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Discussion of tectonic models for Cenozoic strike-slip fault-affected continental margins of mainland SE Asia

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ABSTRACT

Understanding the roles of Cenozoic strike-slip faults in SE Asia observed in outcrop onshore, with their offshore continuation has produced a variety of structural models (particularly pull-apart vs. oblique extension, escape tectonics vs. slab-pull-driven extension) to explain their relationships to sedimentary basins. Key problems with interpreting the offshore significance of major strike-slip faults are: (1) reconciling conflicting palaeomagnetic data, (2) discriminating extensional, and oblique-extensional fault geometries from strike-slip geometries on 2D seismic reflection data, and (3) estimating strike-slip displacements from seismic reflection data.

Focus on basic strike-slip fault geometries such as restraining vs. releasing bends, and strongly splaying geometries approach the gulfs of Thailand and Tonkin, suggest major strike-slip faults probably do not extend far offshore Splays covering areas 10,000's km^2 in extent are characteristic of the southern portions of the Sagaing, Mae Ping, Three Pagodas and Ailao Shan-Red River faults, and are indicative of major faults dying out. The areas of the fault tips associated with faults of potentially 100 km+ displacement, scale appropriately with global examples of strike-slip faults on log–log displacement vs. tip area plots. The fault geometries in the Song Hong-Yinggehai Basin are inappropriate for a sinistral pull-apart geometry, and instead the southern fault strands of the Ailao Shan-Red River fault are interpreted to die out within the NW part of the Song Hong-Yinggehai Basin. Hence the fault zone does not transfer displacement onto the South China Seas spreading centre. The strike-slip faults are replaced by more extensional, oblique-extensional fault systems offshore to the south. The Sagaing Fault is also superimposed on an older Paleogene–Early Miocene oblique-extensional rift system. The Sagaing Fault geometry is complex, and one branch of the offshore fault zone transfers displacement onto the Pliocene-Recent Andaman spreading centre, and links with the West Andaman and related faults to form a very large pull-apart basin.

1. Introduction

Mainland SE Asia is a region of considerable Cenozoic tectonic activity, which includes development of numerous strike-slip faults (Fig. 1). The cause, displacement amount, and structural significance of these faults remains highly contentious, particularly for the Ailao Shan-Red River Fault zone and its relationship to extension in the South China Sea (see review in Searle and Morley (2011)). Two main tectonic scenarios have been proposed: one driven by slab pull of the Proto-South China Sea (e.g. Taylor and Hayes, 1980, 1983; Holloway, 1982; Hall, 1996, 2002; Hall et al., 2008) and the other driven by escape tectonics (e.g. Tapponnier et al., 1986; Leloup et al., 2001; Replumaz and Tapponnier, 2003), see Cullen (2010) for a review.

The slab pull model involves subduction of the Proto-South China Sea under Borneo (Hall et al., 2008). Extension in the South China Seas area rifted the Dangerous Grounds region from Asia, creating sea floor spreading in the South China Sea during the Oligocene–Lower Miocene (Briais et al., 1993; Barckhausen and Roeser, 2004). Spreading ceased when subduction of the Proto-South China Seas crust was terminated by collision of the Dangerous Grounds block with NW Borneo. During extension right lateral shear occurred along the southern half of the NW–SE trending Vietnam margin (e.g. Hayes, 1985; Roques et al., 1997; Huchon et al., 1998; Morley, 2002; Clift et al., 2008).

The escape tectonics model proposes that narrow zones of high-displacement strike-slip faults bounded rigid (i.e. cold) crustal blocks. The major strike-slip faults (e.g. Ailao Shan-Red River (ASRR), Mae Ping and Three Pagodas Faults) are considered responsible for formation of basins on the margin of Indochina (Tapponnier et al., 1986; Fig. 1), including the Pattani, Malay, and Song Hong-Yinggehai Basins. The extreme thicknesses

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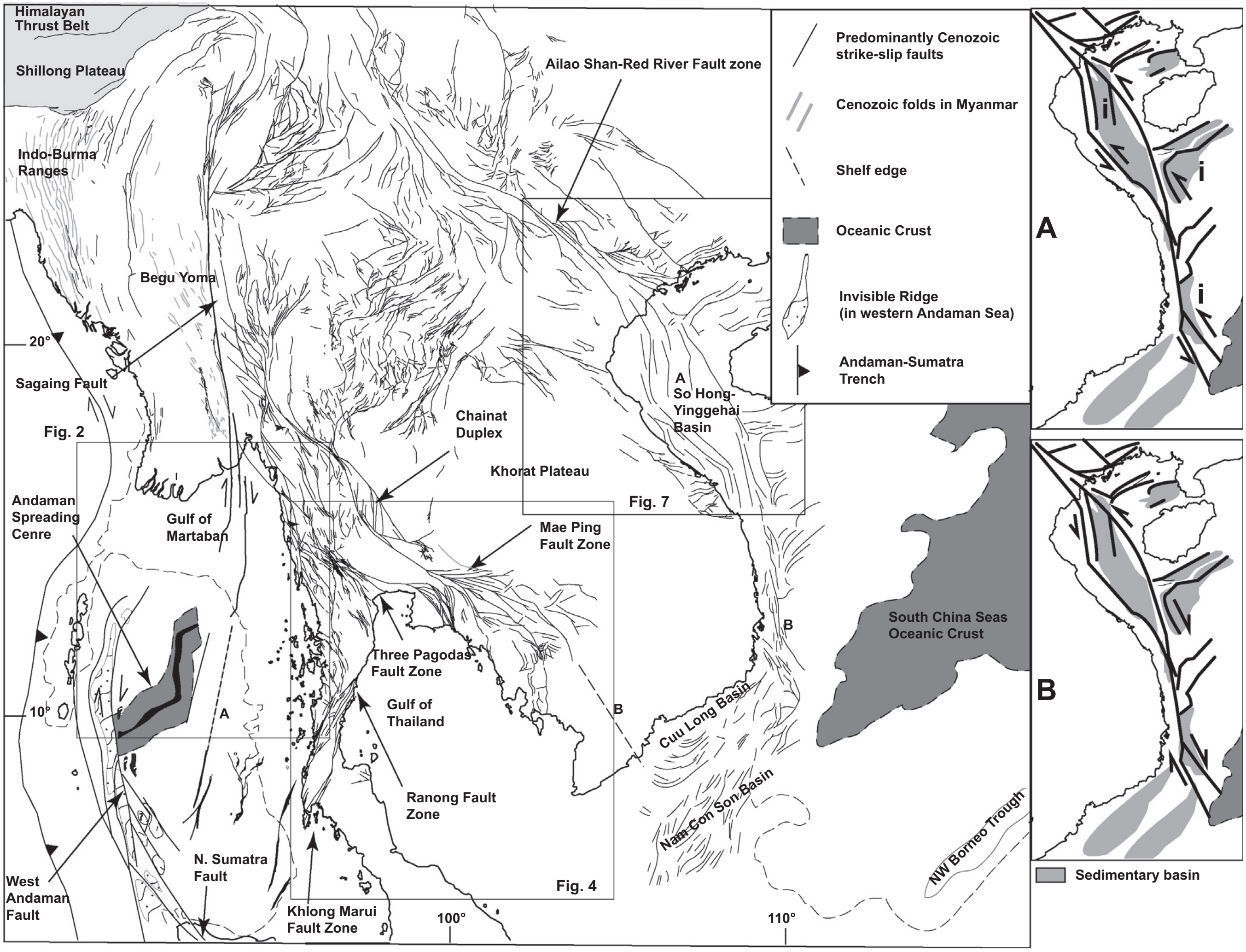

Fig. 1. Regional map of Cenozoic strike slip faults in SE Asia, the map shows all fault (extensional and strike-slip) offshore Vietnam from Fyhn et al. (2009). Faults onshore interpreted from satellite images and geological maps. Areas of folding and thrusting are indicated for the Begu Yoma and Indo-Burma Ranges in Myanmar. Modified from Morley et al. (2011). Inset maps show the two principal models for the Vietnam margin: (A) Escape tectonics (sinistral margin) , e.g. Leloup et al. (2001), Replumaz and Tapponnier (2003); (B) northern sinistral , southern dextral margin (e.g. Roques et al., 1997; Morley, 2002), *i* = areas of apparent restraining geometries in the escape tectonics model that are incompatible with sinistral strike-slip.

(~8–18 km) of these Cenozoic basins are a significant factor for interpreting them as pull-aparts (e.g. Tapponnier et al., 1986; Polachan et al., 1991; Fyhn et al., 2009). The Mae Ping Fault is interpreted to terminate in the fold and thrust belt offshore NW Borneo (Leloup et al., 2001; Replumaz and Tapponnier, 2003). While the ASRR Fault Zone has been linked with the development of the South China Sea spreading centre, which requires a sinistral sense of motion to open the Song Hong-Yinggehai Basin on the NW–SE Vietnam margin (Leloup et al., 2001).

Subduction of the Proto-South China Sea oceanic crust beneath NW Borneo has been invoked to explain Palaeogene–Early Miocene deformation along the NW Borneo margin (e.g. Holloway, 1982; Sandal, 1996; Morley et al., 1998; Morley, 2002; Hall, 1996, 2002). However, the Proto-South China Sea crust does not exist in the escape tectonics model, and displacement caused by the 500+ km extrusion of a large continental block is accommodated by opening of the South China Sea (Leloup et al., 2001; Replumaz and Tapponnier, 2003).

Recent arguments for an offshore extension of strike-slip faults along the NW–SE trending Vietnam coastal margin have led to hybridized versions of the escape tectonic model (Fyhn et al., 2009; Cullen, 2010). For example both authors do not extend the Mae Ping Fault to the NW Borneo margin, and accept the presence of a Proto South China Seas oceanic crust. In the Cullen (2010) model subduction ended during the Oligocene, not the early Miocene. Fyhn et al. (2009) note that their timing of inferred major sinistral motion (predominantly between 40 and 30 Ma) along the entire NW–SE trending Vietnam margin is too early for extrusion to transfer displacement into sea floor spreading in the South China Sea. Despite numerous studies on the offshore data the longstanding absence of conclusive evidence from seismic reflection data for either displacement amount or sense of motion along the putative offshore sinistral extension of the ASRR Fault Zone remains a problem for resolving the appropriate tectonic model for the region.

This paper discusses recent improvements in our understanding of strike-slip fault evolution and geometries in the Andaman Sea, Thailand and Cambodia and how these observations are relevant for the ASRR fault zone and the South China Sea. The discussion then focuses on the Song Hong-Yinggehai Basin and its relationship to the ASRR fault zone as it passes offshore, whether its geometry fits with a typical pull-apart setting or not, and the implications of the basin geometry for the link between the ASRR fault zone and the South China Sea spreading centre.