Geophysical investigation of the crustal structures offshore Eastern Taiwan

Abstract

This research project investigates the crustal structures and tectonic features in the area offshore eastern Taiwan for the purposes of providing basic geological and tectonic framework for the Taiwan ocean drilling proposal, as well as to provide observational constraints on the geometry of the plate boundary between the Philippine Sea and Eurasia plates along the Taiwan subduction-collision zone. This report summarizes the results of the 2nd year study. During this year, main efforts were devoted on compiling and analyzing the geophysical data (especially the bathymetry and seismic reflection data) acquired previously, and scientific results on four different topics have been presented.

A 500-m gridded digital bathymetric data set has been compiled that reveals details of the seafloor topography around Taiwan. The relationships between the bathymetric features and their tectonic implications have been discussed.

For the study offshore eastern Taiwan, two papers have been published. One

discusses the kinematic movements of the southern Ryukyu Arc relative to Taiwan, and presents their geodynamic implications; the other paper reveals trench-parallel stretching and folding of the Ryukyu forearc basins due to oblique convergence of the plate motion.

The last paper focused on the deformation of the Philippine Sea plate in the Taiwan collision zone, and proposes two possible mechanisms to accommodate the *subduction on one side and collision on the other side* geometry of the Philippine Sea plate.

Keywords: Digital bathymetric data, Ryukyu subduction - Taiwan collision system, Forearc basin structure, Huatung Basin.

2. Digital Elevation Model Offshore Taiwan and Its Tectonic Implications

A new 500-m gridded digital bathymetric data set has been produced by compiling available shipboard bathymetric data supplemented by global bathymetric data sets in the area between 18°N and 27°N, and from 117°E to 125°E. Combined with topographic data from GTOPO30, a global land data set in 30 arc-second grid spacing, this new digital elevation model (DEM) reveals the regional as well as local morphology of Taiwan and its offshore area. Spatial resolution of 1 km is achieved in the area off eastern and southern Taiwan where swath bathymetric data are available. In other areas where ship tracks are sparse, a spatial resolution of 4 arc-minute is retained. This DEM provides the best topographic information at present on a regional scale, which helps to reveal many of the morphotectonic features related to the active tectonic processes of subduction and arc-continent collision in this region.

Using 2-D shaded topographic maps and 3-D physiographic diagrams generated from the DEM, the major morphologic features in each tectonic province of the region are presented. The Taiwan Strait is characterized by low relief sea floor with two NE-SW trending depressions and a shallow bank in the center of the strait. Submarine canyons mark the continental slope. In the area off southern Taiwan, N-S trending ridges and troughs are the major morphological features, however, several NE-SW trending lineaments have been identified in the Luzon forearc region. Off eastern Taiwan, submarine canyons and topographic features related to sedimentary processes along the eastern flank of the Luzon Arc are revealed in detail. A prominent N-S trending linear ridge, the Gagua Ridge, located along 123°E on the West Philippine Basin floor is entering the Ryukyu Trench and has produced a big re-entrant at the frontal portion of the Yaeyama Ridge. E-W to NW-SE trending linear shear zones are observed over the Yaeyama Ridge. These linear faults are the results of westward migration of the frontal portion of the accretionary wedge due to oblique convergence. A series of four forearc basins have been identified. Different depths of the forearc basins reflect lateral variation of the forearc region from oblique subduction to collision. Along the northern wall of the Southern Okinawa Trough, faulted slope and subsided shelf blocks suggest that this region is under post-collisional extension, and the active extension of the Southern Okinawa Trough is advancing westward toward Taiwan.

(Liu, C.-S., S.Y. Liu, S.E. Lallemand, N. Lundberg, and D. Reed, 1998, Digital Elevation Model Offshore Taiwan and Its Tectonic Implications. TAO, 9(4), 705-738.)

3. Geodynamic implications of present-day kinematics in the southern Ryukyus

Both newly acquired GPS and structural data in the southern Ryukyu subduction zone allowed us to point out some first-order geodynamic implications of the present-day kinematics. Off Hualien, the Hoping Basin lies on a wide zone undergoing north-south transform motion and associated extension between NE Taiwan and the Yonaguni Island. Indeed, this westernmost segment of the

Ryukyu Arc, which includes the Yonaguni Island, is moving southward 1.4 cm/yr faster than NE Taiwan with respect to South China. The basin could thus have developped as a pull-apart basin controlled by en-*chelon N-S-trending right-lateral strike-slip faults and associated N40*E-trending normal faults during the last 2 m.y., based on present divergence rate. A N50*W-striking valley cutting the southern Ryukyu Arc slope between Yonaguni and Hateruma Islands is explained as a graben caused by the still ongoing differential motion between Yonaguni and Hateruma Ryukyu Arc segments, during the last 400,000 years. If we extrapolate back the present-day kinematics, about half of the southernmost Okinawa Trough might have been formed during the last 2 m.y. The convergence rate between the southern Ryukyu Arc and the Philippine Sea Plate has been estimated to about 10.5 cm/yr in a direction of N312* east of 123*30'E, and N325* west of 123*30'E. The convergence obliquity is thus estimated to be about 40* and 53*, with respect to the N275* striking Ryukyu Trench, west and east of 123*30'E respectively. The convergence obliquity increases to 60* west of 122*40'E, because of the northward turn of the trench close to Taiwan. The Ryukyu accretionary wedge (Yaeyama Ridge) can undergo about 3 to 5 cm/yr of transcurrent motion toward Taiwan assuming a mean degree of partitioning of 0.5.
(Lallemand, S. and C.-S. Liu, 1998, Geodynamic implications of present-day kinematics in the southern Ryukyus. J. Geol. Soc. China, 41(4), 551-564.)

4. Trench-paralle stretching and folding of forearc basins and lateral migration of the accretionary wedge in the southern Ryukyus: A case of strain partition caused by oblique convergence

Detailed seafloor mapping in the area east of Taiwan revealed trench-paralle stretching and folding of the Ryukyu forearc and lateral motion of the accretionary wedge under oblique convergence. East of 12240'E, a steep accretionary wedge is elongated in an E-W direction. A major transcurrent right-lateral strike-slip fault accommodates the strain partitioning by increasing the coupling between the two plates. West of 12240'E, the lowtaper accretionary wedge is sheared in a direction subparallel to the convergence vector with respect to the Ryukyu Arc. The bayonet shape of the southern Ryukyu Arc slope partly results from the recent (re)opening of the southern Okinawa Trough at a rate of about 2 to 4 cm/yr. Right-lateral shearing of the sedimentary forearc with respect to the nonlinear Ryukyu backstop generates trench-parallel extension in the forearc sediment sequence at dilational jogs and trench-parallel folding at compressive jogs. The Hoping Basin lies above a diffuse trench/trench/fault (TTF) or TFF unstable triple junction moving toward the south along a N-S transform zone which accommodates the southward drift of the Ryukyu Arc with respect to Eurasia.

(Lallemand, S., C.-S. Liu, S. Dominguez, P. Schnurle, J. Malavieille, and the ACT scientific crew, 1999, Trench-parallel stretching and folding of forearc basins and lateral migration of the accretionary wedge in the southern Ryukyus: a case of strain partition caused by oblique convergence. Tectonics, 18, 231-247.)

5. **Deformation Of The Philippine Sea Plate Near Taiwan**

The western boundary of the Philippine Sea plate is a complex one. The Philippine Sea plate subducts underneath the Eurasian plate along the Ryukyu arc-trench system while overrides the Eurasian plate along the Luzon arc-trench system. High rates of seismicity observed in eastern Taiwan and its offshore region clearly indicate that the western corner of the Philippine Sea plate near Taiwan is undergoing active deformation. Results from recent

multichannel seismic reflection surveys, the TAICRUST deep seismic imaging experiment and analyses of the earthquake focal mechanisms have provided new insights into the crustal structures and deformation along the plate boundary of this subduction and arc-continent collision zone.

Velocity models derived from wide-angle reflection/refraction data recorded by ocean bottom seismometers (OBS) east of Taiwan, and by onshore instruments deployed across the Coastal and Central Ranges on Taiwan, suggest that an abnormally thick oceanic crust (about 12 km in thickness) underlies the Huatung Basin east of Taiwan (Yang and Wang, 1998; Hetland and Wu, 1998). Crustal thickness increases rapidly toward west, starting from the eastern flank of the Luzon Arc, and reaches 50 km under the Coastal Range (Yeh et al, 1998), indicating the thickening of the Philippine Sea plate due to arc-continent collision processes. Seismic reflection profiles in the Huatung Basin show thick (1 to 3 s TWT) sedimentary strata lying on top of oceanic crust. Beneath these strata, the basement surface exhibits large-scale relief. A prominent unconformity is observed in the northern Huatung Basin that acts as a basal detachment for the upper sedimentary layer showing gravity-sliding structures. Folds and east-verging thrusts are observed along the eastern flank of the Luzon Arc. The sliding of the Huatung Basin sedimentary layer and the folds and thrusts of the Luzon Arc strata suggest that the Luzon Arc is being actively uplifted.

Based on the relative direction of plate convergence between the Philippine Sea and Eurasia plates and the orientation of the southernmost portion of the Ryukyu arc-trench system, the subduction process along the westernmost portion of the Philippine Sea plate is highly oblique (Kao et al., 1998; Lallemand et al., 1999). A tear-fault model has been proposed to satisfy the one side subduction and the other side over-ridding geometry of the Philippine Sea plate at the juncture of the Ryukyu subduction and Taiwan collision zone (Lallemand et al., 1997). However, the well developed E-W to ESE-WNW trending Ryukyu forearc accretionary wedge (the Yaeyama Ridge) near Taiwan and the north-dipping subduction slab mapped from earthquake distribution (Kao et al., 1998) may suggest that the obliquity of the subduction is smaller than anticipated. Preliminary calculation of the Philippine Sea plate deformation indicates that subduction of a rigid oceanic lithosphere along this subduction-collision boundary does not fit the observed earthquake and other geophysical data. By allowing intraplate deformation within the Philippine Sea plate, the distribution and orientation of the strain-rate tensors are consistent with the observed focal mechanisms.

Based on the geophysical observations of the crustal structures and the numerical modeling of the plate deformation, we believe that the Philippine Sea plate is losing some of its rigidity and actively deforming to accommodate the convergence process along the complicated plate boundary near Taiwan.

(Liu, C.-S., L.Y. Chiao, P. Schnurle, S. Lallemand and Y. Font, 1999, Deformation of the Philippine Sea Plate near Taiwan. International Conference on Subduction and Active Collision in Southeast Asia, May 1999, Montpellier, France.)