

東海沖竜洋海底谷における冷湧水の分布： 1995 年度 KAIKO-TOKAI 計画 「しんかい 2000」潜航調査

芦 寿一郎*1 瀬川 爾朗*2 ザビエル・ルピション*3
シークフリード・ラルマン*3 小林 和男*4 服部 陸男*5
ステファン・マゾッティ*2 青池 寛*2

1995 年度日仏 KAIKO-Tokai 計画では、「しんかい 2000」と「ドルフィン 3K」を用い東海沖の竜洋海底谷において、冷湧水の分布と地質構造の解明を目的とし調査を行なった。竜洋海底谷は、その中流部が直線的であること、地震探査断面で深部の堆積層に変形がみられることにより造構性の海底谷と考えられている。今回の潜航は海底谷の中流部の谷底および東西の谷壁において観察を行なったが、断層等の地層の変形は認められなかった。冷湧水については、西側谷壁の直下においてシロウリガイコロニーとバクテリアマットを多数確認した。これらは南西方向に連続するが、崖堆積物の張り出しとともにその密度は減少する。地震探査断面では北西方向に傾斜する地層の反射面が認められるため、生物群集の配列は断層に沿った流体湧出とともに透水性の良い地層に沿った流体湧出の可能性も考えられる。さらに、潜航地点ではガスハイドレートによる BSR がよく発達し、また隆起域であることも考え合わせるとハイドレート起源の流体が湧水に関与しているかもしれない。

キーワード：生物群集、竜洋海底谷、冷湧水、付加プリズム、ガスハイドレート、BSR

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- * 1 東京大学大学院理学系研究科
 - * 2 東京大学海洋研究所
 - * 3 フランス高級大学院地質学研究室
 - * 4 海洋科学技術センター
 - * 5 海洋科学技術センター深海研究部
 - * 6 Geological Institute, University of Tokyo
 - * 7 Ocean Research Institute, University of Tokyo
 - * 8 Laboratoire de Géologie de L'ENS
 - * 9 Japan Marine Science and Technology Center
 - * 10 Deep Sea Research Department, Japan Marine Science and Technology Center

Distribution of Cold Seepage at the Ryuyo Canyon off Tokai : the 1995 KAIKO-Tokai "Shinkai 2000" Dives

Juichiro ASHI*⁶ Jiro SEGAWA*⁷ Xavier LE PICHON*⁸
Siegfried LALLEMANT*⁸ Kazuo KOBAYASHI*⁹
Mutsuo HATTORI*¹⁰ Stéphane MAZZOTTI*⁷ Kan AOIKE*⁷

During the 1995 KAIKO-Tokai project, distributions of cold seepage and geological structures in the Ryuyo Canyon off Tokai were investigated using the submersible "Shinkai 2000" and the ROV "Dolphin 3 K". The Ryuyo Canyon is considered to be of tectonic origin because of its straightness of the middle valley and deformations of seismic reflectors beneath it. During the dives no deformation such as a fault is observed at the floor and the walls of the canyon. *Calyptogena* colonies and bacterial mats are distributed at the foot of the western side wall. Seep sites extend and decrease toward southwest as talus deposits jut into the canyon floor. NW dipping seismic reflectors between the dive sites and the Tenryu Canyon indicate that upward movement of fluids may occur along high permeable sedimentary layers as well as fault planes. Judging from well developed gas hydrate BSRs and uplifts around the dive sites, cold seepage is probably affected by fluids and gases from dissociation of hydrate.

Key words : Biological community, Ryuyo Canyon, Cold seepage, Accretionary prism, Gas hydrate, BSR

1. Introduction

A large amount of fluid is thought to be expelled from landward wedges of subduction zones on the fluid budget estimations (Kastner et al., 1991 ; Le Pichon et al., 1991). Chemosynthesis-based biological communities provide convenient markers of cold seepage sites. After finding, geochemical analysis of water samples are more effective for studies of fluid sources. In the Oregon margin, observations by the submersible Alvin discovered communities of clams and tube-worms at the toe of the accretionary prism and revealed that distributions of these communities were restricted to structurally controlled vent sites (Kulm et al., 1986). Seismic reflection profiles suggest that faults, unconformities and probable high permeable layers work on conduits (Moore et al., 1990).

In the eastern Nankai Trough the accretionary prism caused by offscraping of incoming sediments

on the Philippine Sea Plate has been investigated by the French-Japanese KAIKO projects since 1984. Vents along the frontal thrust were found at the Tenryu deep-sea fan during 1985 KAIKO cruise (Le Pichon et al., 1987). The survey of the 1989 KAIKO-Nankai cruise was focused on the thin-tapered prism toe and the well-continuous ridge named "the Yukie Ridge" 20km landward of the trough axis. Cold seepage at both sites was interpreted to be caused by updip movements of fluids along the shallow detachment and the backthrust, respectively. The studies of fluid chemistry and stable isotope of carbonates indicate that both sites are dominated by biogenic hydrocarbons (Gamo et al., 1992 ; Sakai et al., 1992). Since 1993 the KAIKO-Tokai project has investigated the landward part of the prism to understand differences of fluid sources and budgets between fault-separated segments as well as the tectonic aspect of the prism segmentation. In this

report we present visual observations of the Ryuyo Canyon during Dives 821 and 822 of the "Shinkai 2000" and Dive 265 of the "Dolphin 3 K".

2. Geological background

The survey area of the KAIKO-Tokai project is located in the eastern most part of the Nankai accretionary prism. The Nankai Trough south of this area changes the trend from NE-SW to NNE-SSW and continues northward to the Suruga Trough (Fig. 1). A large number of active faults estimated by seismic reflection profiles are subparallel to both troughs (The Research Group for the Active Faults of Japan, 1991). The Philippine Sea Plate is converging to northwest or west-northwest based on earthquake focal mechanisms and geodetic data inversion (Ishibashi, 1981; Yoshioka et al., 1993). Part of faults, therefore, are thought to have strike slip components (Le Pichon et al., 1994; Thoué et al., 1995).

Two major faults, now named "Tokai Thrust" and "Kodaiba Fault", are developed 34km and 46km landward of the trough axis (Fig. 1). During Dives 116, 117 of the "Shinkai 6500" and Dive 706 of the "Shinkai 2000" (Le Pichon et al., 1994; Fournier and Cadet, 1994), existences of fresh talus and tube worms suggest active crustal movements and probable fluid venting along both faults (Fig. 1). Conspicuous depression off Omaezaki was investigated during 1995 cruise, vestimentiferan tube worms and dead clams including *Calyptogenia* were observed at the fault scarps (Ashi et al., 1995; Thoué et al., 1995). During Dive 824 a huge number of dead clams were also found at the eastern wall of the Tenryu Canyon where the large scarp of the Kodaiba Fault have been eroded by the canyon (Mazzotti et al., this volume).

The Ryuyo Canyon, where Dives 821 and 822 were conducted, is located on the northern slope of the Kodai-Ba Knoll (Figs. 1 and 2). This canyon is subparallel to the Tenryu Canyon at the middle valley and changes the direction rectangularly at both the ends. The Ryuyo Canyon is regarded as an antecedent valley on the ground that the slope of the north-west-trending upper valley dips toward the upper stream (Iwabuchi et al., 1991). Straightness of the

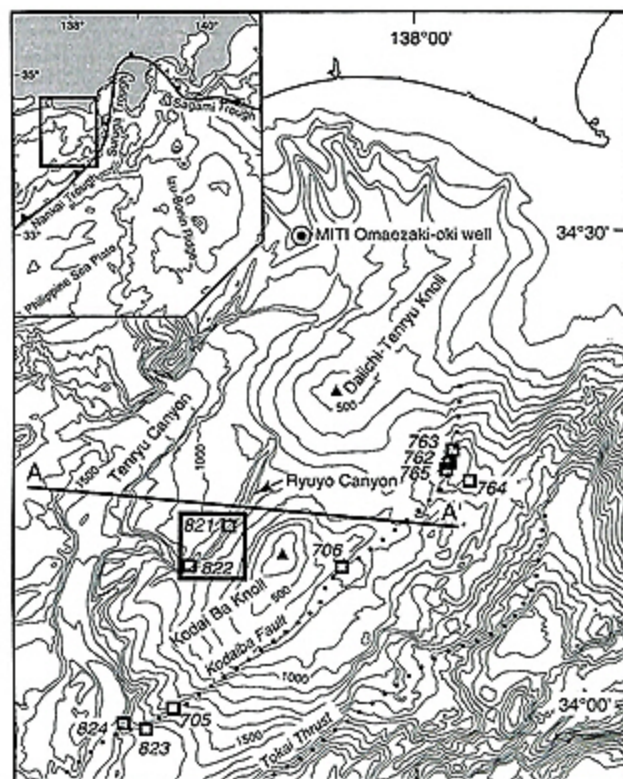


Fig. 1 Bathymetric map with dive sites during the KAIKO-Tokai Project. Rectangle is the area of Fig. 2. Solid line denotes the location of the seismic line shown in Fig. 3.

middle valley and deformations of seismic reflectors suggest that development of the canyon is controlled by NNE-trending faults, although no deformation is observed at the shallow part of the seismic profile (Iwabuchi et al., 1991).

3. Submersible observations

Dive 821 starts from the bottom of the Ryuyo Canyon (1,092m), runs westward to study the canyon wall, and turns eastward to observe the other side wall (Fig. 2). The bottom of the canyon is covered by sediments composed of light-grey mud with very fine sand. No deformation structure on the seafloor was observed except a N-S trending groove probably due to an artificial trail such as a dredge haul.

Near the foot of the western side wall, clam colonies and discolored surface sediments are widely distributed on the canyon floor (Photos 1, 2 and 3). Biological communities vary between 1m and 10m in

diameter. The cause of discoloration is thought to be bacteria propagated on surface sediments. These bacterial mats generally show white patches on highly bioturbated muddy sediments. A typical mat shows circular shape and about one meter in diameter. A large mat up to 10m in diameter seems to consist of aggregates of small size mats (Photo 3). A center of a mat is often characterized by gentle depression suggesting local dewatering of sediments. In some mats, red-blown spots are superimposed on white patches (Photo 3). A short core sample obtained from a bacterial mat exhibits that surface sediments are composed of black sandy silt with hydrogen sulfide smell. Some of the large mats have sharp and straight outlines suggesting structural controls under surface sediments as discussed later. Clam colonies often coexist with bacterial mats, but tend to lack mats where living shells are dense. Living clams with about 9 cm in length are predominant in the center of the colonies in contrast to large clams at the margins. Five clam samples at this site belong to *Calyplogena soyae* type A (Kojima and Ashi, this volume). These biological com-

munities indicate seepage of methane bearing fluids from the seafloor.

The foot of the western side wall is slightly covered by talus debris composed of muddy materials. At the canyon wall more than 40m above the bottom, outcrops and transported blocks were encountered. A semi-consolidated rock taken from the outcrop at a depth of 1,040m is a light-brown sandy siltstone of the early late Pleistocene age (CN13b) based on calcareous nannofossil biostratigraphy. Strata gently dip less than 10° toward northwest. There is no indication of cold seepage in the canyon wall.

In order to examine distributions of biological communities, Dive 821 followed them southward from the point of the first occurrence. Various sized biological communities are almost continuously distributed over 350m along the canyon wall (Fig. 2). A clam colony with vestimentiferan tube worms is located on the muddy talus deposits (Photo 4). Two large *Calyplogena* (20cm in length) sampled at this locality are thought to be a new species based on the mitochondrial DNA analysis (Kojima and Ashi, this volume). Biological communities tend to be found on the talus deposits and gradually decrease in size and number as talus deposits jut out into the canyon floor.

At a scarp 20m above the foot of the wall, a large outcrop shows a gently NW dipping alternation of sandstone and mudstone (Fig. 2). After the observation of the western side wall, Dive 821 crossed the canyon floor. There is no distinctive structure on the floor except N-S trending grooves similar to that mentioned above. The foot of the eastern side wall is also covered by talus deposits including large transported blocks of semi-consolidated mudstone. Shell fragments among muddy talus sediments are observed (Photo 5). At a scarp just above the talus deposits, strata are gently dipping toward NW.

Dive 822 investigated the corner at the lower valley about 8km south of the Dive 821 site (Fig. 2). Large scarps cropping out strata are continuously observed along the western side wall. Gently NW dipping strata are predominant although strata partly dip toward the canyon floor probably due to

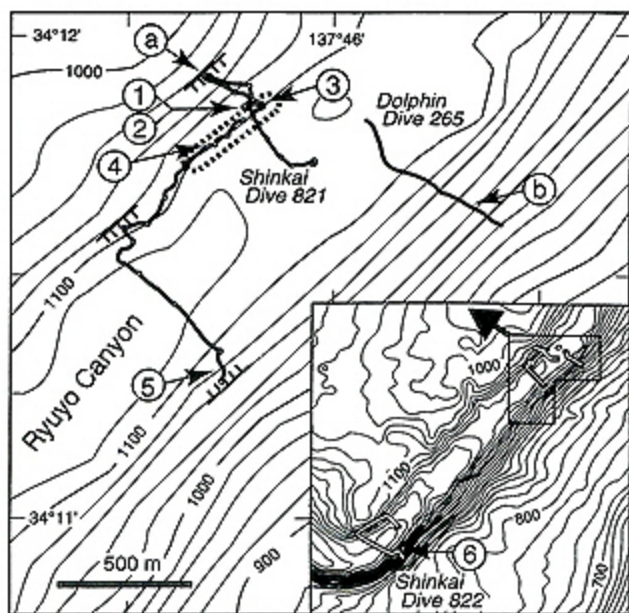


Fig. 2 Ship tracks of Dives 821 and 822 of the "Shinkai 2000" and Dive 265 of the "Dolphin-3 K". Dashed circle indicates distribution of biological communities. Sampling points and photo locations are shown by alphabets and numerals, respectively.

creep. There are few evidences showing that scarps are caused by faulting. The canyon floor consists of highly bioturbated muddy sediments. A NNE-trending small groove is also observed at the canyon axis, but we did not find any manifestation of tectonic deformation. At the eastern side wall several steep scarps are developed. Manganese-coated alternations of sandstone and mudstone exhibit steps-like topography and show about 10° dipping strata toward WNW (Photo 6). Scarps in the eastern wall are also studied during "Dolphin-3 K" (Dive 265). Steep scarps are developed between depths of 1,087m (canyon floor) and 1,053m. A sandy siltstone sampled from an outcrop is the early late Pleistocene age (CN13b) based on calcareous nannofossil biostratigraphy. The slope shallower than 1,000m is very gentle and partly covered by muddy sediment veneer.

4. Discussion

4.1 Structure of the Ryuyo Canyon

The Ryuyo Canyon is considered to be of tectonic origin probably due to NNE-trending faults (Iwabuchi et al., 1991). They also pointed out that these faults are inactive at present because of no deformation at the shallow part of seismic reflectors. Observations during Dives 821 and 822 also indicate no deformation on the seafloor sediments. Strata cropped out on the canyon walls have dips of less than 10° toward NW. Seismic reflection profiles

show NW dipping layers between the Omaezaki Spur and the Tenryu Canyon (Fig. 3). The siltstone samples from both the side walls of the Ryuyo Canyon are the early late Pleistocene age. The late Miocene siltstones are collected from the western scarp of the depression off Omaezaki during Dives 762 and 765 (Ashi et al., 1995). The MITI Omaezaki-oki well, 40km north of both dive areas (Fig. 1), provides correlation between stratigraphies of the hole, on land geology, and the seismic reflection profile (Kato et al., 1989). These results and continuities of seismic reflectors show that strata exposed in the Ryuyo Canyon and the depression off Omaezaki are correlated with the uppermost part of the Kakegawa Group and the upper part of the Sagara Group, respectively.

4.2 Distribution and origin of cold seepage

During Dive 821 biological communities are distributed along the foot of the western canyon. Strictly speaking these seepage sites do not coincide with the base of the canyon wall, but are found in a line of $N50^\circ E$ trend (Fig. 2). Southward decreasing of seepage sites seems to be associated with talus deposits that jut out into the canyon floor. During Dive 822 lack of biological community also suggests that cold seepage is not always associated with the base of the canyon wall.

The alignment of cold seepage may be caused by fluid flow along blind faults or NW dipping high permeable layers. The former is suggested by de-

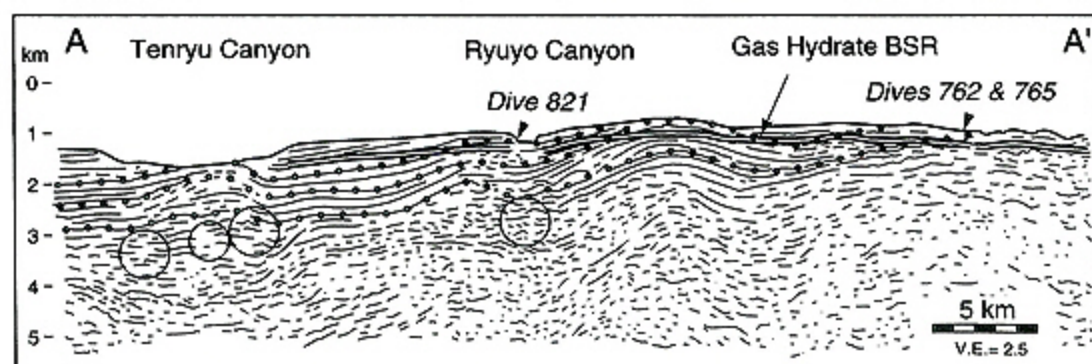


Fig. 3 Sketch showing the seismic reflection profile of the Line C obtained by the Hydrographic Department of Japan (Kato et al., 1983). Dotted lines indicate westward dipping reflectors. Circles are deformations of reflectors suggested by Iwabuchi et al. (1991).

formations of seismic reflectors (Iwabuchi et al., 1991). The latter is consistent with the strike of strata estimated from previous seismic reflection profiles (e.g., Inoma and Sasaki, 1979; Kato et al., 1983). Southward decrease of cold seepage could be attributed to low permeable talus deposit cover.

Whether methane in seepage is biogenic or thermogenic is still unknown because no fluid sampling was done during this study. Bottom simulating reflectors (BSRs) of gas hydrate are widely distributed off Tokai and also observed around the sites of Dives 762 and 821 (Fig. 3). BSR is thought to be appear at the base of gas hydrate stability field under certain circumstances such as existence of free gas beneath the phase boundary and/or massive gas hydrate above it (Miller et al., 1991). Uplift induces pressure drop that makes a stability field of gas hydrate shift upward in a sedimentary column. Local uplift suggested by abandonment of the Ryuyo Canyon (Iwabuchi et al., 1991) may generate a large amount of free gas from hydrate dissociation. Part of methane gas at seep sites may be derived from dissociation of gas hydrate.

5. Summary

During Dive 821 *Calyptogenia* colonies and bacterial mats were observed on the foot of the western wall of the Ryuyo Canyon. No tectonic structure is detected on the floor and the wall of the canyon during Dives 821 and 822. Distributions of seep sites trend N50°E although they decrease southward probably due to cap effects of the talus deposit. The ages of both the side walls of the canyon are the early late Pleistocene from the samples during Dive 821 of the "Shinkai 2000" and Dive 265 of the "Dolphin-3 K". The seismic reflector that correspond to the strata exposed at the Ryuyo Canyon dips about 10° to northwest and correlates with the upper Kakegawa Group. Alignment of seep sites suggest methane bearing fluid flow along faults or high permeable layers. Part of methane may be derived from dissociation of gas hydrate because uplift occurs in the dive sites where BSRs are well developed.

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(Notice) Photos are given on the following page.



Photo 1 *Calyptogenia* colony with bacterial mat on the canyon floor besides the western side wall. Photo location is shown in Fig. 2. Water depth 1,093m, Dive 821.



Photo 2 Close-up photograph of a *Calyptogenia* colony. Water depth 1,093m, Dive 821.



Photo 3 Bacterial mat on the canyon floor. Note red-brown spots on white discolored area. Water depth 1,093m, Dive 821.



Photo 4 *Calyptogenia* colony with vestimentiferan tube worms on muddy talus deposits. Large *Calyptogenia* sampled from this site is studied by Kojima and Ashi (this volume). Water depth 1,090m, Dive 821.

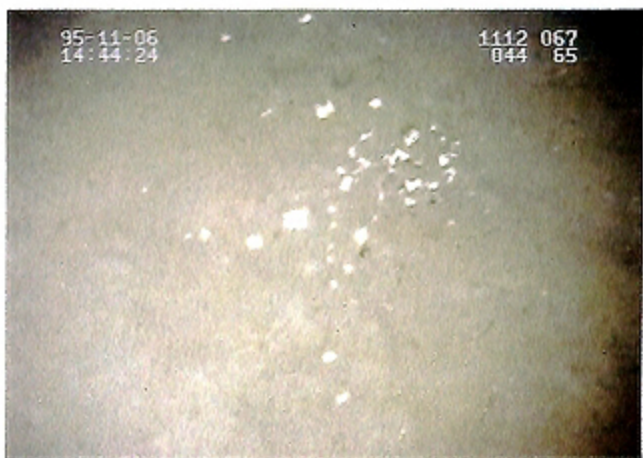


Photo 5 Shell fragments on the foot of the eastern wall. Water depth 1,112m, Dive 821.



Photo 6 Strata gently dipping toward northwest observed in the eastern wall of the canyon. Water depth 1,150m, Dive 822.