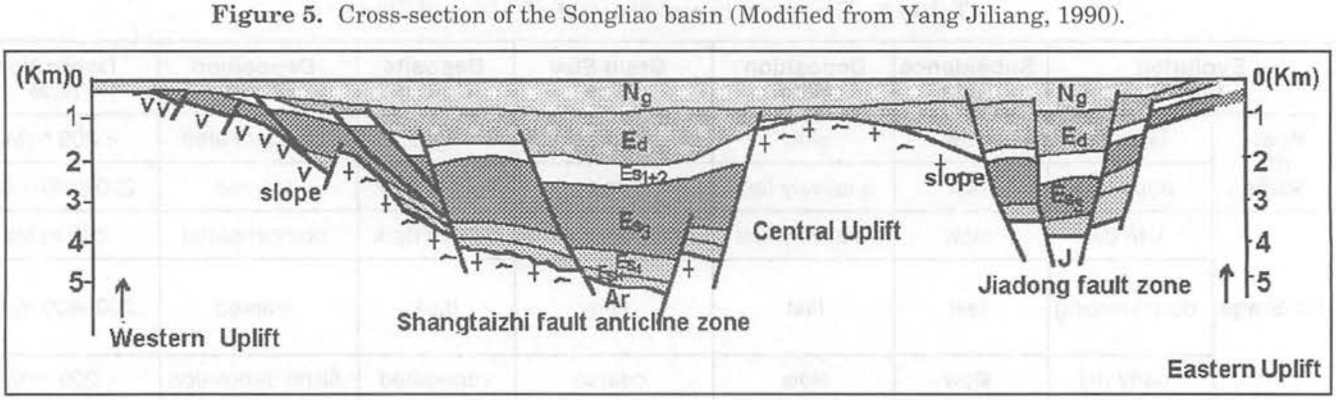


Figure 6. Cross-section of the Liaohe depression (based on Wang Shangwen, 1983).

Their post-rift stage was during Cretaceous. The basins were uplifted, folded, shrunk and disappeared in Tertiary. The rift stage of most basins in the South was in the Paleogene and the post rift stage in the Neogene (Figs. 5, 6, 7). In addition, the basins in the North are relatively simple as single cycle structures, while most of the basins in the South are of multiple depositional cycles.

e. In the same basin, the rift development stage in the West is earlier than in the East, for example, the Jizhong depression of the Bohai Bay basin (Fig. 8), the north Taiwan depression (rift stage during Late Cretaceous-Paleocene) and the Zhedong depression of the East China Sea basin (rift stage during Eocene) (Fig. 10). The Pearl River Mouth basin and some other rift basins also show the same situation.

OCCURRENCE OF RESERVOIR AND SEAL IN THE CHINESE HYDROCARBON BEARING RIFT BASINS

During the development process of rift basins, the distribution of reservoir and seal has certain relationships in the time-space domain.

Distribution of reservoir formation

The distribution of reservoir is closely associated with the development of rift basins, i.e., the different development stage has different reservoir distribution (Tables 4, 5, Fig. 10). In the early development stage of rift basins, the reservoir distribution is obviously controlled by the rift with dominance of diluvial, alluvial and turbidite fan deposits from near sources, and the rift lake basins were filled completely in this stage. When the basin reached the deep-downwarping stage, the subsidence rate increased and the extent of the lake basins enlarged gradually, resulting in the development of delta and littoral sand bodies in the gentle slope, fan delta and turbidite sand bodies in the abrupt slope, and beach sand bars on the highs of buried-hills. In the late rift stage, the subsidence rate decreased and the water body became shallower gradually. The well-developed delta prograded successively lakeward and distributed along the long axis of the basin overlain by fluvial sand bodies. At the end of the rift stage, some basins underwent a process of elevation and erosion. The

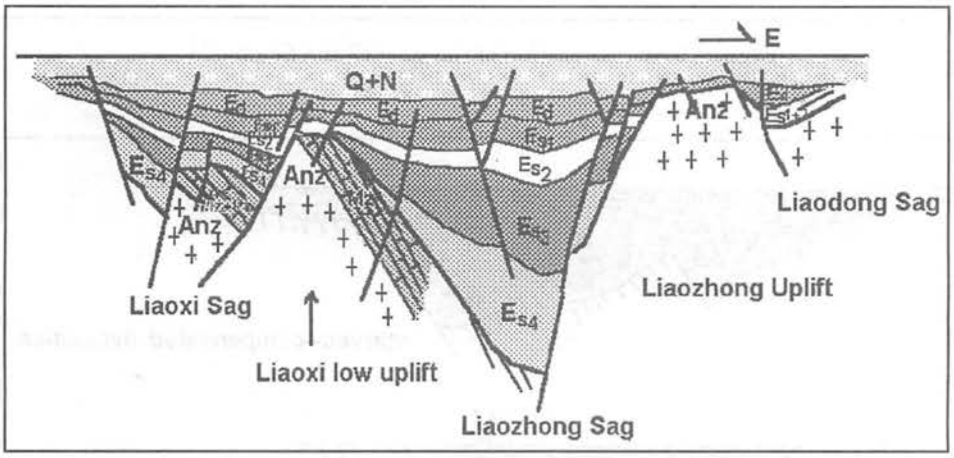


Figure 7. Cross-section of the Liaodong Bay area.

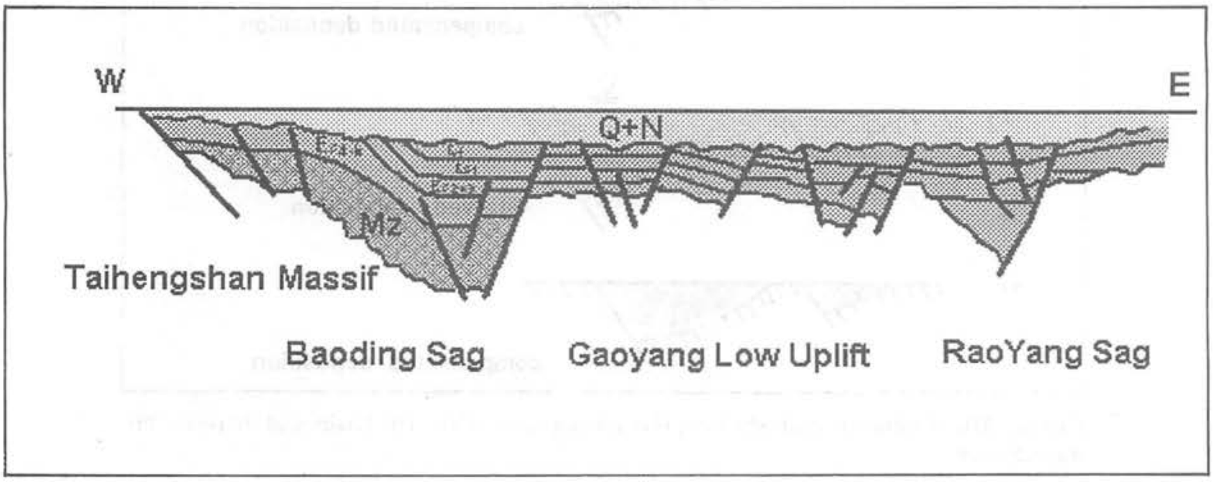


Figure 8. Cross-section of Jizhong depression in the Bohai Bay basin (based on Wang Shangwen, 1983).

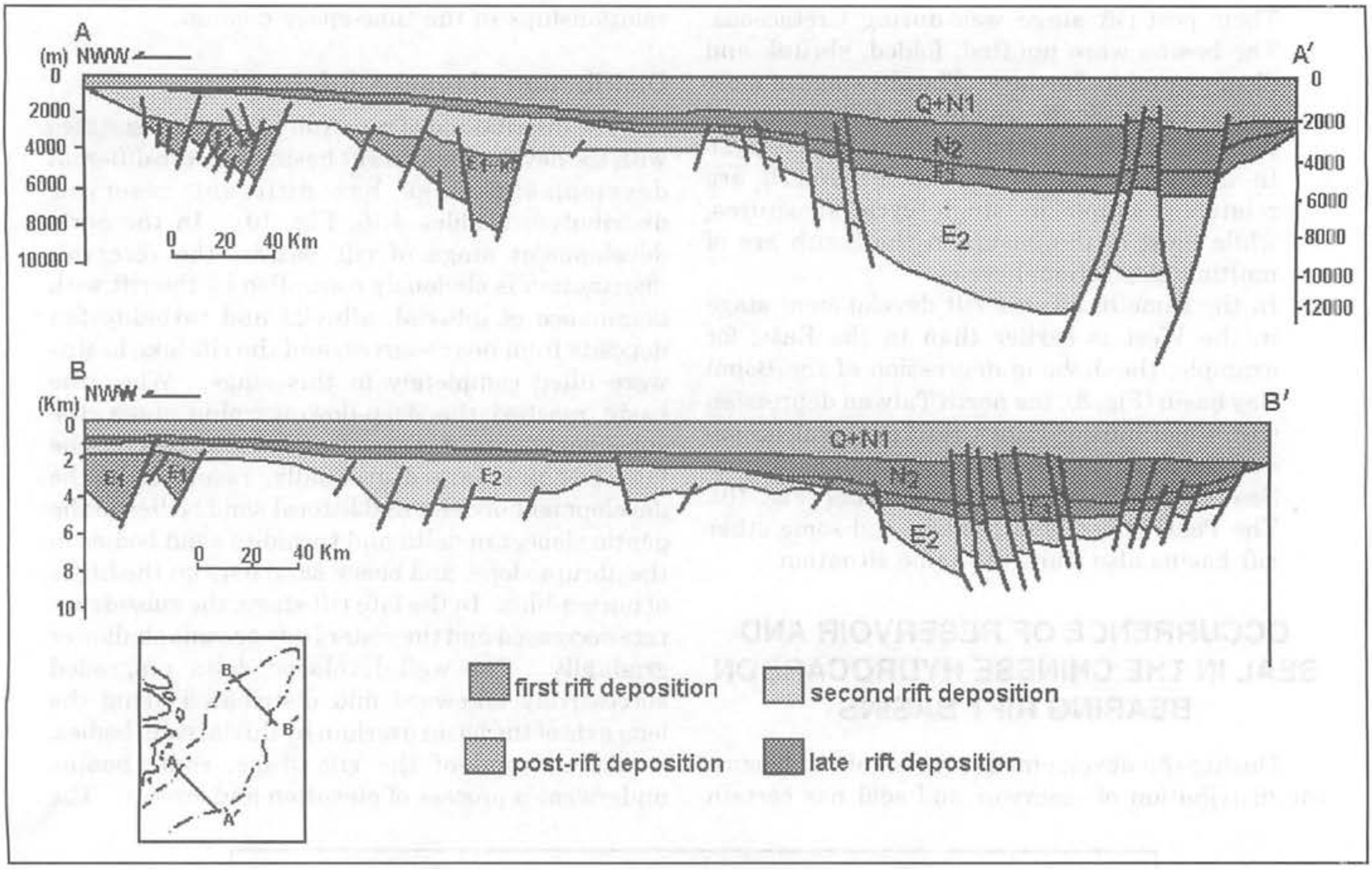


Figure 9. Cross-section of the East China Sea basin.

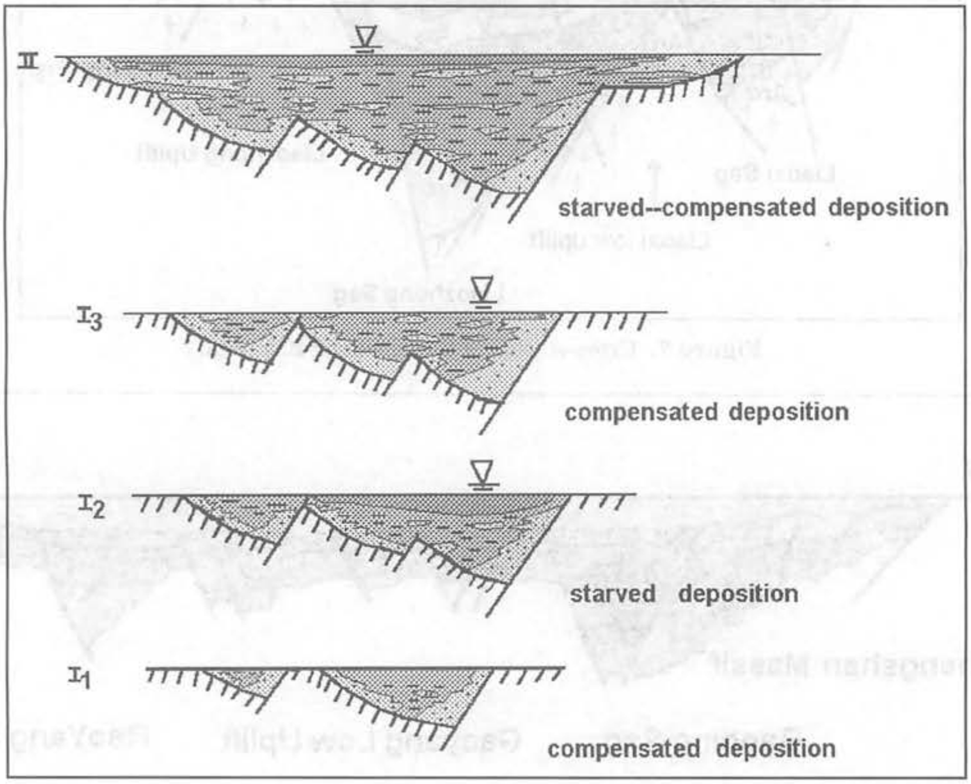


Figure 10. Schematic map showing the development of the rift basin and its reservoir distribution.

Table 4. Evolution characteristics of rift basins of China.

EVOLUTION STAGE		RESERVOIR CHARACTERISTICS		SEAL CHARACTERISTICS	
		Continental Margin Type	Inter-Continental Type	Continental Margin Type	Inter-Continental Type
Post-rift Stage		Tidal sand, tidal delta, delta sand, reef and organic bank	Delta sand, shore sand, channel sand, shoal and sand bank	Bay and neritic mudstone can be regional seal bed	Lacustrine mudstone can be regional seal bed
Rift-Stage	Late rift (I_3)	Delta sand, especially large scale delta along long axis of basin; shore sand and channel sand		Shallow-water mudstone act as local cap rock	
	deep-downwarping rift (I_2)	Delta sand developed on backlimb; shore sand; fan-delta of abrupt slope; turbidites at deep water		Thick lacustrine mudstone act as regional cap rock; slat-grysum at some basins	
	early rift (I_1)	Pluvian fan; alluvial fan and turbidites; occasionally fan-delta sand		Lacustrine mudstone act as local cap rock; salt and gypsum at some basins.	

Table 5. Reservoirs of major oil/gas fields in rift-basins of China.

Basins (Depressions)	Oil/Gas Fields	Major Pay Zone	Major Reservoirs	Rift-Subsidence Stage
Songliao	Daqing oil field	Kqn, Ky	delta sand, lake-arm sand	I_3-II_1
Jiyang	Shengtuo oil field	Es_2	delta sand	I_3
Jiyang	Dongxin oil field	Es_2	delta sand	I_3
Jiyang	Chengdao oil field	upper Ng	fluvial-river sand	II_2
Jiyang	Gudong oil field	upper Ng	fluvial-river sand	II_2
Jiyang	Gudao oil field	upper Ng	fluvial-river sand	II_2
Huanghua	Zaoyuan oil field	Mz, Es_4+Ek	river and lakeshore sand	I_1
Jizhong	Renqiu oil field	Zjw	carbonate fractures	
Dongpu	Pucheng oil field	Es_2, Es_3, Es_4	delta, submerged fan & lakeshre	I_{2-3}
Dongpu	Wenliu oil field	Es_2, Es_3, Es_5	delta and lakeshore sand	I_{2-3}
Liaodong Bay	SZ36-1 oil field	lower Ed	delta, submerged fan & lakeshore	I_2
Liaohe	Gaosheng oil field	Es_4	bank-bar sand	I_1
Liaohe	Shuguang oil field	Es_3-Es_4, Pt, Ar	delta sand, buried hill	I_2
Liaohe	Huanxiling oil field	Es_3-Es_4, Ar	delta sand, buried hill	I_2
Biyang	Shuanghe oil field	Eh_2, Eh_3	submerged fan sand	I_{2-3}
Pearl River Mouth	LH11-1 oil field	lower N_1	reef and organic bank	II_1
Qiongdongnan	Ya13-1 gas field	lower E_3	marine sand	II_1

Table 6. Regional seal beds of major rift-basins of China.

Rift-Basins	Regional Seal Beds	Geological Time
Songliao Basin	Lacustrine mudstone	K
Bohai Bay Basin	Lacustrine mudstone, dolostone, oil shale	Es_3, Es_1, Ed
East China Sea Basin	Gulf or bay facies mudstone	E_1, E2
Nanxiang Basin	Lacustrine mudstone, dolostone, oil shale	Eh_{3-2}
Pearl River Mouth Basin	Semi-enclosed-marine mudstone	N_1
Beibu Bay Basin	Lacustrine mudstone	E_2
Qiongdongnan Basin	Semi-enclosed-marine mudstone	N_1
Yinggehai Basin	Neritic mudstone	N_2

basin then entered into the post-rift stage of thermal subsidence. During the post-rift stage, the isolated rift lakes merged together and enlarged the water body. During this time, the continental rift basins usually communicated with the open sea, forming gulf or lagoon as well as semi-enclosed shallow marine deposits, with dominance of tidal sand bodies, tidal delta or carbonate reef and organic bank sand bars that can serve as reservoirs (Fig. 11a, b). The intercontinental rift basins are characterized by broad lakes with delta and coastal sand bodies as reservoirs. In the late post-rift stage, the deposition featured fluvial sands which are lens-shaped or present in elongated bands, forming big oil and gas reservoirs, e.g., the Chengdao and Gudong oil fields in the Shengli oil province.

Distribution of seal

There are two types of seals in the Chinese hydrocarbon-bearing rift basins. One is the widely distributed regional seal with great thickness, another is the local seal which has limited distribution and small thickness. The regional seal developed at the deep-downwarping stage and the early post-rift stage, whereas the local seal can formed in each development stage of the rift basins. Whether the big oil and gas fields can form or not is closely related to the existence of the regional seal. The basins which have relatively big discoveries so far are basically of high quality regional seal (Table 6). For example, the Sha 3 (late Eocene), Sha 1 (middle Oligocene) and lower Dongying (late Oligocene) formations in the Bohai Bay basin are very good regional seals (Fig. 12). The Zhujiang (middle Eocene) and Hanjiang formations in the Pearl River Mouth basin are of marine mudstone, and the Nengjiang (K2n) and Qingshankou (K2q) formations in the Songliao basin are of thick lacustrine mudstone (Fig. 13). In sags of some basins, several sequences of gypsum-salt beds developed, forming good cap-rocks for the sags, such as the Dongpu sag (Fig. 12). Many oil fields are found to be only sealed by very thin or even a few meters thick mudstone, e.g., the Chengdao, Gudong oil fields (fluvial sand bodies serve as reservoirs), as well as the Huangyan 7-1 and 14-1 hydrocarbon-bearing structures in the East China Sea basin (Fig. 14).

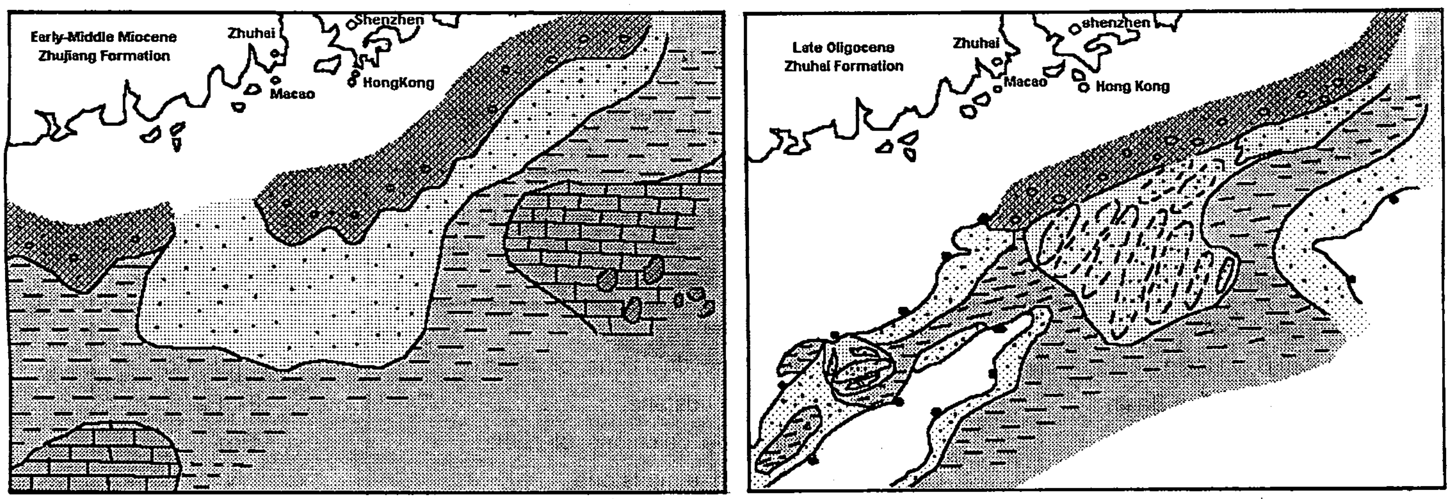
The seal in the single cyclic rift basin is also relatively simple, usually forming one reservoir-seal assemblage, such as that in the Songliao basin (Fig. 13), while the multiple cyclic rift basin has several sets of reservoir-seal assemblages. For example, the Sha 3 thick mudstone in the Bohai Bay basin formed in the deep-downwarping stage is the regional seal for buried-hill oil reservoirs and the reservoir rocks deposited at the early rift stage, whereas the delta sands in the late rift stage sealed by the thick mudstone of Sha 1 and lower Dongying formations in the second deep-downwarping stage, form good regional seal for the many big oil and gas fields, such as the Shuguang, Gaosheng, Huanxiling oil fields in the Liaohe oil province (Fig. 18).

PRINCIPAL FACTORS CONTROLLING THE DISTRIBUTION OF RESERVOIR AND SEAL BEDS

There are many factors controlling the distribution of reservoir and seal beds in the hydrocarbon-bearing rift basins of China. Some major ones are as follows:

Faulting

Faulting is a major factor controlling the sedimentation of rift basins during rifting stage. To some extent, the fault intensity directly controls



(a) (b)

Figure 11. Reservoir distribution of Pearl River Mouth basin during post-rift stage.

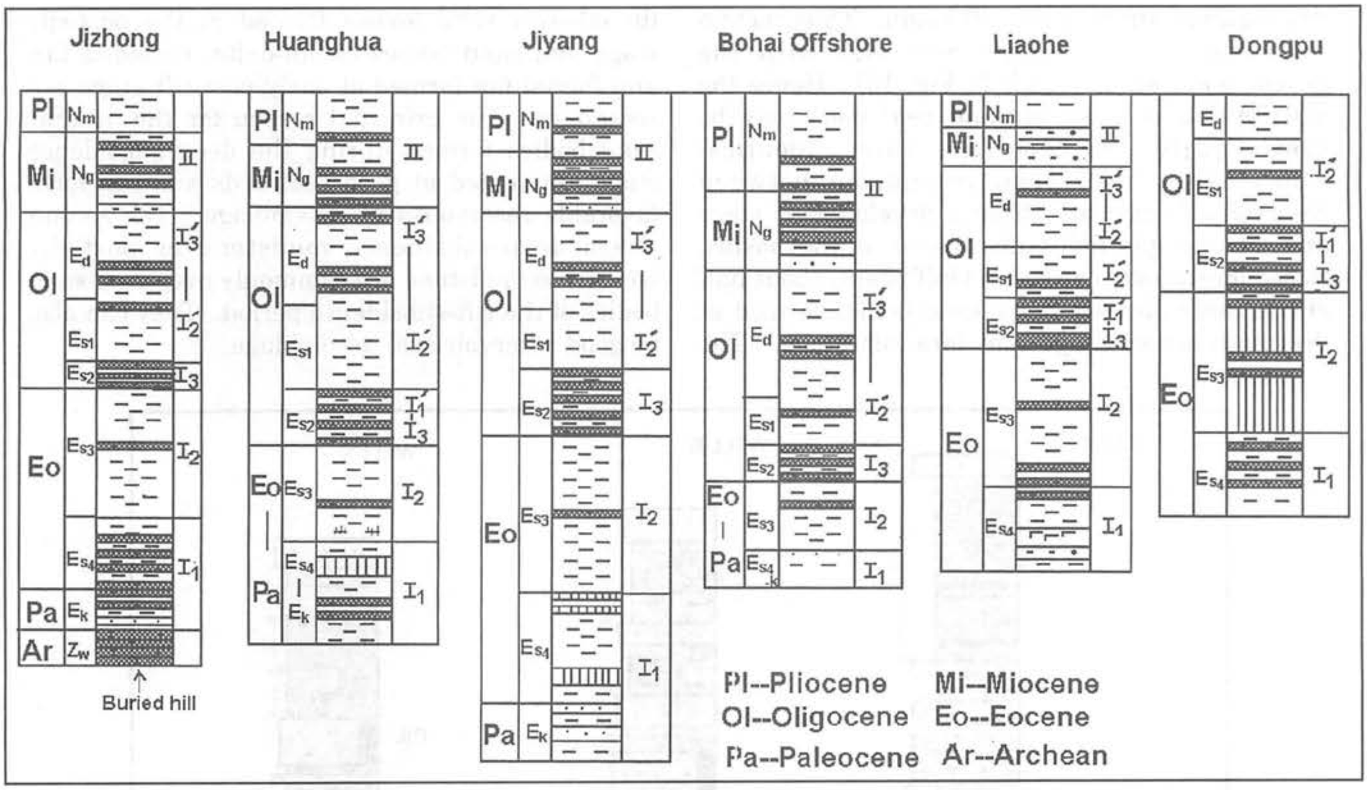


Figure 12. Typical columns of depressions in Bohai Bay basin showing the reservoir and seal beds distribution and developing stage of the rift basin.

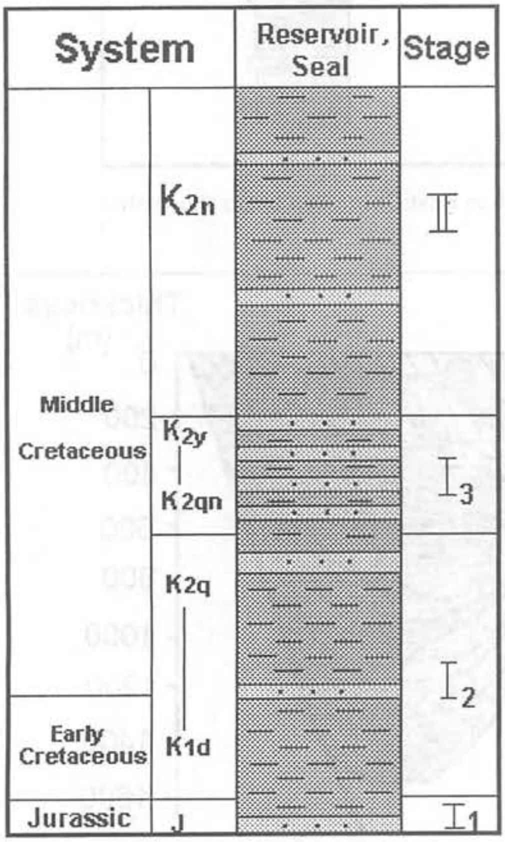


Figure 13. A typical column of Songliao basin showing the reservoir and seal beds distribution.

the size, area and shape of the rift-subsidence basin. Four scales of faults can be recognized at rift-subsidence basin. The first is basin margin, the second is depression margin, the third is sag margin whereas the fourth controls the occurrence and development of local structures at a sag. Those faults at the rift basins of China are mainly identified as growth faults. At the downthrown block of the former three scales of fault, a variety of fan-bodies, fan-delta and turbidites are commonly developed. The thickness and area of these sand bodies are closely associated with the faulting intensity. When a fault is active, the subsidence rate of the rift basin increases, and thus a thick and locally confined sand body develops. It is favorable for mudstone and other fine particle deposition due to lack of material supply, hence produce a starved facies. When a fault vanishes, material supplies are relatively sufficient and good for compensated deposition. Therefore, are suitable for the deposition of thinner but widely spreading sand bodies (Fig. 15).

Development stage of the rift basin

As mentioned above, the development stage of rift basins controlled the distribution of reservoir and seal beds, therefore, it will not be discussed in detail here. One thing that needs to be emphasized is that the deposition rate varies according to the development stage of the rift basin. Thus certain deposition rates roughly coincides with the development stage (Table 3; Fig. 16). Hence the distribution of reservoir and seal beds may be controlled by the deposition rate. Identical relationship have been recognized between reservoirs formed at different development stage and oil and gas fields discovered at the basins. Based on statistics at Bohai Gulf basin, about half of the reservoirs are delta sand bodies formed at deep subsidence stage and late rift stage. The fluvial-river sand bodies formed at the post-rift stage and sand bodies of fan-delta, turbidite fan and fluvial fan formed at early post-rift stage are secondary. The principal reason for this is that sand bodies formed during the deep subsidence stage are seated at good seal beds and can form favorable reservoir-seal assemblage. The second phase deep-subsidence mudstone or post-rift lacustrine mudstone are commonly overlying sand bodies of the rift-subsidence period. They can also be good reservoir-seal assemblage.

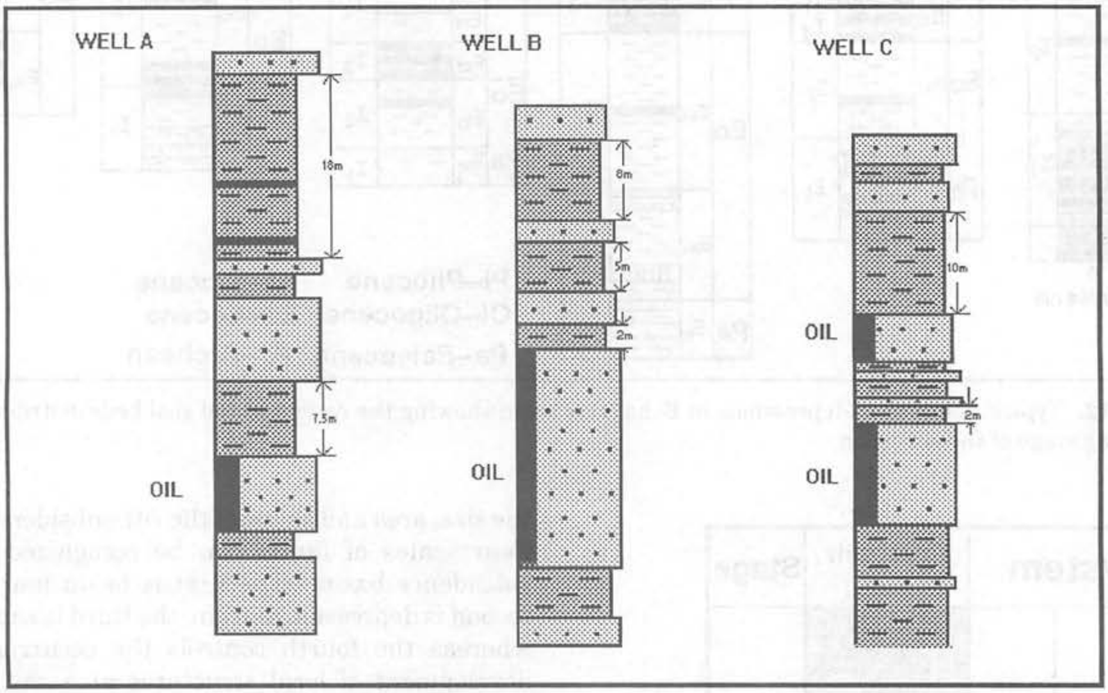


Figure 14. Three wells at Huangyan structure, Xihu depression in East China Sea basin shows that mudstone less than 10 meters may serve as local seal.

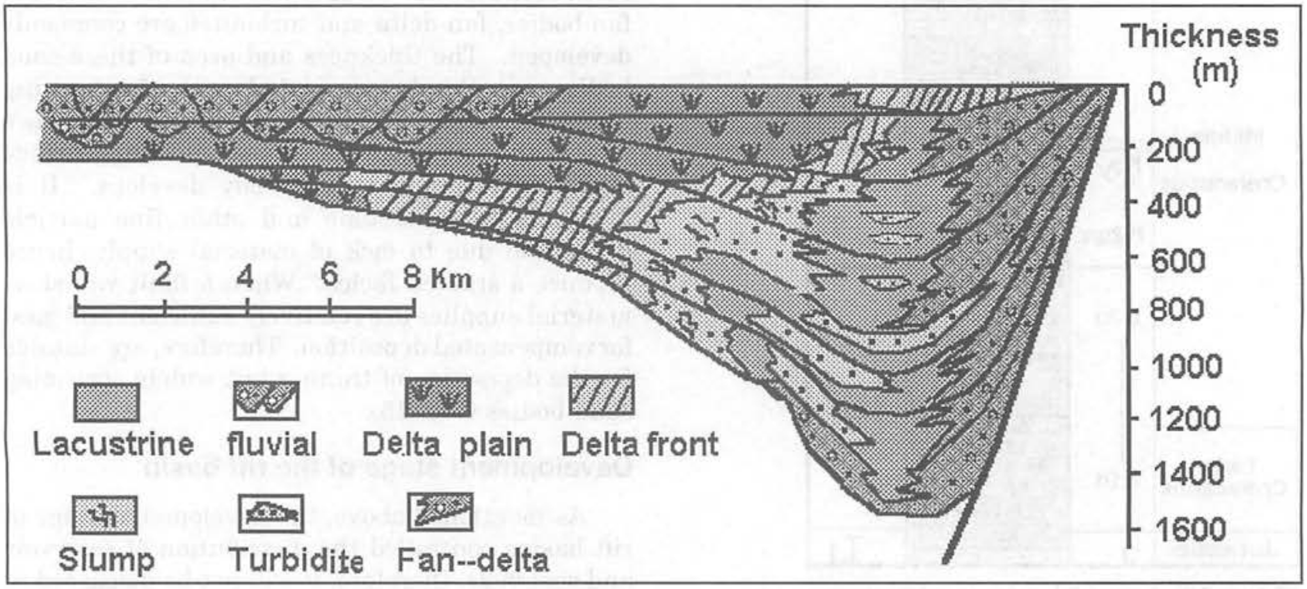


Figure 15. Cross-section showing sedimentary facies of synrift deposition in Subei basin (modified from Tongji University, 1985).

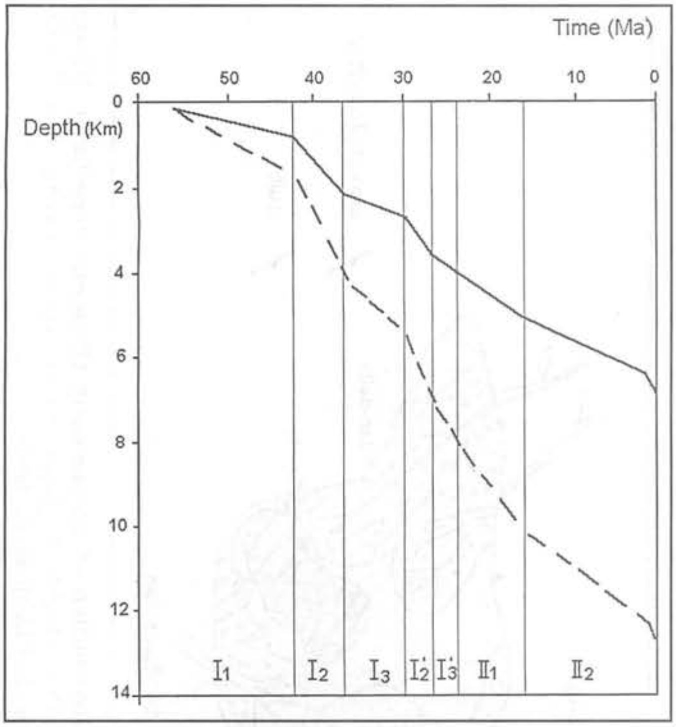


Figure 16. Curve showing subsidence and deposition rate in Bohai Bay basin.

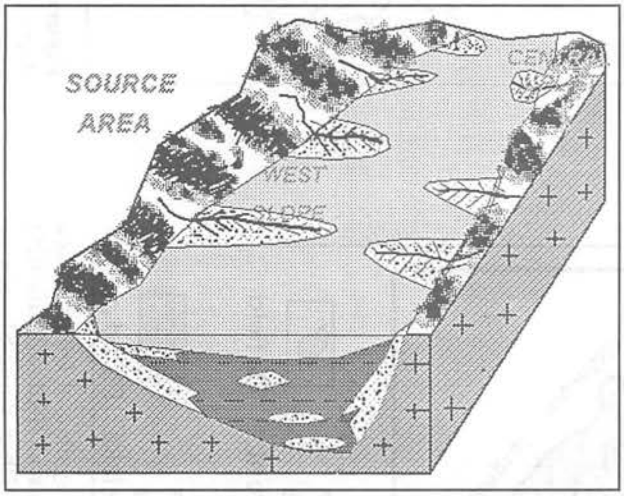


Figure 17. Schematic map showing ancient current and deposition system in Liaohe basin.

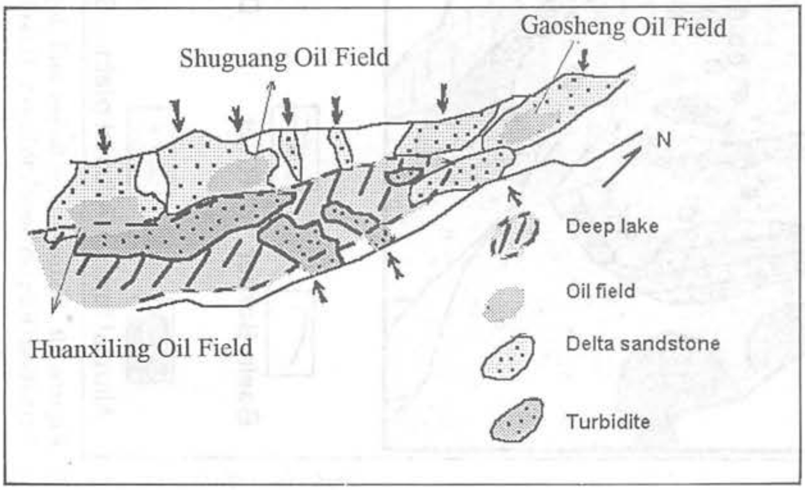


Figure 18. Distribution of reservoir and main oil fields discovered in late Eocene (Es3) of west Liaohe depression (based on Li Yingxian, 1989).

Ancient river

As discussed above, major reservoir beds of rift basin are sand bodies of delta, fan-delta and sand bodies related to them. To some degree, the size and area of sand bodies are closely associated with ancient rivers. From reservoirs of oil and gas fields discovered at rift basins of China, it can be concluded that the reservoir sands of a majority of the big oil and gas fields have some relationship with ancient rivers. Taking Liaohe depression, Liaoning province as an example, at least 4 big ancient rivers injected into its western sag from its western slope and four large scale deltas were formed (Fig. 17). These delta sand bodies are believed to be the main reservoirs of the three big oil fields (Li Yingxian, 1989) (Fig. 18).

At a well-known Chinese oil field, Shengli oil province, there are a variety of large scale fluvial fans and fan-deltas associated with the ancient Huanghe River that developed at hydrocarbon-rich sags such as Dongying and Zhanhua (Qian Kai *et al.*, 1989), and a variety of high-yield oil fields, such as the Tuozhuang oil field and Dongxin oil field, are formed by these sand bodies.

The most famous and biggest oil field of China, the Daqing oil province, is another example. Its reservoir is a combination of sand bodies of the northern river-deltas along the long axis of the basin. This deposition system is formed by ancient rivers of the Nenjing river, Qiqihair river and Beian river (Yang Jiliang, 1990; Yang Wanli *et al.*, 1985). According to statistics, more than 80% of the petroleum reserves discovered in this basin are from this reservoir system.

It can be concluded that the study of ancient rivers is the key for reservoir study. An understanding of the distribution and development of ancient river means a better understanding of the reservoirs. There are three kinds of ancient rivers controlling the reservoir distribution of rift basins of China:

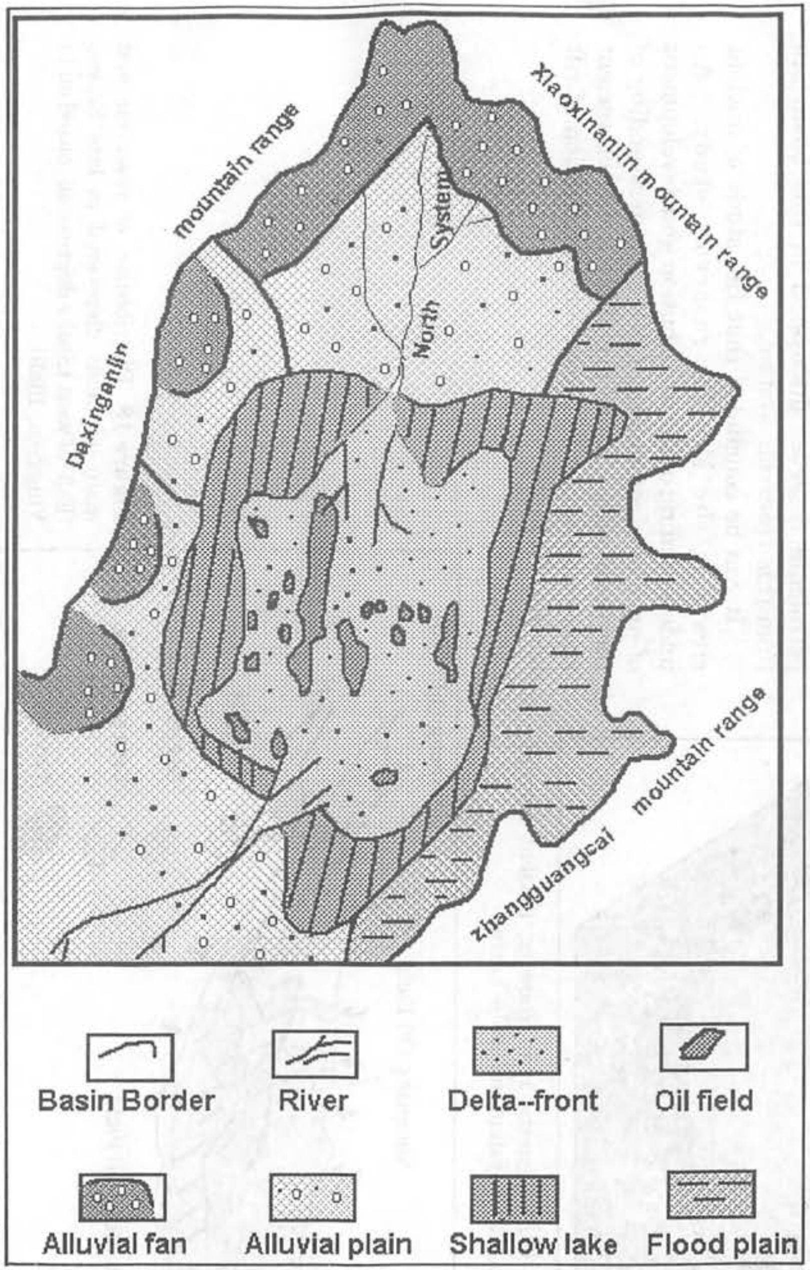


Figure 19. Sedimentary facies and deposition system of Qingshankou formation (K2q) in Songliao basin. It is obvious that oil fields coincide with main deposition system (based on Yang Jiliang, 1990; Wang Shangwen, 1983).

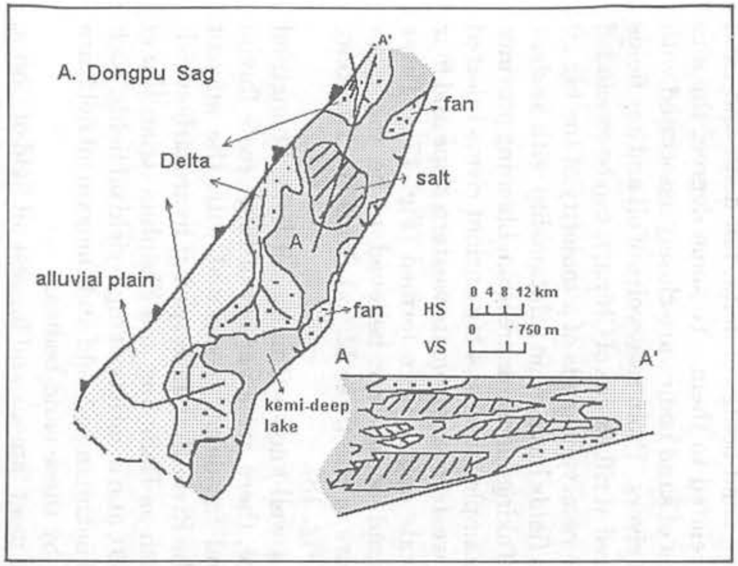


Figure 20a. Distribution of Eocene-early Oligocene deposits in Dongpu depression. Clastic deposits are less developed compare to the salt-gypsum (based on Qi Xingyu *et al.*, 1991; Wu Chongyun and Xue Shuhao, 1991).

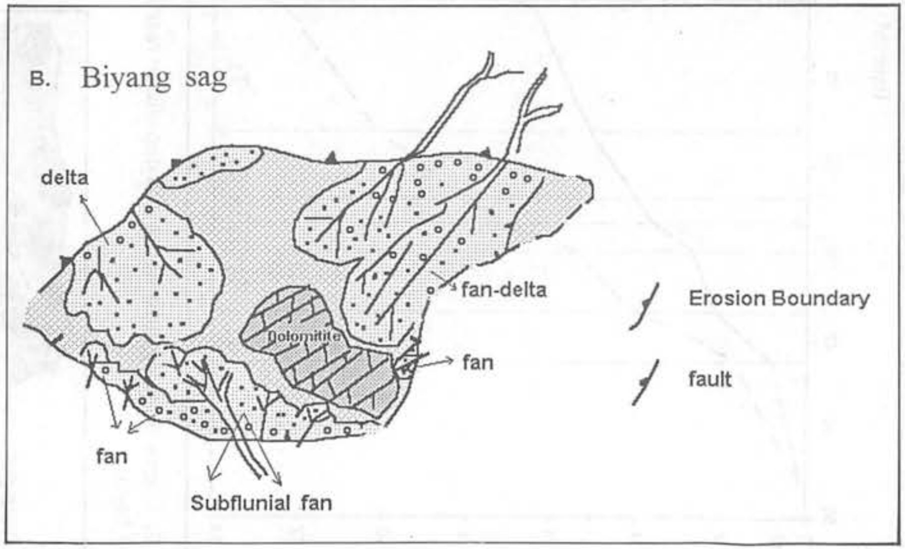


Figure 20b. Distribution of Eocene-early Oligocene deposits in Biyang depression. It shows highly developed clastic deposition compare with salt-gypsum (based on Li Chunju *et al.*, 1989).

1. Rivers along the long axis of basin or rift-depression. It usually has long distance source and large drainage area and form large scale delta systems. The northern deposition system at Daqing oil field is an example (Fig. 19).
2. Rivers on the slope along the short axis of basin or rift-depression. It usually forms small to medium scale delta systems (Fig. 17, 18).
3. Rivers on the abrupt slope along the short axis of basin or rift-depression. It usually has near source, small drainage area and forms sand bodies of fan-delta and submerged deltas. There are also some sand bodies associated with gravity flow and turbidites.

The influences of ancient river on reservoirs are as follows: a) the course and distribution of ancient rivers control the distribution of reservoirs; b) the size and area of ancient rivers control the area and thickness of reservoirs; c) the nature of ancient rivers constraint the reservoir property.

Palaeotopography and old source region

Important function of palaeotopography on reservoir and seal beds are as follows:

1. Palaeotopography controls the distribution and development of ancient rivers, and thus control the distribution of deposition systems.
2. Palaeotopography controls material supply. Palaeotopography high provide source material for the deposition system. Generally, the greater the elevation difference, the more abundant the material supply. Therefore, old high is favorable for compensated and overcompensated deposition. A modern rift-subsidence lake, the Erhai Lake, Yunnan province, is an example. To its west is Diancangshan mountain with heights over 4,000 meters above sea level and to its east is low land (Wu Chongyun and Xue Shuhao, 1991). Thus compensated clastic deposition developed at its western side and there is lack of deposits at its eastern side. During the rift-subsidence phase, rift basins of China usually show abrupt slope on one side and backlimb on another side (Fig. 15). Depositions at abrupt slope side are coarse and thick whereas fine and thin at backlimb side. In fact, the real deposition situation may be constrained by other factors as well.

The influence of palaeo source material or provenance on reservoir and seal beds is closely related to palaeotopography. But it shows some special ties:

1. The ability of palaeo source material to withstand weathering and erosion has direct influence on the amount of material supply. It also has influence on the reservoir property. Parent source materials that are weathering and erosion prone, such as granite, granite gneiss, often provide abundant clastic material and is favorable for formation of fan-delta, delta, alluvial and fluvial reservoirs. The parent rocks of major source for Liaohe oil field, Liaohe depression, are migmatitic granite and granite gneiss (Li Yingxian, 1989). The source rock for the northern part of the Songliao basin, Heilongjiang province are mainly gneiss, schist and widely distributed granite at basin margin (Wu Chongyun and Xue Shuhao, 1991; Yang Jiliang, 1990); while that for Jiyang the depression, Shengli oil province, are dominated by gneiss, granite gneiss from Luxi Uplift (Qian Kai *et al.*, 1989) and that for Biyang sag, Nanxiang basin, Henan province, are mainly of granite (Li Chunju *et al.*, 1989). Parent rock of the basins listed above is weathering and erosion prone type. It provide abundant materials and forms a variety of reservoirs in the basin during basin evolution history, which formed the important hydrocarbon producing area. If the parent rock is resistant to weathering, it will be unfavorable for material supply and difficult to provide adequate supply for clastic reservoir. Jianghan basin, Hubei province of China is an example. The parent rock is dominated by Mesozoic and Paleozoic marine carbonates, partially clastic and locally distributed Lower Proterozoic crystalline rock (Dai Shizhao *et al.*, 1991). Therefore, only small scale of deltas are formed at the basin. In addition, its reservoir property is poor due to poor property of the source material. This is the reason for less oil and gas discovery in Jianghan basin compared to other rift basins of eastern China.
2. Chemical composition of parent rock also has some influence on the distribution and property of reservoir and seal beds in the basin. It is well known that a series of salt and gypsum is widely developed within the lower Tertiary rift basins of eastern China. The influence of palaeo-material source on these deposits should not be ignored although the main reason for it may be the palaeoclimate. For example, some salt, gypsum and other chemical deposits developed at southern part of Huanghua depression, Bohai Gulf basin, Eocene, whereas clastic deposits dominated at its northern part (Wu Chongyun and Xue Shuhao, 1991). The reason for this is that the source material of the southern part is from the Chenning uplift and the Cangxian uplift which have carbonate parent rock (Wu Chongyun and Xue Shuhao, 1991). Soluble mineral of the parent rock was brought to the basin. Source material of northern part is mainly magmatite granite and granite gneiss

from Yanshan fold belt. Another typical example is the difference of Eocene-Oligocene deposition between Biyang sag and Dongpu sag. Geographically, Biyang sag is more to the south than Dongpu sag. And it may be drier than Dongpu. But less salt and gypsum deposited at Biyang sag (Fig. 20a, b) (Li Chunju *et al.*, 1989; Qi Xingyu *et al.*, 1991). The reason may be that parent rock of source material adjacent to Biyang sags is dominated by granite, granite gneiss which provide mainly clastics whereas parent rock of source material adjacent Dongpu sag dominated by Lower Palaeozoic carbonates which provide soluble minerals. It is obvious that difference in chemical composition of material source will result in difference in reservoirs. There are widely distributed deltas at Biyang sag (Li Chunju *et al.*, 1989). It is abundant in good reservoirs with moderate grain size, thickness and good property. Seal beds are also sufficient in deltaic deposits. Transgressive deposition after a deltaic phase and mudstone, peat of delta plain can both act as local seals.

Palaeoclimate

During the evolution process, palaeoclimate change has exerted important influence on reservoir and seal beds of rift basins, especially rift-subsidence and depression lakes of China. The influences are mainly on the following aspects:

1. Variation of palaeoclimate. From south to north of China, hydrocarbon-bearing basins are located at different palaeoclimate belts. Thus the deposits are different. Based on previous research (Xue Shuhao *et al.*, 1989), lower Tertiary rift basin of China can be classified into three types:
   a. humid climate type: Pearl River Mouth basin, Guangdong province is a typical one, which is dominated by clastic filling.
   b. arid climate type: Jianghan basin, Hubei province represent one of this kind, which is dominated by cyclic salt and gypsum deposition.
   c. alternative climate type: One of this type is Bohai Gulf basin, which deposits both widely distributed clastics and partially carbonates, salt and gypsums.
2. Palaeoclimate has decisive influence on salt lake formation. For arid climate, the evaporated volume is largely greater than the injected volume of the salt lake formed. Salt and gypsum layers are good local or regional seals for basins. The alternative climate basin, interbedded clastics and salts can form good reservoir and seal beds. The formation of oil and gas fields at Dongpu sag is a good example (Fig. 14; Fig. 21).
3. The sedimentary cycle is correlated to the palaeoclimate cycle. Palaeoclimate has influence on precipitation, cloud and vegetation, thus exert influences, on grain particle deposition and the type of deposits. The hypothesis proposed by Milankovich has been gradually proven by many researchers (Hays, 1976; Berger, 1984; House, 1985; Mitchum and Wagoner, 1991). A research conducted (Zheng Baoming, 1993) at Bohai Bay basin successfully recognized the Milankovich cycle from lower Tertiary deposits. Although research of this aspect are at preliminary stage, it can be easily understand that humid climate is good for fine grain deposition and form seal bed while relatively arid climate good for coarse grain deposition (Song Guoqi, 1993). This general principle is identical to the distribution of reservoir and seal at rift basins of China.
4. Palaeoclimate changes result in changes of lake level, thus the development and distribution of reservoir and seal. This will be discussed in detail later.
5. Secondary alteration may also happened on reservoir rock due to palaeoclimatic reasons. When the reservoir rock is exposed to or near the surface, weathering and leaching of reservoir rock caused by palaeoclimate may cause variation of reservoir property. Many burial hill oil reservoirs discovered in rift basins are in reservoirs formed by weathering and leaching.

Change of lake level

Two main factors which caused the fluctuation of lake level are: a) palaeoclimate change; b) variation in subsidence rate of lake basin. The direct results of variation in lake levels are due to change of deposition materials and shift of facies. Its influence on reservoir and seal are as follows:

1. Chronic rise of lake level results in transgressive delta. Fast rise of lake level is difficult for delta formation but starved deposition and fine grain deposition which can be very good seal and corresponding to what called condensed section by sequence stratigraphy. Nenjiang Formation (upper K2) of Songliao basin (Ma Lixiang *et al.*, 1992), member 3 of Shahejie Formation (late Eocene) and member 1 of Shahejie Formation to lower Dongying Formation (Oligocene) (Song Guoqi, 1993), are formed at this situation and are very good regional seal beds of the basin.
2. Chronic drop of lake level results in aggradational leaf-shaped delta. Fast drop of lake level is favorable for aggradational bird-foot shaped delta formation. It is corresponding to high stand tract deposition of sequence

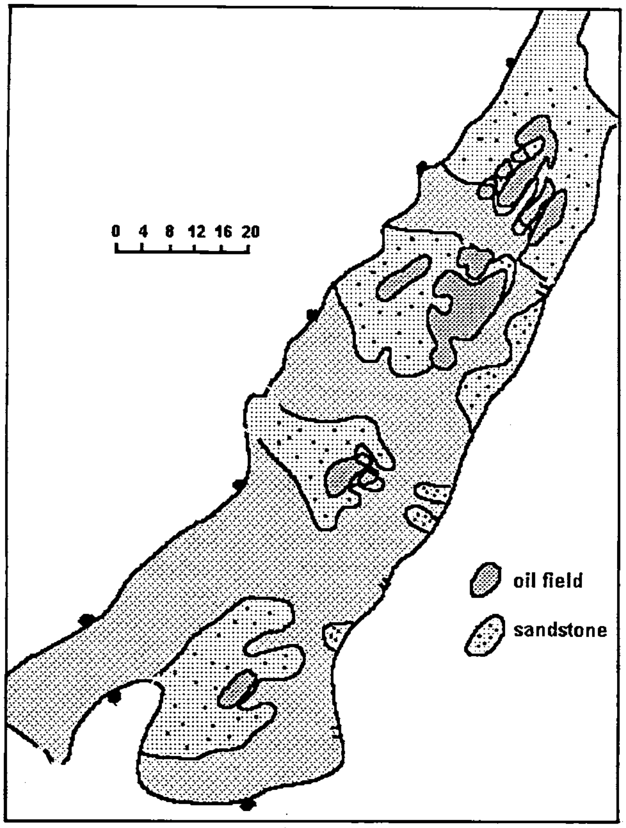


Figure 21. Reservoir sand bodies of later Eocene (Es3) within salt-gypsum bed form oil fields in Dongpu depression. Salt-gypsum bed serve as seal rock of these oil fields (based on Qi Xingyu *et al.*, 1991).

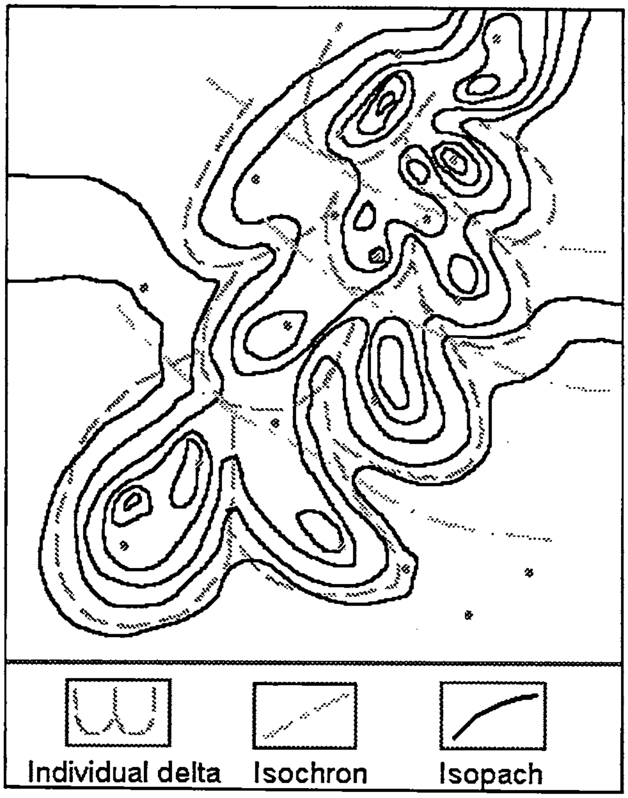


Figure 22. North delta complex in Songliao basin consists of at least four large lobate deltas during sea progradation.

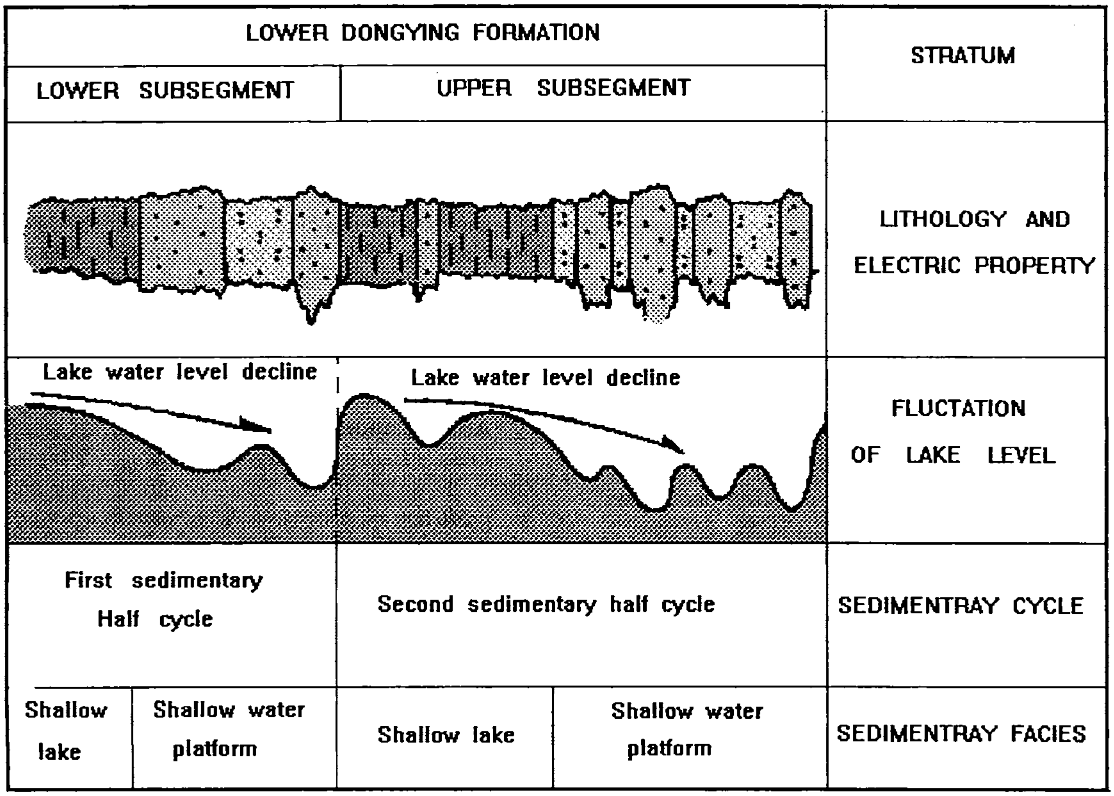


Figure 23. Fluctuation of lake level during lower Dongying formation in Liaodong area.

stratigraphy. Large scale delta system of northern Songliao basin are formed at this situation and composed of several lobate deltas (Fig. 22). It is the most important reservoir of Daqing oil field (Wang Shangwen, 1983; Yang Wanli *et al.*, 1985).

3. Cyclic fluctuation of lake level is favorable for the deposition of interbedded reservoir and seal assemblage. Figure 23 is the reservoir and seal assemblage resulted from two times of fluctuation during lower Dongying Formation (Oligocene) at Bohai Bay basin (Zhu Weilin *et al.*, 1992). The two series of sand are major reservoirs at Liaodong Bay area. One thing need to be mentioned is that there are many sub-fluctuations cycles within the big cycles, which show some similarity within Milankovich climate cycle. That is, mega-fluctuations or fluctuations can be divided into several sub-fluctuations. Thus reservoir-seal assemblages are formed by repetition of multiple cycles. Based on a study of the Shengtuo delta at Dongying sag, the Jiyang depression is formed by 11 cycles with maximum thickness of 500 meters.

From the above discussion, we can conclude that there are many factors exerting influence on or controlling the reservoir and seal of hydrocarbon-bearing rift basins of China, which include not only structural aspects but also aspects of deposition, palaeotopography and palaeoclimate etc. These factors are not single and isolated but closely related to each other. Because of the interaction of these factors, rift basins of China have become unique hydrocarbon-bearing basins with colorful and multiple reservoir-seal assemblages that supports the oil and gas industry of China.

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