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Understanding of the geological and geodynamic controls on the formation of the South China Sea: A numerical modelling approach

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Abstract

A number of previous models have been proposed to explain the formation of the South China Sea, the largest marginal sea basin in Southeast Asia, but no consensus has been reached. In this work, two-dimensional (2D) plan-view models (linear viscous rheology) are constructed to simulate the India–Eurasia collision, its resultant intra-plate deformation and lateral motion along the Red River Fault. We then use 2D cross-section models (a combination of linear viscous rheology and elastic–plastic rheology) to simulate the influence of deep asthenosphere upwelling on lithospheric deformation.

The plan-view models show that the India–Eurasia collision can result in extensive east-southeastward tectonic extrusion, consistent with the prediction of the analogue experiments. During extrusion, the modelled Red River Fault first experienced huge left-lateral shearing and then changed to right-lateral shearing (reversal). The style of shearing motion along the Red River Fault is a function of the distance between the fault and the India–Eurasia collision frontier, which decreases with time and controls relative extrusion movement between the South China Block and Indochina Block. Our models also show that the extrusion can generate extension in an approximately N-S direction in the region containing the present-day South China Sea. Our cross-section models further demonstrate that such horizontal extension can only generate limited thinning of the continental lithosphere in the South China Sea region. In contrast, asthenosphere upwelling is much more efficient in generating lithospheric upper mantle thinning but still inefficient for crust thinning. It is the combination of mechanical extension and asthenosphere upwelling that proves to be the most efficient way to thin the entire lithosphere, and that represents the most likely driving mechanism for the opening and spreading of the South China Sea.

Keywords: South China Sea; Red River Fault; India–Eurasia collision; Numerical modelling

1. Introduction

The South China Sea (SCS) is one of several major marginal sea basins in Southeast Asia. It is located tectonically at the junctions of the Indo-Australia plate, Eurasian plate and Pacific plate (Fig. 1). This suggests that the opening

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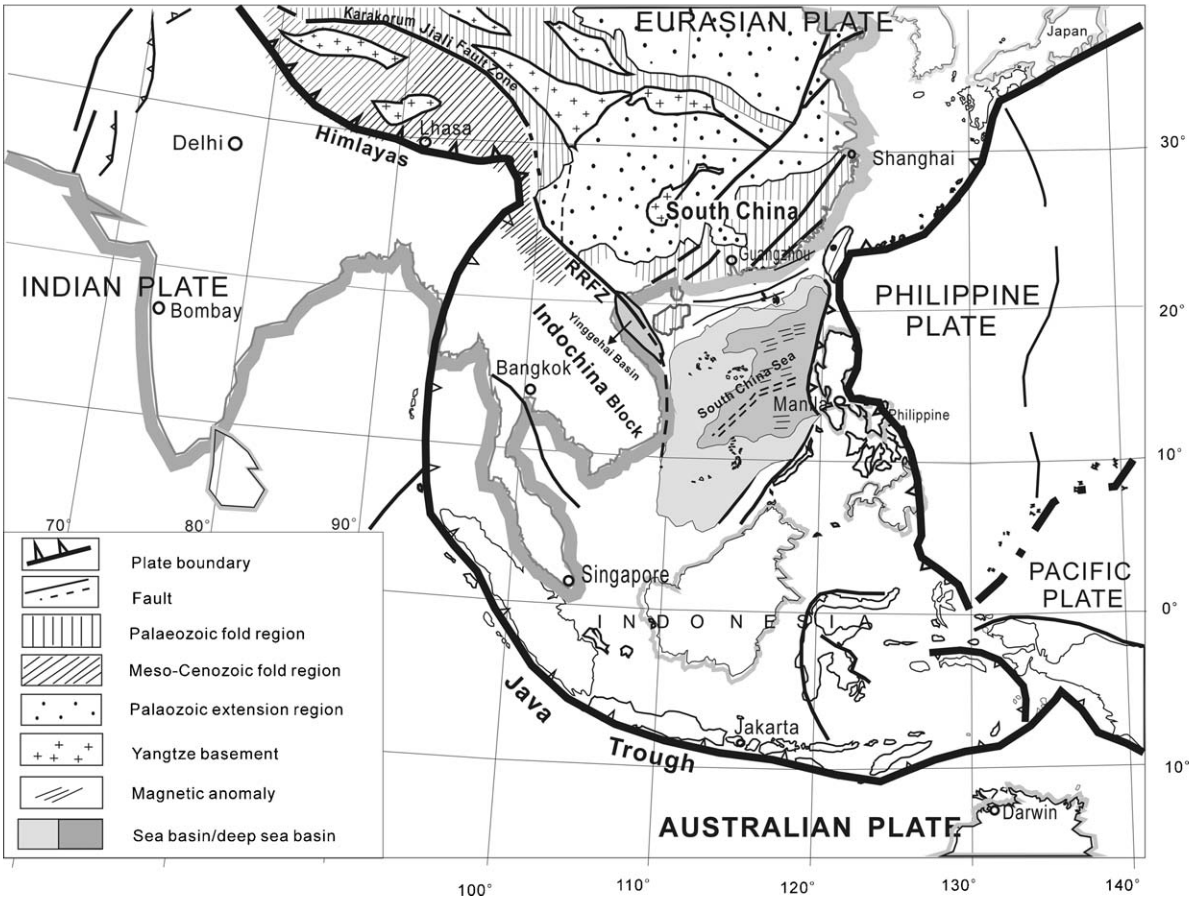

Fig. 1. Schematic map of tectonic and structural outline of the Southeast Asia and neighbouring regions. In the South China Sea area, the plan-view geometry of the oceanic crust is highlighted by the darker grey region within thin lines and magnetic anomaly lineation is illustrated by dashes.

and tectonic evolution of the SCS in the Cenozoic were genetically linked to the complex geodynamic processes associated with the interactions between all the three plates. For this reason, the SCS has attracted intensive structural and geophysical research over the past decades, with a focus on its opening/extensional history and relevant dynamic-tectonic models (e.g. Taylor and Hayes, 1980, 1983; Taylor and Rangin, 1988; Tapponnier and Molnar, 1976; Tapponnier et al., 1982, 1986; Lee and Lawver, 1995; Zhou et al., 1995). There has also been extensive research effort focusing on the stratigraphic structure of the sedimentary sequences of the SCS (e.g. Holloway, 1982; Kudrass et al., 1986; Wu, 1988; Lin et al., 2003), where excellent natural resource potential (e.g. hydrocarbon) exists.

There are numerous tectonic scenario models for the formation of the SCS. These models can be divided into three major groups of hypotheses. The first hypothesis attributes the formation of the SCS to the India–Eurasia continental collision and the collision-resultant tectonic extrusion process (Tapponnier and Molnar, 1976; Tapponnier et al., 1982, 1986). These authors used the similarity between the present-day structural framework in the Southeast Asia and the geometrical features derived from their analogue experiments, and proposed a series of chain-reaction processes leading to the formation of the SCS. The processes include: (1) the India–Eurasia collision led to propagating tectonic extrusion eastward, away from the collision zone; (2) the extrusion led to huge left-lateral shearing along the Red River Fault; (3) finally the shearing and free-rotation along the Red River Fault led to the opening of the SCS as a pull-apart basin. This scenario is supported by evidence from fault movements in the region (e.g. the Ailao Shan-Red River shear zone) and certain magnetic anomaly features in the SCS (e.g. Tapponnier et al., 1990; Briais et al., 1993; Leloup et al., 1995; Lacassin et al., 1997). However, the collision-extrusion model has been challenged by the results of several studies. Houseman and England (1986) and England and Houseman (1986) numerically simulated strain distribution associated with the India-Asia collision zone, and suggested that collision-resultant kinematic energy