A Section Sandbox Modeling on the Evolution of Conjugate Normal Faults

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Abstract: Fault systems can impose considerable effects on structural closure concerned to oil accumulation. It is widely known that conjugate normal faults were developed over extensional basins, but the evolution of the special fault arrays was seldom reported. The Nanpu Sag, located in the north part of Huanghua Depression of Bohai Bay Basin, is a Cenozoic petroliferous extensional fault-block sag. Based on the interpretation of the 3D seismic data in the Nanpu Sag, the geometry of conjugate normal faults were described both in plane and profile, and the evolution was analyzed using balanced cross-section restoration technique, the results indicated that the special faults were formed in a very short geological time and also in weak extensional setting. Further study of the fault system using a section sandbox modeling technique demonstrated that the conjugate normal faults showing X-style were formed contemporaneously in a homogeneous geologic body under extension. With the development of extension, new X-style faults were formed sequentially at the sides of the pre-conjugate normal faults, all the normal faults constitute a complex conjugate style..The evolution of conjugate normal faults in rift basins has seldom been reported systematically, this study gives important evidence and planar sandbox model provides reliable kinematic models to further the understanding of the description of the conjugate normal faults.

1 INTRODUCTION

The fault is a fundermental topic in fault-block basin research. For advanced analysis of the relationship between faults and reservoirs, the study for evolution and deformation mechanism of faults is essential. In the Napu sag, most former work was focused on the description and development of fault system(Liu, 2011; Tian, 2012), but the detailed analysis aiming at special fault style was seldom reported in recent years. In this paper, conjugate normal faults found in this sag were studied.

2 GEOLOGICAL SETTING

The Nanpu sag with 1932 Km^2 area including onshore and offshore, is a classical small but rich petroliferous Cenozoic sag. developed on the basement of North China block. From the fault systems map, it is a half-graben basin faulted in the north and onlapped in the south. The Northwest and Northeast are bounded by Xinanzhuang fault and Baigezhuang fault respectively. The two border faults cut through the basement and controlled the formation and evolution of the Nanpu Sag(Figure 1). Within the Sag, the most newly formed normal faults since Neogene had obvious NNE orientation, which seemed to be controlled under later single extension.

The Nanpu sag was in terrigenous sedimentary environment in Cenozoic time, the strata include: the second and third members of the Shahejie formation in Eocene(Es_{2+3}); the first member of the Shahejie formation in Eocene and Oligocene(Es_1);the third member of the Dongying formation in Oligocene(Ed_3) ;the second member of the Dongying formation in Oligocene(Ed_2) ;the first member of the Dongying formation in Oligocene(Ed_1) ;the Guantao formation in Miocene(Ng) ;the Minghuazhen formation in Miocene(Nm) and Quaternary.

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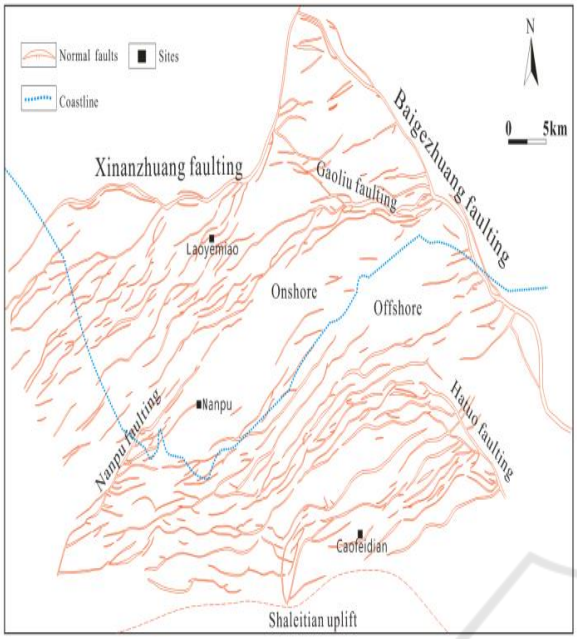

Figure 1: The fault systems of top nm in the Nanpu Sag.

3 FAULTS EVOLUTION ANALYSIS

Based on results of structural interpretations of 3D pre-stack time migration data, structural styles were analyzed in the Nanpu Sag. By the application of balanced geological sections methods, restorations of 29 geological sections with decompaction were finished and Cenozoic deformation phases were accordingly separated.Only extensional structural styles were found in the Nanpu Sag. There are complex structural styles in local structural belts mainly including X-pattern, Y-pattern. The restoration also suggested that the X-pattern faults were formed since the deposition phase of Nm(Figure 2). Although the X-style is complex, almost all the faults in the style were developed in a relative short geological time. Confined to the resolution of strata classification, the detailed development of X-style faults is still not clear, but it was formed from late Cenozoic movement. It was concluded that the lower crust in the Nanpu sag undergone pure shear deformation since Neogene, this mechanism can give a reasonable explaination for the formation of the symmetrical pattern of new faults in sedimentary cover(Figure 3).

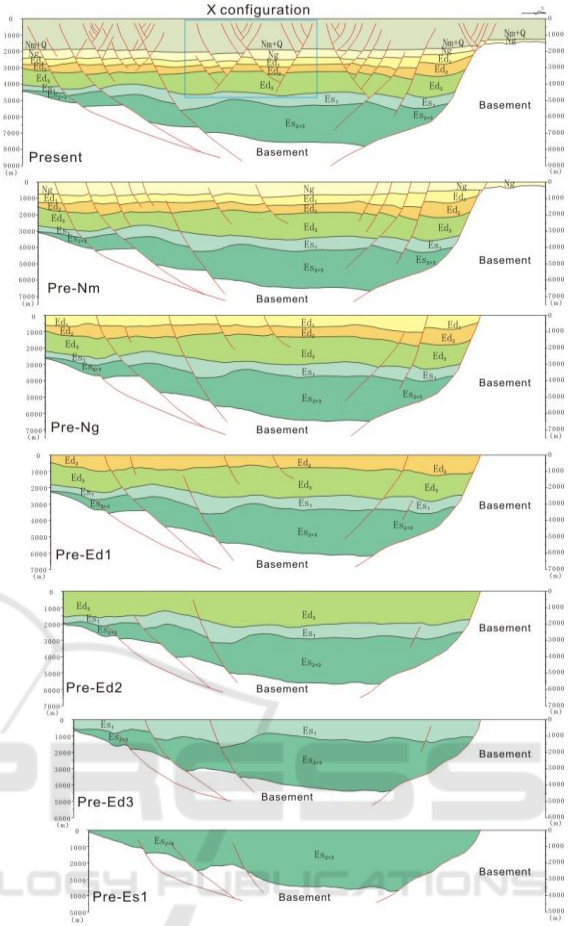

Figure 2: Restoration of a main geological section in the Nanpu sag.

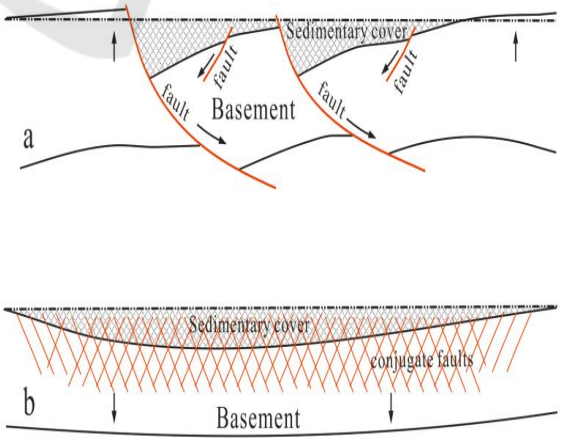

Figure 3: Fault formation mechanism of different models in the Nanpu sag. (a.Paleogene; b.after Neogene).

4 MODEL DESIGN

Sandbox modeling, as a form of physical modeling has proved to be an effective method for the study of deformation mechanisms of extensional basins(McClay and White, 1995)

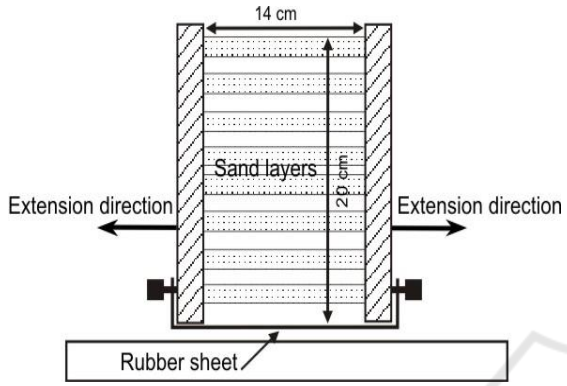

Figure 4: Sketch of side view experimental model.

It was concluded that X-style faults as conjugate normal faults, may happen easier in a very homogeneous deformation under extension. For the sake of homogeneity and clarity, many sandbox modelings were conducted to determine the length between the walls and the thickness of sand layers. The eventual length was designed 14 cm and the total thickness of sand layers was placed 20cm(Figure 4).

Loose quartz sands have been proven to be the ideal material for the physical simulation of brittle deformation in the shallow crust . The sands used in the experiments are 0.3-0.4 mm in diameter, with inner friction angles of 31 °. In the models, one layer of rubber sheet is used for deformation transfer media at the basal of the sag area and connected to the ends of the movable walls respectively. The rubber sheet will be gradually stretched as the motor-driven walls moves outwards, and normal faulting will take place in the overlying sand layers. The displacement velocity is 2.58×10^{-3}s/cm and the total displacement is 3.5 cm. The model has been tested more than twice and similar results have been obtained. The experiments were undertaken on the tectonic deformation physical modeling experimental apparatus of China University of Petroleum, Beijing.

Although the Nanpu Sag had been controlled by the main syndepositional faults during Cenozoic period, for the sake of the observation of the framework, all experiments omitted the syndeposition process but the results could not be affected (Diraison, et al., 2000; Keep, 2003).

5 MODEL RESULT AND DISCUSSION

After 1 cm of extension displacement, two crossing faults with opposite inclination appeared, and constitute the X configuration, but still remain obscure, the lower part of the X-style faults showed larger displacements than the upper part, it meant the deformation was conducted graually from basement to cover. After 2 cm of extension displacement, a new set of faults with opposite inclination cut the upper part of pre-X-style faults, all the faults constitute complex X configuration; After 3.5 cm extension displacement, the newly formed faults were developed at the sides of pre-faults and cut the upper part of X-style faults continuously. It can be imagined that the newly shallow faults would appear with the further extension, more and more complex X-style faults would be shown in the sandbox modeling(Figure 5).

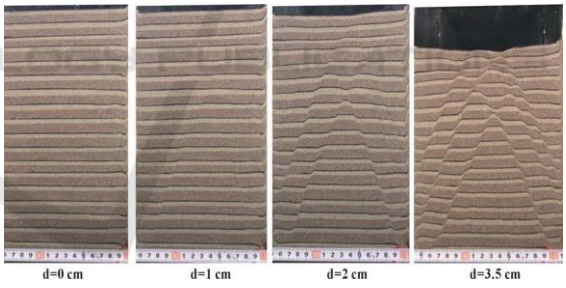

Figure 5: X-style faults sequence of the sandbox modeling.

6 SUMMARY

The Nanpu sag is a classical extensional basin developed in Cenozoic time, X-style faults as a basic structural style were developed since the deposition phase of Nm.

It is known that almost all the X-style faults in the style were developed in a relative short geological time, confined to the resolution of strata classification, the detailed development of X-style cannot be restored by the application of balanced geological sections method. The sandbox modeling reproduced the development of X-style faults, it

discovered that the single X-style normal faults were formed easily in relative narrow geobody under extension because of the relative homogeneous geological background. Simple X-style normal faults were developed under relatively weak extension while the complex X-style normal faults were formed under further extension. It was concluded that the complex X-style faults in the Nanpu sag were controlled by pure shear deformation at the lower crust since Neogene.

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