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Seismic stratigraphy and tectonic structure from a composite multi-channel seismic profile across the entire Dangerous Grounds, South China Sea

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ABSTRACT

We interpret a more than 500 km long composite multi-channel seismic reflection profile across the entire Dangerous Grounds, the South China Sea. Five tectonostratigraphic units are determined, together with seven sequence boundaries. Detailed analysis of extensional features, based on measurements of fault heaves, revealed two major phases of extension, separated by a distinct unconformity, which likely correspond with the beginning of sea-floor spreading in the South China Sea. Early extension occurred during continental rifting (Late Cretaceous–Early Oligocene), and resulted in formation of half-grabens and rotated blocks, controlled by a deeply rooted detachment system. Extension continued in our study area during the drifting phase of the East Subbasin of the South China Sea (Late Oligocene–Early Miocene) until the subsequent opening of the Southwest Subbasin at about 25 Ma, but its intensity decreased markedly thereafter. Deeply rooted detachment systems evolved possibly during this second phase of extension at the continent–ocean transition area. From a coincidence of the lowermost reflections and Moho depth as derived from gravity inversion we tentatively interpret the flattened part of this detachment system as the crust–mantle boundary. It is suggested that the Dangerous Grounds reflect a magma-poor rift system at the initial stage of mantle unroofing. We suggest that a widespread carbonate platform developed across the Dangerous Grounds, concurrent with the period of seafloor spreading in the Southwest Subbasin of the South China Sea. Fault-related stretching factors (β_f) along the line show discrepancies with the whole crustal stretching factors (β_c). The continental crust of the Dangerous Grounds may have experienced nonuniform thinning.

1. Introduction

The South China Sea is located in the interacting region of the Pacific, Eurasian and Indian–Australian plates, and is one of the largest marginal seas along the western Pacific Margin. The area is particularly well suited for studying rift processes at the transition between the extension of the continental lithosphere to the formation of oceanic crust. This is because this relatively young marginal basin currently is in a state characterized by still preserved differences in subsidence and thermal history resulting from rifting. During the Late Cretaceous and Cenozoic, the South China Sea experienced first continental rifting, and subsequently sea floor spreading and then subduction of parts of the oceanic crust to the east and collision to the south (Briais et al., 1993; Luedmann and Wong, 1999; Taylor and Hayes, 1980, 1983; Zhou et al., 1995). Efforts have been made to understand the Dangerous Grounds area from the view point of continental rifting, sedimentation, and deformation, with geological and geophysical data acquired in the past (Clift et al., 2008; Cullen et al., 2010; Hinz and Schlueter, 1985; Hutchison, 2004; Hutchison and Vijayan, 2010; Kudrass et al., 1986; Schlueter et al., 1996). Until now, however, the lack of modern seismic profiling across the entire Dangerous Grounds area has hindered detailed study of tectonostratigraphic patterns and the tectonic framework.

In this study, we present a seismostratigraphic analysis, and we place some constraints on the understanding of the rift dynamics of the Dangerous Grounds. This includes recognition of major structures formed during the rifting phase and subsequent collision related tectonism. Finally, fault-derived extensional factors related to continental rifting are presented. This study will provide a framework for further studies on the degree of symmetry of rift structures, and the mode of thinning of continental lithosphere in a magma-poor extensional setting. The study area comprises the Dangerous Grounds continental fragment and the transition area from the extended continental crust to the oceanic domain of the Southwest Subbasin of the South China Sea (Fig. 1).

There is some confusion in the literature about the naming of the different structures in the South China Sea. In the following text, we have used English names to provide convenience for the readers. In

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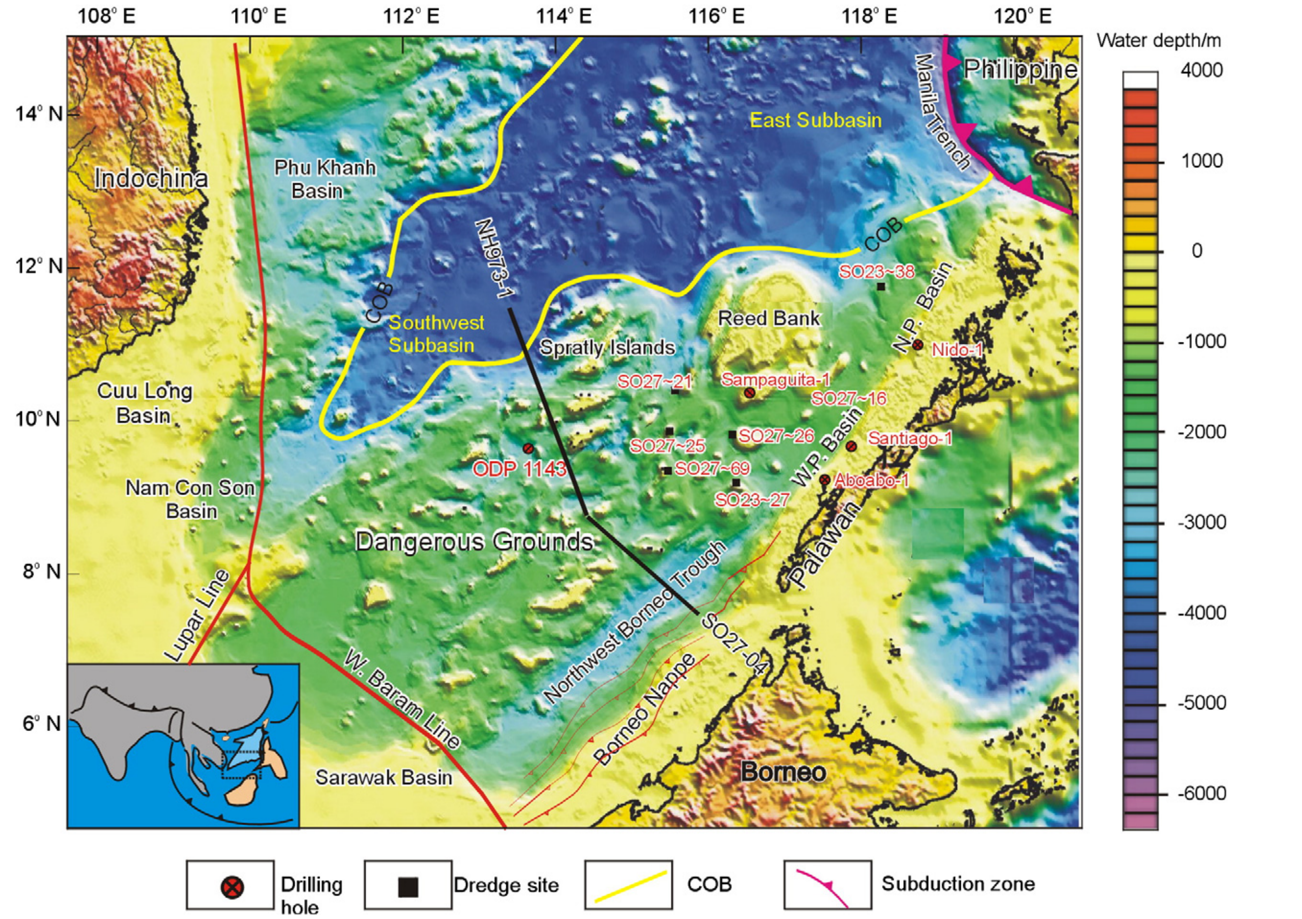

Fig. 1. Morphological features and major tectonic units in the Dangerous Grounds area of the South China Sea. The location of the multi-channel seismic lines, running from the deep oceanic Southwest Sub-basin of the South China Sea towards Borneo is shown as black lines (NH973-1 and SO27-04). Continent-ocean boundary (COB) is shown according to Barckhausen and Roeser (2004). Dredge sites (numbers) are from Kudrass et al. (1986). Well locations are from ODP Shipboard Scientific Party (2000) and Schlueter et al. (1996).

addition we summarize the international and corresponding local names in a table (Table. 1).

2. Geological setting

The study area lies between the oceanic basin of the South China Sea and the Borneo/Palawan. The water-depth in the study area ranges from tens of meters to 3000 m. The area is composed of several continental fragments, such as the Dangerous Grounds and Reed Bank, which are overlain by numerous sedimentary basins (Fig. 1). It is generally accepted that the Dangerous Grounds constitute stretched crust of continental origin (Cullen, 2010; Holloway, 1982; Taylor and Hayes, 1983; Yan and Liu, 2004). The nature and composition of the basement, however, is unclear. A Paleozoic and/or Mesozoic basement may be inferred from dredge samples (Hutchison, 2004; Kudrass et al., 1986; Yan and Liu, 2004). Sampled rocks show a close affinity to those of Southeast Asia, suggesting that the Dangerous Grounds once were a part of the South China continent. After a Cretaceous to Late Paleogene period of rifting, which led to the formation of numerous NE–SW trending half-grabens, the continental fragments were finally separated from the South China continent by seafloor spreading at about 30 Ma (Barckhausen and Roeser, 2004; Briais et al., 1993, Cullen et al., 2010) or earlier (37 Ma; Hsu and Sibuet, 2004). The oceanic basin of the South China Sea consists of three subbasins: the East Subbasin, the Southwest Subbasin (Fig. 1) and the Northwest Subbasin, which is located close to the China margin.

The opening scenario of the South China Sea proposed by Taylor and Hayes (1983) and Briais et al. (1993) has been generally accepted, i.e. sea floor spreading occurring from 30 to 16 Ma (anomaly of 11-5C). The spreading history was complicated by two southward ridge jumps and a southwestward ridge propagation. Refinement of the earlier model has been proposed based on new ship-borne magnetic data (Barckhausen and Roeser, 2004), the timing of seafloor spreading in the central South China Sea has been revised to 31–20.5 Ma (anomaly of 11-6A1). Another difference to the earlier models is that these authors proposed that the rigid block of continental crust which now forms Macclesfield Bank and Reed Bank hindered the propagation of seafloor spreading into the southwestern part of South China Sea oceanic basin until around 25 Ma. The break-up of this block gave way for propagation and also caused a ridge jump in the pre-existing ocean. Hsu and Sibuet (2004) identified

Table 1
Table summarizing the international and corresponding local names for structures in the South China Sea.

Chinese	English	Alternatives
Nansha area	Dangerous Grounds	NW Sabah Trough, N
Nansha Islands	Spratly Islands	Borneo Trough,
Liyue Bank	Reed Bank	Borneo-Palawan
Nansha Trough	NW Borneo Trough	Trough Bankok
Zhongsha Islands	Macclesfield Bank	Shoal
Xisha Islands	Paracel	
Dongsha Islands	Pratas	
Wanan Basin	Nam Con Son Basin	
Zengmu Basin	Sarawak Basin	
Zhongjiannan Basin	Phu Khanh Basin	