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ТЕКТОНИЧЕСКАЯ ЭВОЛЮЦИЯ ПОЗДНЕМЕЗОЗОЙСКО-КАЙНОЗОЙСКИХ БАССЕЙНОВ ВОСТОЧНОГО КИТАЯ И ЕЕ ПОСЛЕДСТВИЯ ДЛЯ СУБДУКЦИИ ТИХООКЕАНСКОЙ ПЛИТЫ

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В течение позднего мезозоя и кайнозоя Северо-Китайский кратон претерпел несколько тектонических перестроек и деформационных событий, в основном вызванных субдукцией Тихоокеанской плиты, что привело к образованию многих нефтеносных бассейнов в Восточном Китае и на прилегающих территориях. На основе анализа, связанного с реконструкцией сбалансированных разрезов, сравнением скоростей погружения и изучением миграции центров осадконакопления в этих бассейнах, ясно прослеживается тектоническая эволюция этих бассейнов и их взаимосвязь. Эволюция бассейна залива Бохай заключается в миграции с юго-запада на северо-восток. Эволюция бассейна северного Желтого моря развивалась в северном направлении, а эволюция бассейна южного Желтого моря – в южном. Развитие бассейна Восточно-Китайского моря активизировалось с северо-запада на юго-восток. С учетом субдукции Тихоокеанской плиты сделаны следующие выводы: (1) структурный рисунок группы бассейнов составляют пояса, простирающиеся субширотно, и блоки, простирающиеся субмеридионально; (2) тектоническая активность в позднемезозойских и кайнозойских бассейнах развивалась с запада на восток как реакция на субдукцию Тихоокеанской плиты в западном направлении, (3) вследствие коллизии Евразийской и Индийской плит и закономерного перехода зоны разлома Тан-Лу от левосторонней к правосторонней кинематике тектоническая эволюция этой группы бассейнов сосредоточена в бассейне Желтого моря, при этом эволюция бассейна залива Бохай происходила в северном направлении, а бассейна Восточно-Китайского моря – в южном.

Позднемезозойско-кайнозойская тектоническая эволюция, бассейны Восточного Китая, субдукция Тихоокеанской плиты

TECTONIC EVOLUTION OF LATE MESOZOIC-CENOZOIC BASINS IN EASTERN CHINA AND IMPLICATIONS FOR PACIFIC PLATE SUBDUCTION

Hongliang Wang and Jintong Liang

During the late Mesozoic and Cenozoic, the North China Craton witnessed a series of tectonic transition and deformation events, caused mainly by the subducting Pacific Plate and forming many petroliferous basins in eastern China and adjacent areas. Based on analysis related to the reconstruction of balanced sections, the comparison of subsidence rates, and the migration of depocenters in these basins, the tectonic evolution of these basins and their relationships with each other are clearly revealed. The evolution of the Bohai Bay Basin shows a migration from southwest to northeast. The North Yellow Sea Basin's evolution developed northward, while the South Yellow Sea Basin evolution migrated southward. The evolution of the East China Sea Basin was activated from northwest to southeast. In combination with the subduction of the Pacific Plate, the conclusions of this study can be summarized in three aspects: (1) The structural pattern of the basin group is characterized by east–west trending belts and north–south trending blocks, (2) tectonic activities in the late Mesozoic–Cenozoic basins evolved from west to east in response to the westward subduction of the Pacific Plate, and (3) due to the collision of the Eurasian Plate and Indian Plate and the transitional pattern of the Tan-Lu Fault Zone from sinistral to dextral, the tectonic evolution of the basin group was centered in the Yellow Sea Basin, with the Bohai Bay Basin evolution migrating northward and the ECSB migrating southward.

Late Mesozoic–Cenozoic tectonic evolution, basins in eastern China, Pacific Plate subduction

INTRODUCTION

A series of late Mesozoic–Cenozoic tectonic deformation and magmatic events were widely developed in eastern China after the formation of the Paleo-Asian continent (Yang et al., 2003; Li et al., 2006). Consequently, the late Mesozoic–Cenozoic basins in eastern China were developed, due to the interactions of the Pacific Plate, Indian Plate, and Eurasian Plate. From previous compilations, the late Mesozoic–Cenozoic basins

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in eastern China evolved regularly, which distinguishes them from the basins controlled by the collision between the Indian Plate and the Eurasian Plate in western China, such as the Tarim Basin, Junggar Basin, Qaidam Basin, etc. This has recently been the subject of heated discussion due to its significance in many research fields (Yin, 1973; Ren et al., 1987; Yang, 2006). These basins are considered to be rift basins according to the characteristics of tensional tectonics and taphrogeny. While some scholars (Suo et al., 2012; Li et al., 2015) believe these basins belong to faulted basins, since they are affected by the extension of the lithosphere and cooling shrinkage of the mantle. Still, owing to the dual impacts of extension and strike-slip faulting, others suggest that these basins are tension-torsional basins (Wang et al., 1999).

However, at present, we reach the consensus that basins in eastern China were developed on the Hercynian folded basement during the late Mesozoic to Cenozoic (Zhang et al., 2015). They mainly underwent three evolutionary stages, including a rifting stage, a rifting-subsidence stage, and a subsidence stage. In addition, the geodynamics of their formation and evolution are related to the subduction of the Pacific Plate. The plate tectonics theory has been introduced in China since the 1990s to study tectonic topics according to plate tectonics (Ma et al., 1983; Ma and Wu, 1987; Ren, 1990; Huang et al., 1997; Xu et al., 2014). Specifically, the structural and tectonic signatures, magmatic events, and the spatial-temporal framework of basins, can be used to reveal interactions between plates along the continental margin in eastern China (Zhu, 1990; Chen and Wang, 1997; Liu, 2007; Chen et al., 2009; Li et al., 2012, 2013). This breakthrough, which also applies to the formation of the late Mesozoic–Cenozoic basins in eastern China, has significantly enhanced the development of research on the regional tectonic evolution of China.

Yet, for all the studies and attention paid to the evolution of basins in eastern China and the destruction of the North China Craton (NCC) (Tian et al., 1992; Liu et al., 2001; Ren et al., 2002; Windley et al., 2010), there is little discussion concerning the connection between the Pacific plate movement and the tectonic evolution of the late Mesozoic–Cenozoic basins in eastern China. Therefore, with data available, this study focuses on four basins in terms of late Mesozoic–Cenozoic tectonic evolution (Fig. 1), namely the Bohai Bay Basin (BBB), the South Yellow Sea Basin (SYSB), the North Yellow Sea Basin (NYSB), and the East China Sea Basin (ECSB). Since these large-scale basins, the time of formation of which dates back to the late Mesozoic–Cenozoic, are located only on the eastern continental margin, discussions regarding their tectonic evolution can typically represent the tectonic evolution characteristics of most basins in eastern China. Along with characteristics of the Pacific Plate subduction, we study the controlling effects of regional tectonic evolution on the formation of sedimentary basins. Furthermore, this study also attempts to clarify how the subduction of the Pacific Plate affects the

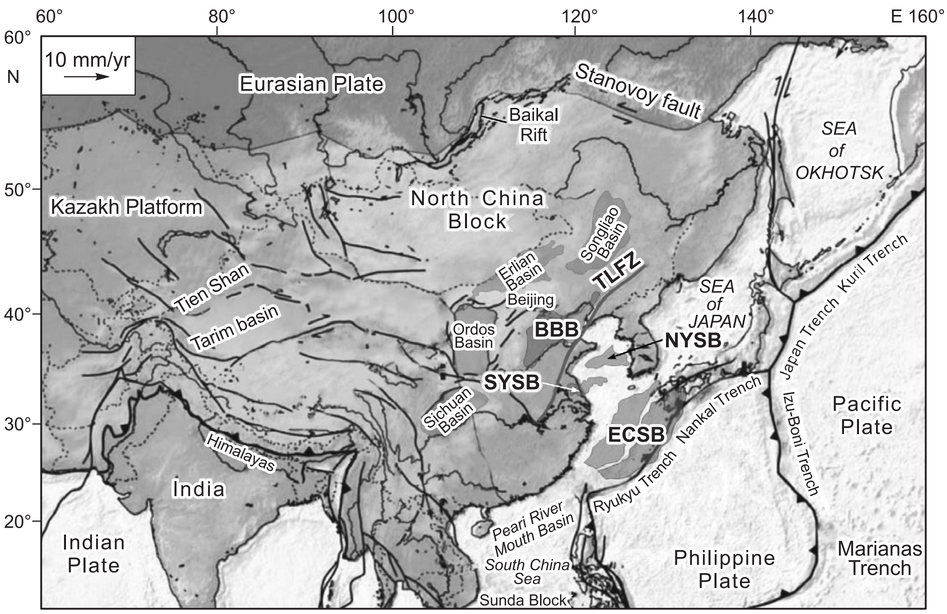


Fig. 1. Map showing the location and tectonic setting of basins in eastern China (modified from (Calais et al., 2003; Castellanos, 2007; Mann, 2012)).

Global positioning system vectors in the red, green and blue areas differ from each other regarding directions and rates. The red line shows the location of the TLFZ (=Tan-Lu Fault Zone). Main basins in eastern China are marked in colors, of which basins in red refer to our study basins. BBB, The Bohai Bay Basin; NYSB, The North Yellow Sea Basin; SYSB, The South Yellow Sea Basin; ECSB, The East China Sea Basin. Geologic and tectonic settings of Eastern China basins are shown in more detail in Fig. 2.

evolution of the late Mesozoic–Cenozoic basins in eastern China. Results of this study may also have significance for the determination of favorable zones and target areas for energy resource exploration in these basins.

GEOLOGIC AND TECTONIC SETTING

Basement structures

The late Mesozoic–Cenozoic basins discussed in this study are mainly controlled by faults in eastern China (Liu, 1986; Xu et al., 1987; Huang et al., 1997; Zhao et al., 2005). Studies suggest that these controlling faults are extensions of basement faults, like the piedmont fault zone of Tai-Hang Mountain and the Tan-Lu Fault Zone (TLFZ) (Allen et al., 1997; Gong et al., 2007; Huang et al., 2015). In the Cenozoic, these reactivated faults formed a series of new faulted basins in eastern China.

As there is a close relation between the TLFZ and the evolution of basins in eastern China, the activity characteristics of the TLFZ and its impact on surrounding areas are inevitably considered. The influence is presented from two viewpoints:

(1) A massive sinistral transpressional structure derived from the TLFZ resulted in different patterns of fault systems (Xu et al., 1987; Zhu et al., 2005; Sun et al., 2010; Zhu et al., 2012; Liu et al., 2015). These faults caused the lithospheric thinning and decreased pressure in the upper mantle, which are the basis of basin formation (Menzies et al., 1993; Gao et al., 2008; Zhang and Dong, 2008).

(2) Those spread to the deep mantle in the late Mesozoic, during which the decreased pressure led to the upwelling of the mantle and caused mantle uplift (Cai et al., 2002; Zhang et al., 2008; Lin et al., 2014; Xu et al., 2014; Li et al., 2015). In the process of mantle upwelling and melting, lithospheric thinning and magmatic eruptions finally formed these late Mesozoic–Cenozoic basins in eastern China.

STRESS STATES

Through analysis of the formation and evolution of the late Mesozoic–Cenozoic basins in eastern China, the tectonic stress system is seen to play a major role (Huang, 1979; Huang et al., 1997; Li and Xu, 2005; Luo et al., 2014; Zheng et al., 2015). Liu (1986) proposed that the conditions of the tectonic stress changed with variation in space and time (Fig. 2). Through analysis of the sedimentary and tectonic evolution of the late Mesozoic–Cenozoic basins in eastern China, the stress states can be divided into the following stages:

(1) In the early Mesozoic, the stress state in eastern China was characterized by compressive stress in general, which is demonstrated by regional uplifts and syncline basins (Liu, 1986; Shu et al., 2004; Ge et al., 2014).

(2) In the late Mesozoic, the stress state in eastern China, especially in the northeast and north China area, was converted into tensional stress. A large variety of faulted basins were formed during this period (Yan et al., 1979; Xu and Wu, 1997; Xu et al., 2012b).

It was these large-scale changes of tectonic movement in the Early Cretaceous that resulted in the variation of paleotectonic features in eastern China. Additionally, other factors, such as the tectonic features of the basement and boundary conditions also contributed to the various evolutionary characteristics of these late Mesozoic–Cenozoic basins.

Subduction of the Pacific Plate

The four basins discussed in this study are all located along the TLFZ in eastern China, which is also in the subduction belt of the Pacific Plate. Thus, when talking about the late Mesozoic–Cenozoic evolution of these basins, the subduction of the Pacific Plate cannot be ignored.

The late Mesozoic subduction of the Pacific Plate witnessed two major changes from 140 Ma to 65 Ma (Sun et al., 2008; Zhang, 2013). The Pacific Plate drifted between 140–125 Ma. About 125 Ma, the Pacific Plate began to subduct northwest wards with a great direction change of about 80 degrees clockwise, forming Andes type compression in eastern China. The second change, happened at about 110 Ma, is characterized by slab roll-back and back-arc extension.

The westward subduction of the Pacific Plate can be divided into four stages during the Cenozoic:

(1) Late Cretaceous to early Paleocene (65–50 Ma): The Pacific Plate exhibited NNW-trending movement (Bao et al., 2013; Zhang et al., 2015), and the subduction rate decreased during this stage from 140 to 120 mm/yr.

(2) Late Paleocene to Eocene (50–32 Ma): The subduction rate continued to decrease, while the subduction direction changed from NNW to NWW until 43 Ma. From 43 to 32 Ma, the subduction rate increased gradually from 40 to 60 mm/yr (Deng et al., 2002; Chen et al., 2015).

(3) Oligocene to Miocene (32–23 Ma): The subduction rate slowly increased to 80 mm/yr by 23 Ma, with the subduction direction remaining stable (Li et al., 2011; Suo et al., 2012).

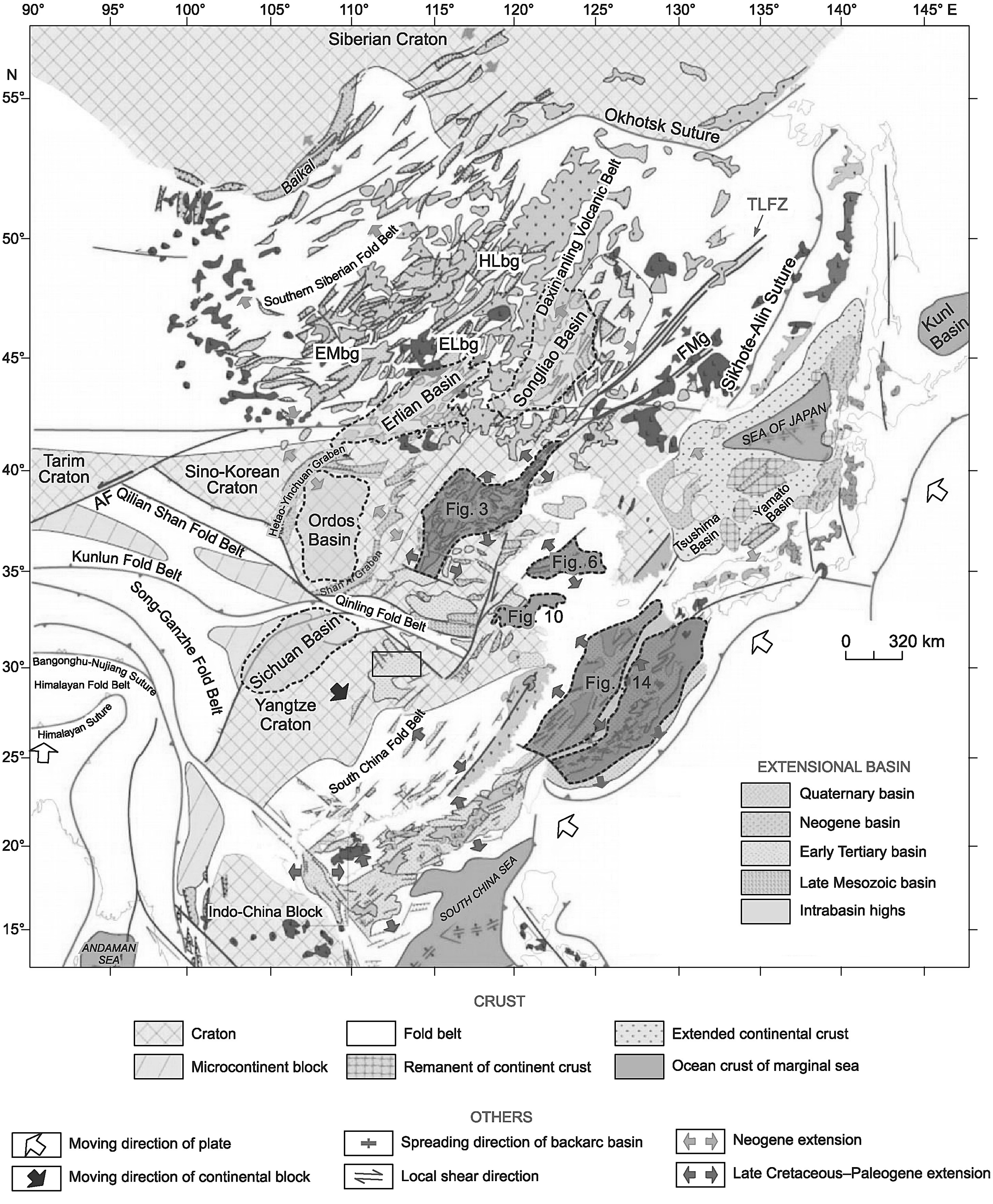


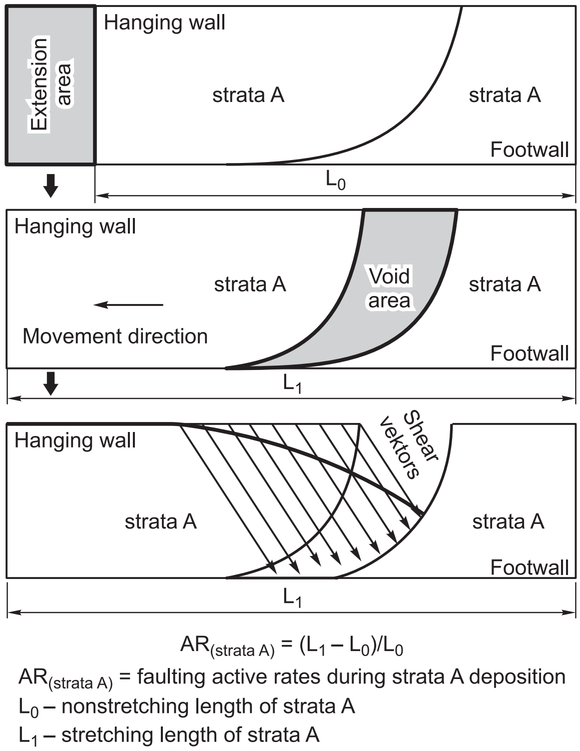
Fig. 2. Maps showing the tectonic framework of basins in eastern China in the late Mesozoic and Cenozoic (modified from (Ren et al., 2002; Gao et al., 1998)). TLFZ, Tan-Lu Fault Zone.

(4) Late Miocene to present (23–0 Ma): The Pacific Plate maintained a NWW-trending subduction with the subduction rate ranging from 80 to 130 mm/yr (Bao et al., 2013).

METHODS AND DATA

The data utilized in this study through the study area includes 2D seismic data of 30 surveys and drilling data in addition to completion reports of 20 wells. We reconstructed balanced cross-section with the "2D

Fig. 3. Oblique cutting model of balanced sections showing method of calculating fault extension rate (Liang et al., 2016).



Move" software. During reconstruction, we propose a mechanical model modified from the balanced cross-section already presented in (Freivogel and Huggenberger, 2003). After construction, a restoration process was implemented to validate the cross-section and to identify and amend errors. Ehasan et al. (2015) discuss the details of this restoration method.

The balanced section technique is a simulation technique about restoring deformation structure into original undeformed condition on the vertical structure, based on geometric conservation principle (Ramsay and Huber, 1987; Fang et al., 2012). Basically, this concept can be explained as when one area is shaped by a compressional stress, the other adjacent area must witness a tensional stress (Zhang et al., 2014). The balanced section technique has been widely accepted as an important model in tectonic analysis since Dahlstrom (1969) first discussed its concepts in detail. During the reconstruction of sedimentation and mechanical mathematical modeling, three principles including volume conservation, area conservation, and length conservation in a closed system are followed (Zhang and Yang, 2007; Yakovlev, 2012; Polyansky et al., 2013). In this study, 16 sections were selected to interpret stratigraphic sequence. After this interpretation, these sections were restored to balanced sections using oblique cutting model (Fig. 3), and extension rates (or compression rates with negative values) were calculated using "2D Move" software. Once the balanced cross-sections are reconstructed, activity rates of controlling faults could be calculated to show the difference through the study area.

It is proposed that tectonic processes of continental margins can cause the subsequent subsidence and sedimentation inside (Royden and Keen, 1980; Sclater et al., 1980). This means if the subsidence or thermal histories are known, the timing and intensity of these processes can be estimated (Royden and Keen, 1980; Tang et al., 2008; Lin et al., 2013). Most importantly, a sharp change of the subsidence rate is closely related to some certain tectonic process. In this study, we cited well subsidence history data from publications (Yang et al., 2003; Li et al., 2006; Ren et al., 2008; Zhang et al., 2009), in combination with which the difference in analyzing appears to be more convincing. Through the comparison of extension rates and subsidence rates, the intensity and migration of subsidence activity in each basin could be clearly analyzed. After determining the evolutionary characteristics of the basins in eastern China, the westward subducting Pacific Plate (Zhu et al., 2011) is also cited in order to clarify the relationship between the evolution of basins in the late Mesozoic–Cenozoic and the subduction of the Pacific Plate.

SUBSIDENCE HISTORY AND TECTONIC EVOLUTION OF BASINS

Tectonic evolution of the BBB

The BBB, with a total area of 2.0×10^5 km^2 (Lu et al., 1997; Tang et al., 2008), is located in the destruction center of the NCC. The structural unit of the BBB is mainly characterized by seven depressions and four uplifts (Fig. 4). Previous studies show that tectonic activities within the Cenozoic BBB migrated regularly, but showed less regular migration rules in the late Mesozoic (Hou et al., 2001; Guo et al., 2007; Ren et al., 2008). This study utilizes the Cenozoic evolution as an example to support these insights. Six sections across each depression in the BBB are reconstructed to reveal the characteristics of the BBB evolutionary history. According to the analysis of the subsidence history (Fig. 5), the depocenters of the BBB were distributed in the western BBB in the early Cenozoic, during which the eastern BBB had a relatively low rate of subsidence. Until the late Cenozoic, when the eastern BBB commenced to subside more extensively, while the depocenters migrated to the eastern BBB. The study by Suo et al. (2012) (Fig. 6) is consistent with this migration of depocenters, which

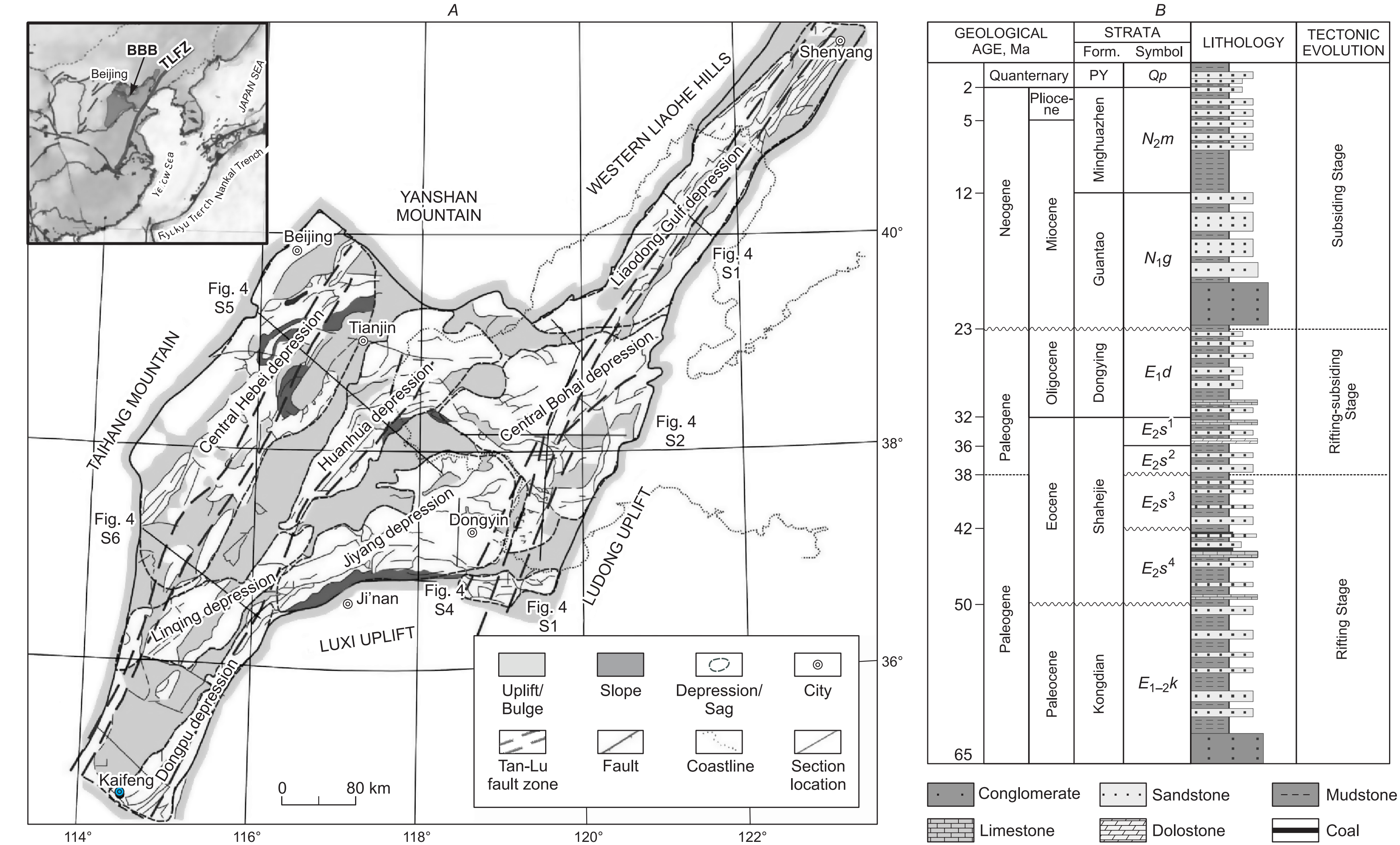


Fig. 4. Tectonic map (*A*) showing the subdivision of the BBB (modified from Li et al., 2012).

To study the tectonic evolution, sections marked in the map are reconstructed using the software "2D MOVE". In combination with the subsidence history, the characteristics of subsidence and tectonic evolution are shown in Fig. 5. (*B*) shows the stratigraphic columns used for the construction of the tectonic subsidence curves and the lithologic types of sediments (modified from (Liang et al., 2016)).

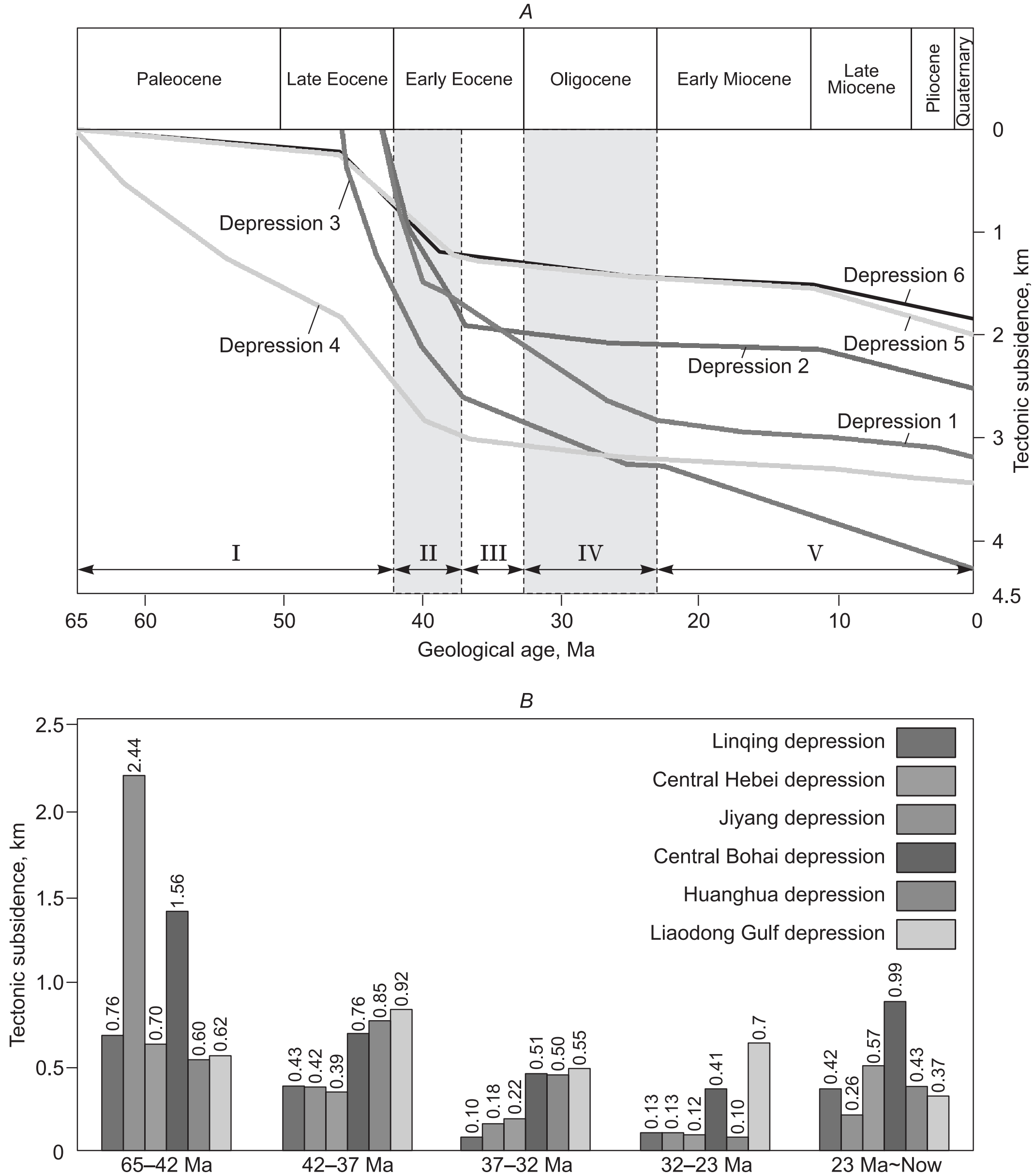


Fig. 5. Analysis of tectonic subsidence during the entire Cenozoic using data collected from previous studies (Ren et al., 2008).

See Fig. 4 for locations of depressions and sections, stratigraphic and lithologic details in the BBB. The curves in color in (*A*) show accelerated subsidence of the main depressions in the Cenozoic. The columns in color in (*B*) show the net subsidence of the Cenozoic BBB in each evolutionary phase.

also indicated the centers of sedimentation and subsidence of the BBB transferred from the southern BBB to the northern BBB at the same time.

Tectonic evolution of the NYSB

The NYSB is located in the Jiao-Liao Uplift with a total area of 2.16×10^4 km^2 (Cai et al., 2004; Wang et al., 2012), which mainly consists of three depressions and four uplifts (Fig. 7). The subsidence rates and curves in the modeling of the subsidence history indicate the range in subsidence rates in the eastern NYSB is larger than that in the western and middle NYSB. A study by Li et al. (2006) (Fig. 8) showed that the eastern NYSB subsided more extensively than the western NYSB in the early Mesozoic, which refers to the eastern area subsiding with a higher rate than the western area (170–65 Ma). The depocenter transferred to the middle

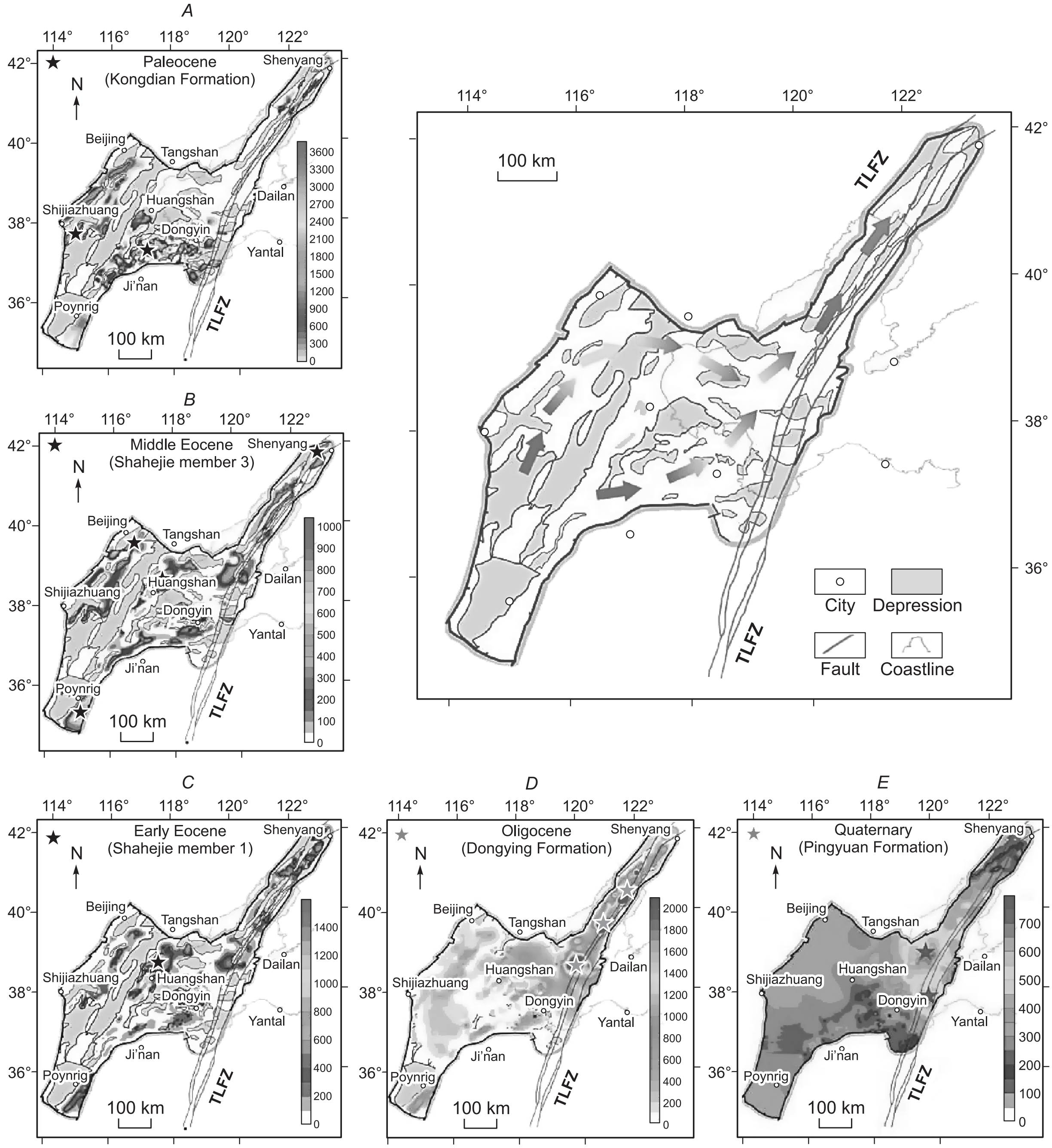


Fig. 6. Contour maps (modified from (Suo et al., 2012)) of the BBB tectonic subsidence in the Cenozoic showing the migration of subsidence centers.

As is shown in this figure, tectonic activity was initiated in the southwest in the early Cenozoic. By the late Cenozoic, depocenters controlled by tectonic activities had spread to the northeast. Arrows in the upper right panel show the migration of subsidence centers, and colors correspond with the other five smaller panel in different geologic time. Stars in other five panels show the subsidence centers in each geologic time. TLFZ, Tan-Lu Fault Zone.

NYSB in the Eocene and spread to the western NYSB during the Oligocene. The subsidence curves show the subsidence rate of the east NYSB was higher than that of the west NYSB in the late Mesozoic, but was lower in the Cenozoic, which confirms the westward migration direction of the depocenters. It is, therefore, concluded that the migration direction of tectonic activities in the NYSB is generally “from east to west” (Gong et al., 2000; Wang et al., 2008) (Figs. 9 and 10).

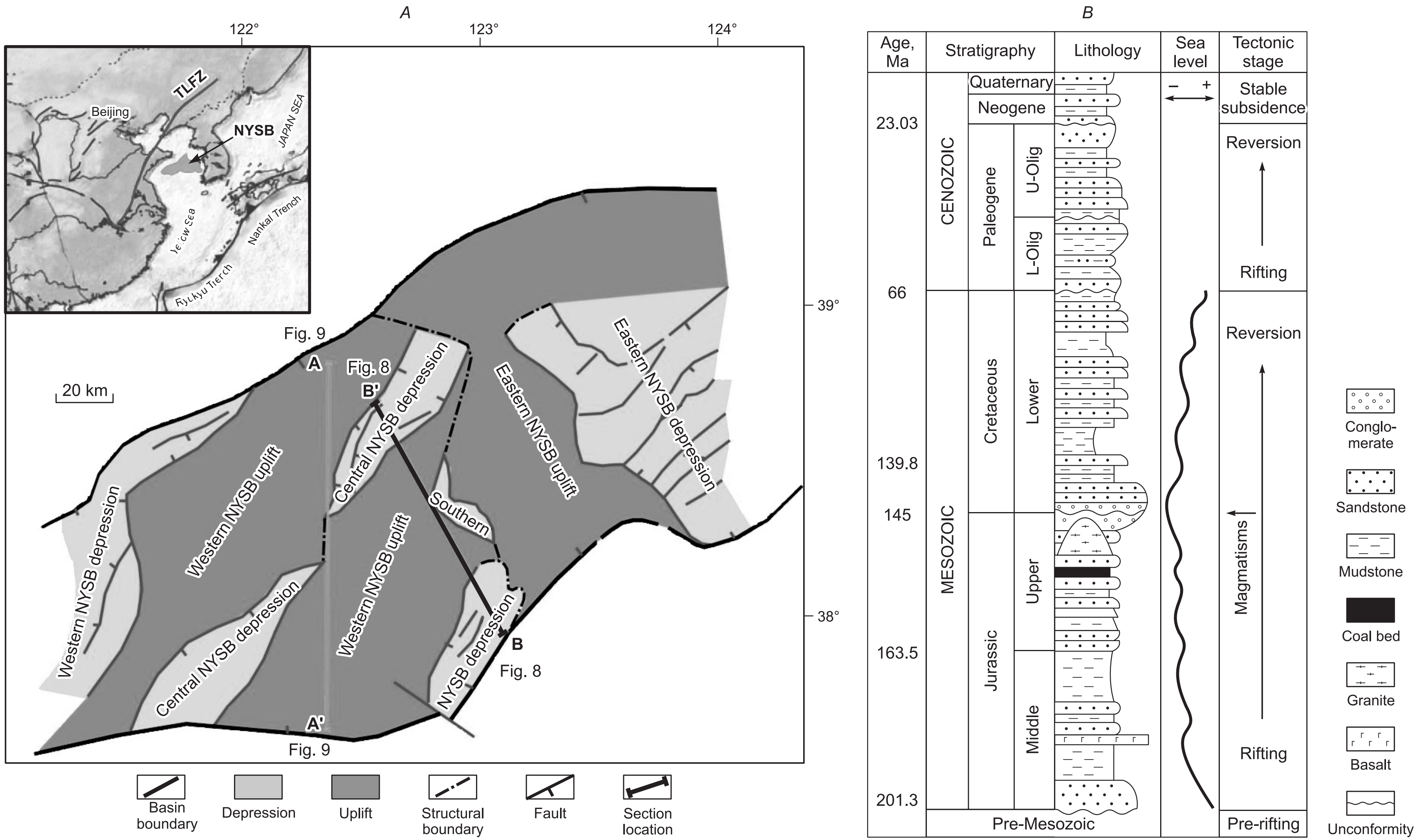


Fig. 7. Tectonic map (*A*) showing the subdivision of the NYSB (North Yellow Sea Basin). (*B*) shows the stratigraphic columns used for the construction of the tectonic subsidence curves and the lithologic types of sediments (modified from (Wang et al., 2017)).

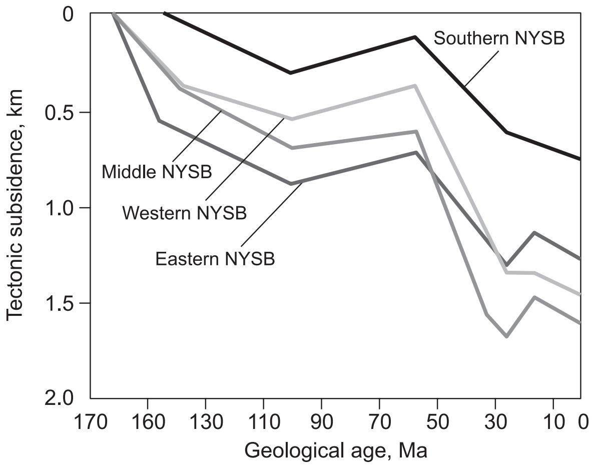


Fig. 8. Analysis of tectonic subsidence curves from different areas in the NYSB (North Yellow Sea Basin).

Data source collected by Li et al. (2006) includes 72 wells. Each curve represents the average rate of subsidence in each area and the slope represents the rate of subsidence. See Fig. 7*B* for stratigraphic and lithologic details used in the NYSB.

Tectonic evolution of the SYSB

Located on the southern Yellow Sea continental shelf (Yao et al., 2005; Hou et al., 2008), the SYSB covers a total area of 6.9 × 10^4 km^2 (Fig. 11). The SYSB underwent at least three rapid subsidence events (Fig. 12) in the late Mesozoic–Cenozoic (Feng et al., 2008; Liu et al., 2014): (1) in the early Mesozoic (250 Ma), the SYSB experienced rapid subsidence; (2) in the Early Cretaceous (135 Ma), the SYSB witnessed another subsidence event in relation to violent magmatic activities caused by activation of the Yangtze plate; and (3) the last slow subsidence stage occurred from 10 Ma to present. The complex variation of the subsidence rate of the SYSB reflects that the evolution of the late Mesozoic–Cenozoic SYSB was characterized by the migration of depocenters regionally from east to west. On the local scale, the depocenter of the north SYSB evolved northward while the south SYSB evolved southward (Figs. 13 and 14).

Tectonic evolution of the ECSB

The ECSB is the largest offshore shelf basin in eastern China (Xu et al., 2012a) with a total area of 2.5 × 10^5 km^2. The central uplift divides the ECSB into two depressions (eastern and western) (Fig. 15). As is shown

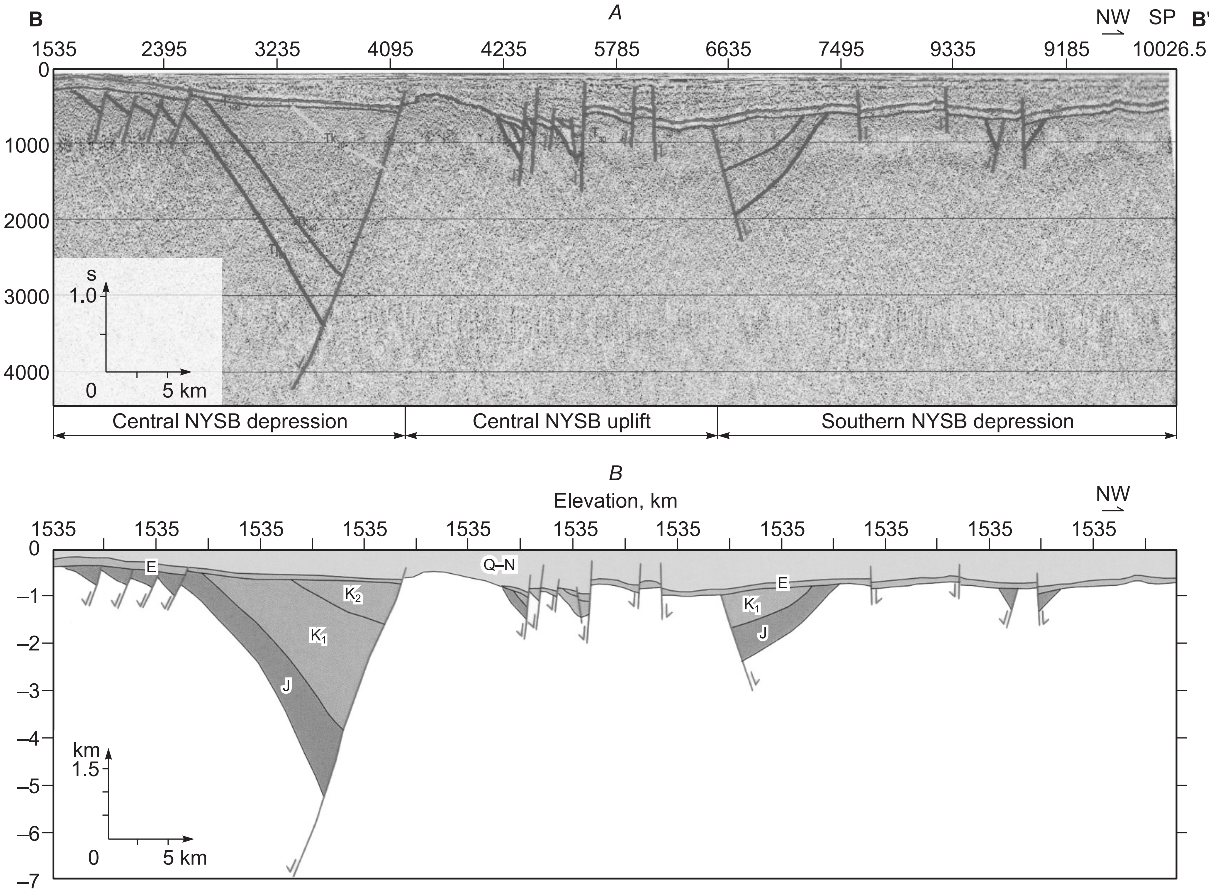
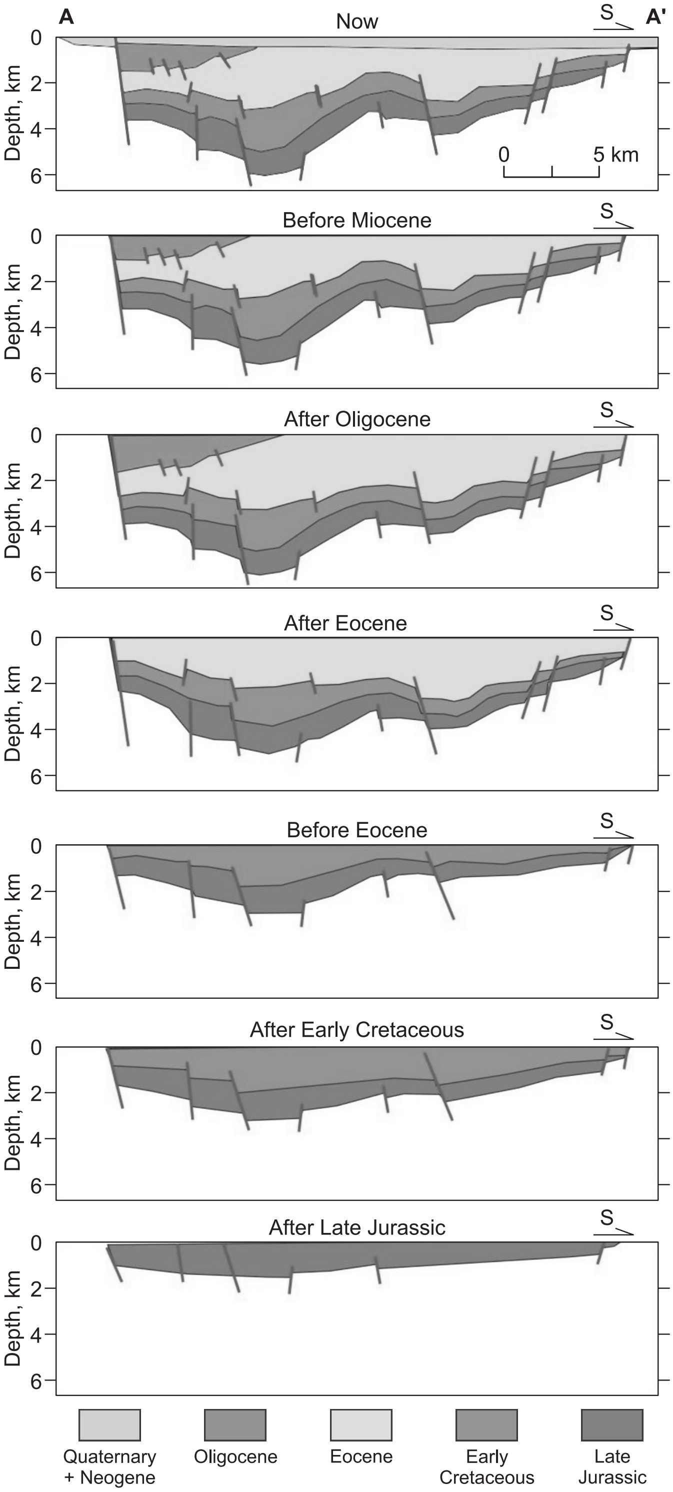


Fig. 9. Structural interpretation of seismic of profile across different sags in the NYSB. See Fig. 7 for the location of this section.

Fig. 10. Balanced geologic section showing the tectonic evolution of the NYSB during the late Mesozoic–Cenozoic. See Fig. 7 for the location of this section.



in the analysis of subsidence rates, in the western ECSB (Fig. 16), the northern area evolved at a higher rate than the southern part before 7 Ma; however, the southern area increasingly turned out to be the main subsidence center with a higher rate after 7 Ma. This shows a southward migration of depocenters, though these two parts show no significant difference in evolutionary history. While in the eastern ECSB, the northern part experienced a more complex series of tectonic activities than the southern part and they differed from each other in evolutionary history (Zhang et al., 2009; Jia and Zheng, 2010; Jiang et al., 2013). However, during the same timeframe, the deformation occurred earlier in the western ECSB and later in the eastern ECSB (Suo et al., 2012). The comparison of extension rates allows us to conclude that the tectonic activities in the ECSB (Figs. 17, 18, and 19) migrated generally from west to east and from north to south from the late Mesozoic to the Cenozoic.

Characteristics of tectonic evolution

Through the comparison and analysis above, the regularity of tectonic evolution inside each basin and the migration of tectonic activities are reflected. The analytical results show that the late Mesozoic–Cenozoic evolution of the basin group in eastern China is characterized by a structural pattern of east-west trending belts and north-south trending blocks. In the northsouth direction, the migration and period of tectonic activities in eastern China varied with time, during which the Yellow Sea Basin (YSB) was the evolution center. Tectonic activities in the southern area evolved towards the southeast and those in the northern area migrated to the northeast since the late Mesozoic. In the eastwest direction, tectonic activities transferred from the western part in the late Mesozoic to the eastern part until the Cenozoic. However, the spatiotemporal differences lie in three aspects: the migration of tectonic activity, periods of rifting activity, and the migration of inversion structures.

Migration of compression activity. Tectonic activities in the four basins formed a roughly west to east trend during the late Mesozoic–Cenozoic. However, tectonic activities in the BBB transferred from southwest to northeast with a migration from land to sea. As for the YSB, tectonic activities migrated northward in the northern part while migrating southward in the southern part. In the ECSB, especially the East China Sea Shelf Basin, tectonic activities evolved from the northern ECSB to the southern ECSB.

In terms of the time scale, the BBB underwent the active tectonic stage from the Late Jurassic to the Early Cretaceous (Figs. 5 and 6), during which time the migration was progressing. A more regular migration was reflected in the Cenozoic. The tectonic compression and denudation in the YSB (Figs. 8 and 12) were

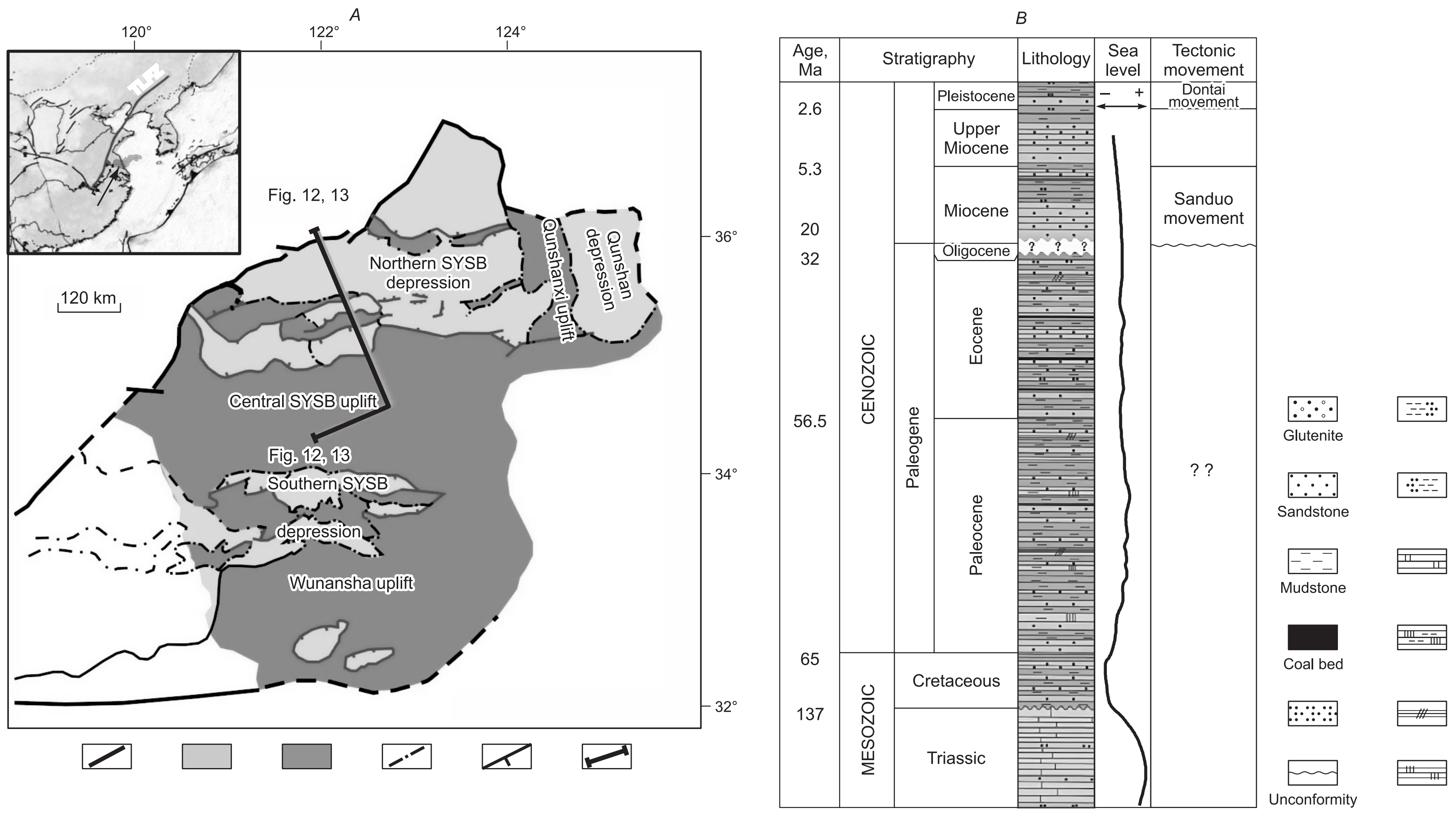
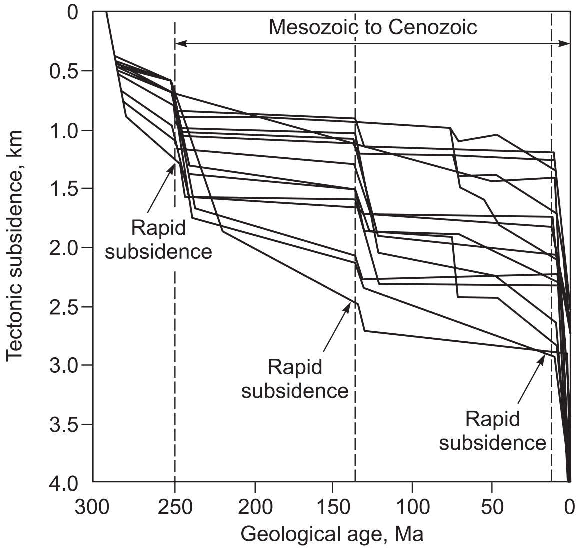


Fig. 11. **Tectonic map (*A*) showing the subdivision of the SYSB (South Yellow Sea Basin). (*B*) shows the stratigraphic columns used for the construction of the tectonic subsidence curves and the lithologic types of sediments (modified from (Zhu et al., 2010)).**

Fig. 12. Analysis of tectonic subsidence curves from different areas in the southern SYSB (modified from Yang et al., 2003).

Three events of rapid subsidence in the late Mesozoic–Cenozoic are marked. By recovering the denudation thickness, data of wells from the southern SYSB is calculated and analyzed in this figure. The slope of each curve represents the rate of subsidence. See Fig. 11*B* for stratigraphic and lithologic details used in the SYSB.



dominant in the early Mesozoic, and a rifting and subsidence period followed. Considering this aspect, the migration pattern of tectonic activities in the YSB was mainly reflected in the late Mesozoic and the Cenozoic. The migration evolved gradually in the ECSB (Fig. 16), the western and eastern parts of which showed different migration patterns. The western ECSB underwent its rifting stage since the Paleocene while the denudation was dominant after the late Eocene. In contrast, the eastern ECSB entered its rifting period in the Eocene and tectonic activities were present throughout the eastern ECSB.

Periods of rifting activity. The late Mesozoic–Cenozoic basin group in eastern China was characterized by a stratigraphic structure of rifting and subsidence in sequence. Because of their location along the TLFZ, periods of rifting activity in these basins are related to changes of stress condition in eastern China. The two-layer structure of the basin group would probably play a major role in periods of rifting activity as well. The tectonic structure is composed of the rifting structure on the bottom and an overlapping structure on the top.

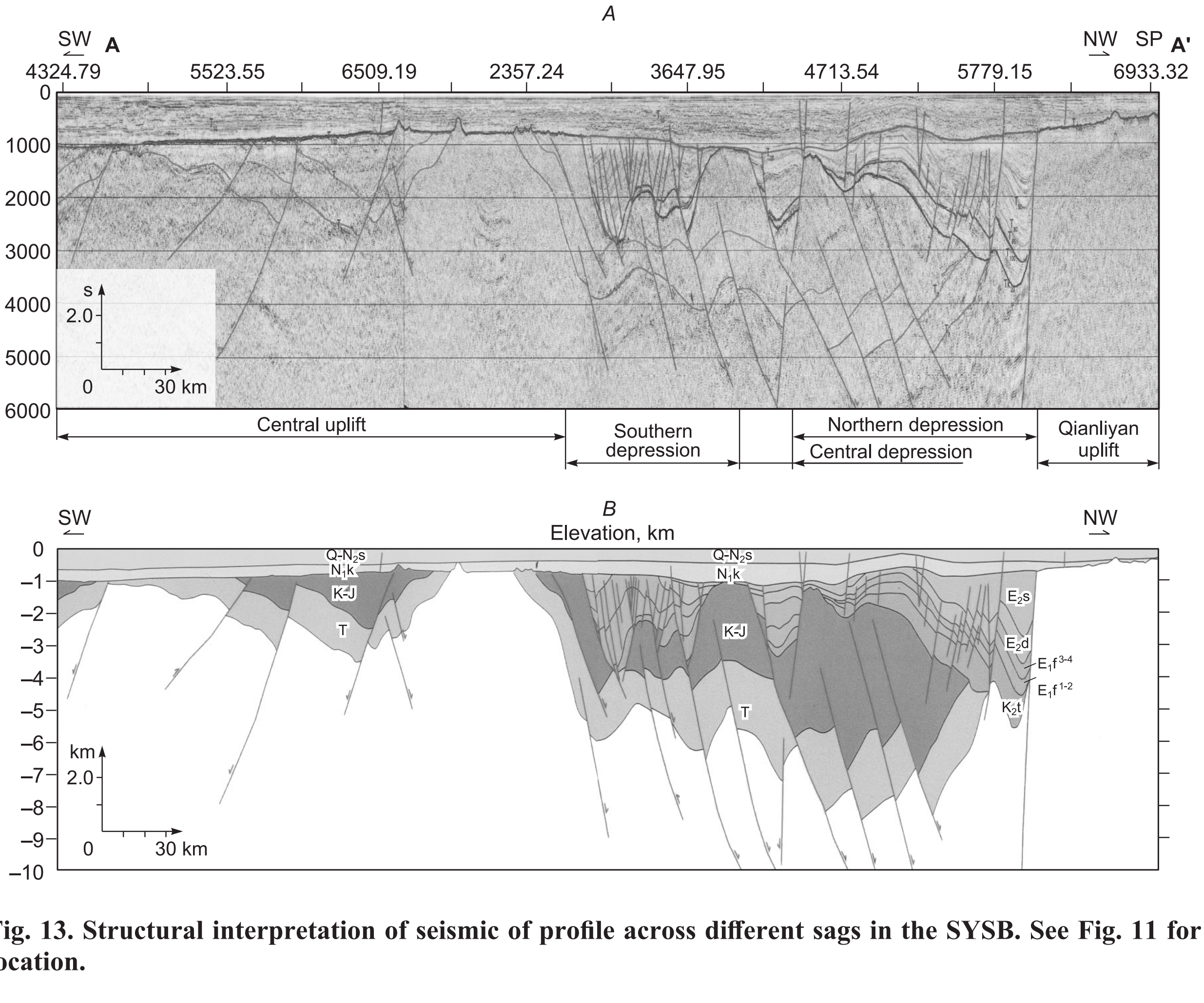


Fig. 13. Structural interpretation of seismic of profile across different sags in the SYSB. See Fig. 11 for location.

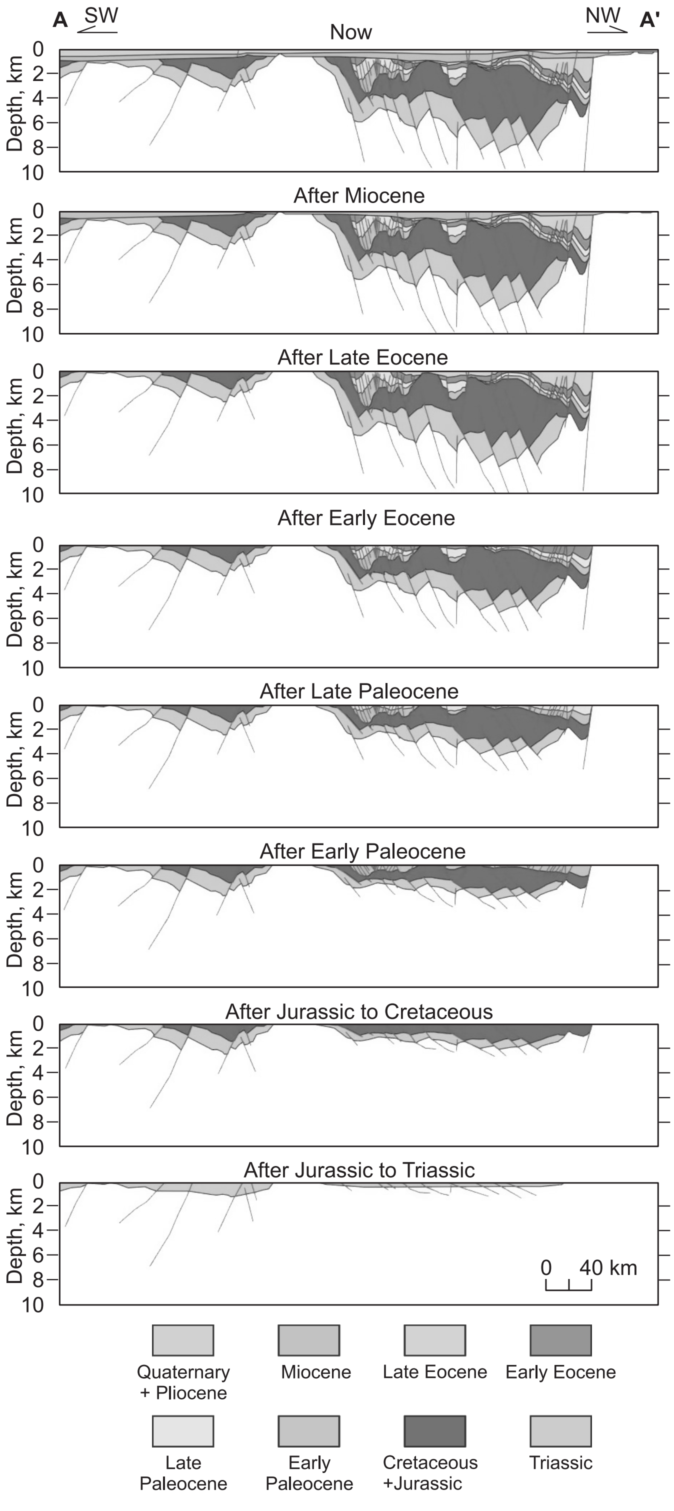


Fig. 14. Balanced geologic section showing the tectonic evolution of the SYSB during the late Mesozoic–Cenozoic. See Fig. 11 for location.

After the tectonic activities in the BBB (Fig. 5) decreased with migration form the west to the east in the Paleogene, these activities evolved into a period of neotectonic movement with an increasing activity rate in the Neogene. Generally, the BBB developed with extensive tectonic actives in the western part in the early stage and lesser activities in the eastern area in the late stage (Fig. 5). The YSB entered its rifting stage in the Late Cretaceous and its subsidence stage in the late Eocene. Completely opposite to that of the BBB, the late Mesozoic–Cenozoic tectonic activities developed more extensively in its late stage than in its early stage. During the evolutionary history of the YSB (Figs. 8 and 12), the rate of tectonic activities in the eastern part is higher than that in the western part. The controlling faults of the western ECSB were activated in the Paleocene, in contrast, those of the eastern ECSB (Fig. 14) were activated in the Eocene to Oligocene. Tectonic activities spread from the western ECSB to the eastern ECSB with a gradually decreasing rate.

Migration of inversion structures. All four basins in eastern China witnessed several periods of reverse rotation during the late Mesozoic–Cenozoic, which formed relevant inversion structures and fold structures. Meanwhile, inversion structures in these basins also developed a west to east migration trend. The main inversion period in the BBB (Fig. 4) evolved in the Early Jurassic as well as from the Late Cretaceous to the early Paleogene with an eastward migration. By the Oligocene, the tectonic stress in this inversion period showed a significant decrease. Meanwhile, the YSB experienced three inversion periods, including the Late Cretaceous, late Oligocene, and early Neogene (Qi et al.., 2017). The intensity of the compressive stress in the YSB still remained strong in the Oligocene and decreased thereafter. Furthermore, the inversion stress in the ECSB (Fig. 17) appeared extensive in the Cenozoic, which could be divided into three stages namely the Miocene, Oligocene, and Paleocene. The northern area of the western ECSB was mainly affected by the Paleocene inversion, while the southern area was mainly affected by the Oligocene structures. Notably, the center of inversion had migrated to the eastern ECSB by the Miocene. It is, therefore, conclude that the fact inversion structures in eastern China evolved from the west to the east occurred in response to the eastward migration of tectonic activities in the four basins during the late Mesozoic–Cenozoic.

IMPLICATIONS OF PACIFIC PLATE SUBDUCTION

Since the four basins described in this study are located in eastern China, the tectonic evolution of which migrated regularly in the late Mesozoic–Cenozoic. One possible explanation for this phenomenon is that it is

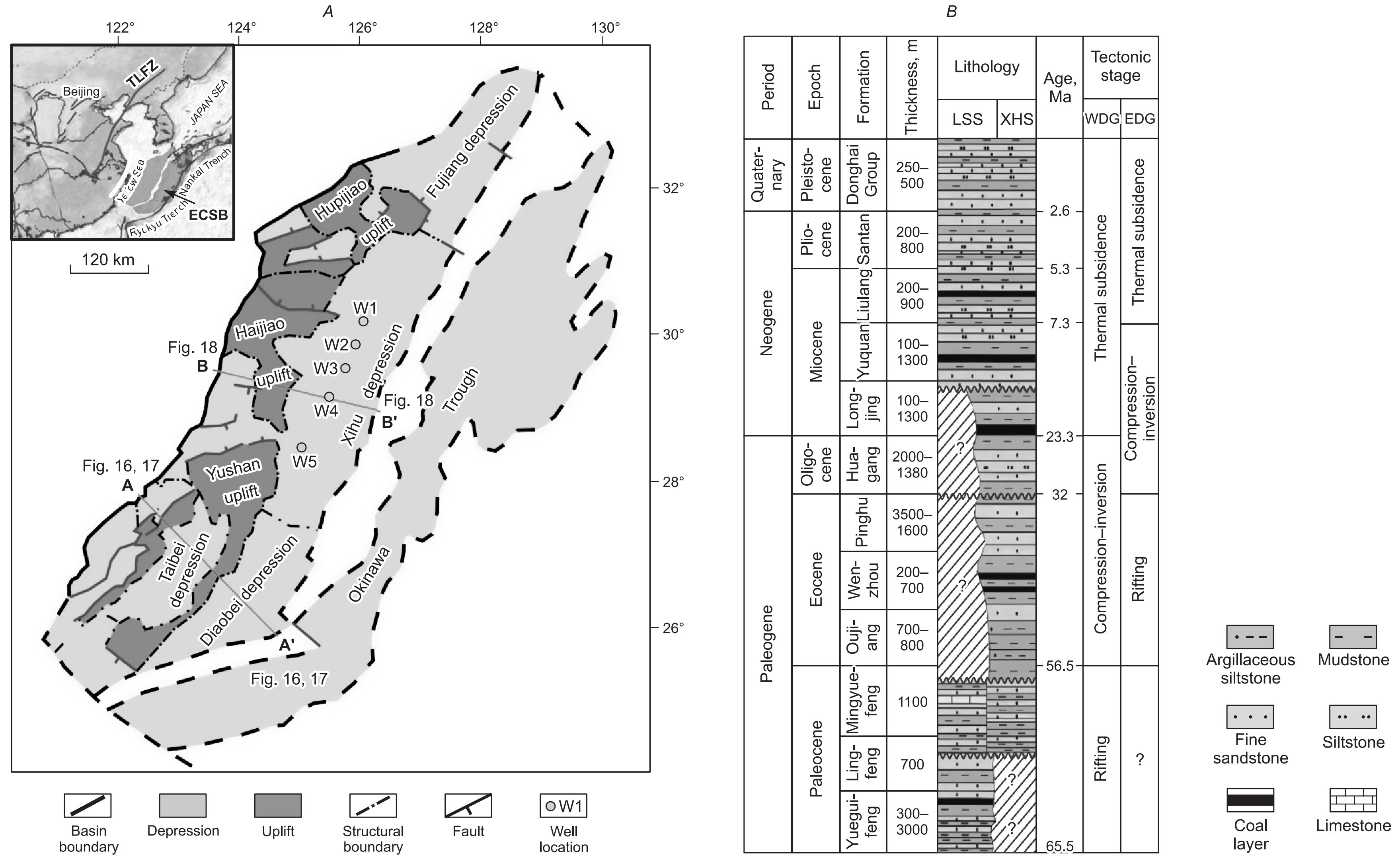


Fig. 15. Tectonic map (*A*) showing the subdivision of the ECSB (East China Sea Basin).

Five typical, including W1, W2, W3, W4 and W5, wells are selected to the tectonic subsidence history, and are marked in gray dots. (*B*) shows the stratigraphic columns used for the construction of the tectonic subsidence curves and the lithologic types of sediments (modified from (Liang et al., 2018)).

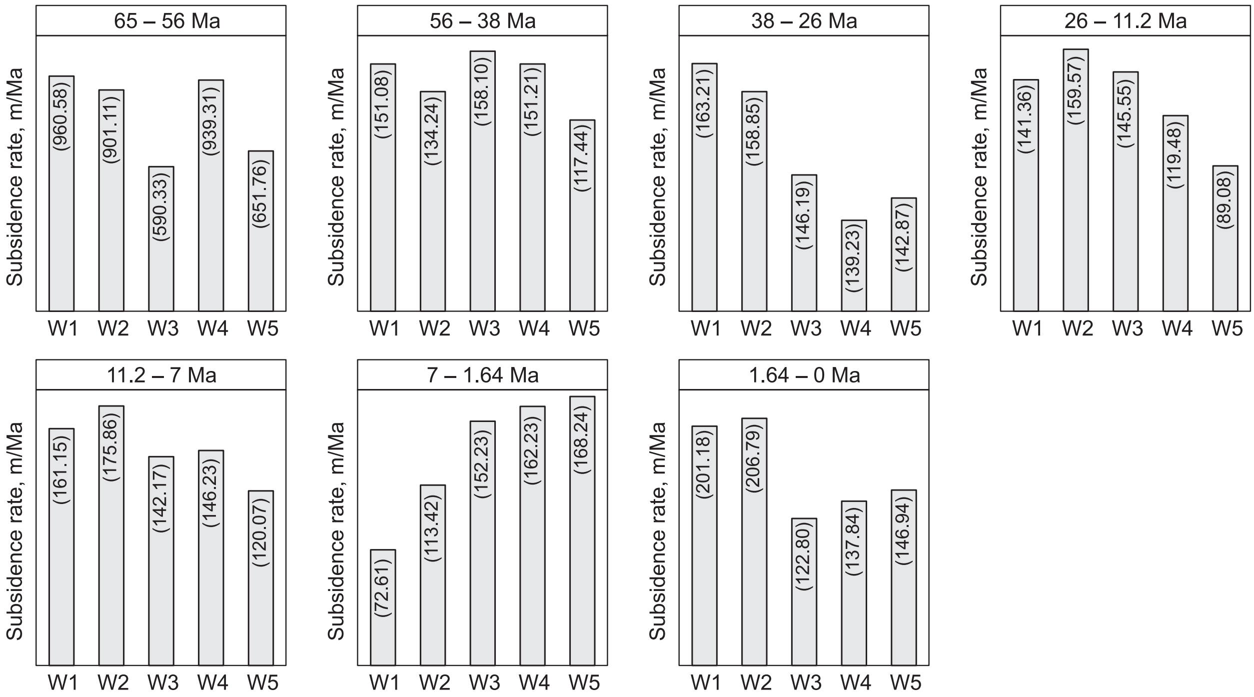


Fig. 16. Chart showing the tectonic subsidence history of five wells (see Fig. 15 for location) in the central ECSB (data source: Zhang et al., 2009).

To show the migration of depocenters more clearly, this chart shows seven periods of geologic age. During each period, the subsidence rate of each well is marked on the column. In the early Cenozoic, the northern areas evolved more violently than the southern areas. By the late Cenozoic, depocenters had migrated to the southern area gradually.

closely related to the westward subduction of the Pacific Plate (Ren, 1990; Ren et al., 1987; Yang, 2006; Yin, 1973). In the late Mesozoic, the Pacific Plate tended to subduct northward with a transition of subduction angle from SW to NNW. In contrast, in the Cenozoic, the subduction seemed to be simple and the subduction angle changed to NWW (Fig. 20).

A few authors consider the evolutionary history of basins to be controlled by a series of geodynamic mechanisms relating to the Eurasian Plate, the deep Pacific Plate, and the boundary conditions between the Eurasian Plate and the Pacific Plate. However, most authors tend to regard the subduction of the Pacific Plate as a major controlling factor (Ma et al., 1983; Ma and Wu, 1987; Huang et al., 1997; Xu et al., 2014). Based on the preceding analysis, this study proposes the dynamic mechanism of plate boundary interactions between the Pacific Plate and the Eurasian Plate plays an important role in basin evolution. Three interpretations for this conclusion are made as follows.

Relationship between subduction and migration of tectonic activity

From the perspective of evolutionary migration, the BBB, the NYSB, the SYSB, and the ECSB in eastern China experienced eastward evolution both in the late Mesozoic and in the Cenozoic. At the same time, the subducting Pacific Plate dipped westward beneath the Eurasian Plate. Thus, the insight that the migration of the basin evolution is related to the subduction of the Pacific Plate is widely accepted. Specifically, the Pacific Plate subduction transitioned from a low angle and high stress to a high angle and low stress in the late Mesozoic (Liu, 2010). The major other change is that the front of the subducted Pacific Plate migrating gradually to the south and to the Okinawa Trough spreading in the Cenozoic. In this study, the two main evolutionary periods of the BBB are related to the two changes in Pacific Plate subduction in terms of direction and subduction characteristics in the late Mesozoic and the Cenozoic. In the late Mesozoic, the single period of evolution of the YSB indicates the late Mesozoic change in subduction characteristics. As for the ECSB in the Cenozoic, this evolutionary period is closely connected to the Cenozoic change in subduction characteristics. Therefore, the fact that the BBB, the YSB, and the ECSB evolved from the west to the east corresponds with the roll-back of the Pacific Plate subduction belt controlled by the Himalayan movement in the Cenozoic.

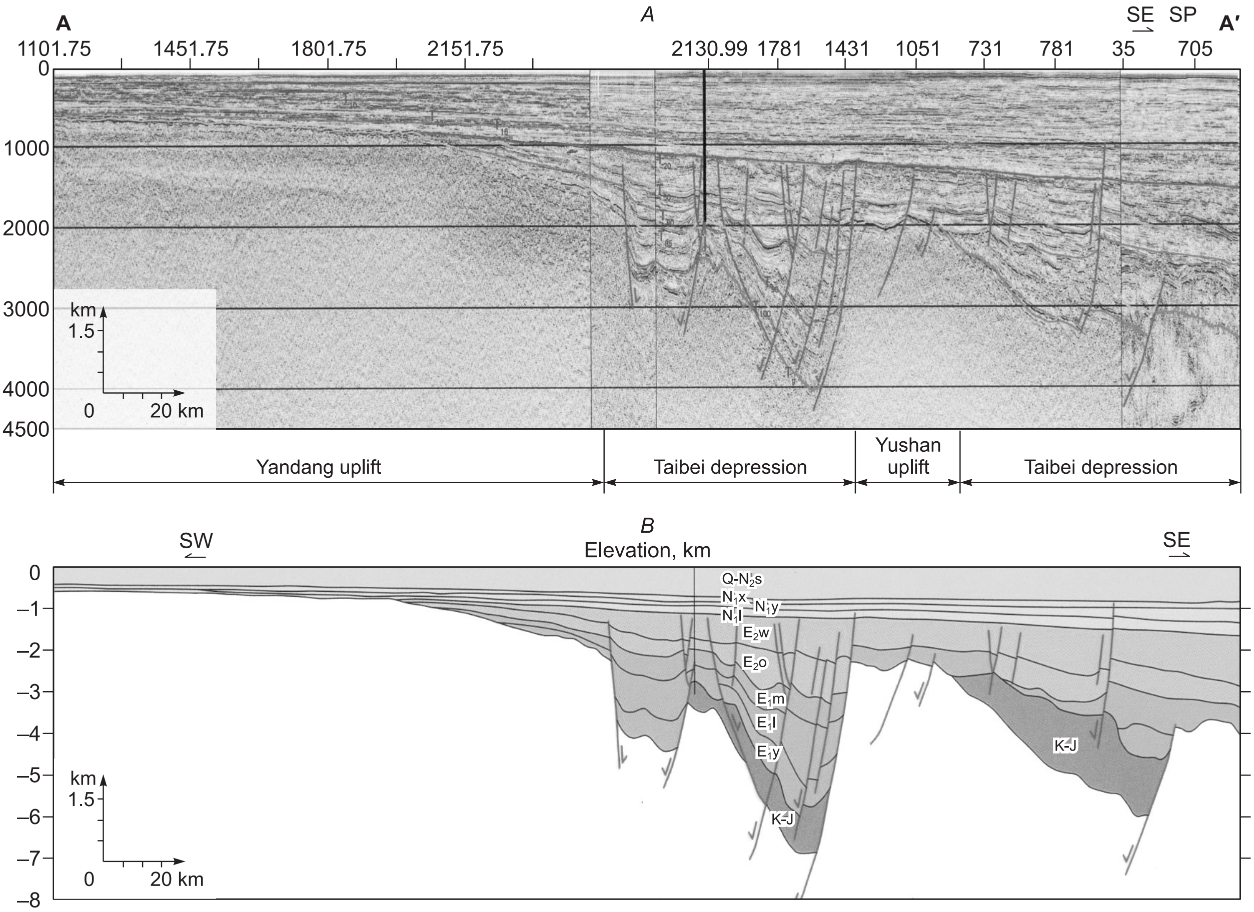


Fig. 17. Structural interpretation of seismic profiles across different sags in the ECSSB. See Fig. 15 for location.

Relationship between subduction and periods of rifting activity

The migration of tectonic activity in the basin group in eastern China is widely considered to be controlled by the TLFZ during the late Mesozoic–Cenozoic, which refers to the transition from sinistral compression to dextral tension. As is reflected in the BBB, for example, the sinistral compression of the TLFZ in the Late Cretaceous enabled it to enter a stage of uplift. The activity center evolved eastward as a consequence of the TLFZ, in terms of its extension in the Cenozoic. A problem that needs to be discussed is whether there is a relationship between basin evolution and Pacific Plate subduction. Notably, the fault characteristics of the TLFZ are under the influence of the adjustment mechanism of the subducting Pacific Plate. More specifically, the sinistral compression of the TLFZ corresponds to the clockwise adjustment from NW to NNW of the Pacific Plate subduction. When the Pacific Plate slowly subducted with an anticlockwise adjustment from NNW to NW, the TLFZ began to enter its dextral extension stage. The relationship is, therefore, convincingly demonstrated by the indirect evidence of the TFLZ.

Relationship between subduction and subsidence history of the basins

Because of the special location along the TLFZ in eastern China, the subsidence characteristics and migration of the depocenters of the BBB, NYSB, SYSB, and the ECSB must be the result of a certain dynamic mechanism. This study believes the subducted Pacific Plate is the dominant factor. Since the late Mesozoic, the western margin of the Pacific Plate has been affected by the dynamic system of the ancient Pacific Plate; and the continental margin in eastern China has evolved from the Andean-type trench-arc system in the late Mesozoic into the Western Pacific Ocean type trench-arc/back-arc system in the Cenozoic. This series of plate movements resulted in formation of fault-block mountains in the YSB. What needs to be pointed out is that the YSB, located in the deformation area caused by both the Eurasian Plate and the Indian Plate, divided the basin group

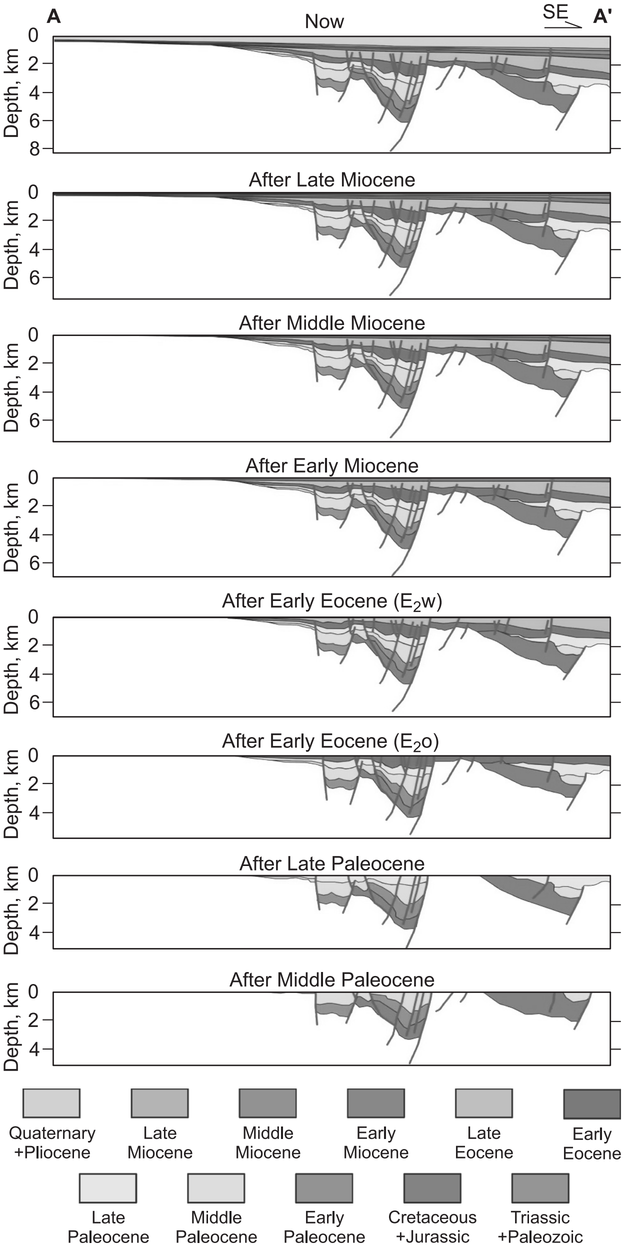


Fig. 18. Balanced geologic section showing the tectonic evolution of the ECSB during the late Mesozoic–Cenozoic.

See Fig. 15 for location. Q–N_2s, Quaternary + Pliocene; N_1x, Late Miocene; N_1y, Middle Miocene; N_1l, Early Miocene; E_2w, Early Eocene (Wenzhou Formation); E_2o, Early Eocene (Oujiang Formation); E_1m, Late Paleocene; E_1l, Middle Paleocene; E_1y, Early Paleocene; K–J, Cretaceous + Jurassic; Mz–Pz, late Mesozoic + early Paleozoic.

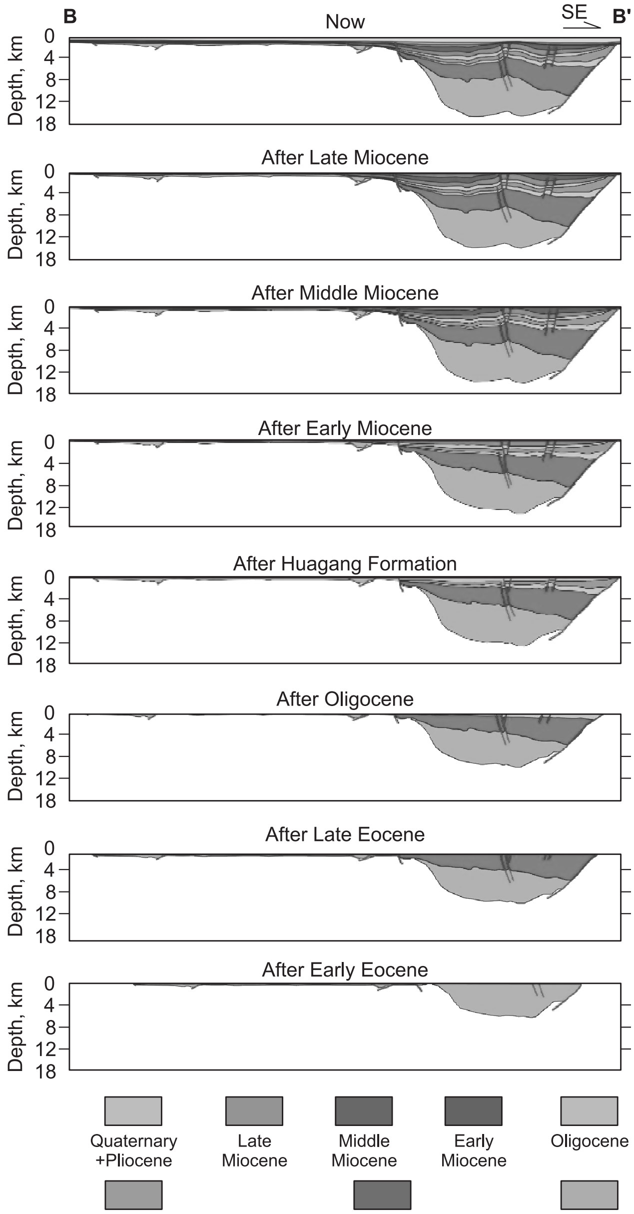


Fig. 19. Balanced geologic section showing the tectonic evolution of the ECSB during the late Mesozoic–Cenozoic.

See Fig. 15 for location. Q–N_2s, Quaternary + Pliocene; N_1x, Late Miocene; N_1y, Middle Miocene; N_1l, Early Miocene; E_3h, Oligocene; E_2p, Late Eocene (Wenzhou Formation); E_2w–E^1, Early Eocene.

into two separate parts. As a result, the northern BBB evolved northward while the southern ECSB developed southward. From the evolutionary migration of the basins, in both the east–west and north–south directions, the relationship to the subduction of the Pacific Plate is obvious.

CONCLUSIONS

As important examples of basins in eastern China, four basins all developed regularly regarding the migration of faulting, the migration of compression and rifting activities, and the migration of their depocenters.

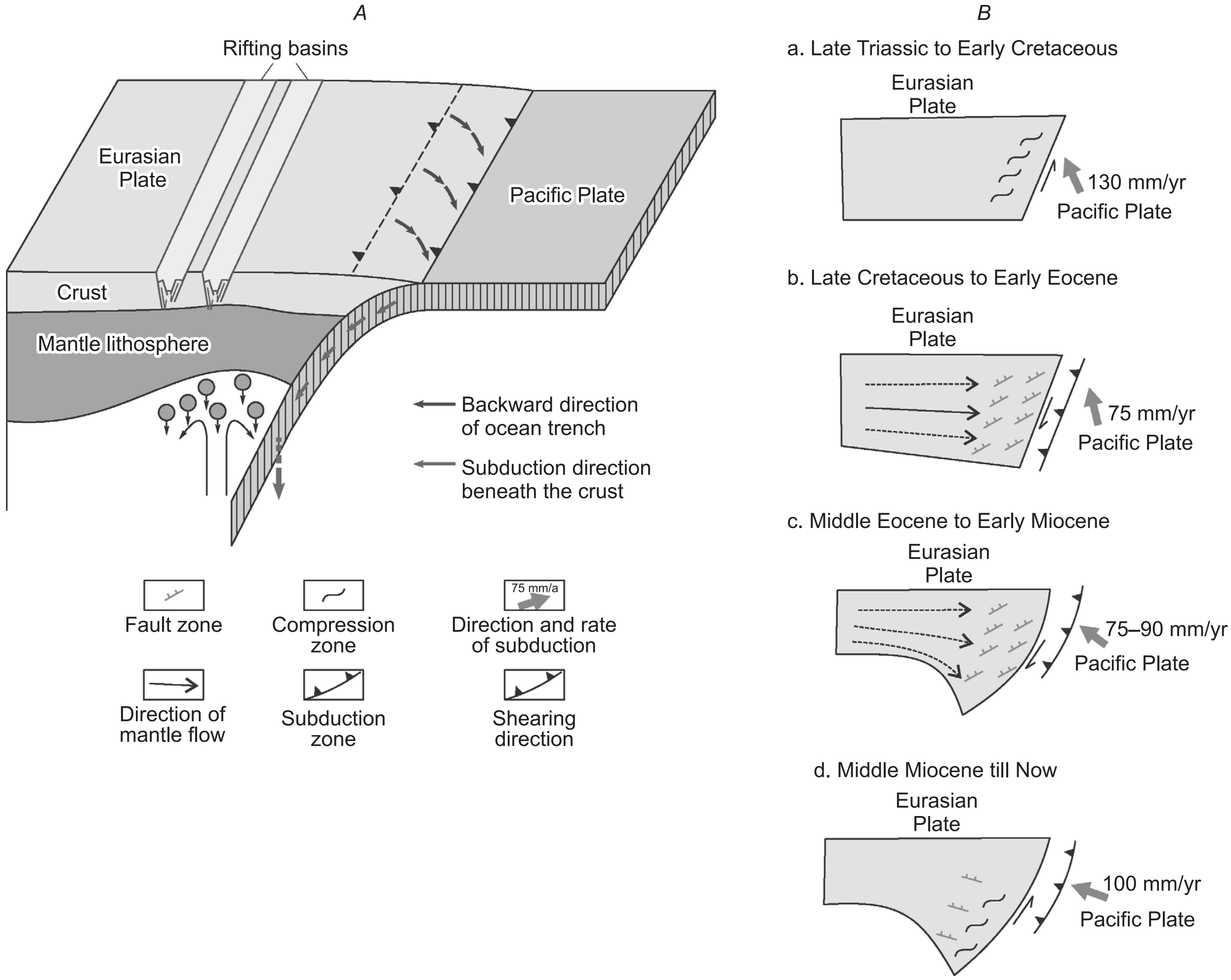


Fig. 20. Maps showing the comparison between the extensional direction of the eastern North China Craton and plate motion in the Pacific Basin, modified from (Zhu et al., 2011).

Map *A* shows the model plate motion relating to the Eurasian Plate and the Pacific Plate. Map *B* shows the subduction process of the Pacific Plate beneath the Eurasian Plate, which is divided into four stages.

These characteristics also show significant implications for the interaction of plates in eastern China, mainly referring to the subduction of the Pacific Plate. Results of this study may also have significance for the determination of favorable zones and target areas for energy resource exploration in these basins. Considering all the geologic data available, the conclusions of this study are summarized as follows.

(1) The structural pattern of the basins in eastern China is distributed in east-west trending belts and north-south trending blocks during the late Mesozoic–Cenozoic.

(2) In response to the roll-back of the subduction belt at the western Pacific Plate margin, tectonic activity in these basins evolved from west to east in eastern China during the late Mesozoic–Cenozoic.

(3) The major other change is that the front of the subducted Pacific Plate migrating gradually to the south and to the Okinawa Trough spreading in the Cenozoic. These subduction changes in the late Mesozoic–Cenozoic played a major role in basin evolution. Consequently, the tectonic evolution of the basin group was centered in the YSB with the BBB evolution migrating northward and the ECSB migrating southward.

(4) Based on the analysis of both the east–west direction and north-south direction of migration, the migration characteristics of basin evolution have significant implications for subduction of the Pacific Plate.

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