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Continent–Ocean transition of the northern South China Sea and off southwestern Taiwan

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Introduction

The northeasternmost South China Sea (SCS) involves four geological provinces: the SCS oceanic crust, Southeast Asian continental margin, Taiwan orogenic belt and Manila subduction zone (Figure 1). The SCS is one of the largest marginal seas of Southeast Asia. The continental margin of the northern SCS has obliquely collided with the northern tip of the Luzon Arc (Philippine Sea plate), which moves northwestwards with respect to Eurasia, whereas the SCS oceanic plate is subducting eastwards beneath the Philippine Sea plate. From Luzon to Taiwan, the convergent setting along the Manila Trench shows a transition from subduction to collision in Taiwan Island. Obviously, studying the continent–ocean transition zone of Eurasia will help to understand the geological processes involved in the collision between the Eurasian and Philippine Sea plates. It will also help to provide reliable geodynamic reconstructions of the SCS. However, in the past, the crustal nature of the northern SCS, the deformation of the northernmost SCS continental margin and the geodynamic evolution of the northern portion of the Manila subduction zone were scarcely known. This Special Issue contains a collection of 10 papers that present recent data and new insights in the northeastern SCS and off southwestern Taiwan.

Crustal nature of the northeastern South China Sea

Located within the Australia/Eurasia convergent setting, the mode of opening of the SCS was largely discussed in the past. Tapponnier et al. (1982) suggested that the formation of the SCS ocean basin is a consequence of the India–Eurasia collision. The continent–continent collision began at ca. 45 Ma with a dramatic decrease of convergence rate from ca. 100 to 60 mm/year (Lee and Lawver, 1995). In this hypothesis, the southeastward extrusion of the Indochina block with respect to Eurasia, along the left-lateral Red River Fault between 44 and 20 Ma, triggered SCS opening. With an opening of the SCS around a pole of rotation located west of SCS, Briais et al. (1993) suggested that seafloor spreading in the SCS is consistent with a left-lateral motion along the Red River Fault. On the contrary, Taylor and Hayes (1980, 1983) suggested that a former subduction occurred along the western side of Palawan and Borneo. However, the mechanism which caused the opening of the SCS ocean basin is still unknown. Wu et al. (this issue) have applied a surface wave tomography in the SE Asia region to better understand the distribution of crustal and lithospheric thicknesses. This contribution should help to reconstruct the geodynamic evolution of the SCS.

The oceanic crust of the SCS was dated from ca. 32 to 15 Ma based on the identification of magnetic lineations (Taylor and Hayes, 1983; Briais et al., 1993). However, due to a lack of marine magnetic data, the age of the northernmost SCS was not well understood. During the past few years, numerous marine magnetic data were collected in the northernmost SCS (Hsu et al., this issue). Hsu et al. have identified several older magnetic lineations in the northern-

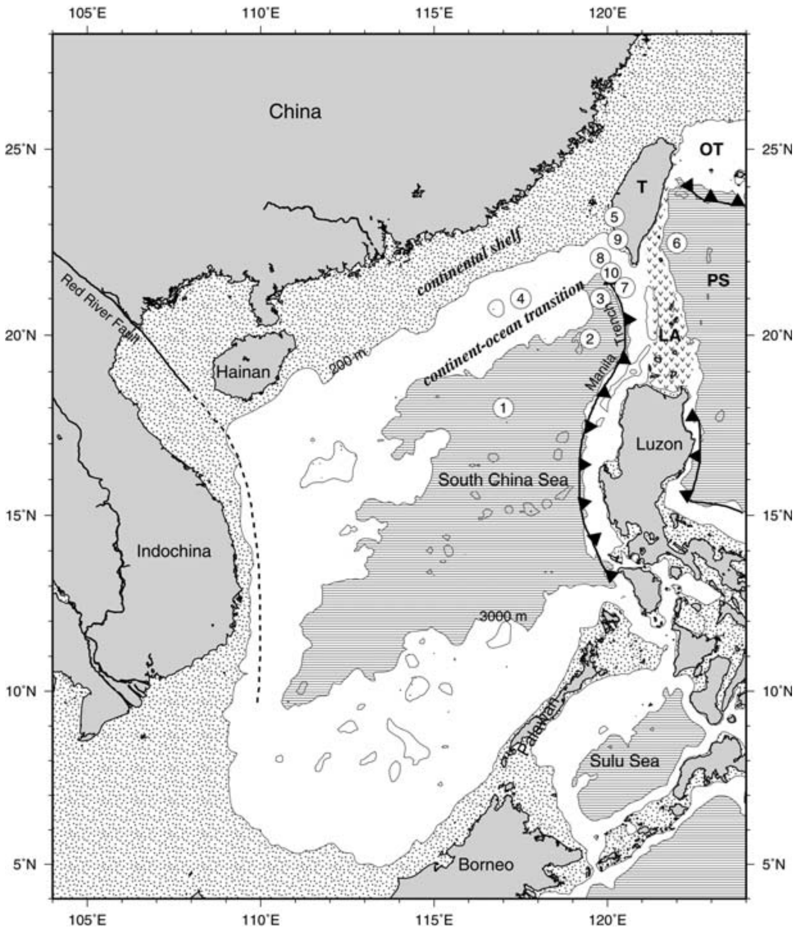

Figure 1. Geological setting of the South China Sea (SCS) and its surrounding area. The numbers in circles indicate the papers presented in the Special Issue of the continental–ocean transition of the northeastern SCS and off southwestern Taiwan. LA, Luzon Arc; OT, Okinawa Trough; PS, Philippine Sea; T, Taiwan.

most SCS and extended northwards the distribution of SCS oceanic crust. The SCS oceanic crust is now dated as old as 37 Ma (Hsu et al., this issue). This finding provides another constraint concerning the reconstruction of the SCS ocean basin. In addition, Yeh and Hsu (this issue) have elaborated the crustal structures of the northernmost SCS using seismic reflection profiles and gravity data.

Crustal structures and deformation of the continent–ocean transition

The continental margin of the northern SCS ocean basin is characterized by a NE–SW trending zone evidenced by high magnetic anomalies (Hsu et al., 1998). Its northeastward continuation seems to terminate in southwest Taiwan. The continental margin of the northern SCS is different from the typical passive continental margins of the Atlantic Ocean (Clift et al., 2001). In addition, part of the extreme northeastern margin, characterized by high magnetic and gravity anomalies, may be linked to former northwestward subduction (Hsu and Sibuet, 1995; Sibuet and Hsu, 1997). However, the deep crustal structures of the continental margin of the northern SCS and off southwest Taiwan are poorly known. The Taiwan orogen might result not only from the collision of the Luzon Arc with the former Ryukyu subduction zone, which extended southwest of Taiwan, but mainly from the subduction of a portion of the Eurasian continental crust, which includes the former Ryukyu arc, forearc and backarc basin system (Sibuet and Hsu, 2004). In this case, Taiwan can be considered as a continental accretionary prism. In this issue, three papers address the problem of deformation of the continental margin of the northeastern SCS.

Tsai et al. (this issue) have examined the crustal structures of the continent–ocean transition zone of the northern SCS. The basement of the continental margin is characterized by seaward rotated normal faults. By contrast, the basement of the oceanic crust displays strong seismic reflections. In between, the transition zone shows a clear change from thick continental crust to thin oceanic crust. As evidenced by a belt of high magnetic anomalies, the continent–ocean boundary could be extended northeastwards beneath the Taiwan orogenic belt. The northern end of this belt is terminated near the epicenter of the disastrous Chi-Chi earthquake in the Taiwan Island. Cheng (this issue) examines the relationship between crustal structures and the seismicity of this junction area by using seismic tomography. He concluded that the high magnetic belt is related to the uplift of the lower crust and is laterally offset by the collision of the Philippine Sea plate. Sibuet et al. (this issue) propose that the continent–ocean transition of the northern SCS extends northeastwards beneath present-day South Taiwan and then beneath the Philippine Sea plate. Because of the heterogeneity of the subducted crust, the overriding crust in the Huatung Basin (westernmost Philippine Sea) has experienced crustal deformations above the NE–SW continuation of the subducting Eurasia continent-ocean transition zone.

Crustal deformation of the northern Manila Trench

The central Taiwan mountain belt has been considerably eroded through time (Dadson et al., 2003). For example, the present-day vertical rate of uplift is similar to the erosion rate of the island, maintaining a constant altitude for the island. The eroded sediments have been deposited in a foreland basin located west and southwest of Taiwan (Chou and Yu, 2002; Lin and Watts, 2002). The foreland basin is a counterpart of the Taiwan mountain belt. The uplift of the accretionary wedge in the east and the deposition of the overlying sediments in the west make it difficult to identify the plate boundary in the northernmost Manila Trench region. Yu (this issue) analyze marine seismic reflection profiles off southwest Taiwan and combine onland geological data to trace the deformation front associated with the Taiwan orogenic belt. Based on swath-bathymetric data and seismic reflection profiles, Liu et al. (this issue) elaborate the details of the deformation pattern in the area offshore southwestern Taiwan, where the Manila subduction complex encroaches the SE Asian continental slope. Based on the structural analysis, they suggest that the termination of the fold-and-thrust structure (i.e. the deformation front) changes its trend from NW to NE and becomes an *en échelon* pattern, rather than a single feature. The Manila Trench connects northwards to the deformation front located west of Taiwan. Huang et al. (this issue) investigate the geological structures in this onshore–offshore transition zone. They find that an uplifted triangular zone associated with the development of back-thrusts is distributed from offshore to onshore southwestern Taiwan. This structural pattern is related to the initial stage of Taiwan mountain building.

Gas hydrates off southwest Taiwan

As a possible natural resource, the worldwide distribution of gas hydrates in the area of permafrost and continental margins has drawn more and more attention. Because of different acoustic impedance between the gas-hydrate reservoir and the underlying sediments, the existence of gas hydrates is generally revealed by the occurrence of the Bottom Simulating Reflector (BSR) on seismic reflection profiles. Off southwest Taiwan, a wide distribution of the gas hydrates in terms of BSR has been reported by Chi et al. (1998). Schnurle et al. (this issue) provide a preliminary analysis of the characteristics of gas hydrates and free gas offshore southwestern Taiwan by using both multi-channel seismic and Ocean Bottom Seismometer (OBS) data. A tomographic ray tracing technique is used to infer the Poisson's ratios at several sites, which helps to understand the bearings and saturation of gas hydrates and free gas in the continental margin off southwest

Taiwan. Multidisciplinary studies of the gas hydrates offshore southwestern Taiwan are certainly necessary in the near future.

Conclusion

The papers presented in this Special Issue show a recent development of tectonic studies in the northern SCS and off southwest Taiwan. The understanding of the crustal structures and deformation has achieved some breakthroughs. For instance, the existence of the late Eocene oceanic crust in the northernmost SCS may be associated with an abrupt decrease of the convergence rate between the India-Australian and Eurasian plates. The distribution and characteristics of the continent–ocean transition zone in the northern SCS and its northeastward continuation are addressed. The crustal deformation studies from offshore to onshore southwest Taiwan help us to understand the embryo-formation of the Taiwan orogen. However, the identification of the deep crustal structures and magmatic intrusions in this region is still not available. The presence of a thick pile of sediments in this area being a major concern, the use of OBS and deep seismic reflection equipments in the near future may be helpful to understand the deep structure of this region.

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