EARTH SCIENCE FRONTIERS
Volume 16, Issue 4, July 2009
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: Earth Science Frontiers, 2009, 16(4): 138–146.

RESEARCH PAPER

Discovery of Compressional Structure in Wuerxun–Beier Sag in Hailar Basin of Northeastern China and Its Geological Significance

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Abstract: The Hailar Basin is a Mesozoic-Cenozoic basin, which is superimposed on the Paleozoic collision orogenic belt of Inner Mongolia–Greater Hinggan Mountain. The basin, trending north-east, consists of five first-order structural units (three depressions and two uplifts), they are, from west to east, the Zhalenuoer Depression, the Cuogang Uplift, the Beier Lake Depression, the Bayanshan Uplift and the Huhe Lake Depression, respectively. The Wuerxun Sag and the Beier Sag are two second-order structural units in the south Beier Lake Depression. Research indicates that in the Early Cretaceous Epoch, the Wuerxun-Beier sag underwent two long-term compressions: NW-SE trending during the Damoguaihe Period to the early Yimin Period, and near EW trending during the end of the Yimin Period, respectively. The compressions led to the inversion of some depression-controlling normal faults in the extensional faulted depression, and formed new fault-propagation fold, fault-bend fold, imbricate structure, duplex structure, pop-up structure, and triangular zone etc. Because of the differences in geometric and kinematic features and the variance in the ratio of the uplift rate of compressional structures to the deposition rate of isostructural growing strata in space, syn-compression strata show different depositional features in different structural positions. These structural features are very similar to those of the orogenic belt. The discovery of two phases of compressional structures in the Wuerxun–Beier Sag proved that the crust of Northeast China was not always in the state of extension and thinning in the Early Cretaceous, but showed the features of superimposition and thickening during the two compression periods, and thus formed the structural framework of the alternative distribution of the compression-depression basins and the intra continental (intra plate) orogenic belt in space.

Key Words: compressional structure; structural feature; fault-related fold; growth strata; Early Cretaceous; geological significance; Wuerxun–Beier Sag; Hailar Basin

1 Introduction

The Hailar Basin is a Mesozoic-Cenozoic basin, which is superimposed on the Paleozoic collision orogenic belt of Inner Mongolia-Greater Hinggan Mountain[1]. The basement of the basin consists of pre-Paleozoic and Paleozoic strata of the marine and marine-terrigenous facies. The cover of the basin consists of Cretaceous, Paleogene and Neogene, and the Lower Cretaceous is the dominant stratum. The total thickness of the cover is up to 6000 m. From bottom to top, the Cretaceous is divided into the Xing'anling Group, the Tongbomiao Formation, the Nantun Formation, the Damoguaihe Formation and the Yimin Formation of the Lower Cretaceous, and the Qingyuangang Formation of the Upper Cretaceous[2]. Geological and geophysical prospecting results have proven that the basin is mainly trending northeast and it can be divided into five first-order structural units (three

Received date: 29-Nov-2008; **Accepted date:** 15-Mar-2009.

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Foundation item: Supported by the National Natural Science Foundation of China (No. 40772125) and Project of Research Institute of Exploration and Development, Daqing Oil Field Inc. (No. 12010022002100277).

DOI: 10.1016/S1872-5791(08)60087-1

depressions and two uplifts) and sixteen sags, and from west to east, the first-order structural units are the Zhalenuoer Depression, the Cuogang Uplift, the Beier Lake Depression, the Bayanshan Uplift, and the Huhe Lake Depression, respectively. The Wuerxun Sag and the Beier Sag are two second-order structural units in the south of the Beier Lake Depression①.

For years, there has been much debate regarding the structural evolution of the Hailar Basin. Researching on geological and geophysical data, Zhang et al.[3] suggested that the structural evolution of the Hailar Basin in Mesozoic and Cenozoic underwent five stages: initial extensional faulting–faulting gestation (Xing'anling Group), faulting and intense extension (Tongbomiao Formation), faulting and rapid subsidence (Nantun Formation), faulting and stable extension (Damoguaihe Formation), and faulting dwindling (after Yimin Formation deposited), respectively. Chen et al.[4] and Luo et al.[5] suggested that the structural evolution of the Hailar Basin underwent four main stages: crust uplifting, faulting, depressing, and dwindling. By the angular unconformity surfaces and three phases of faulted sedimentary cycles between them, Shen et al.[6] divided the evolution of extensional faulting into three extension episodes and three compression episodes. Preceding research of the structural features and evolution of the Hailar Basin mainly focused on the extensionnal structures but failed to identify the abundant compressional structures in the area or lacked recognition of them. The study recently showed that in Early Cretaceous, Wuerxun–Beier Sag underwent not only two phases of extension that formed extensional structures but also two phases of long-term compression, which formed abundant compressional structures①,[1,7,8].

2 Structural features

The Wuerxun Sag and the Beier Sag are two second-order structural units in the Beier Lake Depression of the Hailar Basin, and their structural features and deformation sequences are controlled by the regional tectonic evolution of the Hailar Basin. The main part of the Wuerxun Sag is an asymmetric half graben controlled by the NS trending Western Wuerxun Fault Zone (Western Wuerxun No.1 and Western Wuerxun No.2 fault); its structural pattern is relatively simple, and mainly developed structures indude the Western Wuerxun Fault Zone and associated series of the NS trending fault combination (Middle Wuerxun Fault Zone), the NE trending fault combination (Surennuoer Fault Zone), and the ENE trending fault zone (the Huangqimiao Fault Zone) (Fig. 1). The Beier Sag is much larger than the Wuerxun Sag in size, and its structural pattern is much more complex. The fault basin mainly consists of a series of asymmetric half grabens controlled by the NE trending listric normal faults (e.g. the Sunainuoer Fault Zone and the Dehuo Fault Zone) and the ENE trending listric normal faults (e.g. the Huoduomoer Fault Zone, the Sudeerte Fault Zone and the Aonaohai Fault Zone). Besides, the Beier Sag also develops a few NS trending fault combinations and NW trending fault combinations (Fig. 1).

In the Early Cretaceous, the Wuerxun–Beier Sag underwent four phases of deformation[1,7,8], the NW-SE trending extension during the Xing'anling Period to Nantun Period, the NW-SE compression during the Damoguaihe Period to early Yimin Period, near the EW trending extension during the late Yimin Period, and the near EW compression during the end of the Yimin Period. In the process of compression during the Damoguaihe Period to early Yimin Period and the end of the Yimin Period, many inversion structures and compressional fault-related folds were formed, and thus, complicating the structures in the research area.

3 Geometrical and kinematical features of the compressional structures

The theory of the fault-related fold gave the quantitative relationship among the shape of the fold, the shape of the fault, and the slippage of the fault[9–11]. In recent years, through experimentation, numerical simulation and the reflection characteristics of the abundant seismic profiles, scientists in structure geology have established and improved the geometric and kinematic models of the compressional fault-related fold, and especially by using the theory of the fault-related fold, the quantification of making balanced geological cross section came into reality, thus, giving a reasonable and feasible method of structural modeling and analysis. The proposition of the model of the growth fault-related fold[12–15] made it possible to determine the date and rate of structural deformation precisely[16].

The research of structural features and evolution of the Wuerxun–Beier Sag of the Hailar Basin started in the 1980s, with many scholars carrying out research work in the area, and suggesting that the area underwent several structural evolution stages and that the structural pattern is simple, mainly consisting of asymmetric half grabens[3–5], but they failed to identify the widely developed compressional structures, with the major reasons being: first, in their concept, since the Cretaceous, the tectonic setting of Northeast China was extension, so it was impossible to develop compressional structures; second, the early extension was so intense that the extension amount overwhelmed the compression amount the late compression, even if there were superimposed late compression structures, they were very hard to identify; third, in the research area, the second phase of extension took place after the early compression, which reformed the compressional

① Liu Z H, Liu H J, Li C S, et al. The relationship of the second structural units in Hailar Basin and the compilation method of Juxtaposion and seal diagrams. Research InStitute of Exploration and Development, Daqing Oil Field Inc., PetroChina, 2004.