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Cretaceous anomalous subsidence and its response to dynamic topography in the Songliao Basin, Northeast China

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ABSTRACT

To understand the formation mechanisms and evolution of the Songliao Basin, we applied backstripping and strain rate inversion methods to 20 wells and reinterpret two seismic sections in the Songliao Basin. The obtained data were used to reconstruct the tectonic subsidence history and further assess the potential subsidence mechanisms of this area. The predicted post-rift subsidence based on the uniform stretching model that followed earlier lithospheric thinning events was much lower than the subsidence provided by backstripping. The anomalous subsidence during the post-rift stage was between 200 m and 800 m in the Songliao Basin, and the depocenter of anomalous subsidence moved eastward between ca. 110 and 80 Ma before returning to the west between ca. 80 and 65 Ma. Regional variations in the subsidence rates suggest a possible deficit in the negative buoyancy (mantle loading) that is induced by the sinking slab beneath the Songliao Basin. In addition, the anomalous post-rift subsidence was primarily driven by downward drag pressure from the subducting western Izanagi slab and asthenospheric mantle flow beneath the Songliao Basin. The basement rifting in the Songliao Basin during the early Cretaceous and the normal faulting that occurred during the post-rift stage resulted in a secondary contribution to the anomalous post-rift subsidence. Unlike the Songliao Basin, several early Cretaceous rift basins south of the Yanshan Belt were only filled during the syn-rift subsidence, and the anomalous post-rift uplift of the Yanshan belt was driven by deep mantle flow.

1. Introduction

Anomalous subsidence is defined as the difference between theoretical and observed subsidence (Xie et al., 2006). Theoretical subsidence is calculated using the classical foreland basin model (Pang and Nummedal, 1995; Liu et al., 2004), the uniform stretching model for the rift basin (McKenzie, 1978) or theoretical models for the other basin types. Anomalous subsidence patterns have been observed in the Western Interior Basin of the United States (Liu and Nummedal, 2004), in the Rockall, Faroe–Shetland and Voring Basins in northwestern Europe (Ceramicola et al., 2005), at the Pearl River Mouth Basin (Xie et al., 2006) and in the Yinggehai Basin (Liao et al., 2011) in the northern region of the South China Sea. The driving mechanisms of anomalous subsidence in various types of basins are different. Anomalous subsidence became an important avenue for exploring the dynamic mechanisms of basin evolution. For example, the origin of anomalous subsidence along the northern margin of the South China Sea and its relationship to dynamic topography helped to explain the evolution mechanisms of basins in the northern region of the South China Sea (Xie et al., 2006) and the migration of anomalous subsidence across the western Interior Basin in the Unites States, suggesting that the fundamental driver for subsidence in the Western Interior Basin is the dynamic pull of the sinking Farallon plate (Liu et al., 2011). Despite the wealth of publications regarding the origins of anomalous subsidence in passive continental margin basins (White, 1988; White and McKenzie, 1989; Davis and Kusznir, 2004; Ceramicola et al., 2005; Xie et al., 2006; Liao et al., 2011), anomalous subsidence in continental rift basins is not well understood. The authors of this paper distinguished anomalous post-rift subsidence in the Songliao Basin in northeastern China, and provided information to discuss the subsidence mechanism of the continental rift basin after the cessation of rifting.

The Songliao Basin (Fig. 1), located in the center of northeastern China, is a major Cretaceous intra-continental rift basin on the Eurasian continent (Allen et al., 1997; Wu et al., 2009). During the late Mesozoic period, this basin formed on the eastern Chinese continental margin, which is an ideal area to observe the effects of negative buoyancy due to the insertion of sinking slab material into the mantle. Research on the distribution and migration of anomalous subsidence in the Songliao Basin will reveal

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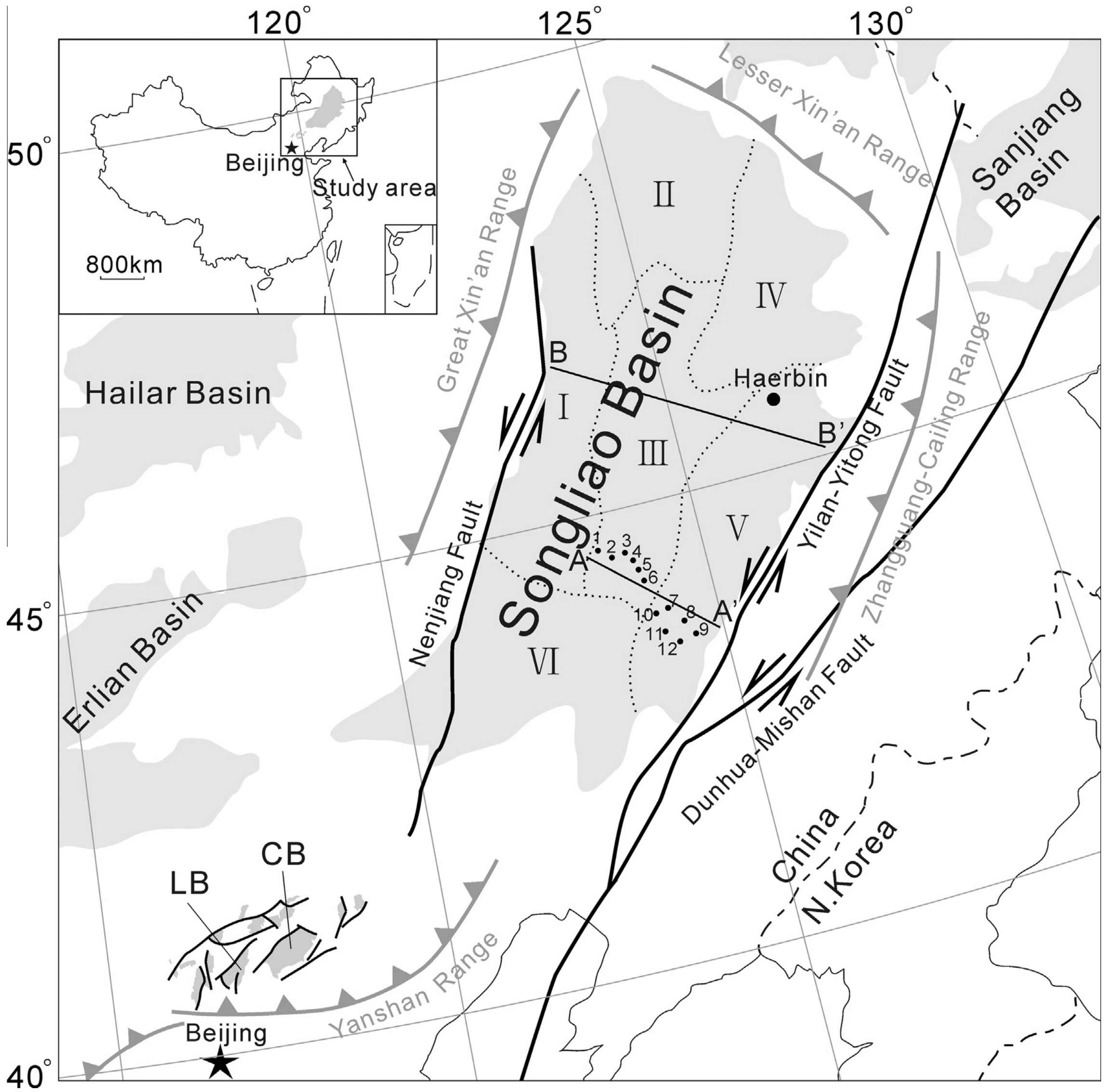

Fig. 1. Location map of the Songliao Basin showing the major structural divisions referred to in the text. I, the western slope zone; II, the northern plunge zone; III, the central downwarp zone; IV, the northeastern uplift zone; V, the southeastern uplift zone; and VI, the southwestern uplift zone. The solid black lines indicates the A–A′ and B–B′ sections, and the dark dots represent the 12 drill holes in the Songliao Basin. The names of No. 1–12 wells are CS1, CS2, DB11, SN101, SN108, SN109, SN22, SN78, SN11, SN10, SN163 and SN12, respectively. The grey shaded areas represent the Cretaceous basins in Northeast Asian and small Cretaceous rift basins in the Yanshan belt including Luanping Basin(LB), Chengde Basin(CB), etc. (Faure et al., 2012; Wei et al., 2012).

the influences of paleo-Pacific plate subduction on northeastern Asia since the late Mesozoic.

The Songliao Basin exhibits the double-layered geologic structure of a rift depression within the deeper layer that is related to syn-rift subsidence and the overlying layer associated with post-rift subsidence. The deeper layer was deposited during the Early Cretaceous, and the upper layer was deposited between the early Cretaceous and late Cretaceous (Huang et al., 2011). The interpretation of the seismic sections shows that the Cretaceous strata in the Songliao basin is commonly subdivided into two sequences that are separated by a regional unconformity at the bottom of the Denglouku Formation (K1d) (ca. 110 Ma) (Fig. 2). The upper post-rift subsidence was much thicker than the syn-rift subsidence. The subsidence rates in the Songliao Basin were accelerated abnormally during the post-rift stage (Li et al., 2014), which differs from the overall decay patterns of post-rift subsidence observed in extensional sedimentary basins that were explained based on the McKenzie's (1978) uniform stretching model.

Different hypotheses regarding the mechanisms of lithospheric thinning and basin subsidence in the Songliao Basin have been proposed. For example, it was proposed that the Songliao Basin is a back-arc rift basin in the western paleo-Pacific subduction zone (Wang et al., 2002; Yan et al., 2002), an active extension basin above a mantle plume (Xiao et al., 2004), or a pull-apart basin with a significant strike-slip component (Ren et al., 1998; Wang et al., 1998). Although the formation mechanisms of the Songliao Basin have been discussed by many researchers, the origins of the anomalous post-rift subsidence are not understood. Consequently, investigating the relationships between the anomalous subsidence and dynamic topography will benefit research regarding the formation mechanisms of the Songliao Basin and the earth surface response to deep mantle processes during paleo-Pacific subduction.