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Neogene residual subsidence and its response to a sinking slab in the deep mantle of eastern China

Xiang Yao, ShaoFeng Liu*, Yu Bai, HuiLi Ji

State Key Laboratory of Geological Processes and Mineral Resources and College of Geosciences and Resources, China University of Geosciences (Beijing), Beijing 100083, China

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A B S T R A C T

Mantle convection could have a significant effect on basin evolution; however, research quantifying this relationship is controversial. To understand the formation mechanism and evolution of the Cenozoic rift basins in eastern China, we applied the back-stripping technique and strain rate inversion modeling to 119 wells from Sangjiang Basin, Bohai Bay Basin, North Yellow Sea Basin, South Yellow Sea Basin, East China Sea Shelf Basin, and four basins within the northern South China Sea margin. The modeled results can be used to reconstruct the tectonic subsidence history and further assess the potential subsidence mechanisms of eastern China. Residual subsidence is defined as the difference between the theoretical and observed tectonic subsidences. Our results show that the residual subsidence since 20 Ma in eastern China generally increases from ~100 to 300 m in terrestrial areas to ~1.2–1.8 km on the continental shelf. Our observed residual subsidence is generally consistent with the present-day dynamic topography that is predicted from mantle flow models, and it is associated with a stagnant slab within the mantle that has been observed by seismic tomography. The migration pathway of the residual subsidence since 20 Ma is consistent with the movement direction of the Pacific and Philippine plates. Therefore, we suggest that the residual subsidence might be a dynamic subsidence induced by a negative buoyancy of the sinking slab in the deep mantle beneath eastern China.

1. Introduction

Eastern China includes a number of Cenozoic rift basins, and the formation mechanisms and evolution of these basins remain controversial. Previous studies have proposed several models for the formation of the continental margin sea basins in the western Pacific, such as Karig's (1971) "back-arc spreading model" based on plate tectonics, Taylor and Hayes's (1983) "Atlantic-type spreading model", and Miyashiro's (1986) "hot areas injection model". In recent years, important progress has been made on the deep dynamic processes of marginal sea basins (Liu et al., 2007; Maruyama et al., 2007; Zhao et al., 2002, 2007). In view of tectonic migration, Suo et al. (2012) proposed that the following formation mechanisms for these Cenozoic rift basins: Late Mesozoic extrusion tectonics, Cenozoic NW-directed crustal extension, regional far-field eastward flow of the western asthenosphere that was caused by the India-Asia collision and eastward jumping, and roll-back of the subduction zones of the Pacific Plate. However, most of these models are based on qualitative analyses and lack quantitative analyses of the subsidence, formation, and evolution mechanisms. Therefore, these models cannot accurately explain how deep mantle convection induced by plate subduction impacts basin formation.

Liu and Nummedal (2004) proposed the concept of residual subsidence, which is defined as the difference between theoretical and observed tectonic subsidence. The residual subsidence can be either negative (which implies that an episode of uplift has occurred) or positive (which implies an episode of subsidence has occurred). Theoretical tectonic subsidence is calculated using the uniform stretching model for rift basins (McKenzie, 1978), the classical foreland basin model (Liu and Nummedal, 2004; Liu et al., 2011; Pang and Nummedal, 1995) or theoretical models for other basin types (Xie et al., 2006). Residual subsidence has been observed in many large basins, including the Western Interior Basin of the United States (Liu and Nummedal, 2004; Liu et al., 2011), and Rockall, Faroe-Shetland and Voring basins on the North Atlantic passive continental margin (Ceramicola et al., 2005) and the northern region of the South China Sea (Xie et al., 2006). The driving mechanisms of residual subsidence in the various types of basins are different. Liu and Nummedal (2004) and Liu et al. (2011) confirmed that comparisons between the migration of anomalous subsidence across the Western Interior Basin in the United States and subduction of the Farallon Plate effectively explained the driving

* Corresponding author.
E-mail address: shaofeng@cugb.edu.cn (S. Liu).

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mechanisms of subsidence in the Western Interior Basin in the United States, and the anomalous subsidence along the northern margin of the South China Sea and its relationship to the dynamic topography helped explain the evolution mechanisms of basins in the northern part of the South China Sea (Xie et al., 2006). The distribution and origin of residual subsidence for the Cenozoic rift basins of eastern China is unclear. In this paper, data from seismic sections and wells were analyzed, and the classic basin analysis theory (McKenzie, 1978; White, 1993, 1994) was combined with quantitative modeling techniques (Chen et al., 2013; Song et al., 2010) to recover the basin subsidence and evolution mechanisms and separate the post-rift residual subsidence from the tectonic subsidence. We reveal the formation mechanisms of these Cenozoic basins and explore the surface response to deep mantle processes by assessing the deep seismic tomography and comparing the temporal and spatial evolutions of the residual subsidence with the dynamic topography calculated by global geodynamic modeling (Conrad and Husson, 2009; Flament et al., 2013; Ricard et al., 1993; Spasojevic and Gurnis, 2012; Steinberger, 2007).

2. Geological setting

The western Pacific active continental margin is the eastern margin of the global convergent system located at the junction of the Eurasia Plate, the Pacific Plate, and the Indian Plate. This region is affected the India-Asia collision and retrogression or roll-back of the subduction zones of the Pacific Plate. The western Pacific active continental margin has a wide basin-arc-trench system, which migrated and jumped seaward and eastward (Suo et al., 2012). The eastern part of China located along the continental shelf of the western Pacific includes a number of Cenozoic rift basins. In this paper, we chose the following basins (from north to south) for subsidence analysis: the Sangjiang Basin, Bohai Bay Basin, Yellow Sea Basin, East China Sea Shelf Basin, and four basins within the northern South China Sea margin (Fig. 1).

Most of the basins were formed by lithospheric stretching during the Paleocene and the subsequent Oligocene thermal subsidence (Bai, 2014; Ji, 2015; Li et al., 2010; Xie et al., 2006; Zhang et al., 2012; Zhu et al., 2010). With the exception of the East China Sea Shelf Basin, the syn- and post-rift stages of the basins can be divided at 23.03 Ma (Fig. 2) according to Zhang et al. (2012), Zhu et al. (2010), and Xie et al. (2006). The post-rift strata consist of Neogene and Quaternary formations that are generally much thicker than the syn-rift Paleogene sediments. The ages of the stratigraphic boundaries in these basins were determined by biostratigraphy and isotopic dating (Bai, 2014; Ji, 2015; Li et al., 2010; Xie et al., 2006; Zhang et al., 2012; Zhu et al., 2010).

3. Methods and data resources

Our subsidence analysis is based on data from 119 actual or synthetic wells from the basins. In this paper, we combined classic basin analysis theory (McKenzie, 1978; White, 1993, 1994) with quantitative modeling techniques (Chen et al., 2013; Song et al., 2010) to calculate the post-rift residual subsidence that exceeded the theoretical thermal subsidence. To extract the residual subsidence, we compared theoretical results with the observed post-rift tectonic subsidence. The back-stripping technique was used to calculate the observed tectonic subsidence, and a 1D strain rate inversion model was used to calculate the theoretical tectonic subsidence (Li and Liu, 2015; McKenzie, 1978; Song et al., 2010; White, 1993, 1994) (Fig. 3).

3.1. Calculation of the observed tectonic subsidence

The back-stripping technique, which is based on the method of Sclater and Christie (1980), was used to calculate the observed tectonic subsidence. This process includes decompaction, water depth and eustatic fluctuation corrections, and Airy isostatic back stripping (Li and Liu, 2015; Liu et al., 2005). The effects of compaction and sediment

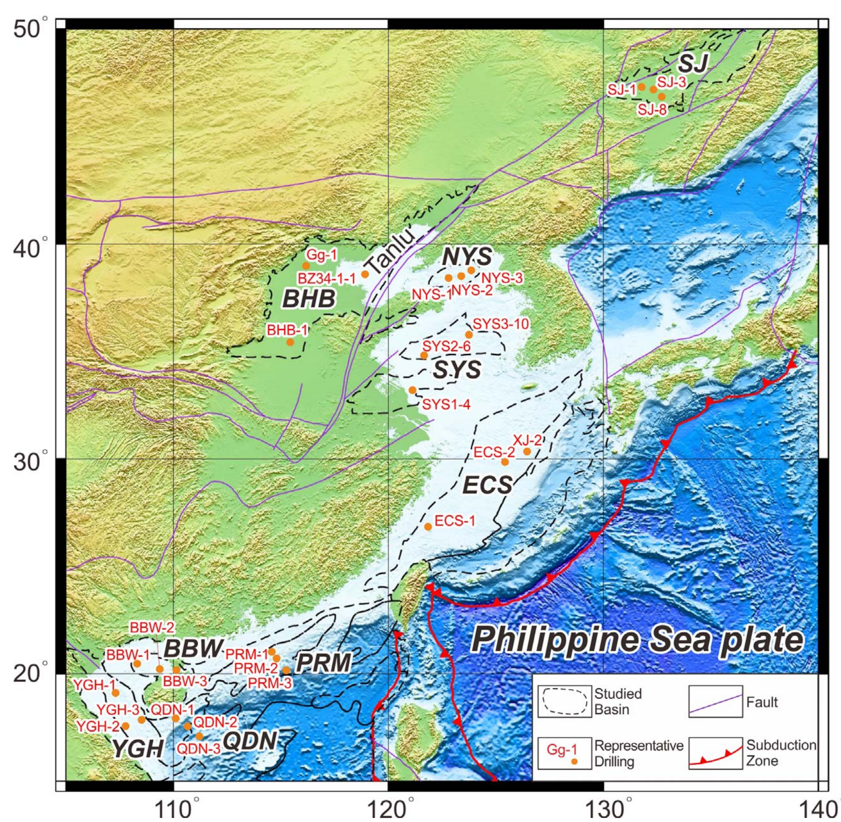

Fig. 1. Locations of the Cenozoic rift basins and selected representative wells used in this study on a simplified tectonic map of eastern China. Abbreviations: SJ: Sangjiang Basin; BHB: Bohai Bay Basin; NYS: North Yellow Sea Basin; SYS: South Yellow Sea Basin; ECS: East China Sea Shelf Basin; BBW: Beibuwan Basin; YGH: Yinggehai Basin; QDN: Qiongdongnan Basin; PRM: Pearl River Mouth Basin. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)