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A possible mechanism for the initiation of the Yinggehai Basin: A visco-elasto-plastic model

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ABSTRACT

The Yinggehai Basin, lying along the trace of the Red River fault zone in the South China Sea, has been related to the movements of the Red River fault zone and the rotation of the Indochina block. However, the tectonic origin of the Yinggehai Basin remains unclear. This paper explores the initiation of the Yinggehai Basin using a visco-elasto-plastic model. This model concentrates on two main aspects: lateral viscosity variations (mainly controlled by temperature) in the lithosphere and internal friction angles of the pre-existing fault zone. Modeling results show that: (1) for a layered viscosity, en echelon faults would likely form when there is no pre-existing strike–slip fault; whereas, the basin would be narrow and deep, if any, when there is a pre-existing fault; (2) for moderate lateral viscosity variations, a large basin forms, even without a pre-existing fault zone; and (3) for strong lateral viscosity variations, a major rift could form over geologic time. Our results indicate that the initiation of the Yinggehai Basin requires moderate lateral viscosity variations (i.e., a pre-existing gentle upwelling of the Mohorovicic discontinuity) but no pre-existing fault. In addition, the initial extension predicted is NE–SW and is generated by the rotation of the Indochina block. This differs from the NW–SE extension that resulted from the movements of the Red River fault zone. This indicates that the left-lateral displacements of the Red River fault zone and the spreading of the South China Sea only influence the basin evolution after its initiation.

1. Introduction

The Yinggehai Basin lies near the southern termination of the largest of the Tibetan strike slip zones, the Red River fault zone (Clift and Sun, 2006) (Fig. 1). The formation of the basin has generally been related to the relative movements and clockwise rotation of the Indochina block along the Red River fault zone (Clift and Sun, 2006; Guo et al., 2001; Rangin et al., 1995; Sun et al., 2003). The Red River fault zone, one of the most important strike–slip faults in Asia, is thought to guide the lateral extrusion of Southeast Asia (Mazur et al., 2012; Tapponnier et al., 1982, 1986). The significant left-lateral displacements of the Red River fault zone also cause seafloor spreading in the South China Sea (Briais et al., 1993; Mazur et al., 2012; Tapponnier et al., 1982, 1986). Thus, the Yinggehai Basin provides important clues to understanding the uplift of the Tibetan Plateau and seafloor spreading in the South China Sea.

Many studies have been done on the Yinggehai Basin that greatly improved our understanding of the basin evolution. He et al. (2002) studied temperature data from 99 oil wells in the Yinggehai Basin. They suggested that the geothermal gradients of the Yinggehai Basin vary from 31 to 43 °C/km, with an average heat flow of 79 mW/m^2 (Fig. 1, inset b; He et al., 2002). Clift and Sun (2006) reconstructed the tectonic evolution of the Yinggehai Basin and explained the nature of its sedimentary fill using the seismic reflection profiles of the basin. Wu et al. (2009) documented the structure of the crust based on wide-angle seismic profiles of the basin. Zhu et al. (2009) estimated the timing and movements of the offshore segment of the Red River fault zone using high-resolution seismic reflection and borehole data. Recently, Mazur et al. (2012) used a three-dimensional gravity inversion to determine the deep structure of the basin. They suggested that: (1) the maximum thickness of sediments reaches 18 km; (2) the Mohorovicic discontinuity (Moho) has a depth of ~23 km; and (3) the crust is about 7 km thick under the center of the basin. However, the tectonic origin of the Yinggehai Basin remains unclear (Clift and Sun, 2006; Mazur et al., 2012; Morley, 2002).

Previous researches provided at least three different mechanisms for the formation of the Yinggehai Basin: the left lateral pull-apart, the right lateral pull-apart, and the transform-extension basin. Gong et al. (1997) as well as Zhang and Hao (1997) analyzed

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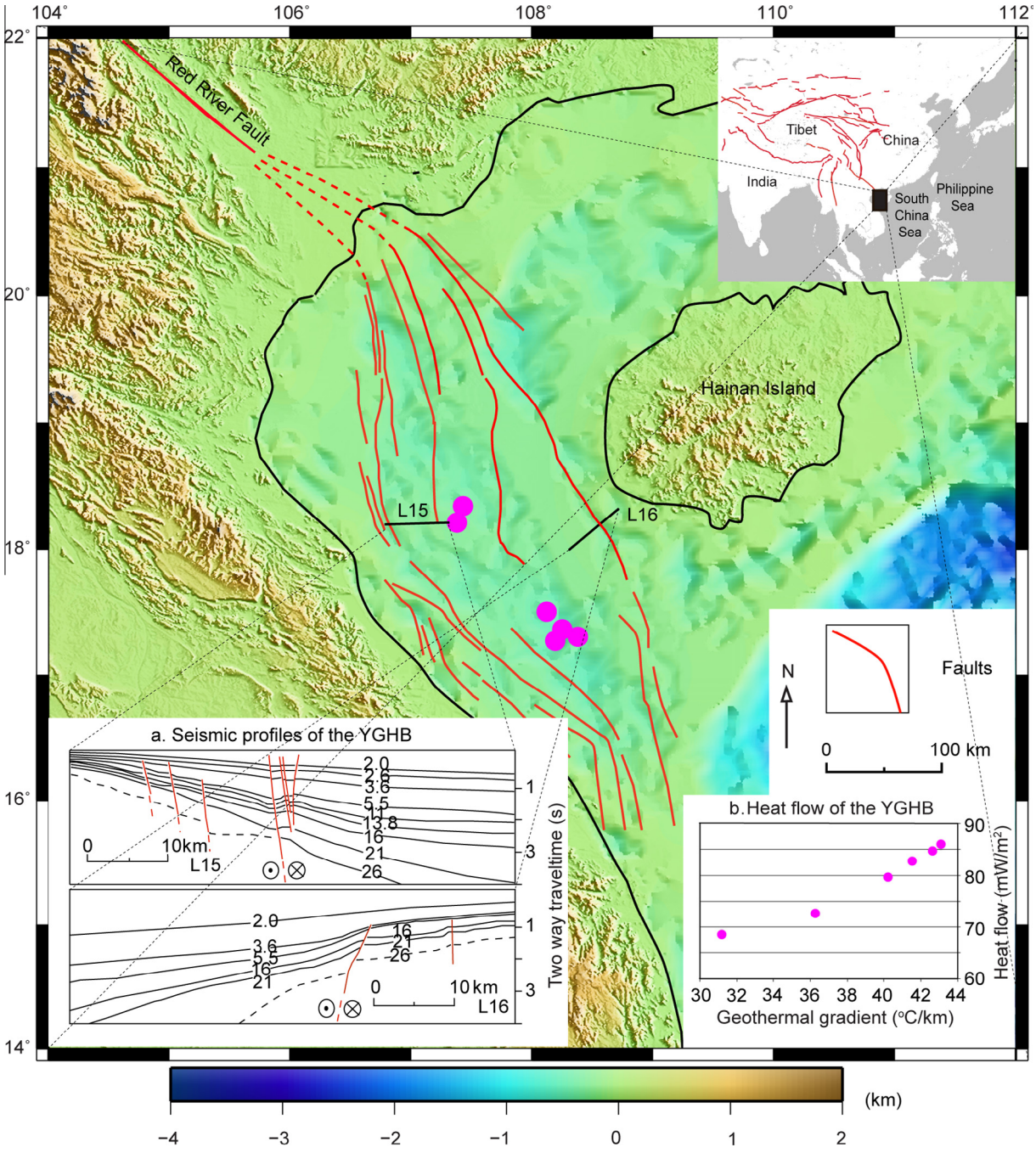

Fig. 1. The tectonic map of the Yinggehai Basin with transverse two-dimensional seismic profiles (L15 and L16 black lines) and heat flow data (pink circles) (Zhu et al., 2009). Inset (a) shows two interpreted transverse two-dimensional seismic profiles and faults (red lines) (Zhu et al., 2009). Inset (b) shows heat flow data (pink circles) provided by He et al. (2002); the values of heat flow at the six sites in the Yinggehai Basin range from 69 to 86 mW/m^2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the migration of the center of deposition and suggested that the basin has been a dextral pull-apart basin since the Oligocene. Guo et al. (2001), Sun et al. (2003) suggested that it is a left-lateral pull-apart basin from the Paleocene to the Miocene based on the movements of the Red River fault zone and a sandbox model, respectively. Li et al. (1999) proposed that it is a transform-extension basin based on seismic profiles and regional tectonics. Clift and Sun (2006) suggested that the basin formed as a strike–slip basin, with its deformation resulting from the movements of the Red River fault zone. Thus, the mechanism for the formation of the Yinggehai Basin remains controversial.

In addition, the Yinggehai Basin provides a unique insight into the opening of the South China Sea (Ding et al., 1999; Zhu et al., 2009). The NE-trending Pearl River Mouth basin lies to the northeast of the NW-trending Yinggehai Basin along the northwestern margin of the South China Sea. And the NE-trending Qingdongnan basin lies adjacent to the eastern edge of the Yinggehai Basin. The Pearl River Mouth and Qingdongnan basins typically appear as extensional passive margin basins associated with the spreading of the South China Sea (Ru and Pigott, 1986; Xie et al., 2006). Ding et al. (1999) also associated the formation of the Yinggehai Basin with the spreading of the South China Sea and suggested that it