

PS Faults and Their Interaction in the Offshore Bohai Bay Basin: Implication for Hydrocarbon Exploration*

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Abstract

Faulting is an important factor controlling hydrocarbon accumulation in the offshore Bohai Bay Basin. Based on the seismic interpretation and structural mapping, the fault systems and their interaction and influence on hydrocarbon accumulation in the offshore Bohai Bay Basin are analyzed. The extensional and strike-slip faults are the most important in the study area, and inversion faults are locally distributed. In plane view, the trends of faults are the NE, NW and EW directions, and the NE-striking faults, which appear flower-structure features in seismic profiles, belong to the Tanlu strike-slip fault, and the NW-trending faults are related with the Zhangjiakou-Penglai strike-slip fault. The EW-striking faults could be classified into the small- and large-scale faults, and the small-scale faults in the shallow strata were resulted from the strike-slipping movement of the Tanlu fault. The large-scale faults, which act as the boundary faults between the uplifts and depressions in the southern region, have quasi-flower structures composed of the major listric faults and branching strike-slip faults in seismic lines, and their formation should be controlled by the early S-N extension and the late strike-slipping movement of the Tanlu fault.

Overall, the amount of the faults in the offshore Bohai Bay Basin is very numerous, and their shapes and strikes are obvious change. Then, the faults interaction in the study area is relatively complicated. In the basin scale, the NE- and NW-trending faults constitute the conjugate shear faults system during the neotectonic time. In addition, abundant small-scale examples of faults interaction, such as the X-pattern normal faults and transfer zones, are also developed well. The recent important breakthrough of hydrocarbon exploration has demonstrated that the faults interaction had exerted significance on the hydrocarbon accumulation, mostly through controlling the formation of traps, hydrocarbon migration, as well as improving reservoir properties.

Faults and their interaction in the offshore Bohai Bay basin: Implications for hydrocarbon exploration

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1 Introduction

The Bohai Bay basin, which is composed of onshore and offshore parts, is a important petroliferous basin in China. After over 40 years of petroleum exploration, the basin has become the second largest oil production basin in China, following only the Songliao basin. Even though, the offshore Bohai Bay basin is considered to host more than one-third of the total estimated petroleum resources of the basin, only about 700 exploratory and production wells have been drilled offshore so far, covering an area of about 50,000 square kilometers. In the offshore part, faulting is the key factor controlling hydrocarbon accumulation, especially the Tanlu fault which traverses the eastern side of the basin influenced the basin formation and hydrocarbon enrichment. In addition, the secondary faults with various geometries and scales and their interaction had also exerted significance in the trap formation and hydrocarbon migration.

2 Geological setting

The Bohai Bay basin, a Cenozoic rift basin with a rhombus-shape and an area of about 200,000 square kilometers, is situated on the eastern coast of China (Figure 1a). The basin is bounded by the Yanshan uplift to the north, Taihangshan uplift to the west, Luxi uplift to the south, and the Jiaoliao uplift to the east (Figure 1b). Traditionally, the development of the basin is closely related to the back-arc extension as the Pacific plate subducted beneath the eastern margin of the Asian continent. However, detailed interpretations of the basin development and the relation between the basin and the Tanlu fault have been controversial for a long time.

The offshore Bohai Bay basin could be divided into numerous secondary structural units involving uplifts and depressions, which are bounded by faults and onlap lines (Figure 2). The strata encountered by the wells include the Paleozoic, Mesozoic, Paleogene (including the Kongdian Formation (E_2k), Shahejie Formation (E_3s) and Dongying Formation (E_3d)), Neogene (including the Guantao Formation (N_1g) and Minghuazhen Formation (N_2m)) and Quaternary. The unconformity between the Paleogene Dongying Formation and the Neogene Guantao Formation implies the end of rifting and initiation of post-rifting, which resulted in the different basin frameworks under and above the unconformity.

3 Fault types and distribution

The interpretation of large amount of seismic profiles show that extensional and strike-slip faults are predominant in the offshore Bohai Bay basin. In addition, a few inversion faults are present in local areas.

Extensional faults are the most important faults in the offshore Bohai Bay basin, which are widespread in the all basin and Cenozoic, and they have changeable trends, geometries and scales. In cross sections, the large-scale extensional faults are listric and ramp-flat faults, the small-scale faults have similar geometries in their upper and lower parts. Several faults could form different combination types, such as “X” and “Y” patterns (Figure 3).

Strike-slip fault, a key fault style in the Bohai Bay basin, are mainly distributed in the eastern part of the basin, which are belong to the NE-trending Tanlu strike-slip fault. Their distribution ranges in plane are bigger and bigger from the north to the south. In addition, some strike-slip faults are attached to the NW-striking Penglai-Zhangjiakou strike-slip fault. In seismic profiles, the strike-slip faults express typical negative, positive and semi-flower structures (Figure 4).

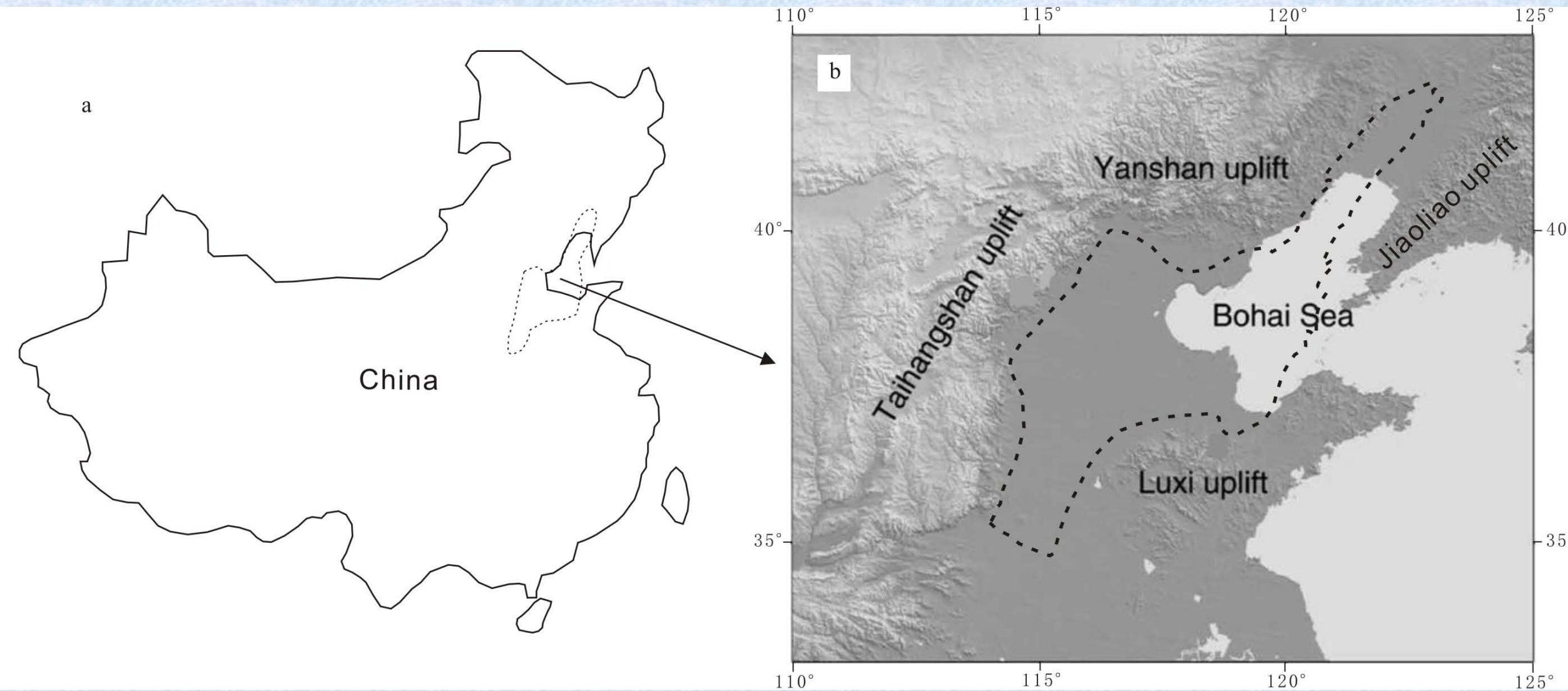


Figure 1. Sketch maps showing the location and geological setting of the Bohai Bay basin

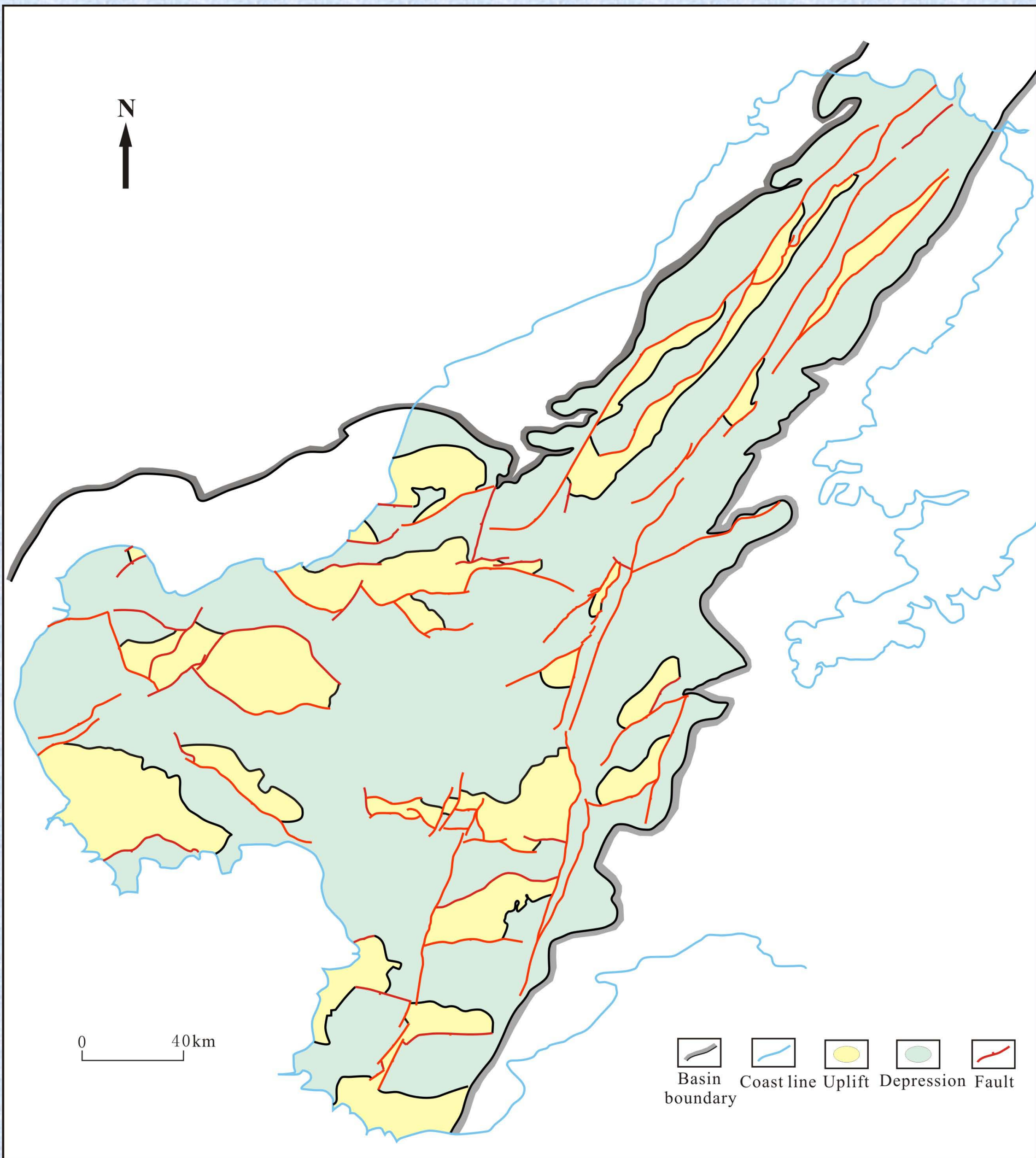


Figure 2. Simplified map showing the division of structural units and major faults in the offshore Bohai Bay Basin

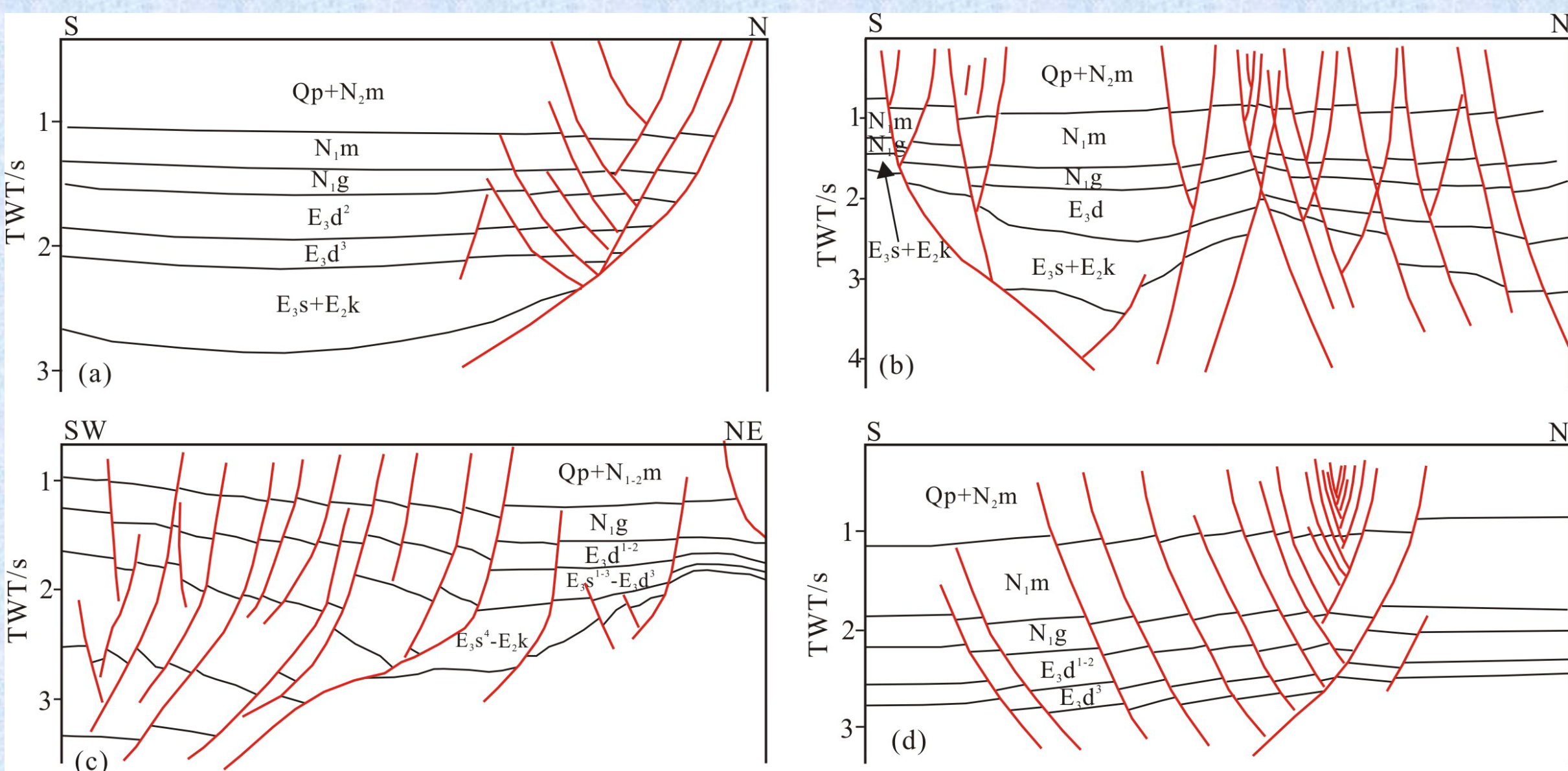


Figure 3. Extensional faults in the offshore Bohai Bay Basin

Inversion faults are locally distributed in the eastern basin. For example, the LZ-No.1 fault in the Liaodongwan depression is a typical inversion fault, whose styles and dips change along its trend (Figure 5).

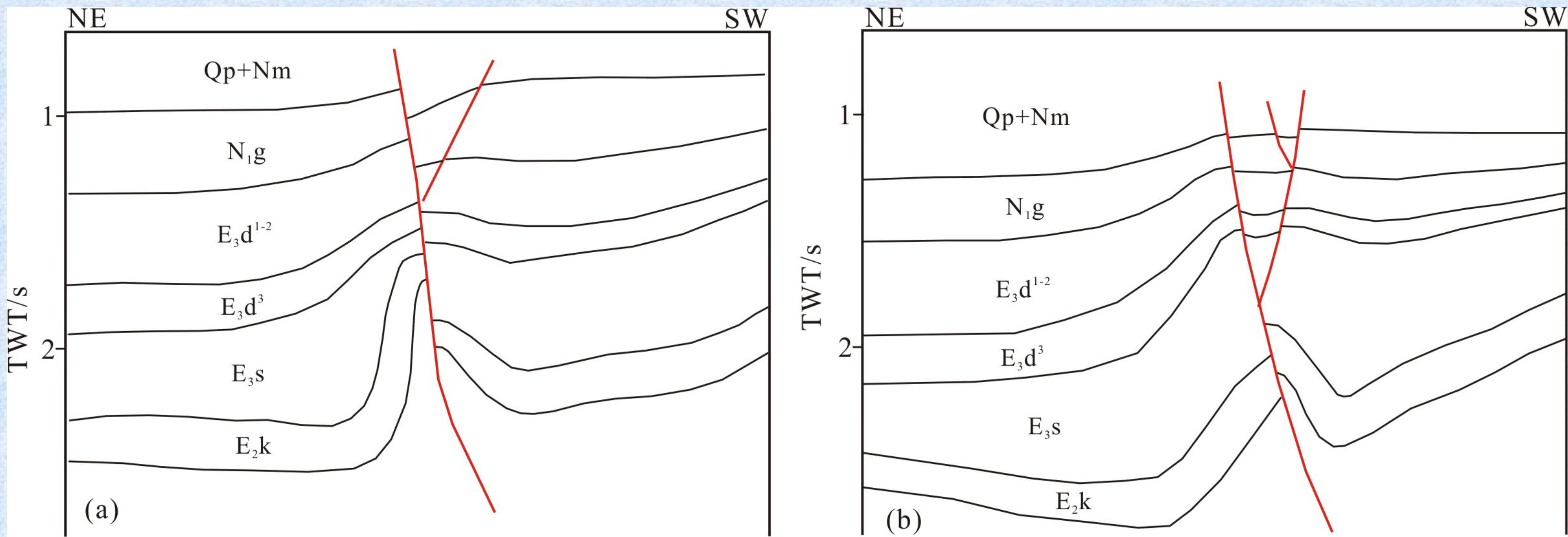


Fig. 5 LZ-No.1 inversion fault in the Liaodongwan depression

In plane view, the main trends of faults in the Bohai Bay basin are the NE, NW and EW directions, and the partition of faults distribution is relatively clear (Figure 6). In the eastern part of the basin, the NE-trending strike-slip faults are the main faults, and the small-scale EW-striking faults are surrounded by the main NE-striking faults, which shows intensive strike-slipping movement influenced by the Tanlu strike-slip fault. In the middle and south parts of the basin, the EW- and NW-striking faults are predominant, which were controlled by S-N extension. The large-scale faults, which act as the boundary faults between the uplifts and depressions in the southern region, have quasi-flower structures composed of the major listric faults and branching strike-slip faults in seismic lines, and their formation should be controlled by the early S-N extension and the late strike-slipping movement of the Tanlu fault.

4 X-pattern faults

Conjugate normal faults or X-pattern faults, two sets of steeply dipping normal faults having parallel strikes but opposite dips, are the key type of faults intersection in the Bohai Bay basin. According to the sectional features, evolution and formation mechanisms, the X-pattern normal faults in the offshore Bohai Bay basin could be divided into incipient and inherited types, including symmetrical and asymmetrical patterns in the seismic sections. The incipient X-pattern normal faults of small-scale were related with the dextral strike-slipping movement of faults, and developed during the simultaneous slip on the crossing faults (Figure 7). The formation of the inherited X-pattern normal faults was resulted from the preferentially reactivation of the pre-existing basement faults (Figure 8). The X-pattern normal faults had also important influence on the formation of the structural and subtle traps and hydrocarbon migration, as well as the reservoir properties in the study area. The structural and stratigraphic traps related with X-pattern normal faults are the favorable objectives for hydrocarbon exploration in the offshore Bohai Bay basin (Figure 9).

5 Faults linkages and transfer zones

There are many intersecting normal faults by hard and soft linkages in the offshore Bohai Bay basin (Figure 10). Consequently, various types of transfer zones had developed well in the overstepping normal faults. According to the dips and assembling characteristics of normal faults, three types of soft linkages of normal faults could be classified, including the synthetic overstepping, convergent conjugate overstepping and divergent conjugate overstepping, and their corresponding transfer zones are relay ramps,

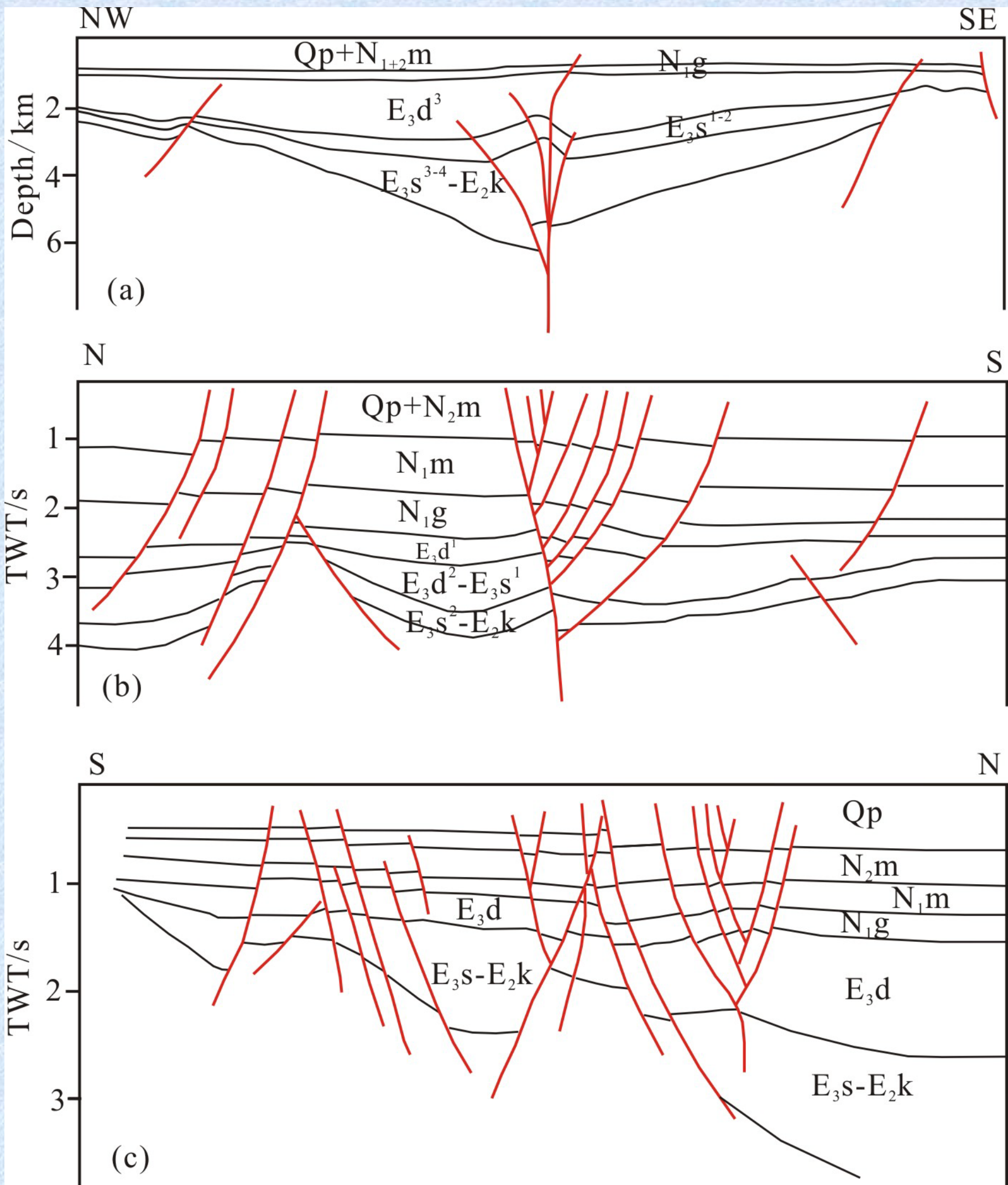


Fig. 4 Strike-slip faults in the offshore Bohai Bay basin

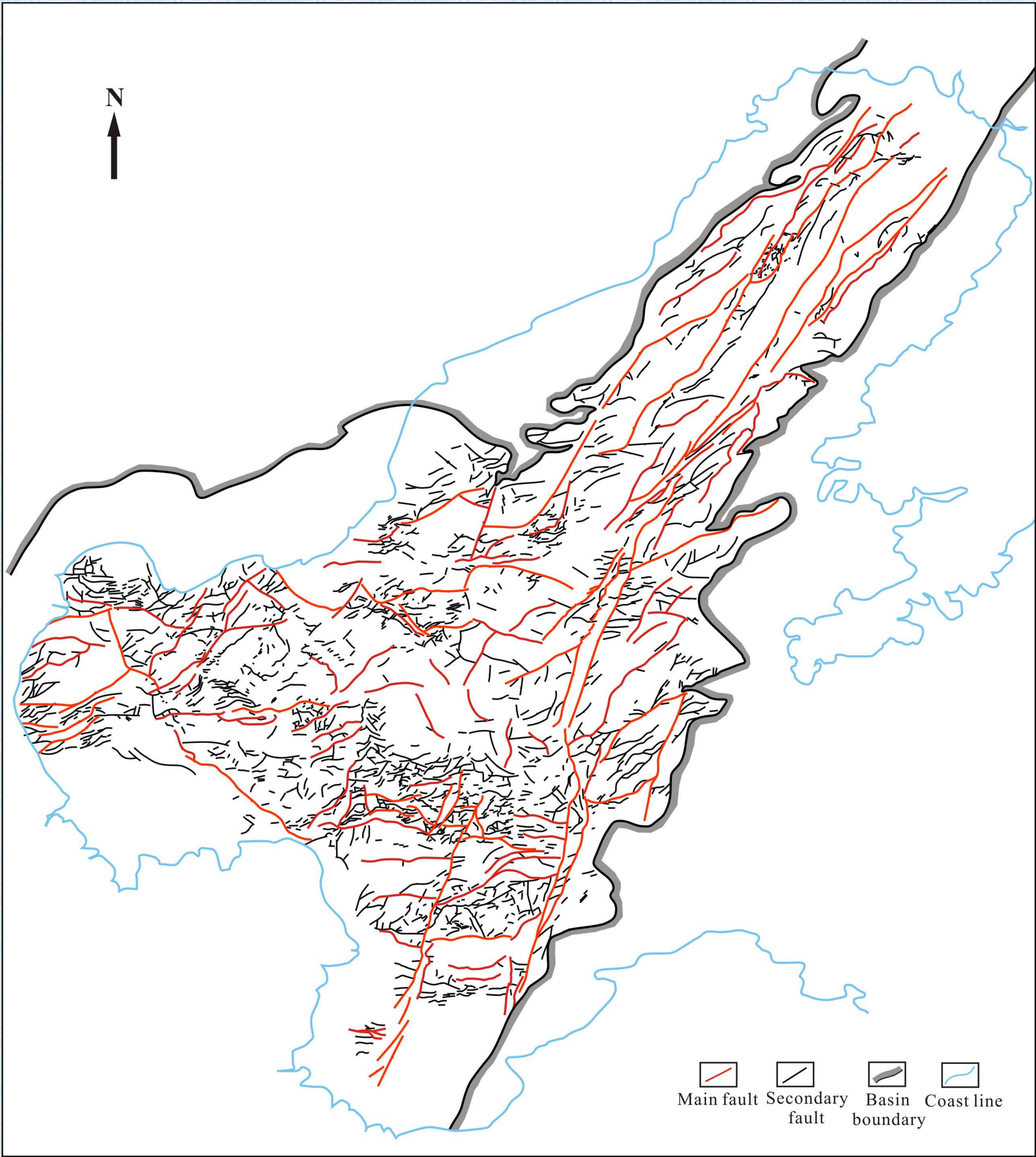


Fig.6 Faults system on the base of the Paleogene in the offshore Bohai Bay Basin

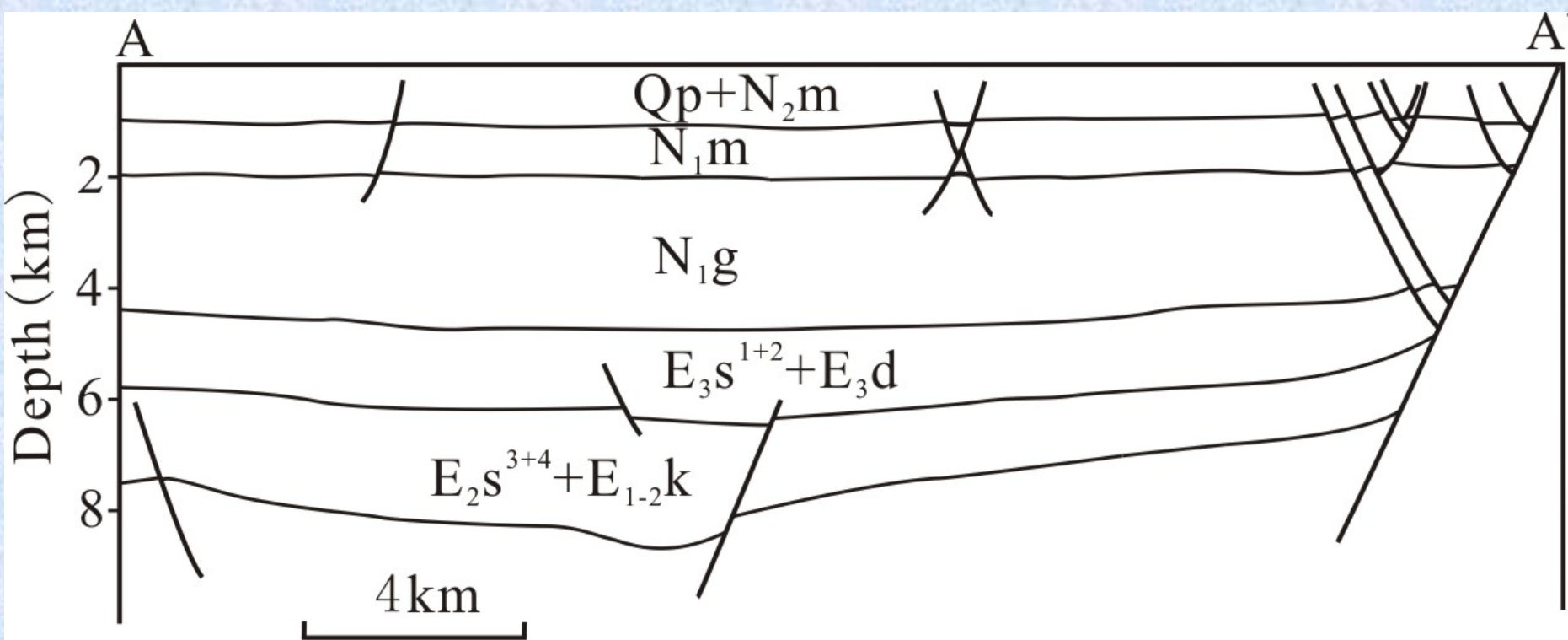


Fig.7 Incipient X-pattern normal faults in the offshore Bohai Bay Basin

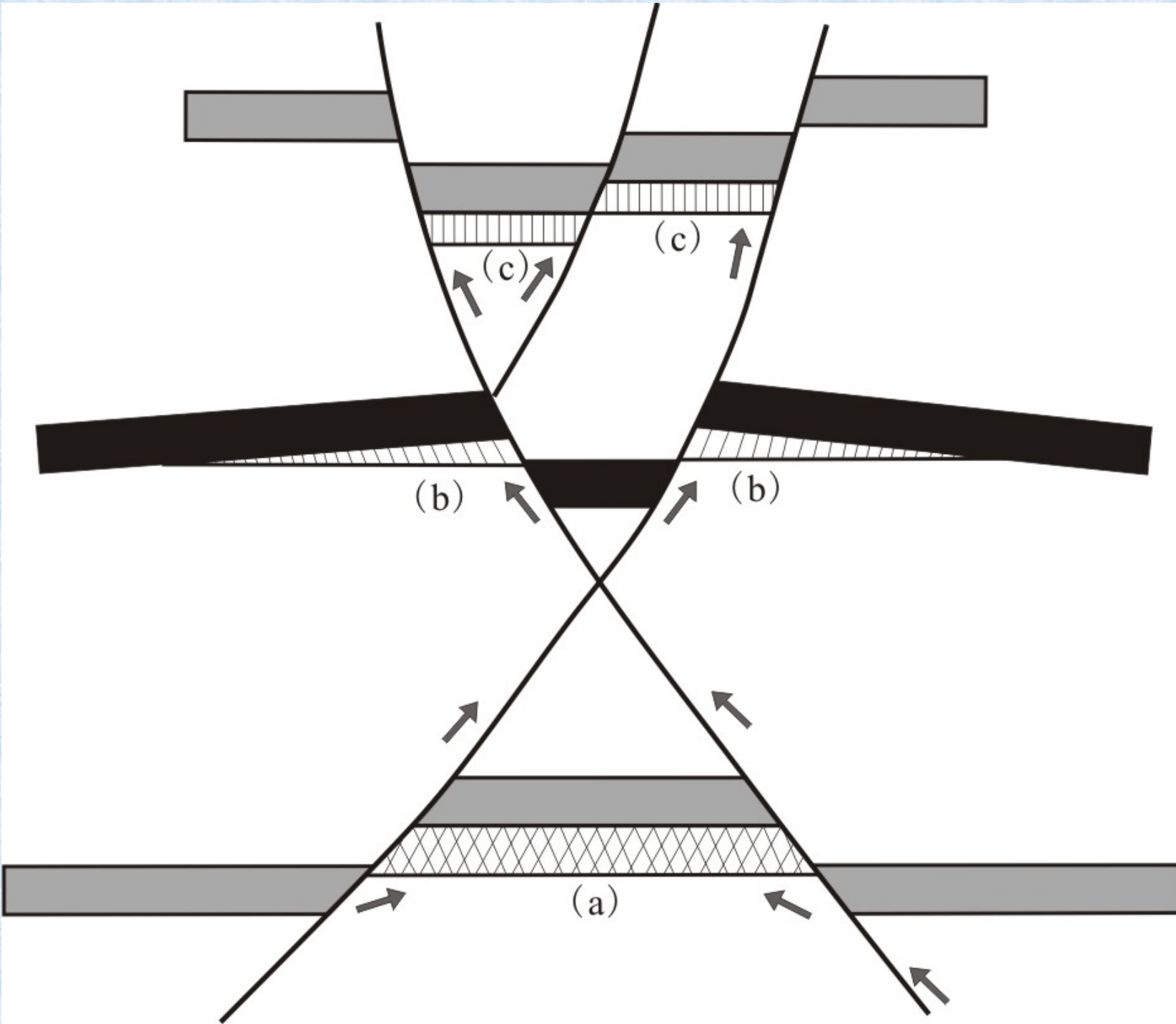


Fig.9 Models of hydrocarbon accumulations related with X-pattern normal faults in the offshore Bohai Bay basin

a-horst/buried hill traps; b-subtle traps in the limbs; c-graben traps

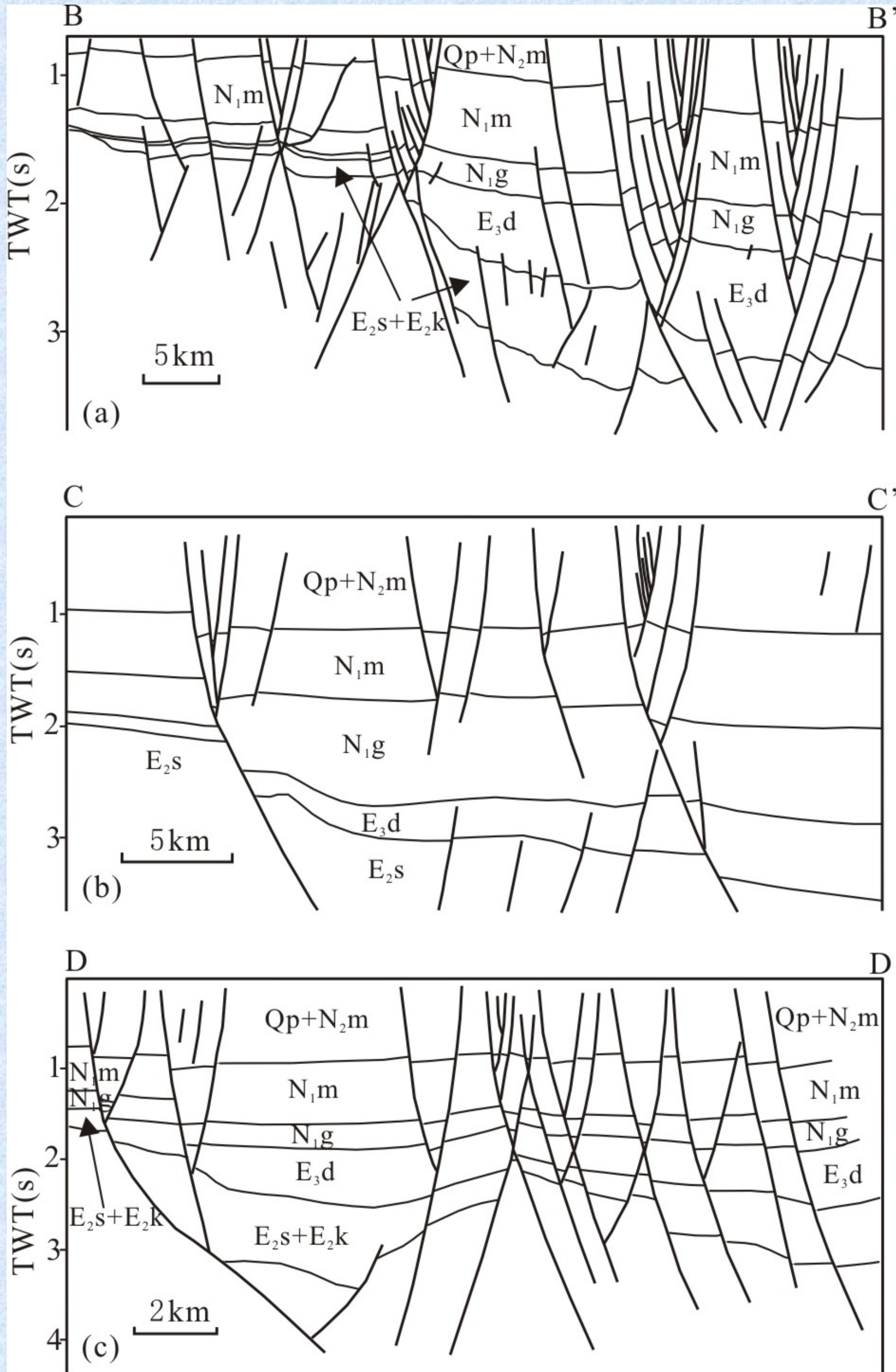


Fig.8 Inherited X-pattern normal faults in the offshore Bohai Bay Basin

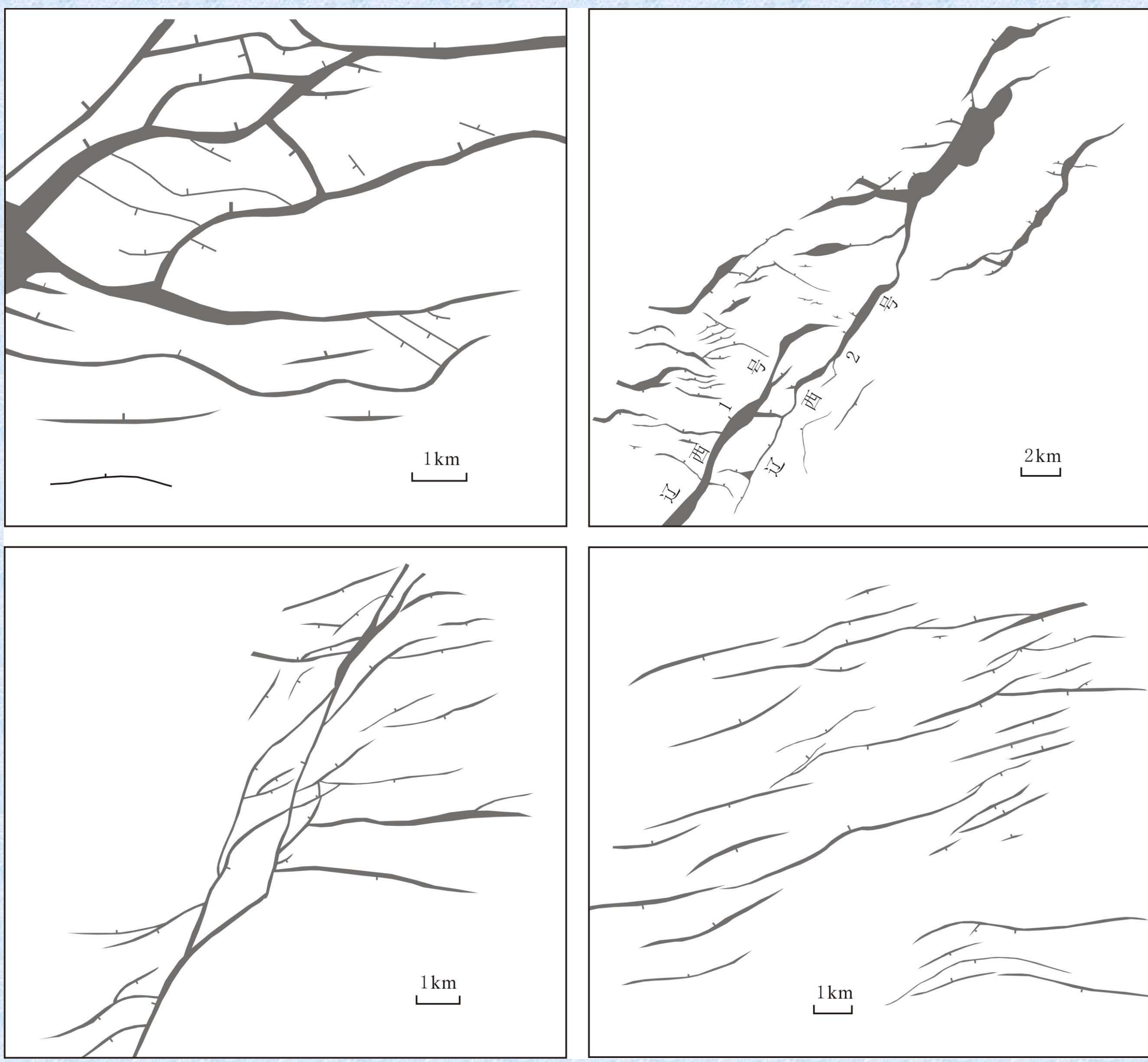


Fig.10 Hard and soft linkages of normal faults in the offshore Bohai Bay basin

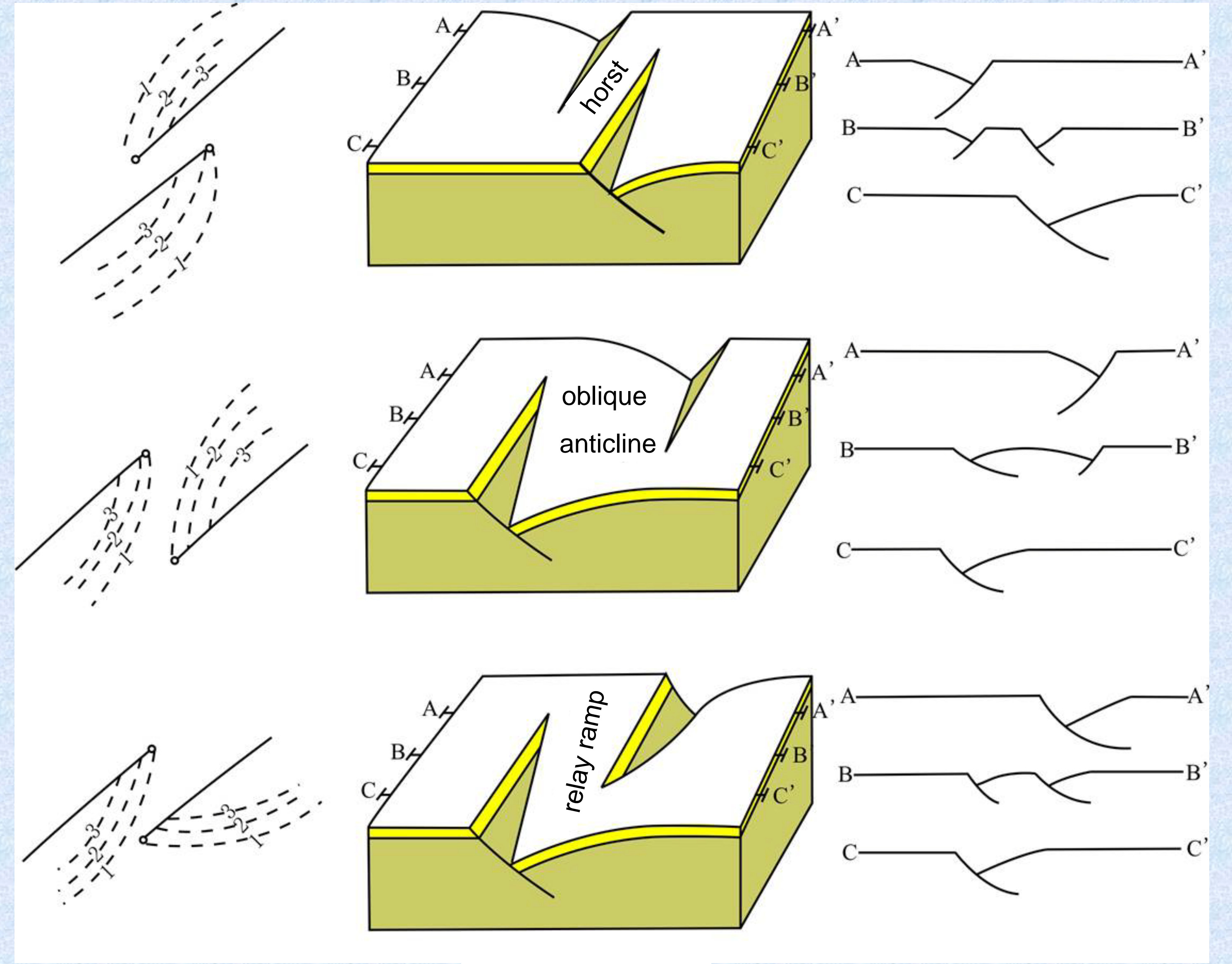


Fig.11 Different transfer zones in the offshore Bohai Bay basin

oblique anticlines and horsts, respectively (Figure 11). The zones transferred the extensional strains and made the three-dimensional strain conversation between the segmented normal faults. The evolution of the transfer zones could be divided into four stages which involve the isolated faults, transfer zones formation, complication and broken (Figure 12). The transfer zones had exerted important influence on the formation of the structural traps , spatial distribution of sedimentary systems and hydrocarbon migration , as well as the reservoir properties in the study area. The transfer zones in the overstepping normal faults with the same dip are the favorable objectives for oil and gas exploration in the offshore Bohai Bay Basin.

7 Conclusions

The extensional and strike-slip faults are the most important in the offshore Bohai Bay basin, and inversion faults are locally distributed. In plane view, the trends of faults are the NE, NW and EW directions, and the NE-striking faults, which appear flower-structure features in seismic profiles, belong to the Tanlu strike-slip fault. The EW-striking faults could be classified into the small- and large-scale faults, and the small-scale faults in the shallow strata were resulted from the strike-slipping movement of the Tanlu fault. The large-scale faults, which act as the boundary faults between the uplifts and depressions in the southern region, have quasi-flower structures in seismic lines, and experienced the early S-N extension and the late strike-slipping movement.

The faults interaction in the offshore Bohai Bay basin is relatively complicated, and the X-pattern normal faults and transfer zones are developed well. The X-pattern normal faults could be divided into incipient and inherited types. Corresponding to the dips and assembling features of normal faults, three types of transfer zones, involving relay ramps, oblique anticlines and horsts, could be classified. The recent important breakthrough of hydrocarbon exploration in the Bohai Bay basin has demonstrated that the faults interaction had exerted significance on the hydrocarbon accumulation, mostly through controlling the formation of traps, hydrocarbon migration, as well as improving reservoir properties.

Acknowledgments

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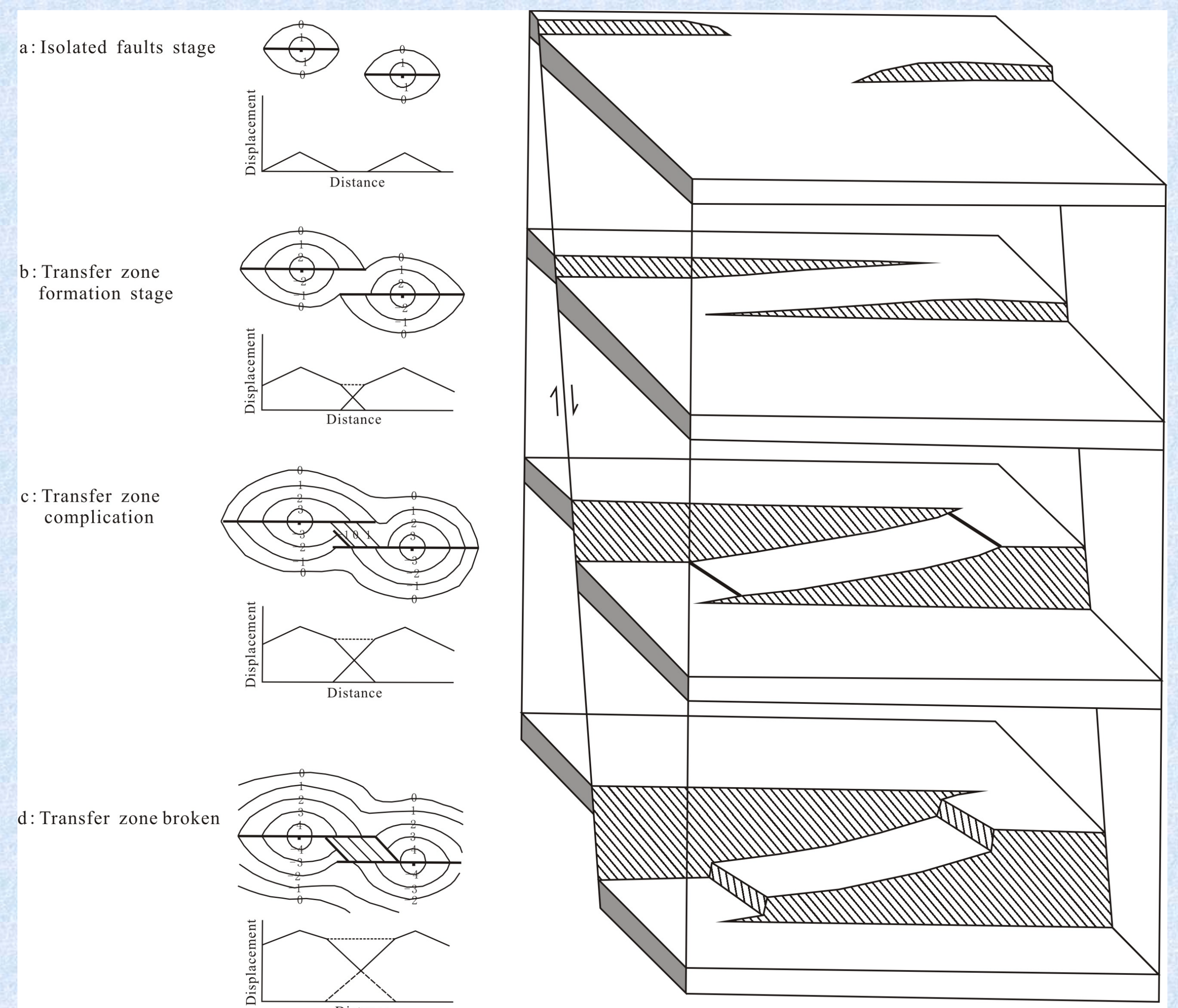


Fig.12 Schematic map showing the evolution stages of transfer zones in the offshore Bohai Bay basin