HIGH-RESOLUTION SEISMIC IMAGES OF THE FORMOSA RIDGE OFF SOUTHWESTERN TAIWAN WHERE “HYDROTHERMAL” CHEMOSYNTHETIC COMMUNITY IS PRESENT AT A COLD SEEP SITE

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ABSTRACT
A high-resolution seismic reflection survey was conducted during the NT07-05 cruise over the Formosa Ridge offshore southwestern Taiwan where strong and continuous bottom simulating reflections (BSR) have been observed. Previous seafloor pictures taken from a deep-towed camera indicate that there are some chemosynthetic colonies. During the NT07-05 cruise, not only large and dense chemosynthetic communities were confirmed at the plume site, ROV Hyper-

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Dolphin has also discovered that both deep-sea mussel *Bathymodiolus platifrons*, and galatheid crab *Shinkaia crosnieri* are vigorously populated at this site. By integrating swatch bathymetry, multichannel seismic and high-resolution seismic reflection data, we now have a better understanding on the structural characters of the cold seep site. The cold seep is situated at the summit of the Formosa Ridge southern peak. Submarine canyons that incised continental slope on both sides of the ridge are the controlling factors of the ridge formation. The sedimentary strata are generally flat lying but have been deformed by mass wasting processes. Strong BSR is observed 400 to 500 ms below the seafloor of the ridge, with many bright reflections beneath it. There is a narrow vertical blanking zone raising from BSR to the crest of the ridge. This narrow zone is interpreted to be the fluid conduit of the seep site. BSR may form a good cap to trap gas below, and this “gas reservoir” is shallower than the canyon floors on either side of the ridge. We suggest that this “ridge type” gas reservoir configuration enables the cold sea water to get into the fluid system, and forms a special kind of “hydrothermal” circulation that feeds the unusual chemosynthetic communities observed at the Formosa Ridge cold seep site.

**Keywords:** gas hydrates, Formosa Ridge, seismic reflection profile.

**INTRODUCTION**

The area offshore southwestern Taiwan is the place where the Luzon subduction system encroaches on the passive South China Sea continental margin [1]. Distinctive fold-and-thrust structures of the convergent zone and horst-and-graben structures of the passive margin are separated by a deformation front that extends NNW-ward from the eastern edge of the Manila Trench to the foot of the continental slope (Fig. 1). Seismic reflection profiles reveal a complex system of faults, mud diapirs, submarine channels, and sedimentary basins in the area [1]. Bottom Simulating Reflector (BSR) is commonly observed on seismic records, suggesting that gas hydrate occurs broadly beneath the seafloor here. BSRs are observed in both the passive margin of the South China Sea continental slope and the submarine Taiwan accretionary wedge, from water depths of 700 m to over 3500 m [2], and are concentrated the most underneath anticlinal ridges in the accretionary wedge terrain and underneath the slope ridges of the passive continental margin. Results of the geochemical investigations in the area offshore SW Taiwan show that some locations exhibit unusually high methane concentrations in the dissolved gases of bottom water as well as in the pore fluid of cored samples [3]. Also, Sulfate reduction depth (SMI) could be as shallow as 30 cm-300 cm at those sites [4].

Active fluid activities are evident from various features such as mud volcanoes, active vents and gas saturated shallow sedimentary layers. In the accretionary wedge terrain, most of the mud volcanoes can be linked to either mud diapirs or thrust faults. Over the South China Sea continental slope, dissociation of gas hydrates should be the main sources of active vents and mud volcanoes observed [5].

![Figure 1. Morphotectonic setting of the area offshore SW Taiwan. Yellow circle shows the location of the Formosa Ridge. Blue arrow indicates the subduction direction of the South China Sea crust underneath the Luzon Arc.](image)
Previous survey in the South China Sea continental margin offshore SW Taiwan has found an active gas plume on top of a slope ridge (now named Formosa Ridge) where a strong and continuous BSR is present below the seafloor (Fig. 2). Pictures taken from a deep-towed camera show that there are some chemosynthetic colonies developed around the gas plume site (Saulwood Lin, personal communication). So in March 2007, a joint Japan-Taiwan ROV diving and geophysical survey cruise (NT07-05 cruise of R/V Natsushima, JAMSTEC) was carried out at this cold seep site for seafloor observation and sampling, and for detailed seafloor mapping and high-resolution seismic investigation. This paper presents the preliminary results of the seismic investigation that reveal an active fluid conduit beneath the cold seep site, and the ridge geometry enables the formation of an unusual fluid circulation system which could be responsible for the co-existing of both “hydrothermal” and “cold seep” chemosynthetic communities.

Figure 2. Multichannel seismic reflection profile MCS719-18 shows a continuous BSR lying 300-450 m below seafloor. NP: Northern Peak. SP: Southern Peak (location of the cold seep site). See Figure 3 for profile location.

MORPHOLOGY
Morphologically, the South China Sea continental slope consists of a series of ridges formed by down-slope cutting of submarine canyons. Most of the submarine canyons were developed in the upper slope zone near the shelf-slope break. Swath bathymetry survey conducted by R/V Natsushima reveals that the NNW-SSE trending Formosa Ridge is bounded by submarine canyons on either side, and the ridge does not extend to the upper continental slope since a canyon cuts across it’s northern end. The Formosa Ridge has two peaks. The northern peak has water depth less than 1100 m while the southern peak (where the gas plume was observed) has a water depth of about 1125 m (Fig. 3).

Figure 3. Swath bathymetry map of the Formosa Ridge and the seismic profile locations. Contour interval is 50 m. Red lines indicate the locations of the single channel high-resolution seismic profiles, blue lines shows the multichannel seismic profile locations. Thick dark lines with line numbers indicate the locations of the seismic profiles shown in this paper. NP: northern peak; SP: southern peak.

SEISMIC PROFILES
Seismic profile MCS719-18 (Fig. 2) provides an along-ridge-axis image of the Formosa Ridge. BSRs are more prominent beneath the gentle southward-dipping slope of the ridge, and are disrupted beneath the northern peak (NP). The sedimentary strata are generally flat lying under the southern part of the Formosa Ridge, but show slightly doming feature under the northern part of the ridge. Local deformation of the sedimentary strata, probably due to submarine mass wasting processes, can be observed in many parts of the profile. A dome-shaped structure, probably a raised basement, is observed under the northern peak of the Formosa Ridge. High-resolution seismic profile F11-12 (Figure 4) reveals detailed sedimentary structures under the southern Formosa Ridge. Flat-lying sedimentary strata have been offset by normal faults down slope, and a very clear BSR is seen about 500 ms below seafloor, and it is disrupted below the peak area where complex reflection pattern and strong
reflections suggest fluid accumulations. A vertical blank zone appears right underneath the southern peak of the Formosa Ridge, gives a strong suggestion on the existing of a fluid vent that connects gas-charged sediment beneath.

DISCUSSION AND CONCLUSION

ROV Hyper-Dolphin has discovered that both deep-sea mussel Bathymodiolus platifrons, and galatheid crab Shinkaia crosnieri are vigorously populated at this site [6]. By integrating swath bathymetry, multichannel seismic and high-resolution seismic reflection data, we now have a better understanding on the structural characters of the cold seep site. The cold seep is situated at the summit of the southern Formosa Ridge. The Ridge was formed on the northern South China Sea continental slope by submarine erosion processes. Submarine canyons that incised continental slope on both sides of the ridge are the controlling factor of the ridge formation. The sedimentary strata are generally flat lying but have been deformed by mass wasting processes. Strong BSR is observed 400 to 500 ms below the seafloor of the ridge with many bright reflections beneath it. There is a narrow vertical blanking zone connecting the BSR to the crest of the ridge. This narrow zone is interpreted to be the fluid conduit of the seep site. BSR may form a good cap to trap gas below, and this “gas reservoir” is shallower than the canyon floors on either side of the ridge. We suggest that this “ridge type” gas reservoir configuration enables the cold sea water to get into the fluid system, and forms a special kind of “hydrothermal” circulation that feeds the unusual chemosynthetic communities observed at the Formosa Ridge cold seep site.

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