Deformational Mechanism and Tectonic Evolution of Mesozoic-Cenozoic Nonmarine Basins from Bohai Bay Basin - China

[1]Rashid A.M. Hussein and [2]Zhu Xiaomin
[1]Sudan University of Science & Technology,
[2]China University of Petroleum, Beijing, China
principal@sustech.edu

Received:07.05.2013
Accepted:21.07.2013

ABSTRACT- Bohai Bay Basin，China, is a rift basin developed in Mesozoic-Cenozoic time span. It was compressionally deformed during Caledonian Orogeny and situated on a Paleozoic platform "old craton" basement and later subjected to extensional stress and induced major strike-slip (wrench) fault. The basin opening transpired on a series of half-grabens trending NNE-SSW in Bohai Bay Basin zone. Models for deformational mechanism and evolution of the Bohai Bay Basin, China, and its tectonic and stratigraphic history were proposed. Two separate scenarios were set for the evolution of Bohai Bay Basin: the first is based on the changes in plate convergence rates along the eastern plate boundary of Eurasia/ Pacific plates which have additional role in the extensional skin of Bohai Bay Basin in certain stage of extension or rifting and the second is a model of three major incidents of extensional tectonism: basement pre-rifting, a syn-rift stage, and a post-rift sag stage were documented for Bohai Bay Basin. The major factor controlling the lacustrine basins is global eustasy; however, the role of global tectonic played a significant control mechanism in the evolution and development of Bohai Bay Basin.

Keywords- *Lacustrine, Nonmarine deposits, Tecconic evolution, Mesozoic Cenozoic span, Rifting, Structural setting, Tectonostratigray, Basin.*

المستخلص-حوض بوهاي بي بالصين هو حوض خفسي نما في الفترة الزمنية بين عصري الميسوزوي والسينوزوي. وقد تشوه انضغاطياً أثناء الأوروجيني الحادثة في الكاليدونيان توضعت علي صخور القاعدة بالرصيف الباليوزوي "راسخ قديم" ومؤخراً تعرضت الي تمدد اجهادي وادي الي فالق مضربي انزلاقي (محرف) . برزت فتحة الحوض علي شكل سلسلة من انصاف أخاديد متجهة ش ش ق- ج ج غ في منطقة حوض بوهاي بي . تم اقتراح نماذج لميكانيكية التشوه ونشؤ وتطور حوض بوهاي بي بالصين ، وتكتونيته والتاريخ الطبقي له. تم وضع تصورين منفصلين لنشؤ وتطور حوض بوهاي بي : الأول ينبني علي تغيرات معدلات تقارب الصفائح عبر الحدود الشرقية للصفيحة الأورآسيوية \ الباسيفية التي لها دور اضافي في تمدد قشرة حوض بوهاي بي في مرحلة محددة من التمدد أو التخسف أما النموذج الثاني فهو يتكون من ثلاثة لتمدد تكتوني للصخور وهي قبل الخسف ، أثناء الخسف وطور انخفاض بعد الخسف وكل هذا موثق لحوض بوهاي بي. النصر الرئيس المسيطر علي الأحواض البحيرية هو التساوية العالمية ، مع ذلك دور التكتونية العالمية لعب ميكانيكية سيطرة مميزة في تطور ونشؤ ونماء حوض بوهاي بي .

INTRODUTION

Lacustrine basins are those basins developed on continental crust and dominated by continental sedimentary infill.

Most of the continental basins in the world were created in the Mesozoic Era, predominantly in the Cretaceous period (Hussein A.M.R, 2011).

Bohai Basin is located in North China platform (J.Y. Ren, K. Tamaki, S.T. Li, J.X. Zhang , 2002) which underwent complex tectonic events during its formation and development phase (geosynclines) before Sinian, and platform development phase from Sinian to Paleozoic.

It is divided by Tai hang Mountain into two parts: east part and west part, within east part developed extensional fault. At the beginning of Tertiary, the whole region became a stable craton and a series of intracratonic faulted rift basins formed. They formed from the rift-filling stage of Eocene and Oligocene to the regional subsidence stage of Neogene, but each had its unique sedimentary set. The Bohai Bay Basin covers an area of 200,000 km^2 of Bohai Bay and its coastal areas (Figure 1).

Insufficient conduct has been given to hydrocarbon exploration in lacustrine rift basins until the end of the 1970s; however, Levorsen (1967) pointed out that substantial amounts of petroleum are also found in sediments of continental or nonmarine origin.

Swain (1964) and Hedberg (1969) proposed that high-wax crude that found in lacustrine Green River sediments reflects continental or nonmarine origin of hydrocarbons. In the 1950s, shows of oil and gas have been found in nonmarine strata of some basins in Mongolia, Brazil, Pakistan, Columbia and Australia. This challenged the idea that oil is solely generated from marine environment. Xie Jiarong (1934) indicated that Permian petroliferous strata in Shaanxi, China, were nonmarine and Tertiary source rocks at Shiyouge in West Jiuquan Basin are terrestrial Cretaceous formations. Pan Zhongxiang(1957) indicated that the petroleum in Triassic and Jurassic in North Shaanxi was formed in fresh water terrestrial formations. In the end of the 1950's Lower Cretaceous lacustrine shales were found in a giant oil field, Daqing oilA field in Songliao Basin in China. In the 1960's China has developed nonmarine oil and gas- bearing formations from Bohai Bay, Jianghan, Nanxiang, North Jiangsu, Beibu Gulf, and Erlian basins.

Current petroleum exploration has resulted in significant increase in information relevant to the structure and tectonic evolution of the Dongpu Sag in Bohai Bay Basin (Sun, et al, 2003a; Xh and Zhou, 2005; Chen et al, 2007; Qi et al, 2006; Zhang et al, 2007, He et al, 2003; including salt tectonics. However, these researches addressed either only one structure or one sedimentary layer, and a comprehensive analysis of the tectonic styles of the Dongpu s

ag is rarely reported. Also, the Dongpu sag underwent complex dynamic regimes, extension and wrench. Allen, M.B. et al, 1998; Qi 2004; Qi and Yang, 2010. Chen et al, 2007 explained that various kinds of rocks were involved in deformation, including clastic rocks and salt rock. Little work has been done on the space-time relationships among the extensional, wrench and salt tectonics.

Shales, as good source rocks, and the prominent successes of petroleum exploration in rift basins (Begawan and Lambiase, 1995) and sand reservoirs including turbidites, deltaic, and fluvial types emphasized the significance of rift basins. Many publications stressed on the economic and scientific interest of lacustrine reservoirs (e.g., Ponte and Asmus, 1978; Ojeda, 1982; Estrella et. al.,

1984 Zhu Xiaomin et al, 1988a).

Many publications emphasized the economic and scientific interest of lacustrines (e.g., Zhu Xiaomin et al, 1988a and Xin Quanlin et al 1989 Ponte and Asmus, 1978; Ojeda, 1982; Estrella et. Al., 1984).

This paper is to propose model of the main features and tectonic development of lacusrtine sequences during the geologic evolution of Bohai Basin, North China, in terms of the plate tectonic breakup of Gondwana in one hand and Pangaea in the other hand. Apparent roles of tectonic on lacustrine Bohai basins are characterized on the basis of data acquired during oil exploration in that basin.

Bohai Bay is surrounded by Taihangshan uplift in the west, Yanshan platform fold belt on the north, Shanxi anticline on the west, Yanliao Highland in the north, East Liaoning anticline-East Shandong "shield" on the east and southwest Shandong anticline on the south (Figure 2). Nonmaring deposits of Bohai Bay basin assessed through integrating geophysical data, structural analysis, and petroleum geology.

REGIONAL GEOLOGY

Bohai Bay Basin, China is a rift basin developed in Meso-Cenozoic rifting with pre-Cambrian basement (or half-graben) and it was compressionally deformed during Caledonian Orogeny and situated on a Paleozoic platform "old craton" basement and later subjected to extensional stress induced major strike-slip (wrench) fault.

During the Archaean and Early Proterozoic, the area of the present Bohai Bay region was composed of crystalline metamorphic rocks that sited in the North China platform "cratonic" basement. The entire North China Platform received thick and laterally extensive shallow-marine deposits during the Early Paleozoic (Wang and Qian, 1997). During the Caledonian Orogeny the intact zone of north and east China uplifted due to the N-S compressional stress.

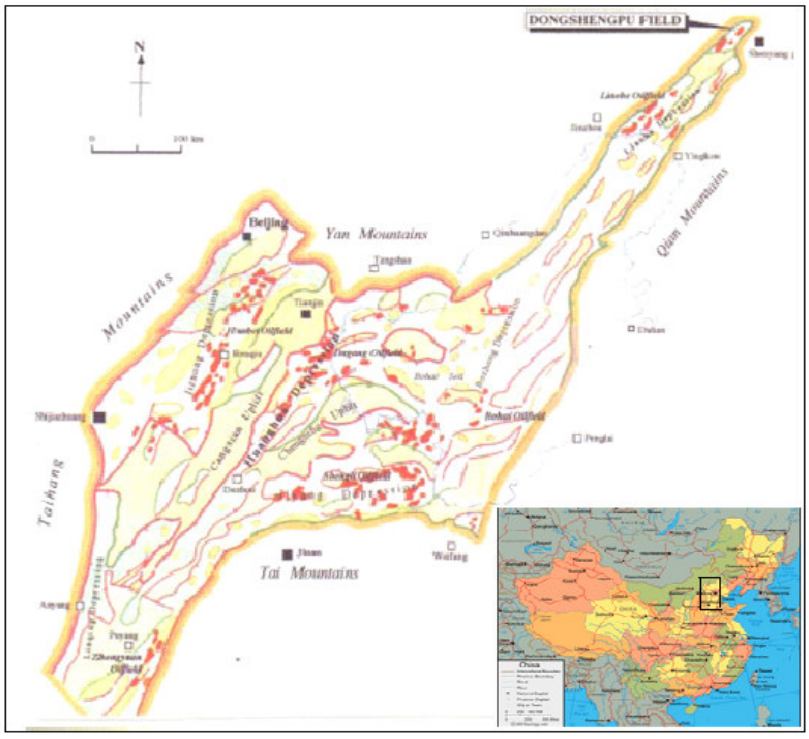

Figure1: Showing Location Map of Bohai Bay Basin (Atlas of Oilfields in China, 1990)

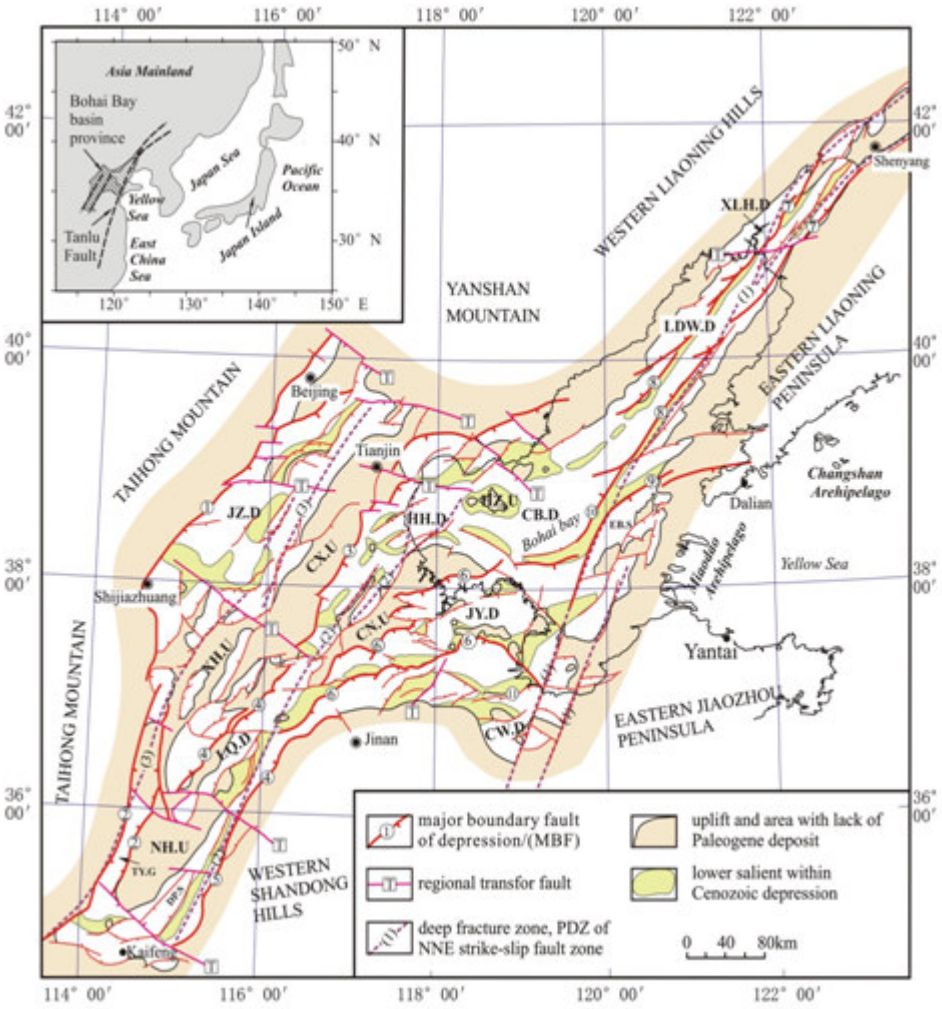

Figure 2: Showing the topographic and structural features of Bohai Bay Basin (Zhu Xioming, 2011)

An Unconformity between the Middle Ordovician and the Carboniferous occurred (Figure 3), followed by deposition of coal-bearing Carboniferous-Permian strata, then strong NE-SW compressional stress associated with widespread uplifting, thrust, faulting and magma intrusion took place due to collision between the North China and the Yangtze plates.

During Late Jurassic-Early Cretaceous a series of NE-trending extensional rift basins with secondary NW-trending sets of horsts and grabens occurred in Bohai Bay and adjacent areas as a result of subduction of Pacific Plate beneath the Eurasia Plate. Following Lower Cretaceous deposition the entire Bohai region was uplifted again in response to the early phase of the Himalayan Orogeny. Extensional rifting rejuvenated during the Eocene and Oligocene consequently vast lacustrine deposition including two major cycles were established. Those two major cycles are: early to late Shahejie period (Sha-4 to Sha-2) and the late Shahejie (Sha-1) to Dongying period which followed by regional uplift in North China resulted in an unconformity between the Oligocene and the Miocene. From Middle Miocene, thermal subsidence dominated the Bohai area, allowing onlap by Late Tertiary fluvial deposits (Figure 3).

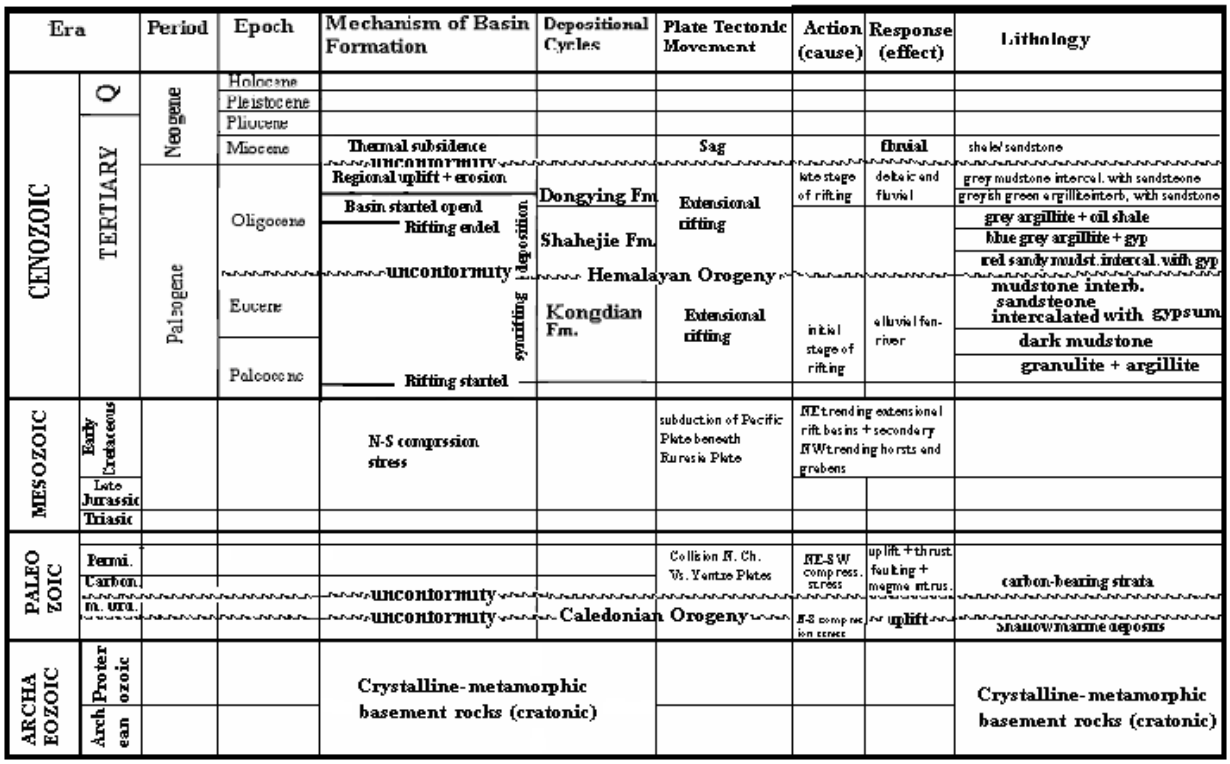

Figure 3: Model Generalized Basin Evolution and Depositional Cycles in Bohai Bay Basin through Space and Time.

Evidence of magmatism in Bohai Bay is strong NE-SW compressional stress associated with widespread magmatism occurred as a result of collision between the North China and the Yangtze plates.

Before 80 Ma, volcanic activities in Bohai Bay Basin were calcalkaline and silicic. Basaltic volcanism occurred since about 80 Ma in the late Cretaceous, and it became more alkaline with time. There was sporadic basaltic volcanism in Shandong and Liaoning in the late Cretaceous.

Paleogene volcanism mostly occurred in Xialiaohe, Bohai, as well as Huabei and Subei Plains. Often the basaltic flows have been covered by more recent sedimentation, but boreholes show that tholeiitic basaltic flows may be over 1000 m thick in places. Volcanic activities peaked in Neogene. In the west of Huabei Plain, Zhangjiakou-Weichang-Chifeng-Jining volcanic fields cover more than 20,000 km2, with both tholeiites and alkali basalts. In the east, along Tanlu Fault and Yilan-Yitong fault systems, there was widespread alkali basaltic eruption, especially Changbaishan volcano group (including Tianchi, Zengfengshan, Wangtian'e), which has been active for over 20 million years.

REGIONAL TECTONIC AND STRUCTURAL SETTING

The major factors controlling the lacustrine basins are global eustasy, however, the role of global tectonic played a significant control mechanism in the evolution and development of Bohai bay Basin (Rashid Hussein, 2008) .

The theory of plate tectonics holds that the entire lithosphere of the earth was broken into six large pieces (plates) and many smaller ones. Any plate may consist, in part, of ocean floor and, in part, of a continent or islands. Two ancient continents had been suggested, the southern continent of Gondwanaland, comprising Antarctica, Australia, the Indian peninsula, Africa,

Madagascar, and South America; and the northern continent of Laurasia comprising Asia, Europe and north America.

In plate tectonics, a subduction zone is where one plate of the earth's surface dives with tremendous force beneath an adjoining plate along a fault. Prior to Devonian, the continental surface was covered by the Epicontiniental Sea whereas minor continental clastics were reflecting panmarine sedimentation period (Ronov, A. B., 1980). At the end of Caledonian Movement, the continental clasitics sediments covered large areas of the continental surface.

In the Permian, the continental sediments attained to the utmost. During the Mesozoic, the continental sedimentation was relatively stable. Detailed correlation can be seen in Fairbridge, (1961) for lithological groups of various transgression and regression records. Vail et al., (1977) summarized the global sea level changes in Phanerozoic.

The beginning of global plate tectonic system can be marked by the break-up of Pangaea. Zhuxia, (1983) suggested that the early stage of this system from the beginning of Permian to the end of Middle Triassic (~280 and 200 Ma ago) was the transitional adjustment stage from Pangaea B to Pangaea A and the global sea level was fallen, hence, the continental sedimentary area widely extended. During the Late Cretaceous the Pangaea continent broke up meticulously and the divergence reached the climax inducing highest sea-level stage continued from 135 to 54 Ma corresponding to the phase when the Kula Plate subducted. Consequently the global sea –level was dropped and meanwhile the divergence of the oceanic ridge slowed down.

Continental basins involve those basins developing on continental crust with sedimentary infill dominated by continental sediments, including those with some marine depositional stages in certain evolution times or with a few transgressive or sea-flooding layers in continental basins period. But the most important point which should be emphasized for those basins is that the hydrocarbon source beds and the "play" sequence must consist predominantly of continental sediments. The importance of this conception lies in the distinguishing of the pericontinental basins, which are zoned from continental through neritic to marine facies or from fluvial plain through delta and shelf to deep ocean areas despite abundant ferruginous clastics exist in them, from the inland sedimentary basins.

The global tectonic setting controlled the distribution of continental basins. When the Late Proterozoic Pangea E broke up, there were no continental basins anywhere. The Caledonian Movement resulted in collisions of some continental margins and created some mountains and forelands. During Mid-Late Carboniferous, the Hercynian Movement enhanced the continental accretion and incorporation, giving rise to the formation of Pangea B and causing the margins of European and North American continents separated from the sea and the global sea level dropped. North (1985) called the continental basins as lacustrine basins. He stressed that almost all important petroleum lacustrine basins are controlled by extensional or vertical faults, most of which occurred during Mesozoic to Early Tertiary.

In terms of plate tectonics, either the divergence and break-up of continent or the accretion and convergence of plates may result in nonmarine basins. The break-up of plates have different evolutions. Some of

them not evolved further when rifted, forming interior continental basins, which occurred mainly in Permian. Some plates broke up completely until the ocean ridge and the passive continental margin basins occurred, and they mainly formed in Late Jurassic and were overlaid by marine sequence.

The nonmarine basins accompanied by accretion and incorporation of continents or terrains are all associated with the Meso-Cenozoic mobile belts. The thermal rifted subsidence is caused by thermal factors which can be classified into two kinds in magmatic properties. As the tectonic setting has been considered in basin classification, it shouldn't be involved in the formation mechanism study.

The distribution of global continental basins is intimately associated with the formation and break-up of Pangea B during Late Carboniferous and Permian. The continental basins of China formed after the formation and break-up of Pangea B, hence, the tectonic settings of the basins can be interpreted in terms of modern plate tectonics.

The plate movement can be attained by convergence or divergence. The degree of convergence of the plates is not equal to that of divergence due to the surface area of the Earth which is not constant. A number of continental fragments or blocks besides several continental plates may occur as a result of the divergence and break-up of continent. The fragments would be stacked and embedded into mobile belt during convergence. Thus, the convergence of continental fragment often causes collisions and stacks instead of subductions.

The marginal regions of the continent are zoned in terms of the crustal constitution rather than the geographic locations of the sea and continent. So, the Yellow Sea and Bohai Bay Basin are of epicontinental seas instead of continental margins

The basement thrusts, also called compressionally faulted blocks, are characterized by thrust faults and accompanying folds. The thrust faults cut both the basement and the overlying sediments. In Bohai Bay Basin, is thought to be of extensional stress field, but it had also undergone strong compressions before Cenozoic, especially during Yanshanian movement before Late Jurassic. The basement thrusts on Huabei and Yangtze cratons have been demonstrated by seismic and drilling data. Because the intensive erosion before Cenozoic, the trusted displacements were generally represented by low topographic relief and were overlain unconformably by Tertiary. As a result, the underlying compressional structures beneath the Cenozoic extensional sequence were often neglected.

in Bohai Bay Basin curved listric-shaped faults with the underlying crustal detachments whether it attaches to the "flat" or the "ramp" of the basal detachmet are common (Figure 4). Deformation in extensional basement-faulted blocks assemblage might be contemporaneous and/ or deuterogenic. The subsiding mechanisms of the basins are ascribed to the block-faulting of the basement despite the type of the basin was post-orogenic, composite block-faults, or intracratonic rift basins. Thus the majority of the faulting system in Bohai is contemporaneous, i.e. growth faults. However; comparing with the pre-basin faults, they are deuterogenic faults. The rate of continental sedimentation plays a significant role on the erosion of fault scarp depending on the pace of the fault displacement. When the rate of sedimentation is low with rapid

fault displacement, fault scarps eroded back. Also, erosion can occur on the opposite updip side of a basin, when rotation of the block by thick skin faulting creates a new base level for sedimentation in the basin low; the updip edges commonly erodes to fill the newly formed depression. The compensation between basin extensional and subsiding rates controls the dip of contemporaneous faults. When the extensional rate is higher, the dips are gentle but when the subsidence rate is compensated by sedimentation, the dips are steep. In other hand, the composite block-faulted and postorogenic faulted basins have basement faults being relatively steep in dips with planar fault surfaces. The basement blocks of pull-apart basins caused by strike-slipping are theoretically vertical in dips but practically they exhibit small step-like basement-faulted blocks with gentle dipping angles. Block-faulting is very extensive in Bohai Bay Basin due to regional influence of Tanlu crustal faulting on Bohai region (Xin Feng, et. al. 2007).

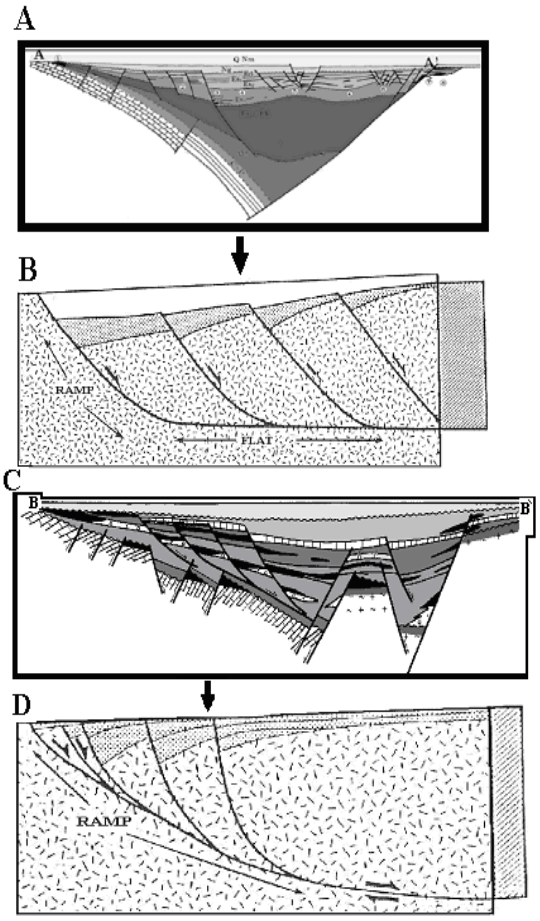

Figure 4: Sections A-À in (A) and B-β in (C) based on reflection seismic data from Bohai Bay Basin. Basin development above a "flat". The initial stage of rifting over a flat is illustrated by (B) diagrammatic cross-section of fault geometries shown in (A). (C) Basin development above an extensive "ramp" complex emphasizing multisubbasins developing over a ramp complex. It is noticed that the fault dips and subbasins widths decrease to the left. (D) Diagrammatic cross-section illustrates fault geometries. For location of sections A-À and B-â see Figure 1-a (A and C sections from Zhang ying hong, CNODC, after personal communication, B and D using uniform fault of Gibbs, 1983).

The tectonic setting of China was interjacent among three plates with unbalanced acting forces in it, and often induced strike-slip deformations in various periods with different wrench directions. The evidences of strike –slip or wrench deformation are the en echelon folds and thrusts or normal fault. There are en echelon extensional structures in Huabei Bohai Bay Basin, which was thought by some geologists of being formed by strike–slip system. We may conclude that either compression or extension was more or less accompanied by wrench deformation and when we study the structural style, we can only take the main one.The flower structure in figure 5 is one of the most typical examples of wrench deformation in Bohai Bay Basin and is characterized by vertical strike-slip faults without obvious vertical displacement. In addition, some areas were dominated by wrench faults, the transitional and transpressional faults are always accompanied by each other.

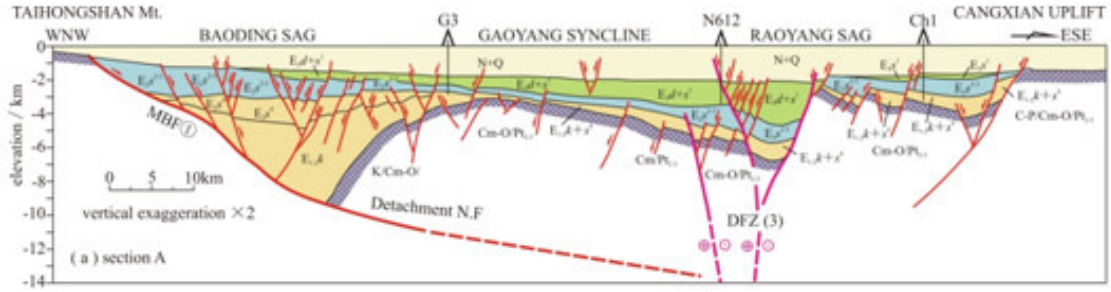

Figure 5: Showing negative flower structure as a cursor for the presence of wrench deformation in Bohai Bay Basin.

The compressional or extensional field of stress can't avoid inducing some wrench deformations. An asymmetrical graben structure with a tilted array of planar to listric faults was produced (Figure 6). The faults within the prerift sequence in the graben become sigmoidal as response to the internal deformation in the graben. These faults become listric within the synrift sequence. The fault nucleation sequence indicates both hanging-wall and footwall nucleation. Many of the faults are nucleated relatively rapidly early in the deformation history and are active throughout the deformation.

China exposed to unbalanced forces due to its position in tectonic setting of triple junction, thus, strike-slip deformations motivated in various episodes with different wrench directions. Accordingly, The Tanlu fault system on the eastern side of the Bohai Bay Basin was dextral strike-slip faults during Tertiary and had much effect on the adjacent basins. Gu Zhiming (1989) suggested that the dextral en echelon faults in horizon and the alternation or combination of the positive and negative flower structures in cross section could be seen in 3-D seismic data along the Niuju-Rongxin faults. The dextral en echelon faults in horizon and the alternation or combination of the positive and negative flower structures in cross sections verify the presence of wrench faults in the area. Figure 7 indicates the major structure assemblages of Bohai Bay Basin.

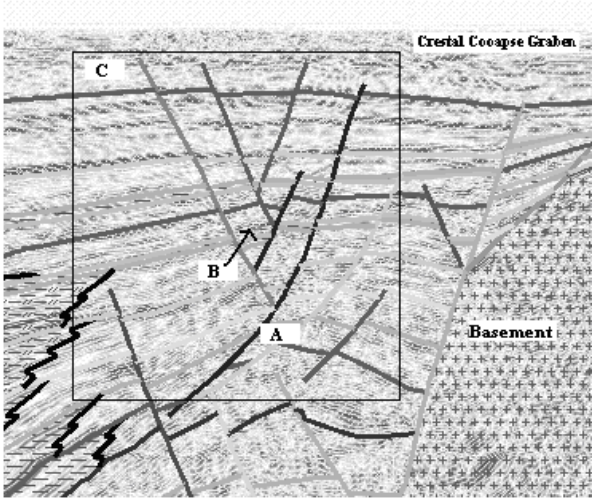

Figure 6: Seismic section across extension of Bohai Basin showing asymmetrical development of planar to listric growth fault arrays with a complex crestal- collapse graben system of antithetic and synthetic faults. A = Pre-rift, B = Syn-rift, C = Post-rift. (the original seismic section from Zhang ying hong, CNODC, after personal communication).

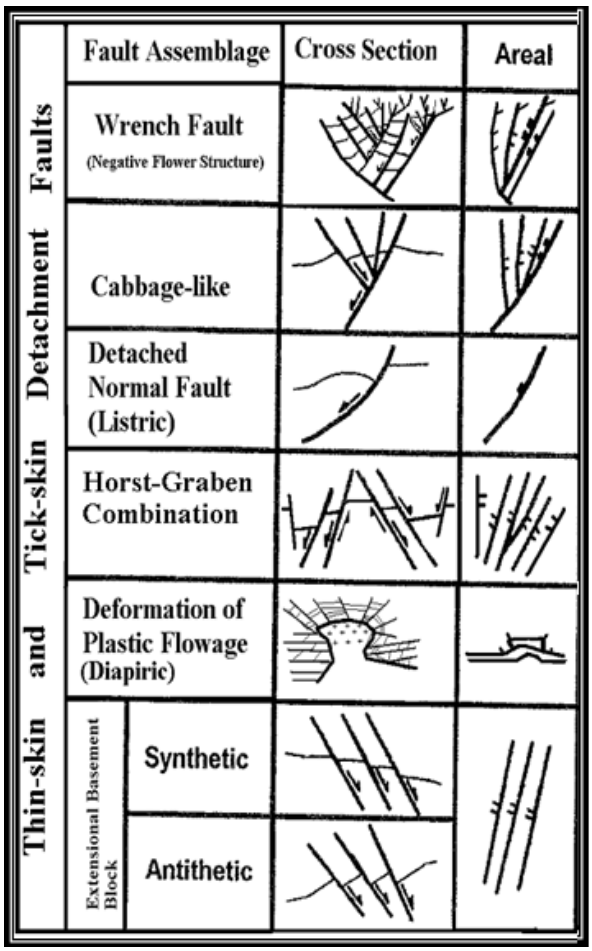

Figure 7: Indicating the major structures in Bohai Bay Basin (complied by the authors from different sorces).

TECTONSTRATIGRAPHIC HISTORY OF RIFTING

Different hypotheses correspond to the mechanism of formation and evolution of Bohai Bay Basin. Time and space of some extensions along eastern margin of Eurasia has been ascribed to the India-Eurasia collision which represents crucial satisfaction of many authors. Although, some others favor the role of Pacific/ Eurasian plate convergence along the eastern plate boundary of Eurasia. Accordingly, this paper built some models illustrating that idea(s). However; it can be suggested that changes in plate convergence rates along the eastern plate boundary of Eurasia had additional role in the extensional skin of Bohai Bay Basin and also reliable; particularly, in certain stage of extension or rifting.

Pacific/ Eurasian Plate-motion exhibits considerable convergence started in the Late Cretaceous up to the late Miocene when and where the rifting accommodated in Bohai Bay region. The most significant rate of convergence occurred during the Tertiary (Figure 8). The convergence rate of Late Cretaceous was of ~ 120- 140 mm/yr, however, the area of Bohai Bay Basin was still unrifted. During the early Tertiary the rate of convergence started to decline constantly and then started initial stage of rifting in Paleocene which infilled with the sediments of Kongdian Formation. During the Eocene the rate of convergence declined drastically to the minimal of ~ 30- 40 mm/yr where the sediments infilling was of Shahejie Formation. The average convergence rate increased in the Oligocene to earliest Miocene and reached ~ 70- 95 mm/yr where the rifting got the final stage and the opened space accommodated by Dongying Formation. Between Oligocene/ early Miocene Epoch an unconformity occurred and rifting finalized. Then during early to middle Miocene the rate of convergence decreased again to ~ 65- 70 mm/yr. The convergence rate increased during the time span from late Miocene to the present to an average of ~ 100- 110 mm/yr. The bottom line is that the Tertiary episode of slow convergence which in turn decreased in accordance with a net reduction in horizontal compressional stress transmitted between the plates of the Pacific and Eurasia which resulted in widespread extension adjacent and along the eastern margin of Eurasia.

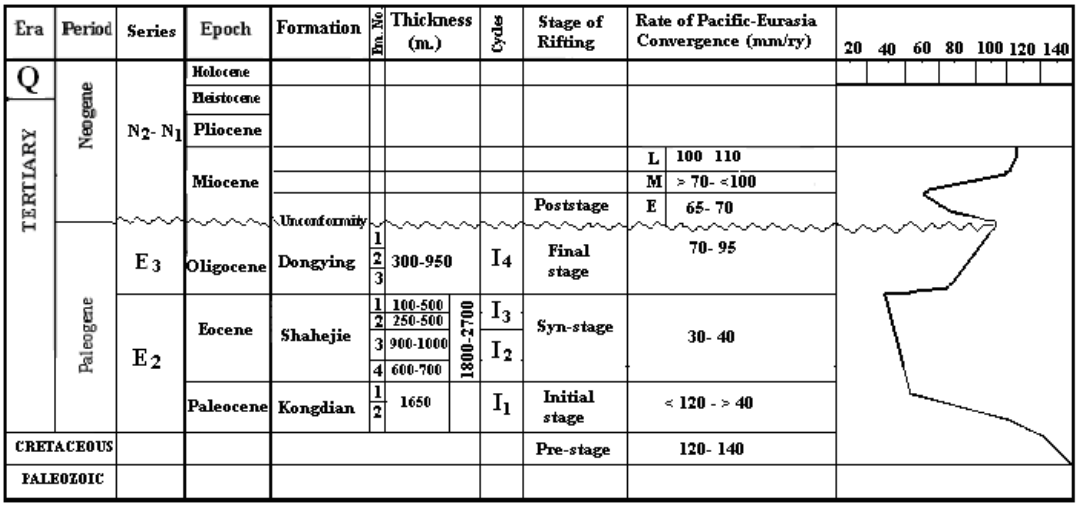

Figure 8: Showing a three-stage model for Bohai Basin history emphasizing thickness of formations and rate of convergence of the Pacific-Eurasia plates along the eastern plate boundary.

Figure 9 illustrates another scenario for the evolution of Bohai Bay Basin. Basement (pre-rifting), a syn-rift stage, and a post-rift sag stage are three stages of evolution of Bohai Bay Basin. Basement represents the pre-rifting time span of Precambrian and prior to the Tertiary. Syn-rift phase startd from late Paleocene to late Oligocene across a diffuse set of half-grabens indicated by condensed trends and ages. Basin opening established on episodes of half-grabens trending NNE- SSW. Kongdian Fm, Shahejie Fm, and Dongying Fm. are the major depositional cycles accommodated during the syn-rift stage of Paleocene, Eocene, and Oligocene respectively. Rifting ended during the late Oligocene then uplift and erosional episode of unknown origin occurred. From Late Oligocene strike-slip faulting documented in Bohai Basin depocenter indicates the importance of right-stepping pull-apart control on the younger sag segment reached to deepen during Miocene.

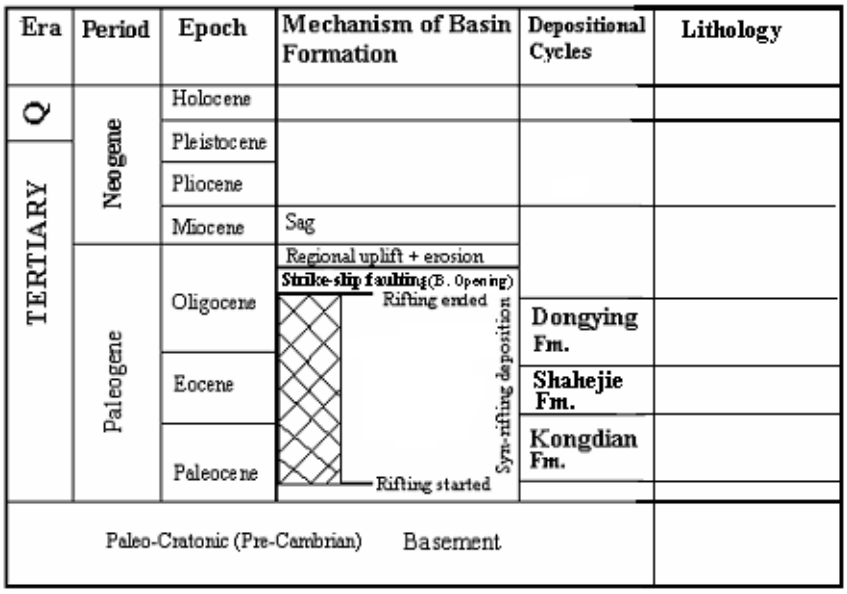

Figure 9: Showing mechanism of Bohai Bay Basin including the depositional cycles.

In Bohai Bay Basin depocenter controls the distribution of lithologic facies. During Eocene, the depocentre was located at Dongying depression with lofty reliefs around it. During Oligocene, the depocentre shifted to the north of Jiyang superdepression. Shift of depocentre generally was from south to north, but the main attribution of the lacustrine basin was located at the east end and the west end of the longitudinal basin axis.

Based on plate tectonics it can be concluded that, thermal upwelling of the mantle pads or plumes caused the surface uplift and fractures on the domal background, forming grabens and horsts or composite half-grabens in Bohai Bay Basin, in which there may have occured some of basic magmatic flows. Based on this concept Bohai Bay Basin is considered to be situated on intracratonic rift basin (Figure 10) where the sediments are of nonmarine alloctonous clastics.

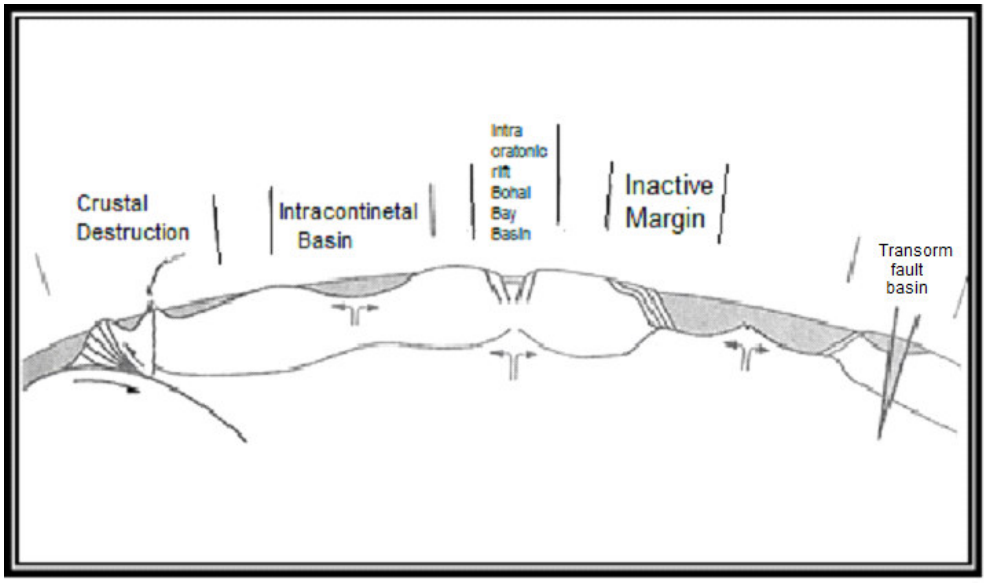

Figure 10: Showing the sites of Bohai Bay Bain in intracratonic rift (After Rashid Hussein, 2008).

Figure 11 shows different stages in a rift-drift sequence; the Bohai Bay Basin reached stage 3 and developed to lacustrine environment. Bohai Bay Basin had exposed to some marine invasion some times, however, it is still of nonmarine lacustrine deposits. It has experienced several cycles of rifting. Each rifting cycle resulted initially in the deposition of minor amounts of fanglomerate and fluvial sediments which grade rapidly into fine-grained lacustrine sediments in the subsiding troughs. Continual deposition and compaction through long time span induced gradual subsidence leading to change of the depositional environment (in some zones) from lacustrine to fluvial, resulting in a mega coarsening-upward sequence. This mode had repeated at least three times: Late Jurassic to Early Cretaceous, Late Cretaceous to Early Tertiary, and Late Tertiary.

The deposits of the rift stage are usually starved and well developed hydrocarbon source rocks and evaporites. Until the later stage of the basin evolution, the mantle material cooled, causing the Bohai Bay rift failed basin and the entire crustal surface subsided. From then on, the basin entered the post-rift or sag stage, when the deposits are mainly of alluvial plain facies. According to the formation mechanisms of the basin, the structures include faulted blocks, growth faults and rollover anticlines in the early stage, and diapiric or diaper-strike structures due to the doming of plastic rocks in the late stage and at last developing drape structures, the combination of the structures resulted in multi-layer and multi-type traps. The reservoir rocks consist of various porous or fractured rocks in pre-rift (basement) and/ or sag sequences. Thus, abundant oil and gas reserves are accumulated. However, the oil/ gas potentials of these basins should be considered within the Lower Tertiary rift sequence in Bohai Bay Basin because they extruded within the Tertiary Epoch. Regional tectonic events influenced the rift evolution in Bohai Basin. This can be seen in Figure 12

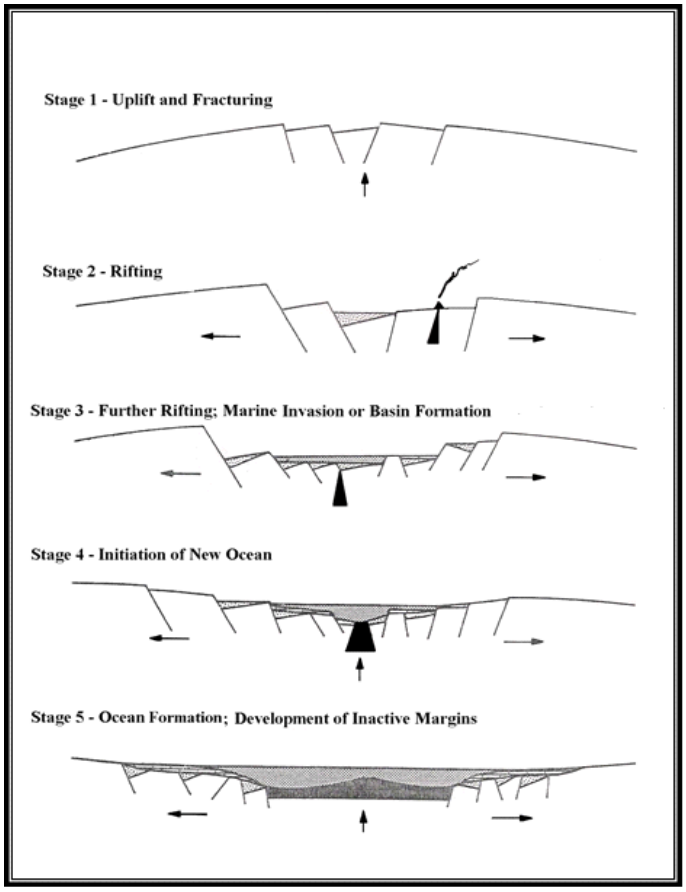

Figure 11: Showing different stages in a rift-drift sequence. Bohai Bay Basin, North-east China reached stage 3 and developed to lacustrine environment; it had exposed to marine invasion but still represent nonmarine deposition (Adapted from Rashid Hussein, 2008).

DISCUSSION FOCUSING ON TECONIC AND STRATIGRAPHIC FRAMEWORK OF BOHAI BAY BASIN

The stratigraphic framework of rifting and basic sedimentary pattern is determined by the paleotectonic setting. Under extensional tectonic background, which prevails throughout the Mesozoic-Cenozoic rift-subsidence basins of eastern China, sedimentation is characterized by a great volume of subsidence, high sedimentation rate, associated with frequent eruptions of basic volcanics along faulted zones. During the stage of extensive spreading, a thick sequence of dark mudstone was often formed under a deep-water environment with continuous sediment starvation. Several dark mudstone intervals, consequently a large volume of source rocks, may be formed in some rift-subsidence basins as a result of multiple-staged down-faulting. The continuous subsidence of a basin will favor the transformation of organic matter towards hydrocarbon and increase the prospect for exploration. Bohai bay was closed-semi-closed basin and has been indirectly affected by sea water several times during the Eocene and the Oligocene. Consequently, the biota living in saline and semi-saline environments prevailed and had high allometric variation, thus forming many local species and genus

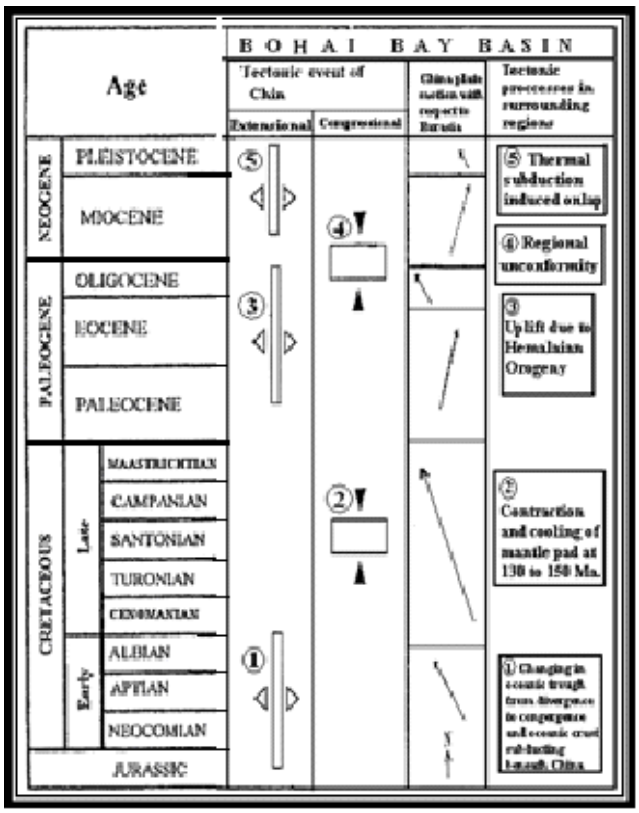

Figure 12: Showing different regional tectonic events in China including Bohai Bay Basin.

.The detritus of land plants, pollen and spore , Charophyta and Gastropoda were concentrated on the margin of the lake, while the quantity of the plankton increased toward the center of lake, for instance the Bohai algae of dinofllagelates became major palaeontologic molecule. This pattern of spatial distribution in the lake basin was controlled by the structure of the lake basin. The ecological association created the various system of ecological balance and the base of petroleum-generating precursor.

The Paleogene Bohai Bay Basin is a transitional zone of coastal depression. In terms of paleoclimate this basin is located in the northern subtropical zone, right between humic northeast China and arid central China. Thus, it is of transitional nature. Apart from this climate background, tectonic activity controls the evolution of the basin. In the history of basin development there were invasions by sea water, generating a brackish environment with specific fossil assemblage. So Paleogene Bohai Bay Basin belongs to humid-arid transitional offshore rift-depression.

Tectonostratigraphic framework and basic sedimentary patterns of Bohai Bay basin are characterized by short-distanced source, narrow and incomplete lithofacies zones (Zhu Xiaomin, and Xin Quanlin, 1987c), and limited distribution as a result of high relief, high topographic gradient and strong tectonic separation within the basin (Figure 14). The deposition of fan delta and turbidite are commonly seen in Lower Tertiary rift-subsidence of Bohai Bay Basin. In addition, sedimentation existed throughout the Mesozoic-Cenozoic rift-subsidence is characterized by a great volume of subsidence, high rate of sediment influx associated with frequent

eruptions of basic volcanics along faulted zones. During Plaeogene, which is the most extensive stage of spreading, thick sequence of dark mudstone intervals, consequently a large volume of source rocks may be formed as a result of multiple-stage down-faulting. The continuous subsidence of a basin will favor the transformation of organic matter towards hydrocarbon and increase the prospect for exploration.

Figure 14: Iliustrating tectonostratigraphic framework and sedimentary facies distribution of Bohai Bay Basin and showing multiple-stage of down-faulting. (after Zhang ying hong, CNODC, 2003)

CONCLUSIONS

Bohai Bay basin is a nonmarine sedimentary basin developed during Meso-Cenozoic in a paleo-platform and folded belt has later existed as stable subsidence zone for a long time span. As a result, it had undergone relatively a complete history of tectonic evolution, sedimentary development, and hydrocarbon-generation.

It has been proved that nonmarine petroleum basins have very suitable geological conditions to form oil and gas pools. A series of giant oil and gas fields has been found besides lots of medium to small sized ones. This might enhance understanding of petroleum geological conditions of the Meso-Cenozoic nonmarine petroleum basins. This supports and enriches the theory of the petroleum formation and occurrence in nonmarine petroleum basins.

During the major lake development stage of a half-graben, the block-faulting was strong, the lake was wide and deep, thus, the source rock of large size and reservoir bodies were developed. Three sets of large stratigraphic-unconformities were regarded. Contemporaneous structure such as rollover and diapiric anticlines were developed. Petroleum concentrated in the middle petroleum bearing formation system in Dongying, Dongpu, and Liaodong depression. The Dongying Depression is situated in the southeastern part of the Jiyang Subbasin. During the Paleogene, the block-faulting activities were known as a long-inherited development, the structures were mainly of contemporaneous faults and syndepositional structures.

Three EW- trending contemporaneous faults were developed on the northern flank, a series of rollover structures were scattered along their downthrown side, such as the Yonganzhen, Minfeng, Shenglichun, Lijin and Binnan. Dongxin diapiric-anticlinal belt combined with the contemporaneous faults was located in the center. All of these structures were solidified at the end of the Dongying Formations, and are the major petroleum-bearing structures in the depressions. These structures are distributed in or around the Lijin source center, and combined with the deltaic sandstone bodies of the Shahejie Formation trending east-west, thus comprising a good. Late Oligocene time in Bohai Bay Basin was the period of development and solidification, in addition to generation and migration of hydrocarbon.

During this period, the northern area rose, as a result, the northern area possesses a high pressure gradient and large oil supply, thus, it acted as the major area of oil and gas migration and accumulation. The formed rollover anticlines and diapiric structures combined with contemporaneous faults provided the space favorable for oil and gas fields.

REFERENCES

[1] Allen, M. B., Macdonald, D. I. M., Xun, Z., Vincent, S.J., & Brouet-Menzies, C. (1998). Trans-tensional deformation in the evolution of Bohai Basin, northern China. In:

[2] Holdsworth, R.E., Strachan, R.A., & Dewey, J.F., Continental Transpressional and Transtectensional Tectonics. Geological Society of Landon, Special Publication no 135, pp. 215–229.

[3] Bally, A.W., D. Bernoulli, G.A. Davis, and L. Montadert, 1981: Listric normal faults: OceanologicaActa, 26th International Geological Congress Proceedings, Paris, p. 87-101.

[4] Begawan, S. R., and J. J. Lambiase, 1995, Preface, in J. J. Lambiase, ed., Hydrocarbon habitat of rift basins: The Geological Society of London Special Publication no. 80, p. vii-viii.

[5] Chen, S. P., Tang, L. J., Qi, J. F., Qu, D. M., & Sun, M.S. (2007a). Roles of salt in deformation:

[6] Compression of the salt-related structures between Kuqa depression and Dongpu Depression. Acta Geologica Sinica Vol.81, No.6, pp. 745-754.

[7] Crowell, J. C., 1973, Origin of Late Cenozoic basins in Southern California, in W. R. Dickinson ed: Tectonics and Sedimentation, Society of economic Paleontologists and Mineralogists.

[8] Ellis, P. G. and McClay, K. R., 1988, Listric extensional fault systems- results of analogue model experiments Basin Res. 1, 55-70.

[9] Estrella, G. O., M. R. Mello, P. C. Gaglianone, R. L. M. Azevedo, K,.Tsubone, E. Rosseti, J. Concha, and I. M. R. A. Bruning, 1984, The Espirito Santo Basin (Brazil) source rock characterization and petroleum habitat, AAPG Memoir 35, p. 252-271.

[10] Fairbridge, R. W.1961, Eustatic changes in sea level, in L. H. Ahrens ed. Physics and Chemistry of the Earth, Pergamon Press.

[11] Gibbs, A. D., 1984, Structural evolution of extensional basin margins J. Geol. Soc. London, 141: 609-620.

[12] Gibbs, A. D., 1987, Development of extension and mixed-mode sedimentary basins. In: Continental extensional Tectonica (Eds M. P. Coward, J. F. Dewey and P. L. Hancock, Spec. Publ. Geol. Soc. London No, 28, 19-33.

[13] Gibbs, A. D., 1989, Structural styles in basin formation, Memorial University of New foundland, St. John's Newfoundland.

[14] Guirad, R. and Maurin, J., 1992, Early Cretaceous rifts of Western and Central Africa: an overview. In: P. A. Ziegler (Editor), Geodynamics of Rifting, volume II. Case History Studies on rifts: North and South America and Africa. Tectonophysics, 213: 153-168.

[15] Harding, T. P., Lowell, J. D., 1979, Structural Style, their plate-tectonic habitats and hydrocarbon traps in petroleum provinces, AAPG Bull, Vol. 63, NO, 7.

[16] He, Y. W., Yao, H. F., Duan, H. M., Chang, J. H., & Liu, Y. Z. (2003). Es3 salt-structural types of Dongpu depression and seismic identification. Oil Geophysical Prospecting, 38, 5, 552-556.

[17] Hussein, A.M, R, 2008, Limnogeology: Sedimentology, Sequence Stratigraphy, and Tectonic Evolution of Mesozoic-Cenozoic Lacustrine Systems: Examples from Bohai Basin, China; and Muglad Basin, Sudan, Ph.d Dissertation, University of Petroleum, Beijing, China. pp.

[18] Hussein, A.M, R, 2012, Tectonostratigraphic Development of Lacustrine Deposits of Mesozoic-Cenozoic Basins, Muglad Basin, Sudan. Journal of Science, International University of Africa, 2, 14- 44

[19] Jackson, J. A. and White, N. J., 1989, Normal faulting in the upper continental crust: observations form regions of active extension J. Struct. Geol, 11, 15-36.

[20] J.Y. Ren, K. Tamaki, S.T. Li, J.X. Zhang, (2002) Late Mesozoic and Cenozoic rifting and its dynamic setting in Eastern China and adjacent areas,

Tectonophysics 344, 175– 205.

[21] Levorsen, A. L., 1967, Geology of Petroleum, 2nd edition, W. H. Freeman.

[22] Lister, G. S., Etheridge, M. A. and Symonds, P. A., 1986, Detachment faulting and the evolution of passive continental margins: Geology 14: 246-250.

[23] North, F. N., 1985, Petroleum Geology, Allen and Unwin Inc.

[24] Ojeda, H. A. O., 1982, Structural framework, stratigraphy and evolution of Brazilian marginal basins, AAPG Bulletin, v. 66.p. 732- 749.

[25] Pan Zhongxiang, 1957, Petroleum generation in nonmarinefacies in northwestern China, Petroleum Exploration, No. 4.

[26] Ponte, E. C., and H. E. Asmus, 1978; Geological framework of the Brazilian continental margin, Geologische Rundschau. V.68, p. 201.

[27] Qi, J. F. (2004). Two tectonic systems in the Cenozoic Bohai Bay Basin and their genetic

[28] interpretation. Chinese Geology , Vol.31, No.1, pp. 15-22.

[29] Qi, J. F., Wang, D. R., Chen, S. P., Zhao, Y. B., Cheng, X. S., Xie, C., Xu, Z. Q. (2006). Impact of geometry and kinematics of Lanliao fault on structural styles in Dongpu Sag. Oil & Gas , Vol.27, No.4,. 451-459.

[30] Qi, J. F., & Yang, Q. (2010). Cenozoic structural deformation and dynamic processes of the Bohai Bay basin province,China. Marine and Petroleum Geology, Vol.27, No.4. 757-771.

[31] Ronov, A. B., 1980, Quantitative analysis of Phanerozoic Sedimentation, Sedimentary geology, vol. 25.

[32] Sun, S. M., Peng, S. M., & Wang, X.W. (2003a). Segmentation characteristics of Lanliao fault in Dongpu depression. Acta Petrolei Sinica, Vol.24, No.4, pp. 26-30.

[33] Swain, F.M. 1970, Nonmarine organic geochemistry, Cambridge.

[34] Vail, P. R., Mitchum, R. M, and Thompson, S. 1977, Seismic Stratigraphy and Global Chanes of Sea Level, Part 4: Global Cycles of Relative Changes of Sea Level, in: Seismic Stratigraphy applications to hydrocarbon exploration, Charles E. Payton (Editor), AAPG, p. 83-97.

[35] Wan, T. F., Zhao, W. M. (2002). On the mechanism of intraplate deformation in Chinese continent. Earth Science Frontiers, Vol.9, No.2, pp. 451-463.

[36] Wang B. and Qian K., 1997, Geologic Research and Exploration Practice in Shengli Petroleum Province, Petroleum Industry Press. PP.335.

[37] Xie Jiarong,1934, Shaanxi Basin and Sichuan Basin, Journal of geography, v. 1, No. 2.

[38] Xin Feng, Xian-Huan Wen, Bo Li, Ming Liu, Dengen Zhou, Michael Q. Ye, Dongmei Hou, Qinghong Yang, and Lichuan Lan 2007, Water Injection Optimization for a Complex Fluvia Heavy Oil Reservoir by Integrating Geological, Seismic, and Production Data, Society of Petroleum Engineers Inc. SPE Annual Technical Conference and Exhibition held in Anaheim, California, U.S.A. 11-14 Nov.

[39] Xu, H.Z., & Zhou, X.K. (2005). Gas genesis and accumulation history of Wenliu gas pool in

[40] Yin, A., & Harrison, M.T. (2000). Geological evolution of the Himalayan-Tibetan orogen.

[41] Annual Review of Earth Planetary Science, No. 28, pp. 211-280.

[42] Zhang, K. X., Qi, J. F., Zhao, Y. B., & Chen, S. P. (2007). Structure and evolution of Cenozoic

[43] in Dongpu Sag. Xinjiang Petroleum Geology, Vol.28, No.6, pp. 714-717.

[44] Zhang, Y. M., Yu, B., & Yang, J. (2008). Controlling factor and model of coal-bed gas in Dongpu depression. Inner Mongolia Petrochemical Industry, No.10, pp. 222-224.

[45] Zhu xia, 1982, Global paleotectonics and Paleozoic petroleum basins, Oil and Gas Geology, Vol. 4, No. 1.

[46] Zhu Xiaomin and Xin Quanlin, 1988, Grain size reatures of a delta and Turbidite fan at the third member of Shahejie Formation in Huimin Depression. Journal of the East China Petroleum Institute, Vol. 11, No. 1.

[47] Zhu Xiaomin and Xin Quanlin, 1987, Application of Markov Chain method to Establishmen of sedimentary model, ACTA Sedimentologica Sinica， V.5, No.4.