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Research paper

Deep crustal structure of the conjugate margins of the SW South China Sea from wide-angle refraction seismic data

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ABSTRACT

The South China Sea is the largest marginal basin of SE Asia, yet its mechanism of formation is still debated. A 1000-km long wide-angle refraction seismic profile was recently acquired along the conjugate margins of the SW sub-basin of the South China Sea, over the longest extended continental crust. A joint reflection and refraction seismic travel time inversion is performed to derive a 2-D velocity model of the crustal structure and upper mantle. Based on this new tomographic model, northern and southern margins are genetically linked since they share common structural characteristics. Most of the continental crust deforms in a brittle manner. Two scales of deformation are imaged and correlate well with seismic reflection observations. Small-scale normal faults (grabens, horsts and rotated faults blocks) are often associated with a tilt of the velocity isocontours affecting the upper crust. The mid-crust shows high lateral velocity variation defining low velocity bodies bounded by large-scale normal faults recognized in seismic reflection profiles. Major sedimentary basins are located above low velocity bodies interpreted as hanging-wall blocks. Along the northern margin, spacing between these velocity bodies decreases from 90 to 45 km as the total crust thins toward the Continent–Ocean Transition. The Continent–Ocean Transitions are narrow and slightly asymmetric – 60 km on the northern side and no more than 30 km on the southern side – indicating little space for significant hyper-stretched crust. Although we have no direct indication for mantle exhumation, shallow high velocities are observed at the Continent–Ocean Transition. The Moho interface remains rather flat over the extended domain, and remains undisturbed by the large-scale normal faults. The main décollement is thus within the ductile lower crust.

1. Introduction

The South China Sea (SCS) is one of the largest submerged continental provinces of SE Asia, covering a surface of nearly 1500 × 1000 km. Convergence of the Pacific plate toward Eurasia during the Mesozoic and the Cenozoic times has shaped the region, plate rollback leading to the progressive dislocation of the South China continent (known as South China Block) and the formation of a series of marginal basins at the edge of Sundaland. Whereas Sulu Sea and Celebes Sea opened as back-arc basins, the origin of the SCS involves the formation of a proto South China Sea probably floored with oceanic crust that has now been subducted (Pubellier et al., 2003). The V-shaped morphology of the SCS results from the mid-Neogene propagation toward the SW of a now extinct NE-SW spreading center (Taylor and Hayes, 1983; Briais et al., 1993; Huchon et al., 1998, 2001).

Bathymetry and gravity data show complex longitudinal morphologic variations along the entire SCS province. While the eastern part of the SCS northern margin exhibits 400 km of extended crust, its western part shows nearly 800 km of extended continental crust (Fig. 1) which makes it one of the widest rifted margin in the world. This variability can be partly attributed to the heterogenous nature of the crust of the South China Block, in relation to a complex evolution of accreted terranes of Gondwana

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origin since the Phanerozoic time (Pubellier et al., 2003), including Kwangsian (middle Paleozoic), Indosinian (Triassic), and Yanshanian (Jurassic–Cretaceous) phases (Wang et al., 2012). The age and distribution of Jurassic–Cretaceous granites along the South China Block and the present-day southern margin of the SCS (including Dangerous Grounds and Palawan blocks) attributed to the Yanshanian tectonic phase advocate for an Andean-type arc inheritance. This arc was associated with the northwestward-dipping subduction of the Paleo-Pacific plate below the South China Block during the Middle Jurassic–Middle Cretaceous (Jahn et al., 1976; Schülter et al, 1996; Yan et al., 2010; Wang et al., 2012).

Longitudinal contrast along the northern margin suggests that different modes of extension prevailed along the continental margins of the SCS (Hayes and Nissen, 2005). Today, fully dynamic models using non-linear thermo-mechanical properties are able to reproduce the great diversity of styles of observed structures at continental margins by introducing depth-dependent rheology and complex combination of pure (McKenzie, 1978) and simple shear (Wernicke, 1985) deformation in the crust and the mantle (Huismans and Beaumont, 2003; Huismans et al., 2005; Lavier and Manatschal, 2006; Huismans and Beaumont, 2011). This led to more sophisticated models such as polyphase faulting, sequential faulting, crustal embrittlement and depth-dependent stretching (Reston, 2005; Ranero and Pérez-Gussinyé, 2010; Pérez-Gussinyé et al., 2003; Davis and Kusznir, 2004; Lavier and Manatschal, 2006; Huismans and Beaumont, 2011).

In the light of these recent advances, the SCS is an exceptional natural laboratory. It makes an interesting area to study the cause of lateral discrepancies in structural style found along SCS rifted margins during rifting. Although the northern margin of the SCS was intensively studied, the western segment of the SCS that represents the widest area of extended continental crust remains poorly explored. A recent 1000-km-long wide-angle refraction seismic profile has been acquired in this least studied part of the SCS province, the conjugate margins of the SW SCS (Fig. 1). Here, we perform a joint reflection and refraction seismic travel times inversion to build a 2-D velocity model of the thinned continental crust of the SW conjugate margins. We analyze the links between the distribution of P-wave velocities with depth and the petrological layering of the continental crust. We then suggest possible implications in terms of rheological behavior of the continental crust under the extension processes involved during the opening of the SW SCS.

2. Data acquisition, processing and modeling

2.1. Data acquisition

In June 2011, Chinese and French scientists from the Guangzhou Marine Geological Survey and from the Geological Laboratory of École Normale Supérieure conducted a joint geophysical experiment on board the R/V Tan Bao across the SW sub-basin of the SCS. The experiment consisted in the acquisition of a ∼1000-km-long

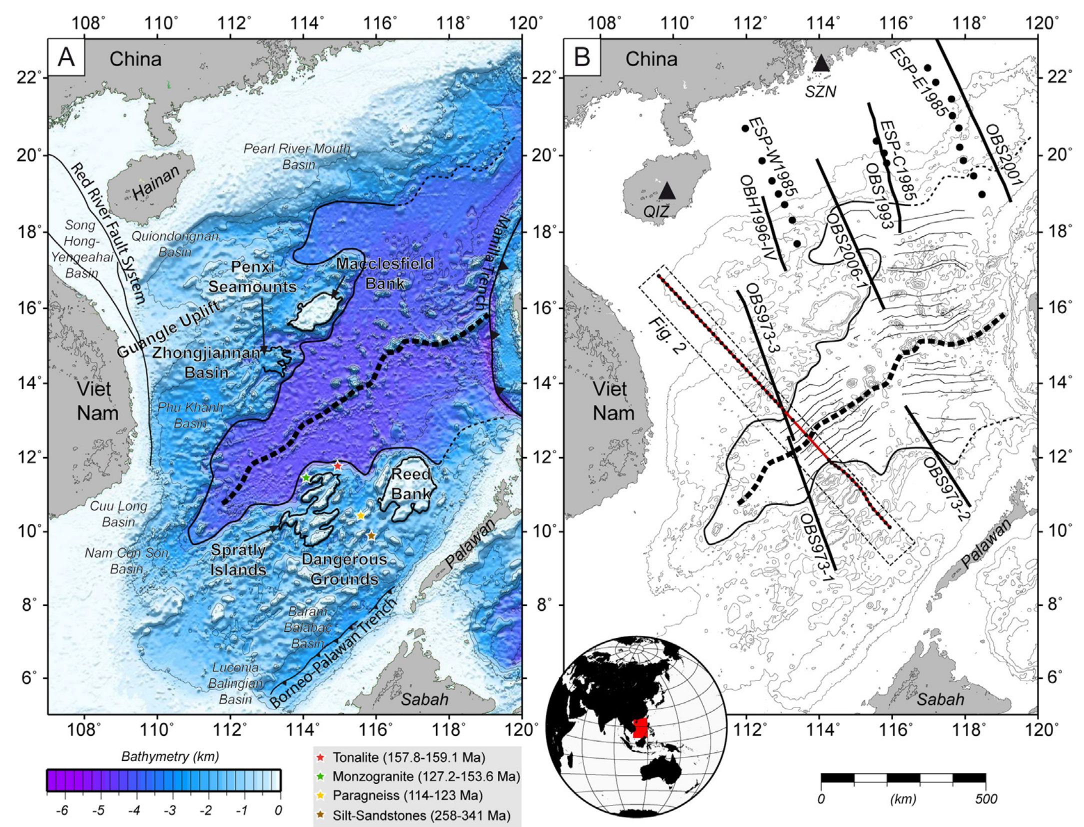

Figure 1. The South China Sea (SCS). A) Bathymetric map (Smith and Sandwell, 1997) showing the main geological provinces and countries adjacent to the SCS. The thin black line indicates the Continent-Ocean Transition (COT). The heavy dashed line corresponds to the SCS spreading center (from Briais et al., 1993). The colored stars represent the locations of dredged samples. Associated lithologies and ages (from Kudrass et al., 1986; Yan et al., 2010) are displayed at the bottom of the figure. B) Bathymetric map contoured every 1000 m showing the main refraction profiles acquired in the SCS, ESP-W1985; ESP-C1985; ESP-E1985 (Nissen et al., 1995); OBS 1993 (Pin et al., 2001); OBH 1996-IV (Qiu et al., 2001); OBS 2001 (Wang et al., 2006); OBS 2006-1 (Wu et al., 2012); OBS 973-1 (Qiu et al., 2011); OBS973-2 (Ruan et al., 2011); OBS 973-3 (Lu et al., 2011). Interpreted magnetic anomalies shown in thin black lines are from Briais et al. (1993). A red line indicates the shot positions of the OBS profile presented in this study, while small black dots display the OBS positions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).