[PS]Crossing Conjugate Normal Faults and Hydrocarbon Accumulation in the Offshore Bohai Bay Basin, Eastern China*

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Abstract

Conjugate normal faults are two sets of steeply dipping normal faults having parallel strikes but opposite dips, which are commonly developed in regions of extensional setting. Intersecting and crossing conjugate normal faults can produce the characteristic of simple and complex X-pattern faults system in cross-section. Although many studies on conjugate normal faults have been completed, there is some controversy on their formation processes and mechanisms. The high-quality 3-D seismic data in the offshore Bohai Bay Basin, which is a Cenozoic rift basin with a rhombus-shape and one of the largest oil production basins in eastern China, clearly shows numerous simple and complex conjugate normal faults, which offers good examples for analyzing conjugate normal faults. According to their properties, the conjugate normal faults in the study area could be divided into two types, which involve the incipient and inherited conjugate normal faults. The incipient conjugate normal faults with small scales and simple X-pattern in cross-sections are limited to the vicinity of the Tan-Lu strike-slipping fault, and develop in the Neogene and Quaternary. The inherited conjugate normal faults have larger scales, and occur in wider areas. In cross-section, the inherited conjugate normal faults have complex X-patterns and formed linked faults system. The strata faulted by the inherited conjugate normal faults involve the pre-rift basement, syn-rift Paleogene and post-rift Neogene. In addition, the two types of conjugate faults have different formation mechanisms. The incipient conjugate normal faults were related with the dextral strike-slipping movement of the Tan-Lu fault, and formed during the simultaneous slip on the crossing faults. However, the development of the inherited conjugate normal faults resulted from the preferentially reactivation of the pre-existing basement faults. The unique conjugate assemblage of the X-pattern normal faults offer abundant traps for hydrocarbon accumulation, which involve faulted block traps, faulted anticline traps and buried hill traps. The faults are also favorable migration pathways along which oil and gas could migrate from deep source rock into shallow reservoirs.

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1 Introduction

Conjugate normal faults are two sets of steeply dipping normal faults having parallel strikes but opposite dips, which are commonly developed in regions of extensional setting. Intersecting and crossing conjugate normal faults can produce the characteristic of simple and complex X-pattern faults system in cross-section. Although many researches on conjugate normal faults have been completed, there are some controversy on their formation processes and mechanisms. The high-quality 3D seismic data in the offshore Bohai Bay Basin clearly show numerous simple and complex conjugate normal faults, which offers good examples for analyzing conjugate normal faults.

2 Geological setting

The Bohai Bay basin, a Cenozoic rift basin with a rhombus-shape and an area of about 200,000 km^2, is situated on the eastern coast of China (Figure 1). It is also one of the largest oil production basins in China. The basin is composed of land and offshore parts, and 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 (Fig.1). 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. The Cenozoic strata in the offshore Bohai Bay basin are composed of the Paleogene Kongdian Formation (E_2k), Shahejie Formation (E_3s) and Dongying Formation (E_3d), Neogene Guantao Formation (N_1g) and Minghuazhen Formation (N_2m), and Quaternary Pingyuan Formation (Qp). The unconformity between the Dongying and Guantao formations has an important role during the basin evolution, which represents the end of rifting and the initiation of post-rifting. There are obvious difference of fault populations above and below the unconformity (Figure 2).

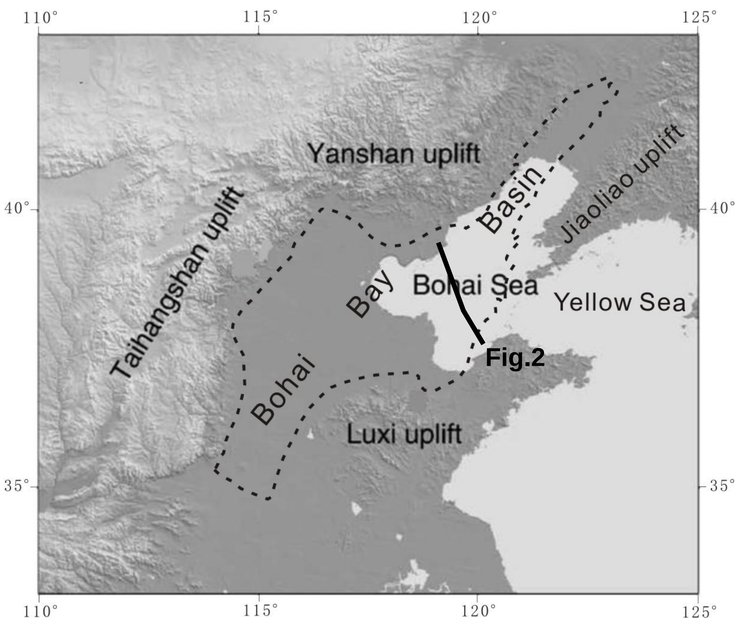

Fig.1 Location of the Bohai Bay basin in China

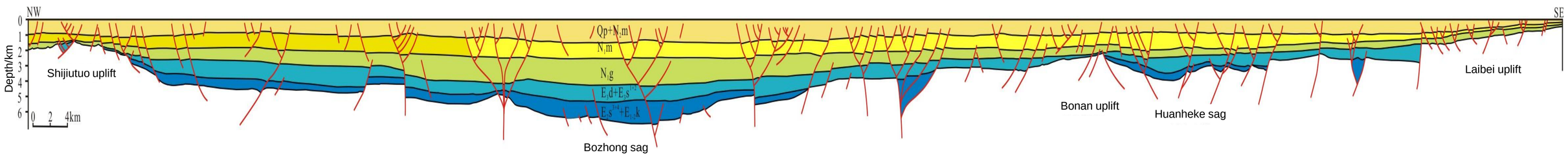

Fig.2 Regional cross-section of the offshore Bohai Bay basin

3 Types of Conjugate normal faults

The new seismic data demonstrate that conjugate normal faults are common in the offshore Bohai Bay basin. In the intersection region of crossing conjugate normal faults, strata usually thin and a graben rests directly above, or slightly offset from, a horst. According to their properties, the conjugate normal faults in the study area could be divided into two types which involves the incipient and inherited conjugate normal faults (Figures 3, 4). The incipient conjugate normal faults, which are limited to the vicinity of the Tan-Lu strike-slip fault, have small scales and throws. In cross-sections, they have simple and symmetrical X-patterns, and they cut through the Neogene and Quaternary (Figure 3). In contrast, the inherited conjugate normal faults have larger scales, and also occur in wider area. The inherited conjugate normal faults have complex X-pattern and formed linked faults system in cross-sections. The strata faulted by the inherited conjugate normal faults involve the pre-rift basement, syn-rift Paleogene and post-rift Neogene (Figure 4).

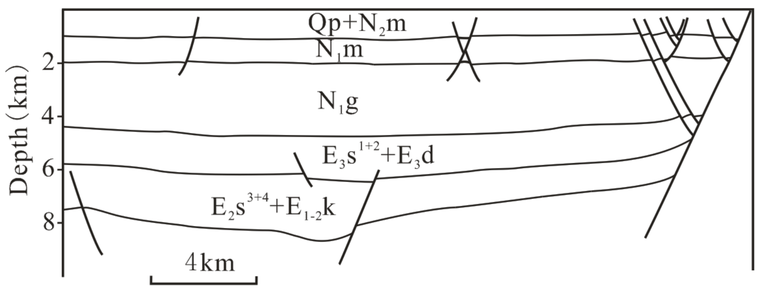

Fig.3 Incipient X-pattern normal faults of the offshore Bohai Bay Basin

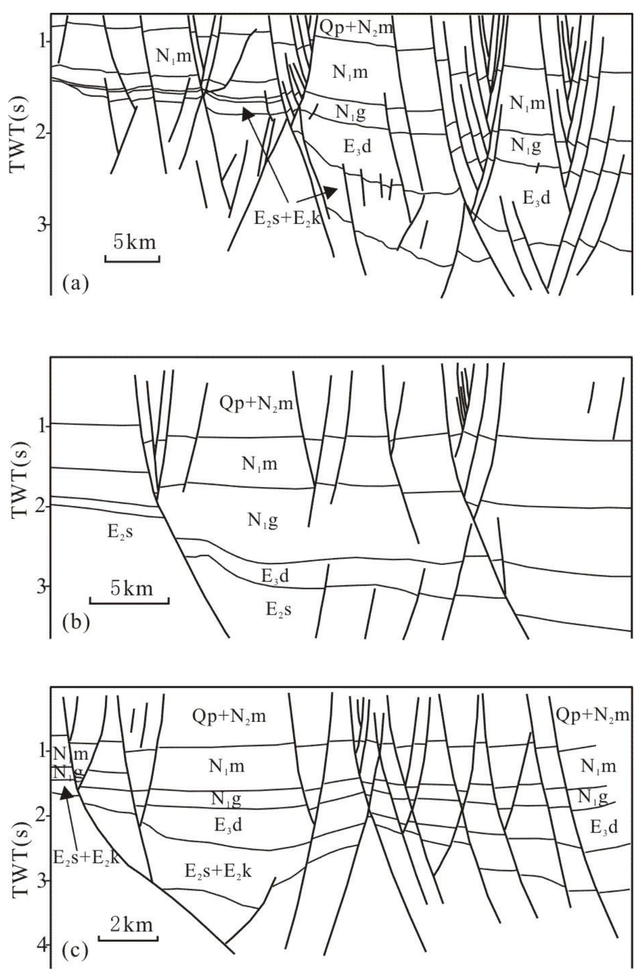

Fig.4 Inherited X-pattern normal faults of the offshore Bohai Bay Basin

4 Mechanisms of conjugate normal faults

Previous studies interpreted simultaneous motions of the crossing conjugate faults which must be accompanied by volume redistribution and fault-block deformation. Ferrill et al. (2000) showed alternating sequential slip on the crossing faults could produce crossing fault patterns without area modification in cross section. We think that the two types of conjugate faults in offshore Bohai Bay basin have different formation mechanisms. The incipient conjugate normal faults are limited to the vicinity of the Tan-Lu strike-slip fault. Their formation should be related with the dextral strike-slipping movement of the Tan-Lu fault. During the simultaneous slip on the crossing faults, the small amount of shortening in the direction of the horizontal maximum principal stress is accommodated and confirmed by rotation and folding (Figure 5). However, the development of the inherited conjugate normal faults were related with reaction (continuous activities) of basement faults. The slip of crossing conjugate faults is sequential rather than simultaneous. Ferrill et al. (2000) established a series of models of development of crossing fault patterns based on various preferentially reactivated fault system. According to the models, it could be found that the inherited conjugate normal faults in the study area are resulted from the preferentially reactivation of the pre-existing basement faults (Figure 6).

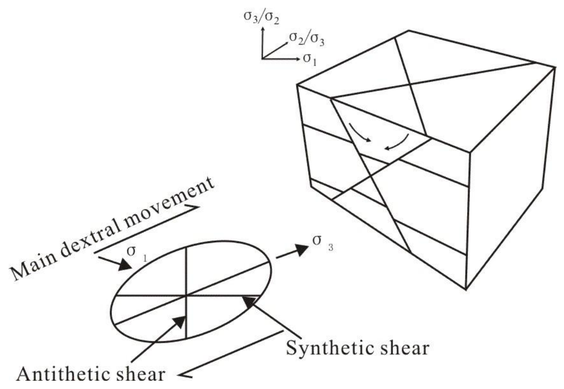

Fig.4 Formation model of the incipient X-pattern normal faults in the offshore Bohai Bay Basin

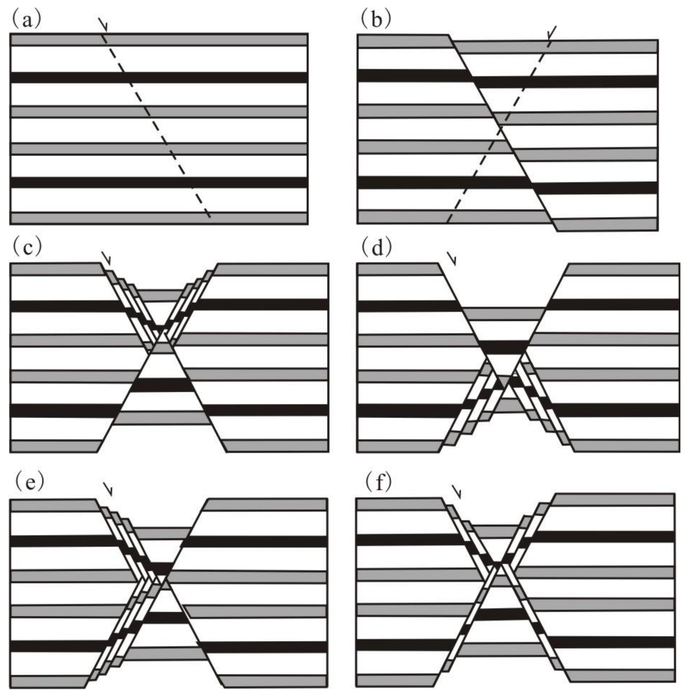

Fig.5 Development Models of inherited X-pattern normal faults (Modified from Ferrill et al., 2000)
a-before X-pattern normal faults; b-initial X-pattern normal faults; c-deep fault segments are preferentially reactivated; d- shallow fault segments are preferentially reactivated; e-fault segments on the right side of the fault system are preferentially reactivated; f-no preference for reactivation of faults segments of the fault system

5 Conjugate normal faults and hydrocarbon

The hydrocarbon exploration has demonstrated the close relationships between crossing conjugate normal faults and hydrocarbon accumulations in the offshore Bohai Bay basin. Some oil and gas fields have been discovered in the graben, horst and lateral limbs, such as the BZ13-1S, QHD34-3, BZ25-1S and BZ34-1 oilfields (Figure 6). The unique conjugate assemblage of the X-pattern normal faults offer abundant traps for hydrocarbon accumulation, which involve faulted block traps, faulted anticline traps and buried hill traps (Figure 7). The faults are also favorable migration pathways along which oil and gas could migrate from deep source rock into shallow reservoirs. Ferrill et al. (2000) also pointed out that conjugate normal fault systems are likely to produce bulk permeability anisotropy in reservoir rocks that can be approximated by a elongate permeability ellipsoid, with greatest permeability parallel with the line of intersection.

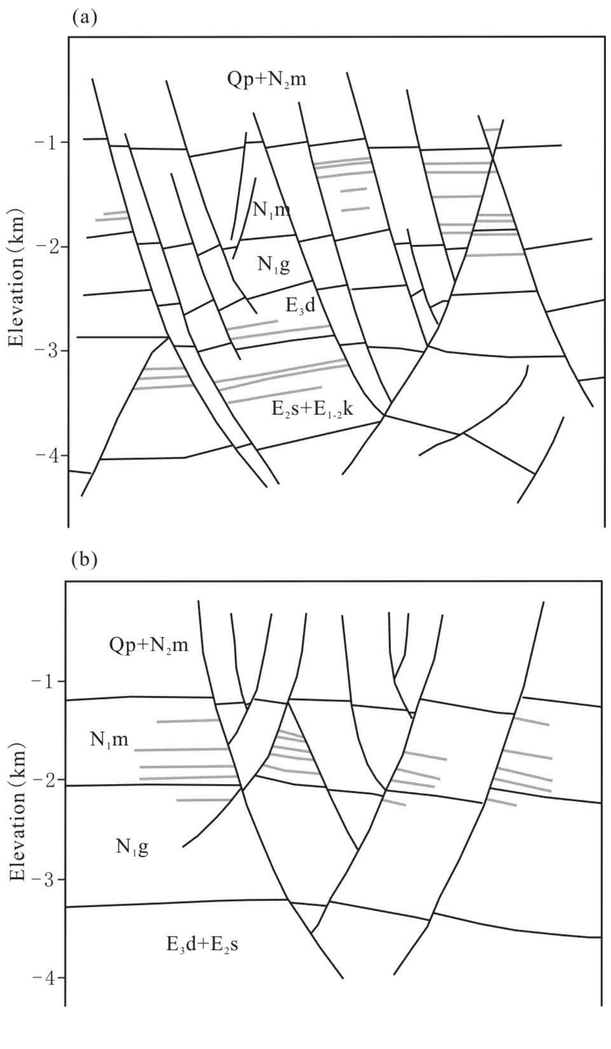

Fig.6 Oil and gas fields related with X-pattern normal faults in the offshore Bohai Bay basin
a-BZ34-1 oilfield; b-QHD34-3 oilfield

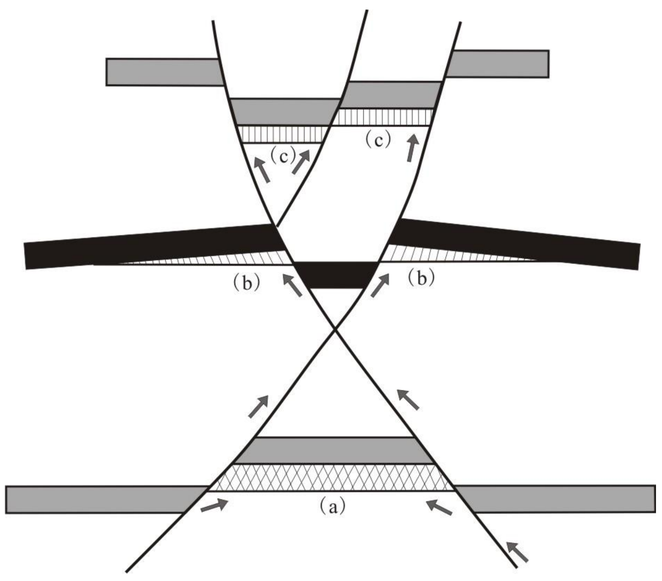

Fig.7 Models of hydrocarbon accumulations related with X-pattern normal faults in the offshore Bohai Bay basin
a-horst/buried hill traps; b-subtle traps in the limbs; c-graben traps