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Escape tectonism in the Gulf of Thailand: Paleogene left-lateral pull-apart rifting in the Vietnamese part of the Malay Basin

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ABSTRACT

The Malay Basin represents one of the largest rift basins of SE Asia. Based on a comprehensive 2-D seismic database tied to wells covering mainly Vietnamese acreage, the evolution of the Vietnamese part of the basin is outlined and a new tectonic model is proposed for the development of the basin. The Vietnamese part of the Malay Basin comprises a large and deep Paleogene pull-apart basin formed through Middle or Late Eocene to Oligocene left-lateral strike-slip along NNW-trending fault zones. The Tho Chu Fault Zone constitutes a significant Paleogene left-lateral strike-slip zone most likely associated with SE Asian extrusion tectonism. The fault zone outlines a deep rift that widens to the south and connects with the main Malay Basin. In the central northern part of the basin, a series of intra-basinal left-lateral fracture zones are interconnected by NW to WNW-trending extensional faults and worked to distribute sinistral shearing across the width of the basin. Extensive thermal sagging throughout the Neogene has led to the accommodation of a very thick sedimentary succession. Moderate rifting resumed during the Early Miocene following older structural fabric. The intensity of rifting increases towards the west and was probably related to coeval extension in the western part of the Gulf of Thailand. Neogene extension culminated before the Pliocene, although faults in places remains active. Late Neogene basin inversion has been attributed to *c.* 70 km of right-lateral movement across major *c.* N–S-trending faults in the central part of the basin. However, the lack of inversion in Vietnamese territory only seems to merit a few kilometers of dextral inversion.

1. Introduction

Cenozoic rifting in the Gulf of Thailand has often been regarded as the result of the Indian–Eurasian collision. However, the generally very thick post-rift succession buries most of the syn-rift deposits to a depth below the reach of conventional seismic data in large parts of the Pattani and Malay basins, and only little regional seismic data of adequate quality have been published. Consequently, knowledge of Paleogene rifting in the Gulf of Thailand remains fragmentary and contrasting geodynamic models exist (Tapponnier et al., 1986; Pollachan and Sattayarak, 1989; Tjia, 1994; Watcharanantakul and Morley, 2000; Hall and Morley, 2004; Hall, 2009) (Fig. 1).

The formation of the basins has been attributed to either right- or left-lateral pull-apart rifting or to rift-perpendicular to oblique extension (Tapponnier et al., 1986; Kong, 1994; Tjia, 1994; Bustin and Chonchawalit, 1995; DEN, 1998; Leo, 1997; Ngah et al., 1996; Madon and Watts, 1998; Watcharanantakul and Morley, 2000; Morley, 2001; Morley et al., 2004, in press; Morley and Westerway, 2006). Supporting sinistral transtension, major left-lateral shear zones originate from near the East Himalayan Syntaxis and transect the onshore central and northern part of SE Asia and has been suggested to continue or splay offshore in the Gulf of Thailand and in the South China Sea (Tapponnier et al., 1986, Leloup et al., 1995, 2001; Rangin et al., 1995; Hall, 2002; Morley, 2002; Hall and Morley, 2004; Fyhn et al., 2009a,b) (Fig. 1).

Based on analysis of a dense grid of 2-D seismic data comprising more than 18,000 line-kilometers tied to 14 exploration wells, mostly covering the Vietnamese part of the gulf, new light is shed on the timing and style of the Tho Chu Fault Zone (Fig. 2). A new model for rifting in the eastern Gulf of Thailand is suggested that links Paleogene rifting in the Malay Basin to significant left-lateral motion across the Tho Chu Fault Zone and relates more moderate Neogene extension in the northwestern part of the basin to widespread extension in the western part of the gulf and the Andaman Sea.

2. Geological setting

2.1. Pre-collisional geology

A series of north- to south-trending latest Paleozoic to early Mesozoic structural belts underlie the Gulf of Thailand (Metcalfe, 1996; Sone and Metcalfe, 2008). The belts formed in response to the amalgamation of

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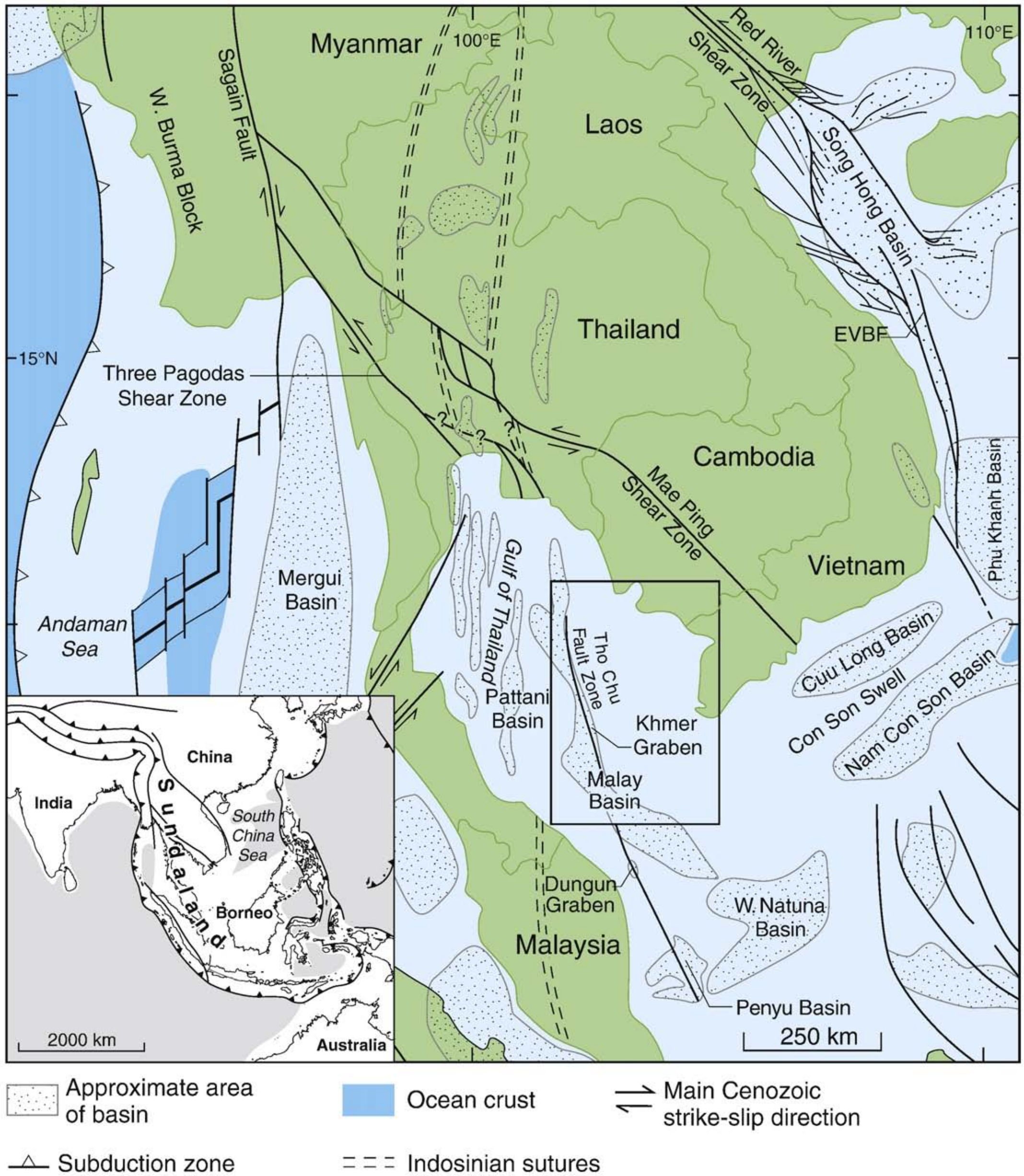

Fig. 1. Location of major Cenozoic basins, areas underlain by oceanic crust and simplified structural outline of the region. The study area is outlined and shown in detail in Fig. 2. Basin and fault outline adapted from Fyhn et al., 2009a and references therein. Insert map illustrates greater SE Asia and the location of Sundaland. EVBF = East Vietnam Boundary Fault.

smaller Gondwana derived continental plates that constitute the Sundaland core of SE Asia (Fig. 1). The structural belts have been reactivated by subsequent tectonic activity and are suggested to parallel and floor the N–S to NNW–SSE-trending rift systems in the central part of the Gulf of Thailand (Morley et al., 2004, in press; Sone and Metcalfe, 2008; Fyhn et al., in press). During Paleocene to Early Eocene time major compression in the Tho Chu Fold Belt underlying and flanking the Tho Chu Graben (known also as the East Graben) together with the parallel Kampot Fold Belt occurred (Fyhn et al., in press). The belts can be traced to onshore Indochina and Thailand where they outline several 100 km long fold and thrust belts transecting major parts of the region.

2.2. Lateral shearing and escape tectonics

The Mae Ping and the Three Pagodas shear zones constitute major nested, overall NW-trending structural lineaments onshore that accommodated substantial Eocene–Oligocene left-lateral displacement associated with the extrusion of SE Asia forced by the collision of India and Eurasia (Tapponnier et al., 1986; Lacassin et al., 1993, 1997; Morley 2002; Morley et al., 2007). Mid crustal metamorphic core complexes with pervasive left-lateral fabric align part of the shear zones and together with restraining bend geometries document their left-lateral strike-slip history (Lacassin et al., 1993, 1997; Morley 2002; 2004; Smith et al., 2007; Morley et al., 2007). Thermochronometric investigations along the shear zones suggest termination of the main left-lateral movements before the Neogene followed by moderate right-lateral inversion alternating with left-lateral reactivations documented by smaller scale brittle deformation (Smith et al., 2007). Based on the offset of regional geological markers Tapponnier et al. (1986) suggested a combined left-lateral offset of several hundred kilometers across the two shear zones. Morley et al. (2007) estimated at least 100 km of left-lateral movement across the Mae Ping Shear Zone. However, some of the offset may have occurred during Late Cretaceous to Early Paleogene accretion events and thus