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Post-rift geodynamics of the Songliao Basin, NE China: Origin and significance of T11 (Coniacian) unconformity

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ABSTRACT

The T11 unconformity lies between the Qingshankou and Yaojia Formations in the post-rifting sequence of the Cretaceous Songliao Basin, NE China. It is intimately associated with petroleum reservoirs and considered to be a disconformity forming in the tectonic quiet stage. We present the interpretations from new seismic surveys and cored sections of the Cretaceous Continental Scientific Drilling borehole (CCSD-SK-1) in order to resolve the nature and origin of T11 unconformity. The T11 is often a low-angle unconformity with underlying Qingshankou Formation having been deformed and eroded prior to deposition of the Yaojia Formation. In the post-rift evolution of the basin it marks an abrupt change from a deep lake to shallow lake or subaerial environment, documented by reddening of the lacustrine mudstone, extinction of the ostracod assemblages and a great increase of coarse detrital inputs. The sharp change of depositional environment, the truncation of gentle folds and the cluster of volcanic and paleoearthquake activities, all happened simultaneously, immediately before the development of T11 unconformity, indicating a significant regional compressional uplift event in the basin. The timing of the T11 unconformity formation is within the interval 88–86.2 Ma. Correlations with coeval unconformities in other Cretaceous sedimentary basins in eastern Asia indicate that this compressional uplift coincided with an episode of global plate reorganization between the Eurasian and Paleo-Pacific plates that culminated at 88–87 Ma. During this short interval the northeast Asian margin, in eastern China, South Korea, Japan and Russian Far East experienced widespread violent volcanic and granite emplacement activity triggered by compression resulting from rapid and orthogonal slab subduction. The post-rift basin tectonic inversion occurred during T11 (Coniacian) time; thereafter the basin again evolved in an extension regime. Two subsidence phases in post-rift history took place as the direct consequence of Coniacian compression peak, which defined the distribution of oil sources and reservoirs.

1. Introduction

Past decades of investigation have revealed that rift basins are the most obvious manifestation of extension structures which cover a vast area of eastern Asia. These basins originated in Later Jurassic–Cretaceous time and their evolution can be divided into syn-rift and post-rift stages (Charles et al., 2013; Chen and Dickinson, 1986; Graham et al., 2001, 2012; Meng, 2003; Ren et al., 2002; Tian et al., 1992). However, the thermal subsidence systems are prone to disruption or inversion by compressional stresses. Because eastern Asia adjoins the convergence zone with the western Paleo-Pacific plates during Mesozoic time, changes in plate interaction overprinted the post-rift subsidence of sedimentary basins causing significant departures from a purely thermal subsidence curve (Honza, 1995; Jolivet et al., 1989; Ren et al., 2002; Tamaki and Honza, 1991; Ziegler and Cloetingh, 2004).

The Cretaceous Songliao Basin of northeastern China covers an area of ~260,000 km^2 (Fig. 1), and is well known as one of the largest rift basins in the world. The post-rift history of the basin was investigated after the discovery of oil in the middle of the stratigraphic section in 1959. Several hypotheses have been proposed to define the timing and geodynamic processes responsible for changes of the stress field during deposition of the post-rift sedimentary sequence of the basin (Hu et al., 1998; Li et al., 2012; Ren et al., 2002; Song, 1997; Zhao et al., 2013). However, its complicated history remains far from a comprehensive understanding. Remarkably, there is a series of unconformities in the Songliao Basin which not only subdivide the Cretaceous

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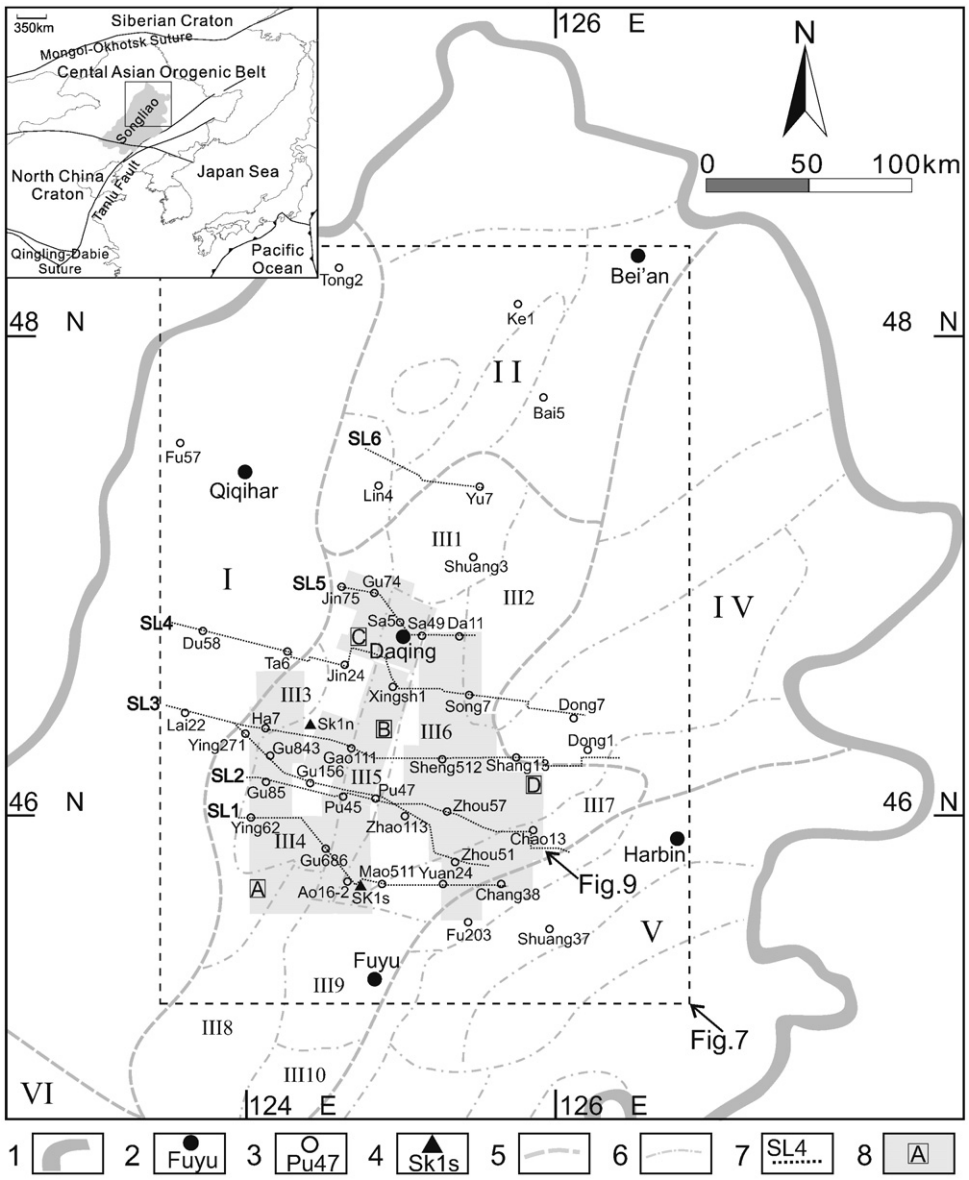

Fig. 1. Major structural divisions of the Songliao Basin and seismic data used in this study. The box outlined by dashed lines is the location of Fig. 7. Structural units: I, Western Slope Zone; II, Northern Plunge Zone; III, Central Downwarp Zone; III1, Heiyupao Sag; III2, Mingshui Terrace; III3, Longhupao–Honggang Terrace; III4, Qijia-Gulong Depression; III5, Daqing placanticline; III6, Sanzhao Depression; III7, Chaoyanggou Terrace; III8, Changling Sag; III9, Fuyu Uplift; III10, Shuangtuozi Terrace; IV, Northeastern Uplift Zone; V, Southeastern Uplift Zone; VI, Southwestern Uplift Zone. Key: 1—basin boundary, 2—settlement, 3—well, 4—Cretaceous Continental Scientific Drilling borehole, 5—first order structural boundary, 6—second order structural boundary, 7—2D seismic lines, 8—3D seismic grid: A—QJGLLP3D, B—CYLP3D, C—XSGDLP3D, D—DBLP3D.
Modified after Feng et al. (2010).

stratigraphic column but also represent substantial breaks in the regional depositional record. They provide important information about the sedimentation and deformation processes, as well as the tectonic forces behind them.

The unconformity between Qingshankou and Yaojia Formations, generally referred to "T11", is the most important geodynamic boundary in the post-rift history of the Songliao Basin. It controlled or was in para-genesis with formation of the main oil plays. It has been assumed previously that the T11 unconformity represents a disconformity as responses to paleoclimate change or lake level variation (Chi et al., 2002; Wang et al., 1994; Yang et al., 1985; Ye et al., 2002), during the tectonic quiet stage when broad subsidence was prevailing in the Songliao Basin (Hu et al., 1998). In our opinion the geodynamic processes that resulted in formation of the T11 unconformity were poorly understood, and thus more detailed analyses of high-quality new data sets were needed.

In this paper we synthesize the (1) high quality seismic imagery and continuous sections of cored wells, and (2) detailed high-precision absolute age determinations for strata above and below the unconformity. We present newly obtained 3D seismic reflection data sets and multichannel 2D cross-basin seismic lines. Many new chronologic dates have been obtained in the course of the multidisciplinary study of the Cretaceous Continental Scientific Drilling borehole (CCSD-SK-1) in the Songliao Basin (Feng et al., 2013; Wang et al., 2013a). These offered us unique opportunity to probe into the complexity of the T11 unconformity, its nature and geodynamic setting. We propose that the origin of the T11 unconformity reflects the Late Cretaceous interaction between the Pacific plate and Asian continental margin. Our study provides more accurate constraints on the age and plate tectonic setting of the basin tectonic inversion in the post-rift stage.

2. Geologic setting

The Songliao Basin is a major Cretaceous rift structure in the eastern part of the Central Asian Orogenic Belt (Li et al., 2012; Ren et al., 2002). It