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研究ノート

Report of Multi-Channel Seismic Reflection and Submersible *Shinkai 6500* Studies at Kyushu-Palau Ridge †

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Abstract

The Kyushu-Palau Ridge has the inflection point at about 24°N. In the northern part of the ridge, north of 24°N, it tends NNW-SSE, whereas it runs along a NNE-SSW direction further south, the southern part. Two multi-channel seismic reflection profiles across the Kyushu-Palau Ridge at both part were examined. Both profiles document the rift architecture of the Paleo Kyushu-Palau Ridge. The submersible *Shinkai 6500* dive was performed to observe the acoustic basement exposed in the Sui-shin Depression. Submersible observation revealed that the acoustic basement is composed of consolidated hemipelagic sedimentary rocks.

Key words : Kyushu-Palau Ridge, Multi-channel seismic reflection profile, *Shinkai 6500*, Rifting, Consolidated hemipelagic sedimentary rocks

Introduction

The northern part of the Philippine Sea Plate is characterized by the Izu-Ogasawara (Bonin) Arc, the Kyushu-Palau Ridge (KPR), and the Shikoku Basin. These are volcanic arcs and the back-arc basins that were formed as the results of the westward subduction of the Pacific Plate beneath the Philippine Sea Plate (Uyeda and Ben-Avraham, 1972 ; Ben-Avraham and Uyeda, 1983 ; Seno and Maruyama, 1984). Thus, this region has evolved through several arc formation, rifting, and back-arc spreading episodes. The opening of the Shikoku Basin started at about 25 Ma and ended at 17 Ma (Kobayashi and Isezaki, 1976 ; Kobayashi and Nakada, 1978).

Rifting of the Paleo KPR, that is, extension of the Paleo Izu-Ogasawara Arc lithosphere has not been described well, although active rifting of intra-oceanic island arcs has been studied well especially in the Sumisu Rift, the Izu-Ogasawara Arc (eg. Taylor et al., 1991). This paper briefly presents geologic interpretation of the migrated record of multi-channel seismic reflection profiles (MCS) across the KPR, combined with *in situ* observation by the submersible *Shinkai 6500*.

Geologic Background

The Kyushu-Palau Ridge is an about 2600km long submarine ridge that connects Kyushu at 32°N and the Palau Islands at 8°N. It roughly divides the Philippine Sea Plate into the eastern and the western part. The KPR has the inflection point at about 24°N ; to the north of 24°N, we call it the northern part in this paper, it tends NNW-SSE, whereas it runs along a

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NNE-SSW direction further south, the southern part (Fig. 1). The boundary of the KPR with the Shikoku Basin is marked by sharp and steep east-dipping scarps. In some places these scarps are stepwise with sedimented depressions between them. The escarpment is supposed to have been formed during the initial rifting of the Paleo Izu-Ogasawara Arc and subsequent fast subsidence of the Shikoku Basin (Kasuga et al., 1987 ; Kasuga et al., 1992 ; Okino et al., 1994 ; Kobayashi et al., 1995). The western margin of the KPR, on the other hand, gradually increases its water depth to reach relatively flat basins covered by thick sediments such as the Kikai, the Amami Sankaku "Triangle", the North Daito, and the South Daito Basins.

Dredge hauls, seismic profiles, and piston cores were collected through various cruises and the results revealed that the KPR is composed of volcanic and plutonic complex with shallow marine calcareous sediment caps, with turbidite sequences (eg. Shiki et al., 1985). The evolution of KPR is documented by the DSDP and IPOD Sites 296 and 448 (Ingle J. C., Jr., Karig D. E., et al., 1975 ; Kroenke L., Scott R., et al., 1981).

Bathymetry and seismic reflection studies

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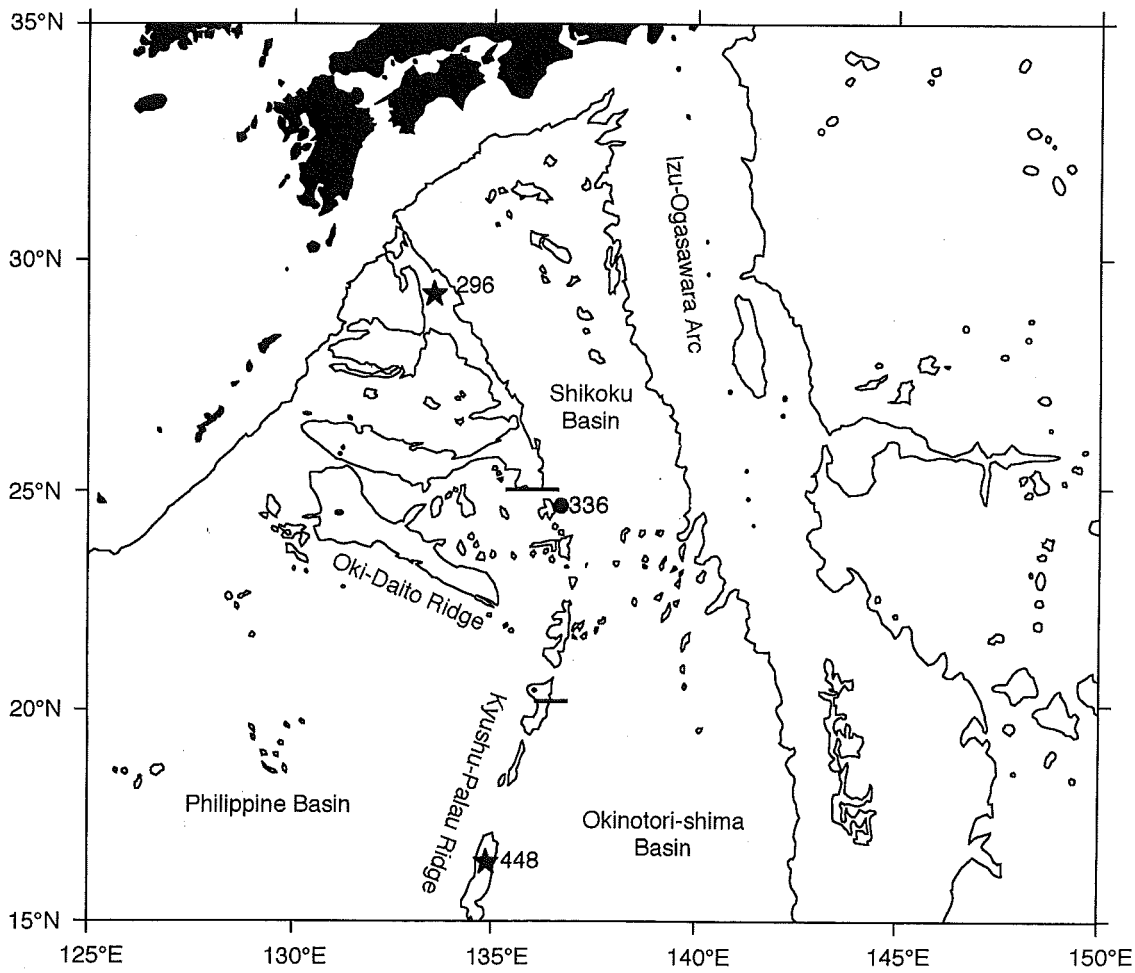

Fig. 1 Major geologic features in the Philippine Sea represented by the 4000 m contour. Note the inflection of the Kyushu-Palau Ridge at about 24°N. Bold lines across the Kyushu-Palau Ridge refer to the MCS lines at 25°N and 20°24'N. Asterisks denote the DSDP drilled sites. Closed circle shows the *Shinkai 6500* Dive #336 site.

(JHD) has conducted geophysical surveys in the southern waters of Japan by S/V *Takuyo* and S/V *Meiyo* of JHD under *Continental Shelf Surveys Project* since 1983. The areas surveyed by this project includes southeastern part of the East China Sea, northern part of the Philippine Sea and westernmost part of of the North Pacific Basin. Since then, JHD has obtained narrow multibeam echo sounder *SeaBeam* swath bathymetric data, single- and multi-channel seismic reflection profiles, magnetic and gravity anomalies, and dredge hauls in the surveyed area. The ship navigation was performed by a hybrid system of Loran C, NNSS, and GPS.

As mentioned above, the KPR has the inflection point at about 24°N. It shows the marked difference between the northern part and the southern part of the ridge. The northern part of the KPR is composed of an elongated ridge morphology overlain by seamounts. On each seamounts, more than two crests are aligned in NE-SW direction which are oblique to the ridge axis. The number of the seamounts are relatively dense in the northern part, on the other hand, its are relatively scarce and isolated in the southern part. Another characteristics is that the stepwise topography is common in the northern part, whereas it is obscured in the southern part. These features might indicate the difference of the early volcanic activities and the subsequent mode of rifting of the Paleo KPR. To shed light on these characteristics, we examined two multi-channel seismic reflection profiles in the northern part of the ridge at 25°N, and in the southern part at 20°24' N.

MCS at 25°N

The morphology of the KPR at 25°N is characterized by the stepwise topography as indicated in Figs. 2 and 3. One of the prominent characteristics of the topography at 25°N is that there exists an associated depression of great water depth exceeding 6000 m. We tentatively named this depression *Sui-shin Depression* in this article. A terrace structure develops at between the foot of the Higashi-suisei Seamount and the Sui-shin Depression.

We have a 12-channel seismic reflection profile of E-W section at 25°N. The MCS profiler data were processed by on-shore studies through stacking, filtering, and deconvolution to obtain better refined cross sections. The vertical scale of the profiles is expressed in two-way acoustic travel time. The MCS profile at 25°N shows representative geomorphology and acoustic stratigraphy of the KPR to the Shikoku Basin transitional area. In other words, the MCS profile at 25°N well documents the rift architecture of the Paleo KPR. Based on the profile, the border faults delineate two structural provinces across strike from west to east ; that is, the proto-remnant arc and the rift basin (Fig. 3).

Proto-remnant arc : The eastern flank of the proto-remnant arc which is comprising now the KPR (Higashi-Suisei seamount at 25°N) rises about 1000 to 1500 m above the adjoining sedimented "rift basin" floor. Four to five east dipping tilted fault blocks are identified in the proto-remnant arc.

Rift basin : The proto-remnant arc is bounded to the east by the rift basin. Adjacent to the proto-remnant arc, a tilted but less subsided and thinly sedimented rift basin lies between the border fault and the Sui-shin Depression. The locus of maximum sediment thickness and basin subsidence occurs at the Sui-shin Depression. The Sui-shin Depression might have been

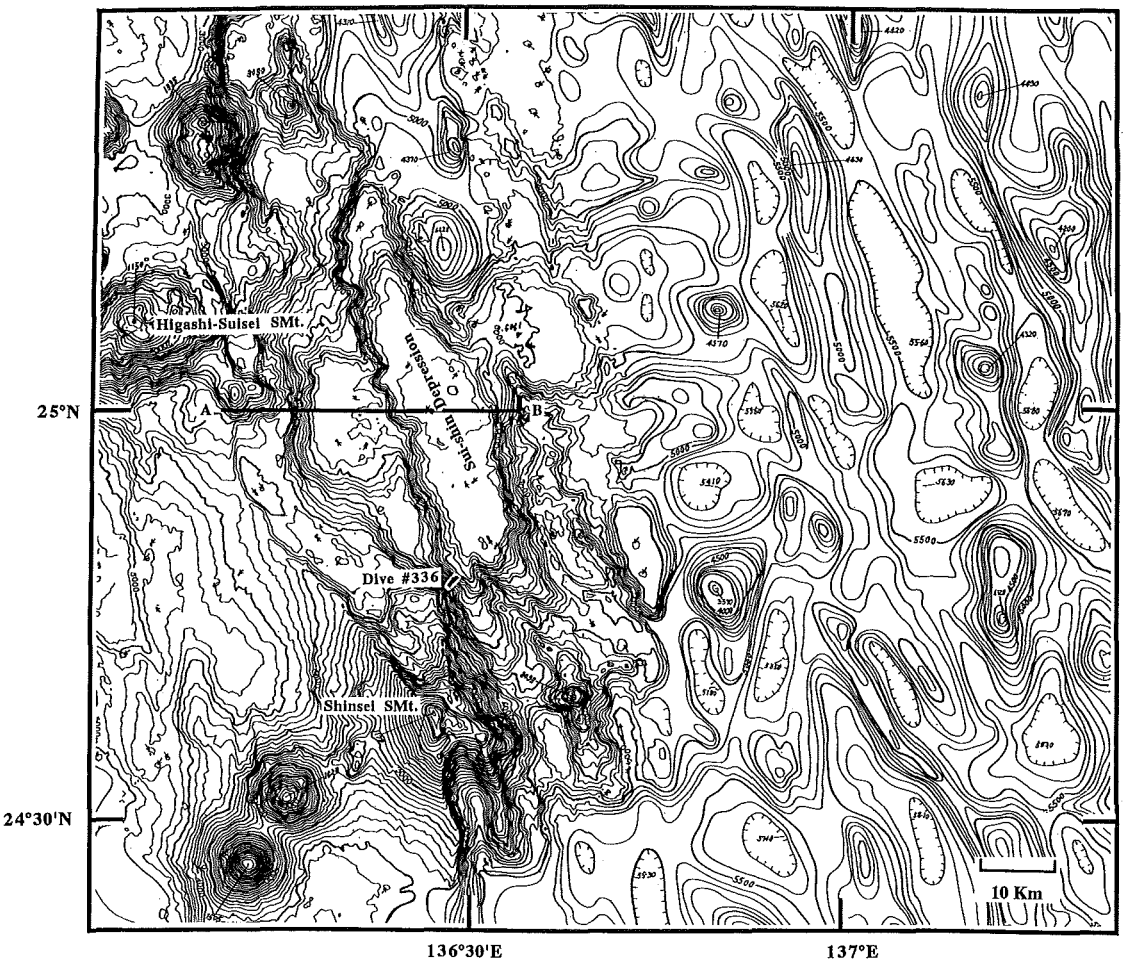

Fig. 2 Bathymetric map of the Kyushu-Palau Ridge area near 25°N. Contour interval is 100 m. The bold line indicates the 12-channel seismic profile across the Sui-shin Depression (See Fig. 3). The track of the *Shinkai 6500* Dive #336 are also shown.

a synrift basin. In the Sui-shin Depression, four acoustic units (Units A, B, C, and D) are observed in descending order. Unit D is an acoustic basement. In Units A, B, and C, stratified reflectors are observed. Unit A is relatively transparent, but has weak parallel reflections. Closely spaced, relatively high-amplitude reflectors are observed within the Unit B. Total thickness of Units A and B is about 1.2 sec in the Sui-shin Depression. Unit C can be identified only in the Sui-shin Depression, and the seismic character of this unit is discontinuous.

MCS at 20°24'N

We have a 24-channel seismic reflection profile of E-W section at 20°24'N near the Okinotori-shima Island. Although the MCS profile at 20°24'N is obscure, we can identify tilted blocks dipping eastward at between CDP #4720 and #4960 (Figs. 4 and 5).

Submersible observation

The submersible *Shinkai 6500* dive on KPR was conducted during the *Y96-11 "Trans-Philipp '96"* cruise of R/V *Yokosuka* in 1996 for the first time. The ship navigation was based on GPS. The *Shinkai 6500* Dive #336 was carried out along the southwestern steep slope of the Sui-shin Depression between 5770 m and 4770 m depth in the KPR at 24°27'N, which is comprising the foot of the Shinsei Seamount.

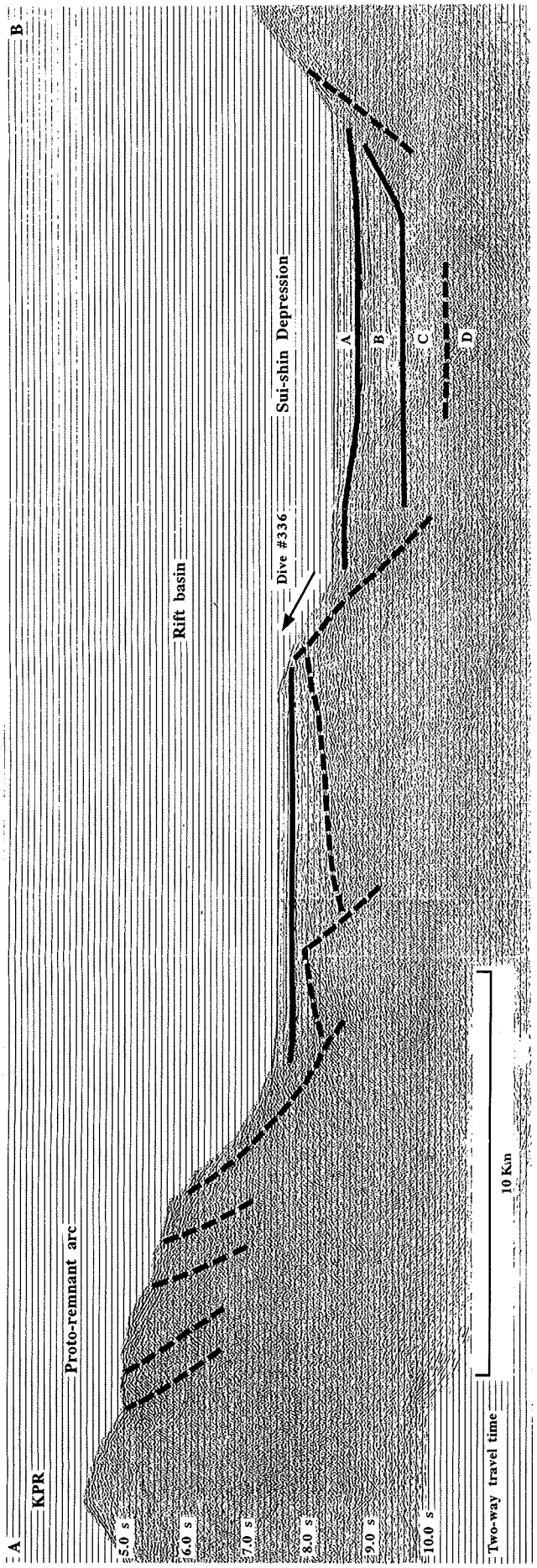

Fig. 3 12-channel seismic profile across the Sui-shin Depression at 25°N.

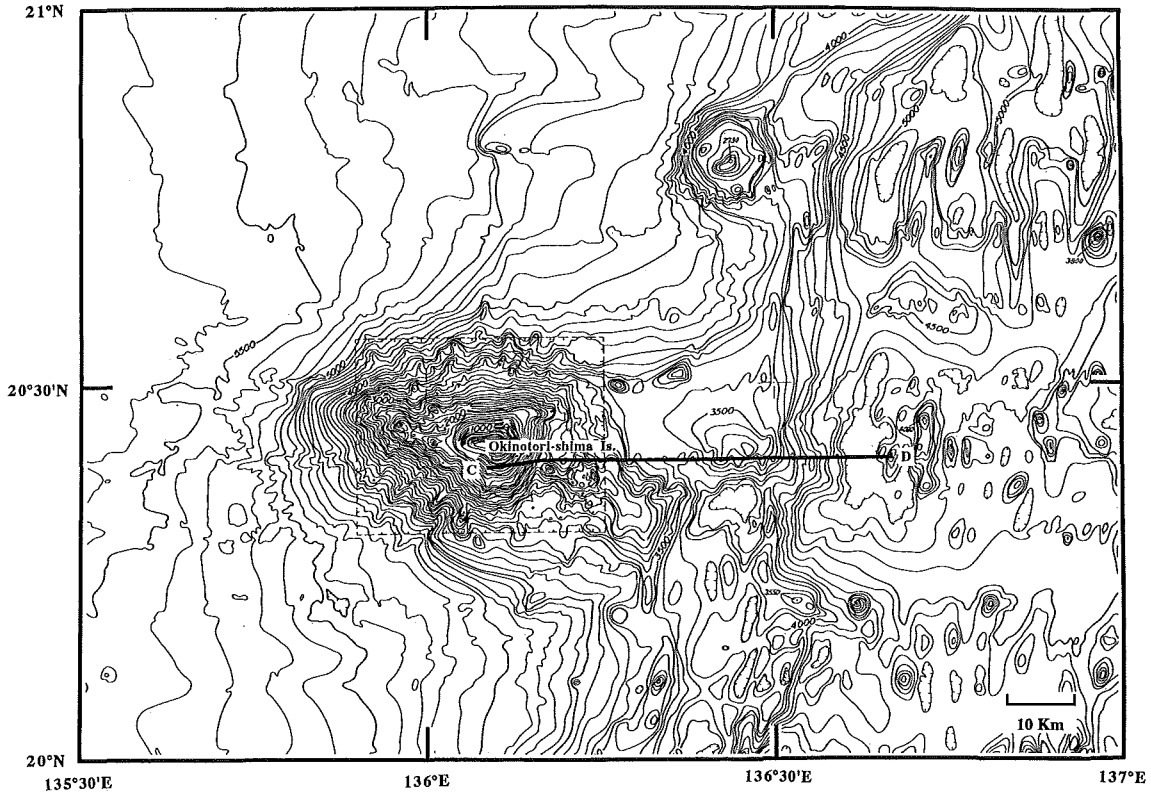

Fig. 4 Bathymetric map of the Kyushu-Palau Ridge area near 20°24'N. Contour interval is 100 m. The bold line indicates the 12-channel seismic profile across the Sui-shin Depression (See Fig. 3).

The dive point was so selected to observe the acoustic basement Unit D of the MCS at 25°N. The purpose of the dive is to characterize the early stage volcanic rocks from KPR and associated back-arc basin basalts induced by opening of the Shikoku Basin. The Dive #336 was navigated using ship to submersible slant ranging and narrow multi-beam *HS-10* bathymetry. The relevant data sets collected from the *Shinkai 6500* include continuous video coverage from forward- and downward-looking cameras, nearly continuous 35mm still photographic coverage.

As the result of the Dive #336, to the contrary to the primary purpose, the southwestern steep slope of the Sui-shin Depression at 24°27'N traced in this dive exposes the clear bedding structures of sedimentary rocks up to 1000 m in vertical distance, although the slope is almost covered by Fe-Mn oxide, and is partly covered by hemipelagic soft sediment.

Nineteen sedimentary samples from 5 stops were collected during the Dive #336. All of collected 19 rock samples are consolidated hemipelagic sedimentary rocks ranging from fine sandstone to siltstone with lamination in various color (gray, brown and green). Relatively angular shapes of the rocks suggest that these samples were come from close outcrops. They are all coated by Fe-Mn oxide of 1 to 5 mm thick. Two types of siltstones are recognized. The fine portion of the most of the samples shows reddish to greenish color. But several samples show olive color. Frequently, thin volcaniclastic sand layers (2 to 3mm) are interbeded with the sedimentary structures, such as cross lamination and flame structures. Usually, these thin sand layers show greenish color and are very fine to fine in grain size. Some thick sand layers (2 to 3cm) show dark

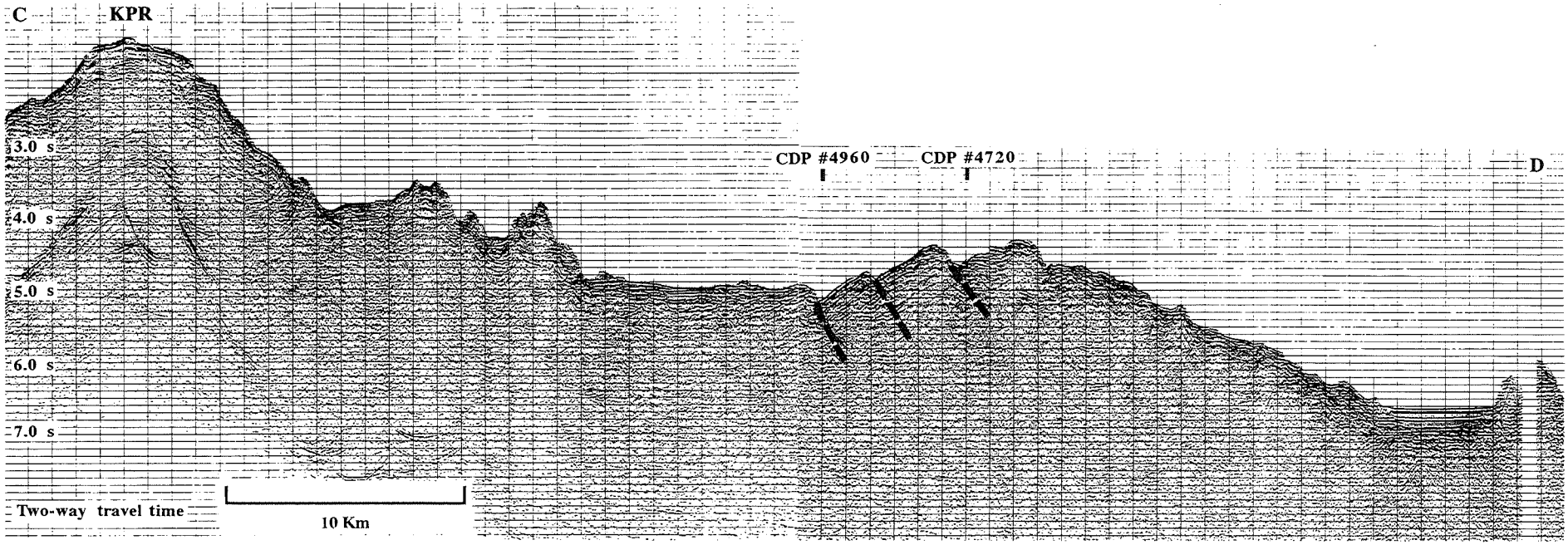

Fig. 5 24-channel seismic profile across the Kyushu-Palau Ridge at 20°24'N.

gray and include coarser grain of color minerals. Such coarse sand layer change suddenly their thickness within a same layer. Normal and reverse micro faults are recognized in some samples. Distinctive foraminifera layers are observed in two samples in a few cm thickness, which they might be derived by turbidity current. Those rubbles are so intensely affected by lithification such as compaction and diagenesis that the source sediments might have been buried in the very deep ground.

Summary

The rift architecture of the Paleo KPR are documented in the multi-channel seismic profiles in both northern and southern part of the present KPR. The acoustic basement exposed in the Sui-shin Depression is consolidated hemipelagic sedimentary rocks. These rocks could be the basement rocks of the volcanic edifice of the KPR. If so, these rocks had been existing before the igneous activity of the KPR, and relatively huge land mass such as the Oki-Daito Ridge might be expected as a provenance of them. It is very important to determine the ages of these rocks by using radioraria dating. These ages are the key to understand the evolutionary history of the Philippine Sea Plate.

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References

Ben-Avraham Z. and Uyeda S., 1983, Entrapment origin of marginal seas, *In Hilde T. W. C. and Uyeda S. eds., Geodynamics of the Western Pacific-Indonesian Region., Geodynamics Ser. AGU,* **11**, 91-104.

Ingle J. C. Jr., Karig. D. E., et al., 1975, Site 296, *Init. Repts. DSDP,* **31**, 191-274.

Kasuga S., Iwabuchi Y., and Kato S., 1987, Results of ocean bottom survey in the area connecting Shikoku Basin with West Mariana Basin (in Japanese with English Abstract), *Rept. of Hydrographic Res.* **22**, 113-134.

Kasuga S., Kato Y., Kimura S., and Okino K., 1992, Characteristics of arc-trench systems and back-arc basins in the Southern Waters of Japan : Outline of the geophysical survey by the Hydrographic Department of Japan (in Japanese with English Abstract), *Rept. of Hydrographic Res.* **28**, 9-45.

Kobayashi K. and Isezaki N., 1976, Magnetic anomalies in the Sea of Japan and the Shikoku Basin : possible tectonic implications, *In Sutton G.H., Manghnani M. H., and Moberly R. eds., The geophysics of the Pacific Ocean Basin and its margin, Geophys. Monogr., AGU,* **19**, 235-251.

Kobayashi K. and Nakada M., 1978, Magnetic anomalies and tectonic evolution of the Shikoku inter-arc basin, *J. Phys. Earth* **26**, S391-S402.

Kobayashi K., Kasuga S., and Okino K., 1995, Shikoku Basin and its margins, *In Taylor B. ed., Backarc Basins : Tectonics and Magmatism, Plenum Press, New York,* 381-405

Kroenke L., Scott R., et al., 1981, Site 448 : Palau-Kyushu Ridge, *Init. Repts. DSDP,* **59**, 111-319

Okino K., Shimakawa Y., and Nagaoka S., 1994, Evolution of the Shikoku Basin, *J. Geomag. Geoelectr.,* **46**, 463-479

Seno T. and Maruyama S., 1984, Paleogeographic reconstruction and origin of the Philippine Sea, *Tectonophysics,* **102**, 53-84

Shiki T., Mizuno A. and Kobayashi K., 1985, Data listing of the bottom materials dredged and cored from the Northern Philippine Sea, *In Shiki T. ed., Geology of the Northern Philippine Sea : Geological results of the GDP cruises of Japan, Tokai University Press, Tokyo,* 23-41

Taylor B., Klaus A., Brown G. R., and Moore G. F., 1991, Structural Development of Sumisu Rift, Izu-Bonin Arc, *J. Geophys. Res.,* **96**, 16113-16129

Uyeda S. and Ben-Avrahamz., 1972, Origin and development of the Philippine Sea, *Nature,* **240**, 176-178

九州・パラオ海嶺におけるマルチチャネル反射法音波探査および潜水調査船「しんかい6500」による調査報告（要旨）

小原泰彦，石井輝秋，藤岡換太郎，加藤幸弘
原口　悟，春日　茂，佐々木智之，金松敏也
坂本　泉

九州・パラオ海嶺は北緯24度付近を境にしてその走向が変化している．すなわち，北緯24度以北ではNNW-SSE方向に，以南ではNNE-SSW方向の走向となり，北緯24度付近を境にしてそれぞれ北部地域，南部地域と名付ける．北部地域，南部地域をそれぞれ横切るマルチチャンネル反射法音波探査の断面を解析し，それぞれの断面から古九州・パラオ海嶺のリフティングの記録を読み取った．「彗新凹地」に露出している音響基盤を観察する目的で潜水調査船「しんかい6500」による潜航調査が行われ，その結果，音響基盤が固結した半遠洋性堆積物からなることが明らかとなった．