

# **Tectonic, geochemical and biological studies in the eastern margin of the Japan Sea - preliminary results of Yokosuka / Shinkai 6500 YK01-06 Cruise -**

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In the eastern margin of the Japan Sea, twelve dives of submersible "Shinkai 6500" have conducted for the study of active faults, cold seepages and biological activity related to the seepages. Many slope collapses and deformations covered with thin muddy sediments have been observed during the four dives along the Okushiri Ridge to the west of Hokkaido, suggesting that the ridge between the 1993 off-SW Hokkaido and the 1940 off-Shakotan earthquakes has a higher potential of future earthquakes than surrounding areas. Water samples around bacterial mats from two sites showed high content of CH<sub>4</sub>. The plenary studies for microbial diversity analyses of sediments around the mats showed unique bacterial assemblages. Another dive tried to collect the Pogonophora. Three dives have surveyed in and around the source area of the 1983 Japan Sea earthquake, and the result of the dives strongly suggests that the Okushiri Ridge is not the source area of the earthquake. Dive #634 at the western margin of the Sado Ridge observed many broken rocks of various sizes, suggesting that the slope is underlain by active faults, which have been quiet for about thousands years.

**Keywords :** Japan Sea, dive survey, active fault, earthquake, cold seepage, bacterial mat

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## 1. INTRODUCTION

The eastern margin of the Japan Sea is believed to be a convergent plate boundary between the Amurian and Okhotsk Plates (e.g. Wei and Seno, 1998). Source areas of large-earthquakes ( $M > 7$ ) during the last few centuries align along the continental slope of this margin without overlap, and a few seismic gaps have been pointed out (Ohtake, 1995). Many active faults and folds are known in this area, while a clear plate boundary cannot be defined from geologic structures (Fig. 1). Besides, activities of offshore active faults are not known.

YK01-06 cruise (25th June to 20th July) of R/V Yokosuka, the mother ship of Shinkai 6500, aimed at the studies of geological, geochemical and biological processes in the Japan and Kuril Trenches and the eastern margin of the Japan Sea. Fifteen dives of submersible Shinkai 6500 have been conducted during the cruise.

In addition, bathymetric surveys of the western margin of the Kuril Trench, northern part of the Japan Sea and southern part of the Japan Basin have clarified

detailed sea-bottom morphologies. In the Japan Sea, active faults, cold seepage and biological community are the main targets. Different area of scientists joined in this cruise and dived twelve times to investigate these processes and the relations among them (Fig. 2, Table 1). This paper includes dive reports prepared by observes of the twelve dives and preliminary results of post cruise studies. The list of the dives including observers, objectives, date, location and depth are shown in Table 1.

To the west of Hokkaido, there is a possibility that a seismic gap 50km or more in length exists between the

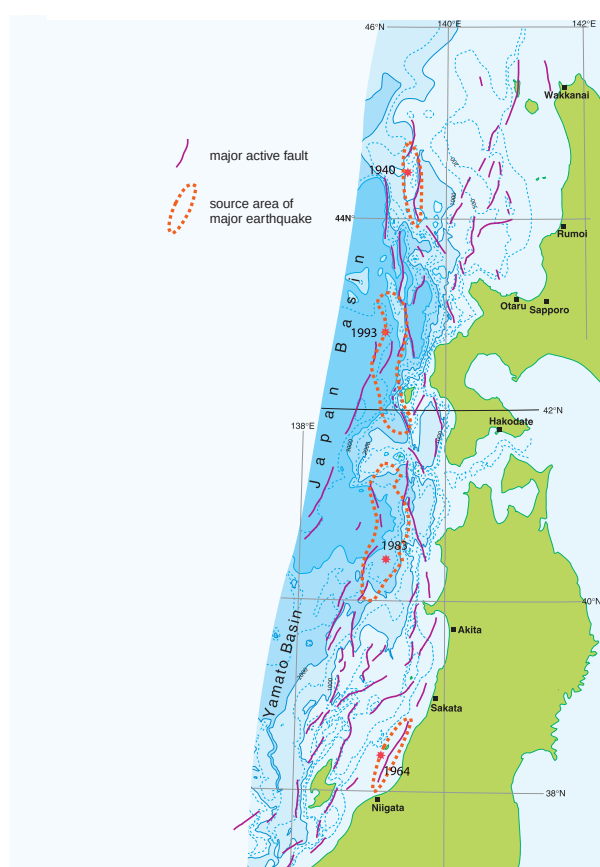


Fig. 1 Active faults and source areas of major earthquakes in the eastern margin of the Japan Sea

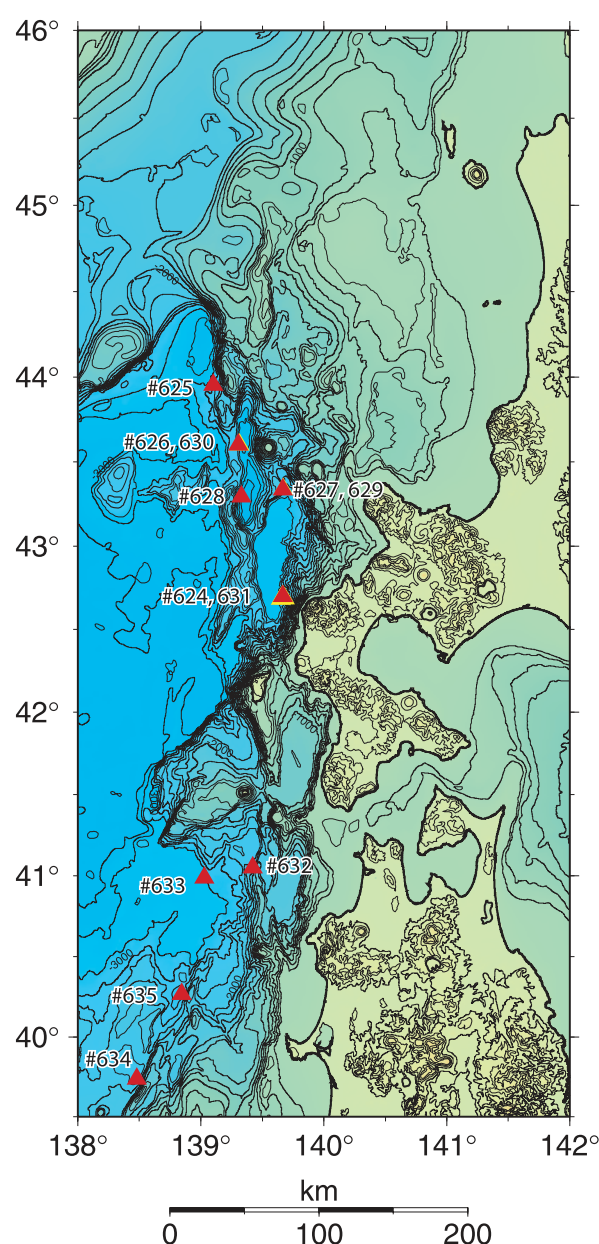


Fig. 2 Dive sites in the eastern margin of Japan Sea during the YK01-06 Cruise.

| Dive# | Date    | Observer<br>Affiliation       | Pilot<br>Co-pilot         | Main Objective                                                                                                 | Sub Nav. | Start<br>End   | Lat. (N)<br>Lat. (N) | Long. (E)<br>Long. (E) | Depth (m)<br>Depth (m) |
|-------|---------|-------------------------------|---------------------------|----------------------------------------------------------------------------------------------------------------|----------|----------------|----------------------|------------------------|------------------------|
| 621   | 27-Jun. | Y. Nogi<br>JAMSTEC*1          | S. Suzuki<br>T. Sakurai   | Isolation of novel piezophilic microorganisms and analysis of the microbial diversity in Japan Trench Sediment | SSBL     | 12:21<br>14:43 | 39-20.59<br>39-20.48 | 144-36.05<br>144-35.94 | 6,271<br>6,274         |
| 622   | 28-Jun. | K. Fujioka<br>JAMSTEC         | T. Maki<br>H. Higuchi     | Deep-sea seep community at the Kuril Trench revisited                                                          | SSBL     | 12:19<br>14:02 | 41-18.26<br>41-18.47 | 144-45.27<br>144-45.14 | 5,535<br>5,332         |
| 623   | 29-Jun. | S. Kojima<br>Univ. of Tokyo   | T. Yoshiume<br>Y. Nanbu   | Phylogenetic evolutionary study of the chemosynthetic community on the landward slope of the Kuril Trench      | SSBL     | 11:36<br>14:37 | 41-17.12<br>41-17.52 | 144-46.04<br>144-45.61 | 6,269<br>6,068         |
| 624   | 01-Jul. | C. Kato<br>JAMSTEC            | I. Kawama<br>T. Komuku    | Study of the microbial diversity in the bacterial mat caused by cold seep activity at North Japan Sea          | SSBL     | 11:28<br>15:46 | 42-42.06<br>42-41.98 | 139-40.09<br>139-40.75 | 3,135<br>3,038         |
| 625   | 02-Jul. | K. Satake<br>AIST*2           | Y. Sasaki<br>H. Higuchi   | Earthquake potential along the eastern margin of Japan Sea                                                     | SSBL     | 11:30<br>16:01 | 43-57.24<br>43-57.35 | 139-06.11<br>139-08.80 | 2,954<br>2,588         |
| 626   | 03-Jul. | F. Nanayama<br>AIST           | S. Suzuki<br>Y. Nanbu     | Earthquake potential along the eastern margin of Japan Sea (Part 2)                                            | SSBL     | 11:51<br>15:59 | 43-36.34<br>43-36.05 | 139-19.57<br>139-17.49 | 3,305<br>2,916         |
| 627   | 05-Jul. | Y. Okamura<br>AIST            | T. Sakurai<br>T. Maki     | Earthquake potential along the eastern margin of Japan Sea (Part 3)                                            | SSBL     | 11:18<br>14:10 | 43-20.34<br>43-20.39 | 139-40.18<br>139-39.17 | 2,994<br>2,561         |
| 628   | 08-Jul. | A. Takeuchi<br>Toyama Univ.   | T. Yoshiume<br>T. Komuku  | Seismogeology and seabed ecology along the eastern margin of Japan                                             | SSBL     | 11:44<br>15:45 | 43-17.63<br>43-17.55 | 139-19.85<br>139-18.41 | 3,622<br>3,342         |
| 629   | 09-Jul. | Y. Sasayama<br>Kanazawa Univ. | S. Suzuki<br>I. Kawama    | Biological survey of the Shiribeshi SMT                                                                        | SSBL     | 11:30<br>15:45 | 43-20.18<br>43-20.36 | 139-40.04<br>139-39.96 | 2,979<br>2,973         |
| 630   | 10-Jul. | T. Gamo<br>Hokkaido Univ.     | T. Sakurai<br>Y. Sasaki   | Geochemical surveys for cold seepage along the Okushiri Ridge west of the Shiribeshi Seamount                  | SSBL     | 11:29<br>15:53 | 43-36.06<br>43-36.02 | 139-18.24<br>139-17.90 | 3,176<br>3,034         |
| 631   | 11-Jul. | A. Takeuchi<br>Toyama Univ.   | T. Yoshiume<br>H. Higuchi | Seismogeology and seabed ecology along the eastern margin of Japan (Part 4)                                    | SSBL     | 11:27<br>15:55 | 42-42.04<br>42-42.58 | 139-40.07<br>139-40.14 | 3,147<br>3,122         |
| 632   | 13-Jul. | Y. Okamura<br>AIST            | I. Kawama<br>Y. Nanbu     | Earthquake potential of Okushiri Ridge, west of Tsugaru                                                        | SSBL     | 11:08<br>16:15 | 41-03.10<br>42-02.15 | 139-25.32<br>139-26.84 | 2,278<br>1,735         |
| 633   | 14-Jul. | A. Takeuchi<br>Toyama Univ.   | Y. Sasaki<br>T. Komuku    | Seismogeology and seabed ecology along the eastern margin of Japan (Part 5)                                    | SSBL     | 11:48<br>16:00 | 40-59.28<br>40-59.19 | 139-01.76<br>139-02.97 | 3,313<br>3,180         |
| 634   | 15-Jul. | K. Satake<br>AIST             | S. Suzuki<br>H. Higuchi   | Earthquake potential of along the eastern margin of Japan Sea                                                  | SSBL     | 11:19<br>16:11 | 39-44.24<br>39-43.38 | 138-28.75<br>138-30.97 | 2,676<br>2,308         |
| 635   | 16-Jul. | A. Takeuchi<br>Toyama Univ.   | T. Maki<br>I. Kawama      | Seismogeology and seabed ecology along the eastern margin of Japan (Part 6)                                    | SSBL     | 11:53<br>16:00 | 40-16.11<br>40-15.61 | 138-50.72<br>138-52.88 | 3,049<br>2,682         |

Table 1 List of dives in the eastern margin of Japan Sea during the YK01-06 Cruise.

\*1; JAMSTEC (Japan Marine Science and Technology Center)

\*2; AIST (National Institute of Advanced Industrial Science and Technology)

source areas of the 1993 off-SW Hokkaido and 1940 off-Shakotan earthquakes. Four dives (#625, 626, 627, 628; Fig. 2) investigated active faults in this area and tried to identify recent seismic events of the faults. These dives discovered bacterial mats on the slopes of Okushiri Ridge and many string worms at the foot of the slope of Minami Shiribeshi Knoll. Additional dives were conducted for further study of the bacterial mats (#630) and biological colonies (#629). Another large-scale bacterial mats have discovered in 1999 by Shinkai 6500 dive #485. The site was revisited twice (#624, 631; Fig. 2) in this cruise to collect living bacterial mats and geochemical samples. The 1983 Japan Sea earthquake occurred to the west of Tsugaru Peninsula (Fig. 1). Detailed seismological studies of the source area of the earthquake suggest that the earthquake faults would be exposed along small-scale faults extending north from the northern edge of the Sado Ridge. Geologic structure in and around the source area indicates that the Okushiri ridge is the largest fault system in this area, but seismological studies suggest that the ridge has not broken during the earthquake. Three dives (#632, 633, 635; Fig. 2) have surveyed to confirm the source area of this earthquake.

In the southern part of the eastern margin of Japan Sea, another seismic gap may exist between the 1964 Niigata earthquake (or the 1833 Shonai-oki Earthquake) and the 1983 Japan Sea Earthquake. Many active faults are distributed in this area, especially in the Sado Ridge. The western margin of the ridge is one of the largest faults and a major candidate of a future earthquake in the seismic gap. Dive #634 surveyed the fault scarp and recent seismicity (Fig. 2).

Through the dives in the Japan Sea, deep-sea cold seepage and biological colonies have been major interests. Distinct cold seepages accompanying bacterial mats have been observed at three sites, while colony of bivalves and string worms have been discovered during the most dives. Two dives (#630, 631) were conducted to collect water sample from cold seepages, and dive #629 tried to sample benthos. It is necessary to clarify the relationships between the active faults, colonies and cold seepages for full understanding of the natural processes in the eastern margin of the Japan Sea.

## 2. DIVE REPORTS

### 2.1. Dive #624 : West of the Cape Motsuta (C. Kato)

Takeuchi and his co-workers reported that a wide-spreading bacterial mats were found at the eastern wall of Shiribeshi Trough in Japan Sea at a depth of 3,145m (Figs. 3 and 4) during their survey to study the large earthquakes and bottom disturbances in the Okushiri ridge (Takeuchi et al., 2000). The existing of these bacteria mats might be caused by cold seep activity, effected by the 1993 off-Southwestern Hokkaido earthquake (M7.8, 42°47'N-139°12'E). To analyze the microbial community and diversity of the bacterial mats related to the cold seep activity, we proposed this diving investigation to obtain the mat samples using the pressure retaining sampler and the sterilized sediment sampler. The following projects should be performed using these mat samples;

- 1) Analysis of the microbial diversity in the DNAs isolated directly from the bacterial mat samples obtained by the sterilizing sediment sampler.
- 2) Isolation of novel piezophilic bacteria from the samples obtained by the pressure-retaining sampler, using the DEEP-BATH system.
- 3) Identify the animal community around the bacterial mats area.
- 4) Analysis of the chemical components of the mat samples.
- 5) Geological aspect.

We are also interested to compare the microbial diversity of the cold seep environments at Japan Trench land slope and at north Japan Sea.

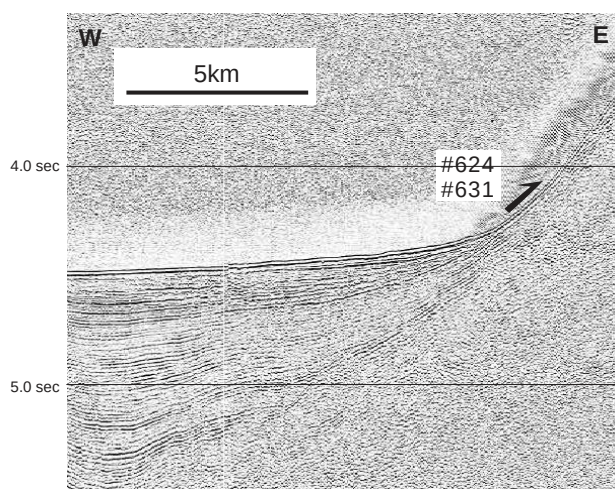


Fig.3 Seismic profile across the southern slope of the Shiribeshi Trough near the dive route #624 and #631.

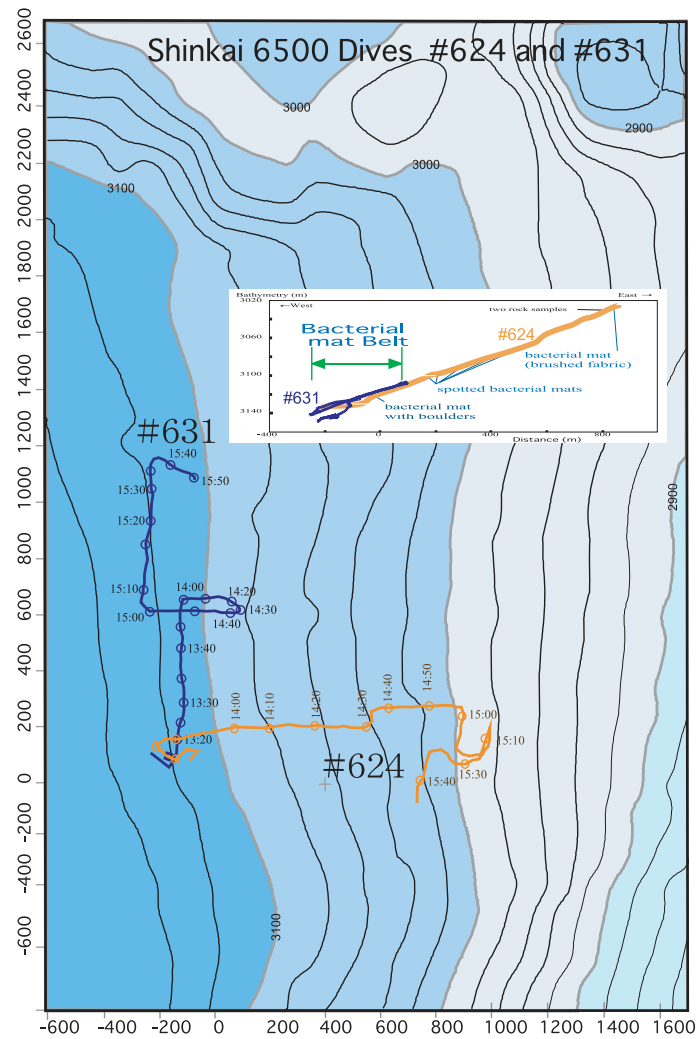


Fig. 4 Route map of Shinkai 6500 dive #624 and 631.

We observed many of the bacterial mats at a depth of about 3,000-3,100m on this diving site. Most of the mat shapes are like "Pancer body" called "Pancer Mat" (Fig. 5A), and some them are like "After brash painting" called "Brash Mat" (Fig. 5B). Interestingly, many of the rocks located at the bacterial mats are attached by white colored bacteria, and their shapes look like some fountains which water (cold seepage?) pass through (Figs. 5C and 5D). Fig. 5E mentions that two kinds of the mats and sediment area together. We recognized that the sediment depth of the mats were deeper in Panther mats than Brash mats, according to the trial of the push core sampling. Probably, the mat shapes are according to the depth of sediment, and cold seepage activity. We have succeeded to obtain the mat sediments using the pressure-retaining sampler and several sterilizing mud samplers. More detailed studies must be necessary to under-

stand the microbial community at this area, not only for microbial subjects, but also chemical and geological studies.

We also observed many of invertebrates like isopoda, amphipoda, snails, sea cucumbers, and worms. But we had never seen any fishes, clubs, and big deep marine animals. This may be caused that the environment of the bacterial mats are pretty toxic for such animals, because of hydrogen sulfide concentrations. This environment looks like reducible with not enough oxygen existing. To confirm this point, chemical analysis of the environmental water should be performed.

Several faults were observed around the bacterial mats. These faults might be caused by some geological activities, and such activity leaded the cold seepage. More detailed studies must be necessary to understand the reason of the cold seepage related the bacterial mats

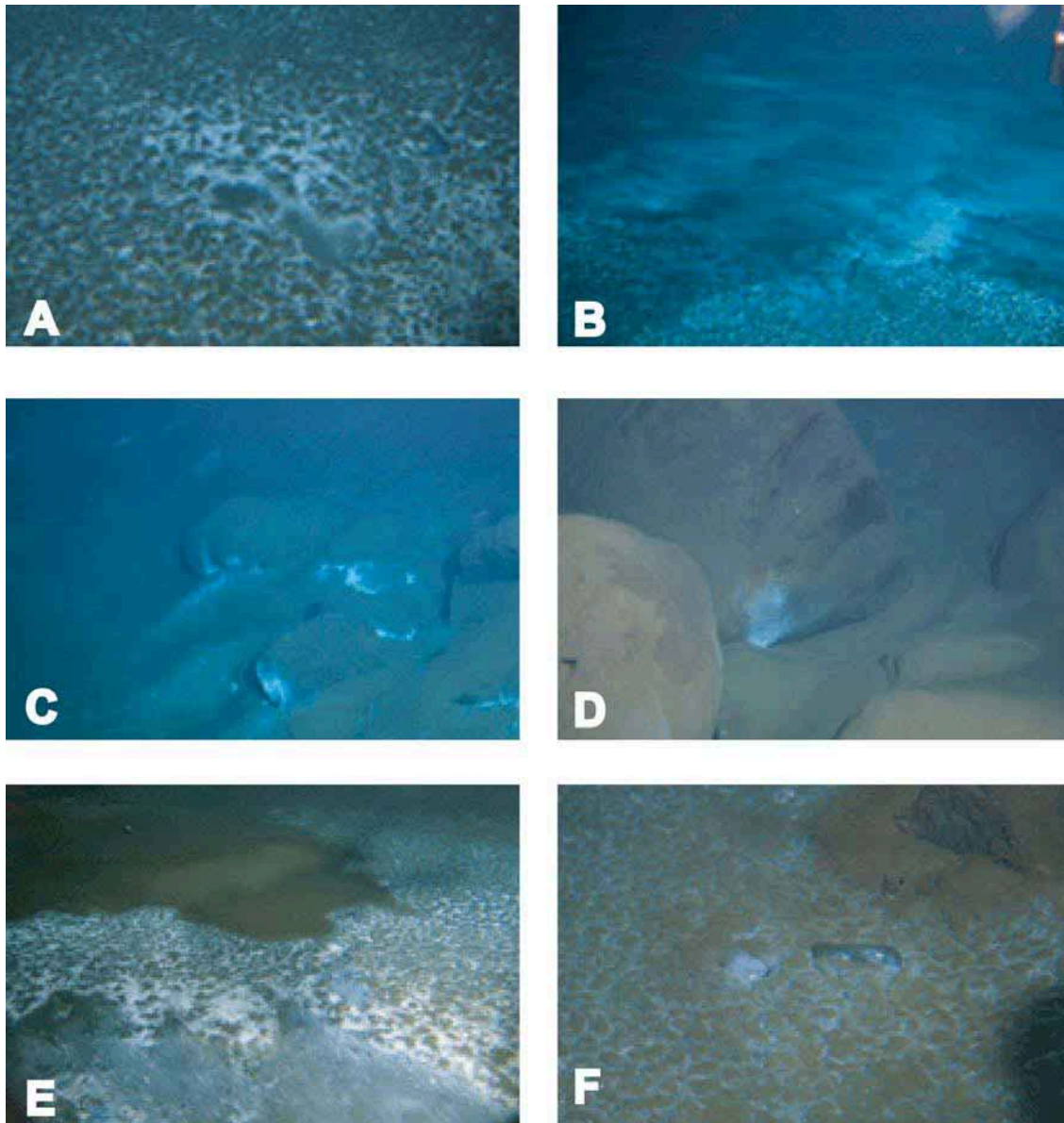


Fig. 5 Photos of bacterial mats.

and some of geological movements.

As mentioned in above, several rocks were painted by bacterial mats. Those painting might be caused by cold seep from under the rocks. Geochemical analysis should be necessary to confirm this point. These rocks were volcanic rocks, which were falling down from the land (F. Nanayama, personal communication).

## 2.2. Dive #625 : Western slope of Kaiyo seamount (K. Satake)

The diving site was on the western edge of the Kaiyo seamount, where an active fault has been inferred from

the GSJ's seismic profile records (Fig. 6). We landed near the slope foot and climbed up the slope toward the east, observing the bottom geology and sampling push-cores and rock. The payload included a sample box, 3 markers, 5 push-corers, 2 sterilized core samplers, and the Kumade sampler. In total, we obtained 5 core samples, 3 rock (mudstone) samples and shells.

The dive route can be classified into 4 segments (Fig. 7, 8): bottom flat at about 2,950m depth, the lower slope (height difference of 100m), middle plateau (depth about 2,840m), and the upper slope (250m high).

On the bottom flat, other than our own ballast and

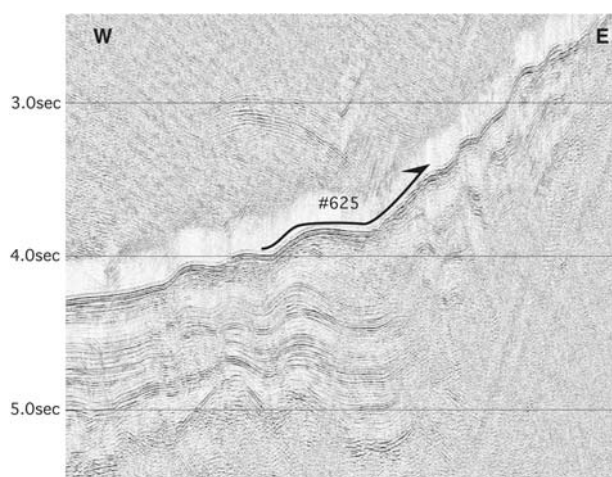


Fig. 6 Seismic profile of the western slope of Kaiyo seamount near the dive route #625.

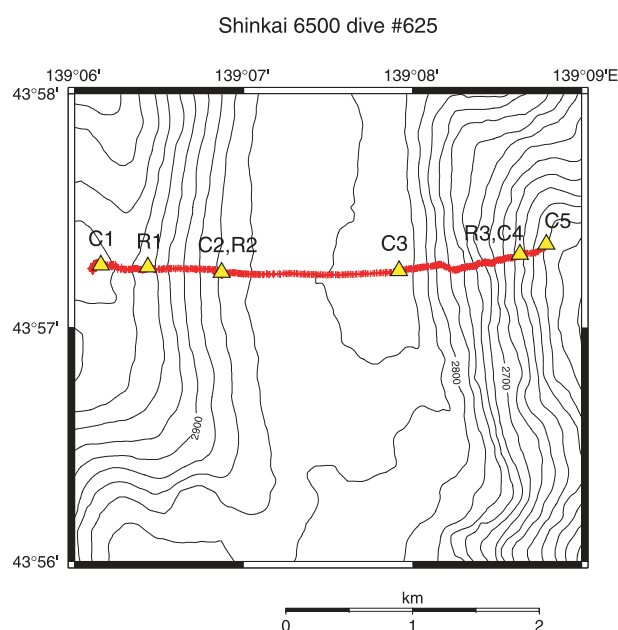


Fig. 7 Route map of Shinkai 6500 dive #625. Locations for rock (R) and core (C) samples.

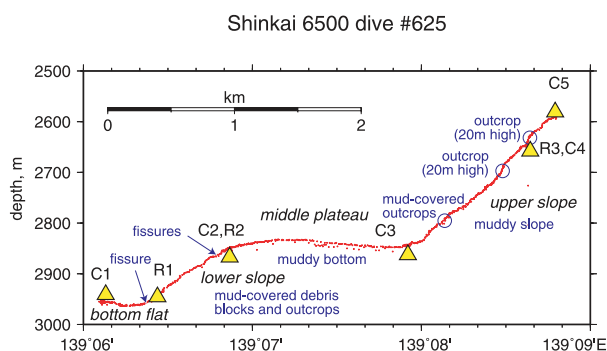


Fig. 8 Cross-sectional view of the dive route. Locations for rock (R) and core (C) samples and bottom geology are shown.

small cobbles, the bottom is totally covered with mud and no geological or biological features were observed. We collected push-core sample (C1, yellow). Many small fish (a kind of shrimp?) were observed. Near the foot of the lower slope (the depth of about 2,950m), a shallow fissure covered with mud was observed (Fig. 9A). Many small, semi-transparent bivalve shells were seen inside the fissure. Debris blocks and outcrops started to appear. They are mostly buried in mud (Fig. 9B). We sampled one of debris blocks, but the mudstone block, named R1, did not retain its shape and could not be distinguished from later sample, R2. A small outcrop, seemingly old, was also observed.

On the lower slope, debris deposits and outcrops, both covered with mud, were continuously observed. At some outcrops, horizontal strata were clearly observed, while debris blocks show random orientation of strata. They are both covered with mud.

Near the top of the lower slope, fissures started to appear again. Some fissures show relatively fresh exposure, but they appear to be collapse or re-activation of old ones (Fig. 9C). We stopped at one of fissures to make push-core (C2 black) and rock (R2) sampling. The rock sample is a mudstone block, but did not retain its shape and was mixed with R1 in the sample box. We obtained a few bivalve shells from R1 and R2 samples.

We moved across the middle plateau at a relatively high speed. The bottom is covered with mud and little geological or biological features were observed. Near the foot of the upper slope, we sampled push-core C3 (red).

On the upper slope, three large-scale outcrops were observed, but other parts were buried in mud. The first outcrop, covered with mud, is around the depth of 2,810m. The second one, about 20m high, is at the depth of about 2,700m, and associated with debris blocks. The third one, also about 20m high, is at 2,640m depth. Relatively fresh gravel deposits from the collapse of this outcrop were observed at the foot, where we sampled push-core C4 (green) and rock R3 (Fig. 9D). The core contains sediments from slope collapse. The rock sample was a mudstone boulder with calcareous nodule inside. The buried part was coated by blackish hydrogen sulfide. From the top of the last outcrop (Fig. 9E), muddy slope continued. At the edge of a collapse head-wall (2,588m), we sampled push-core C5 (white) before leaving the bottom. The core contains volcanic ash.

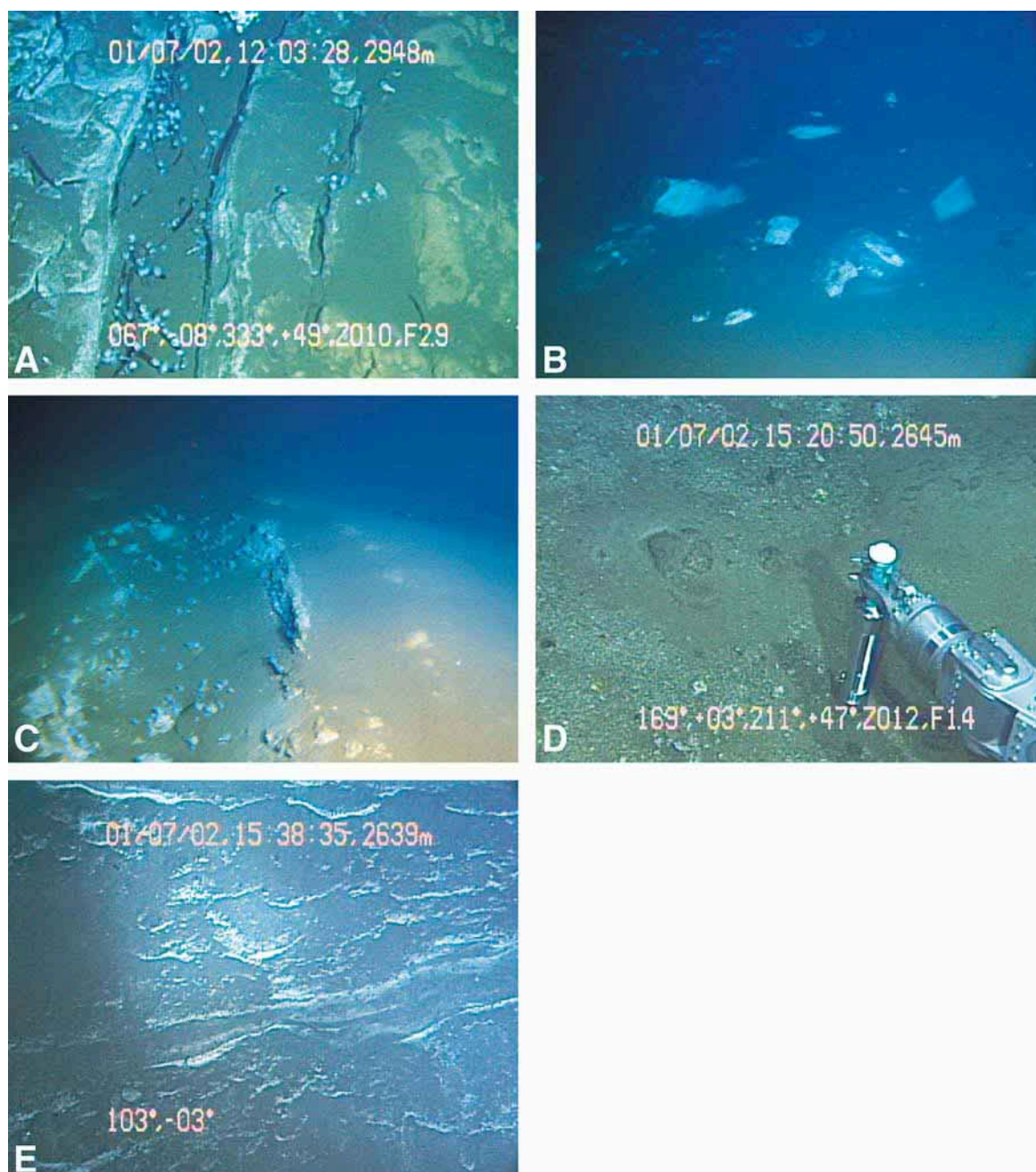


Fig. 9 Sea-bottom photos of dive #625.

(A) Small fissure slightly covered with mud near the foot of the lower slope. Small semi-transparent bivalves are seen inside the fissure. (B) Debris deposits partially buried in mud, near the sampling site of R1 (water depth of 2,945m). The large debris block shows the original strata. (C) Fissure near the top of the lower slope (2,843m). Relatively-fresh exposure and bivalves are seen inside the old fissure which is almost buried in mud. (D) Sampling push-core (C4) at the bottom of an outcrop on the upper slope. The surface is covered with coarse sediments. (E) One of the outcrops on the upper slope.

Fissures, debris deposits and collapse headwall indicate sea bottom disturbance(s) due to past earthquake(s) in this region. The locations of fissures, at the foot and top of the lower slope, suggest that the active fault exists beneath the lower slope. The fresh features may indicate a recent event such as the 1940 Shakotan-oki

earthquake. However, such fresh features are small in size and spatially limited. Most of the large-scale features are covered with mud, indicating that the most recent event occurred on the active fault west of the Kaiyo seamount was old, possibly an order of hundreds to thousands of years.

### 2.3. Dive #626 : Eastern slope of the northern Okushiri ridge to the west of the Shiribeshi Ridge (F. Nanayama)

The dive #626 surveyed the eastern slope of the Okushiri Ridge to the west of the Shiribeshi seamount in the seismic gap between the 1940 and 1993 earthquakes (Figs. 1 and 2). This part of the Okushiri Ridge accompanies west dipping reverse faults (Fig. 10). In order to examine the past earthquake activity of these submarine faults, we made visual observation of the ocean bottom and core sampling

During #626 dive, we attempted to survey in this area for the following objectives; (1) observation of geology and geomorphology about the eastern slope of the northern Okushiri ridge, (2) description of seismic deformation and debris avalanche deposits, (3) collection of palaeoseismic event deposits from the base of the slope using push cores, and (4) description and sampling seep-endemic organisms such as bacteria mats by sterilized core samplers.

We landed near the slope edge at 43°36.3406'N, 139°19.55'E, 3,305m in depth on the eastern slope of the northern Okushiri ridge where thick soft mud deposited (Figs. 11 and 12). There were no outcrops or debris, and we got the yellow push-core sample (C1) at this point. Then, we transited forward 250° on muddy sea bottom.

At 43°36.1044'N, 139°18.8302'E, 3,305m, we discovered large outcrop of more than 32m height composed of highly deformed sandstones (Fig. 13A). We collected two rock samples (R1) from the outcrop and described onboard. The appearance of the rocks is black with partially alternated brown color along layer, composed of

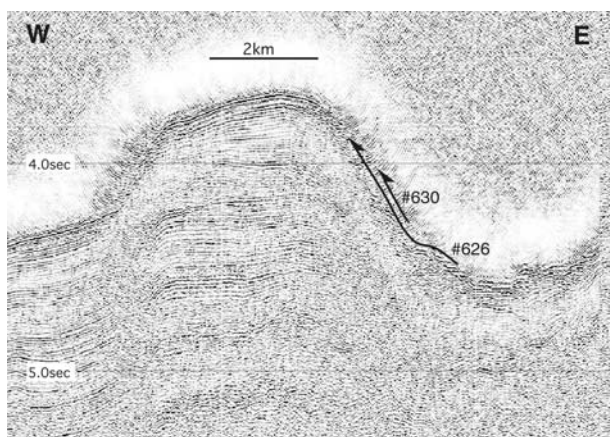


Fig. 10 Seismic profile of Okushiri Ridge near the dive route #626.

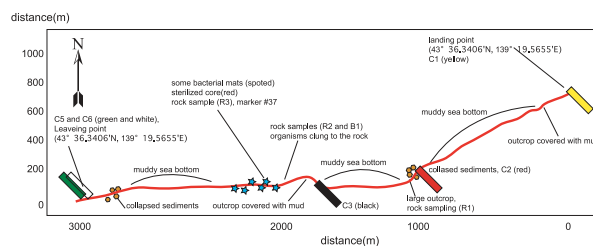


Fig. 11 Route map of dive #626 by Shinkai 6500 showing types of sea-bottom sediments and sampling points.

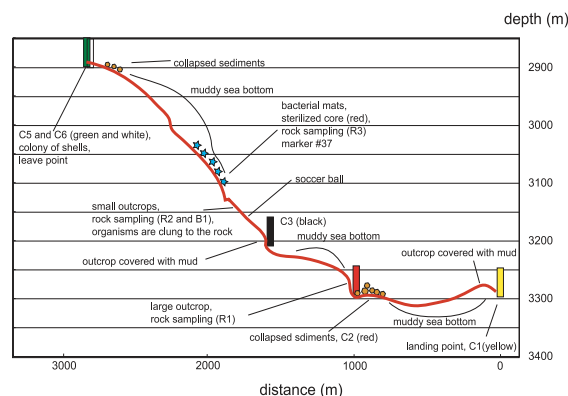


Fig. 12 A cross section of dive #626 route by Shinkai 6500 showing observations and sampling points.

fine to medium angular grained sandstone composed of quartz, feldspar and basic volcanic rock fragments with granulated pyrite grains. Much pumices inferred volcanic influence of the area. Furthermore, there are large debris avalanche sediments on the foot of the outcrop (Figs. 1 and 2). Debris avalanche sediments composed large blocks (d=1 to 3m), however these are buried by soft mud more than 5cm (Fig. 13B). We think that these debris avalanche deposits were not so young and didn't occur recently including the 20th century.

At 43°36.0864'N, 139°18.3724'E, 3,216m, we got the black push core (C3) from an edge of steep slope located by sonar data of Shinkai 6500, however we could not find outcrop and debris here (Figs. 11 and 12). At the 43°36.0929'N, 139°19.1980'E, 3,149m, we got two rock samples (R2) from the small outcrop buried by soft mud. There were many unknown polychaete or small bivalve (B1 sample) described by Dr. S. Kojima. According to onboard description, these sandstones have much volcanic influence similar to the sample from the large outcrop.

At 43°36.0886', 139°17.9176'E, 3,031m, we also discovered some bacterial mats at the upper slope, and

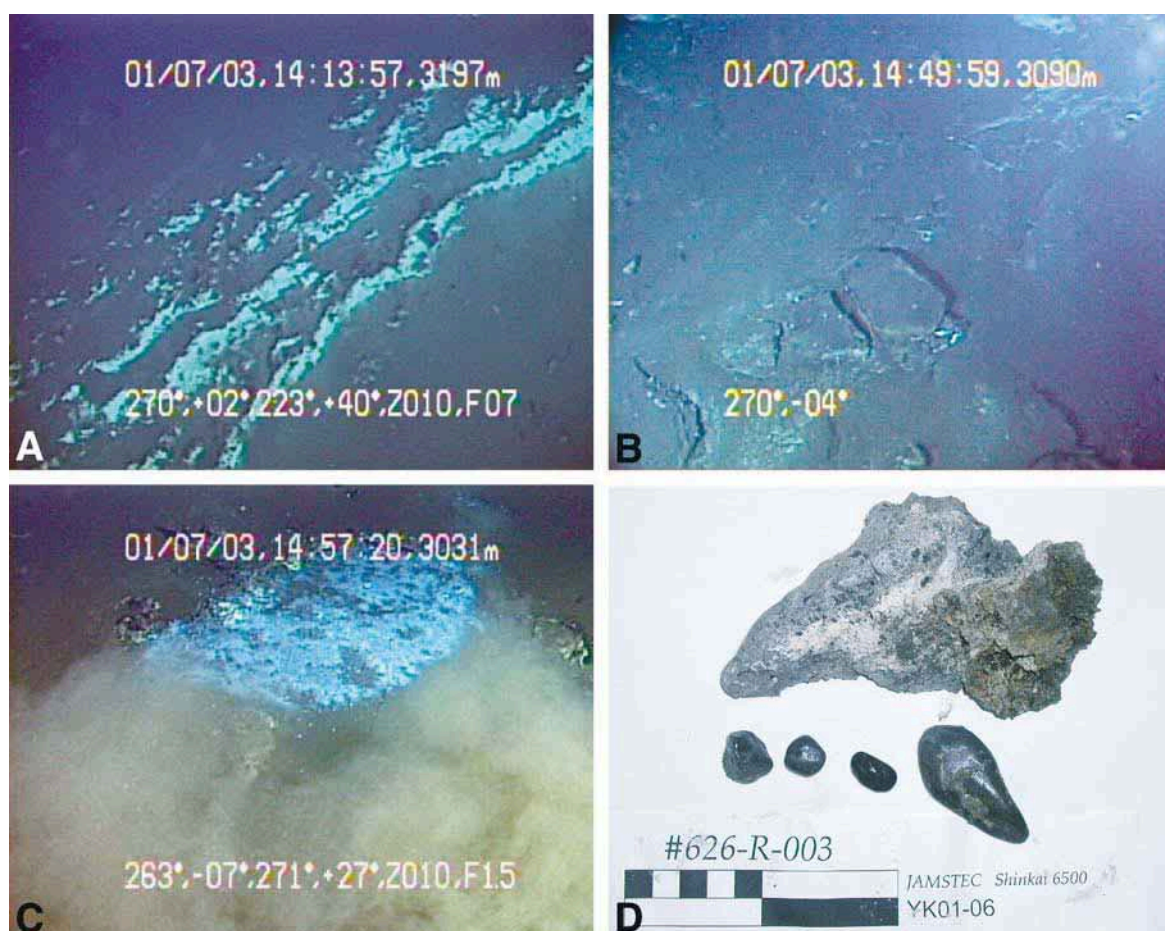


Fig. 13 Sea-bottom photos of dive #626. (A) Mudstone outcrops covered with soft mud drape at 3,197m. (B) Sandstone blocks on the foot of large outcrop at 3,090m. (C) Bacteria mats on the muddy sea-bottom at 3,031m. (D) Carbonates of mudstone gravels with strong smell of hydrogen sulfide bellow the bacterial mat were collected by the Kumade sampler at 3,031m.

collected sediment samples using a sterilized core sampler (red) and the Kumade sampler (Figs. 11, 12 and 13C). Furthermore, we collected sediments bellow the bacterial mat by using the Kumade sampler (R3). The samples were carbonates of gravels with strong smell of hydrogen sulfide (Fig. 13D). No animal was obtained from the sediment samples. The #37 marker was left at this site. According to onboard descriptions, by the appearance of the rocks was cream white color. Black rounded mudstone gravels (max d=5.5cm) and angular volcanic sandstone gravels are cemented by carbonate materials. Carbonate materials are divided into two types; one is coarse grain, the other is poor-sorted matrix with much sand grains.

At the end point of the dive (43°36.0511'N, 139°17.4925'E, 2,916m), we collected two push cores named white and green (C5 and C6), all of which were soft mud. We lift off the last point (Figs. 11 and 12).

#### 2.4. Dive #627 : Minami Shiribeshi Knoll, an eastern branch of the Okushiri Ridge (Y. Okamura)

The 1993 off-SW Hokkaido earthquake have occurred along the Okushiri Ridge around the Okushiri Island. At the northern end of the source area of the earthquake, the ridge branches off into two ridges in NNW and NNE direction (Fig. 1). The western branch continues to the north for more than 150km as a main ridge of the Okushiri Ridge, while the eastern branch extends about 50km and disappears south of the Shiribeshi Seamount. The Minami Shiribeshi knoll, the target of this dive, is located on the eastern branch of the ridge.

The knoll is a hanging wall anticline of a west-dipping reverse fault system, which has uplifted up to 1,500m (Fig. 14). The fault is inferred to have grown during the Quaternary time, while its recent activity is not known. This knoll is located between the source areas of 1940 Shakotan-oki and 1993 off-SW Hokkaido

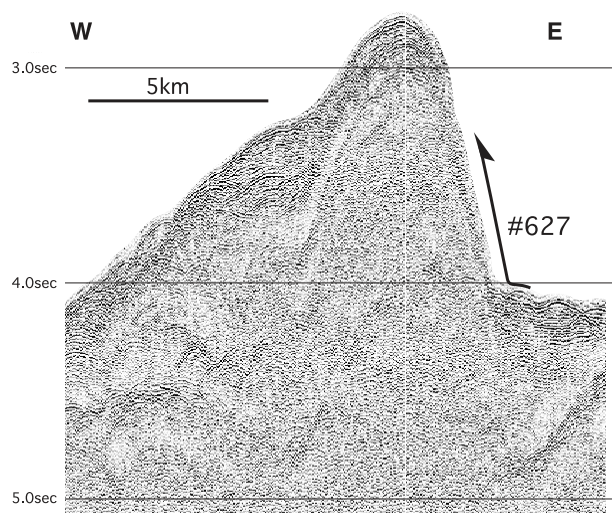


Fig.14 Seismic profile across Minami Shiribeshi Knoll near the dive route #627.

earthquakes and possibly in the seismic gap.

This dive aimed at making clear the recent activity of the fault below the knoll. If the fault is active, it is expected that slope failure is observed and debris flow deposits can be collected by push coring at the eastern slope of the knoll.

Landing point is a basin floor at about 400m from the foot of the slope (Fig. 15 and 16). The floor is covered with muddy sediments, and small rock fragments are scattered (Fig. 17A). Two push cores were collected at the landing point. Green push (C001) core dropped after sampling, so white (C002) core tried at the same point. Sediments in the push cores indicated that the basin floor is covered with a recent turbidite layer. Then we moved to west. As we close to the slope, small rock

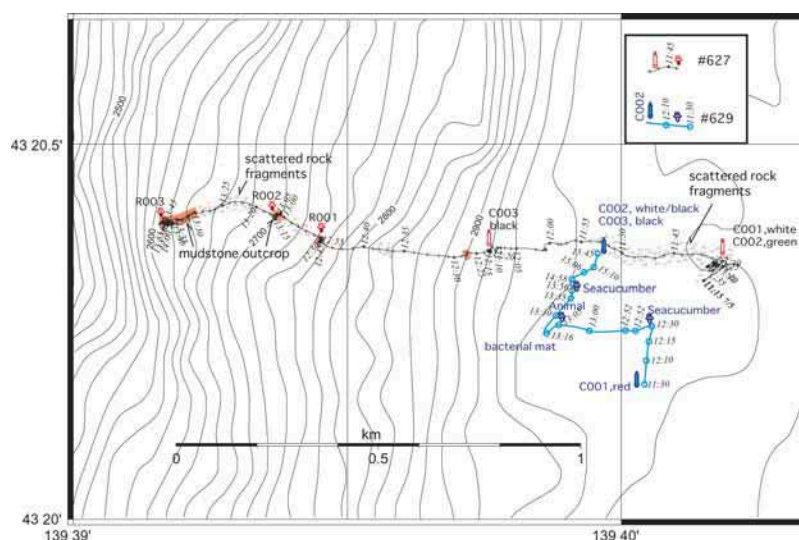


Fig. 15 Route map of Shinkai 6500 dive #627 and #629. Locations for rock (R) and core (C) samples and bottom geology are shown.

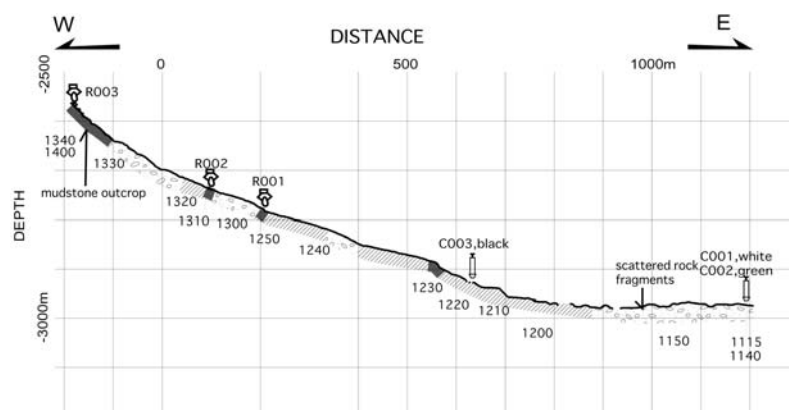


Fig. 16 Cross section of the dive #627 route. Sampling points for rock (R) and core (C) as well as bottom geology are shown.

fragments decrease and muddy sediments cover the sea-bottom. Many thin tubes peculiar to the worms are observed on the muddy sea-bottom. A push core (C003, black) was collected near the base of the slope.

The lower slope is covered with smooth muddy sediments, and small-scale outcrops and blocks of mudstone are sparsely distributed (Fig. 17B). Muddy sediments

cover the upper surface of outcrops and blocks, and shells and unknown hair-like living things cover the side of the blocks (Fig. 17C). Mudstone samples were collected at two sites (R001, 002). Grooves trending dip direction were observed on the muddy slope, which are inferred to be tracks of sliding blocks.

The upper slope is composed of cliffs of mudstone

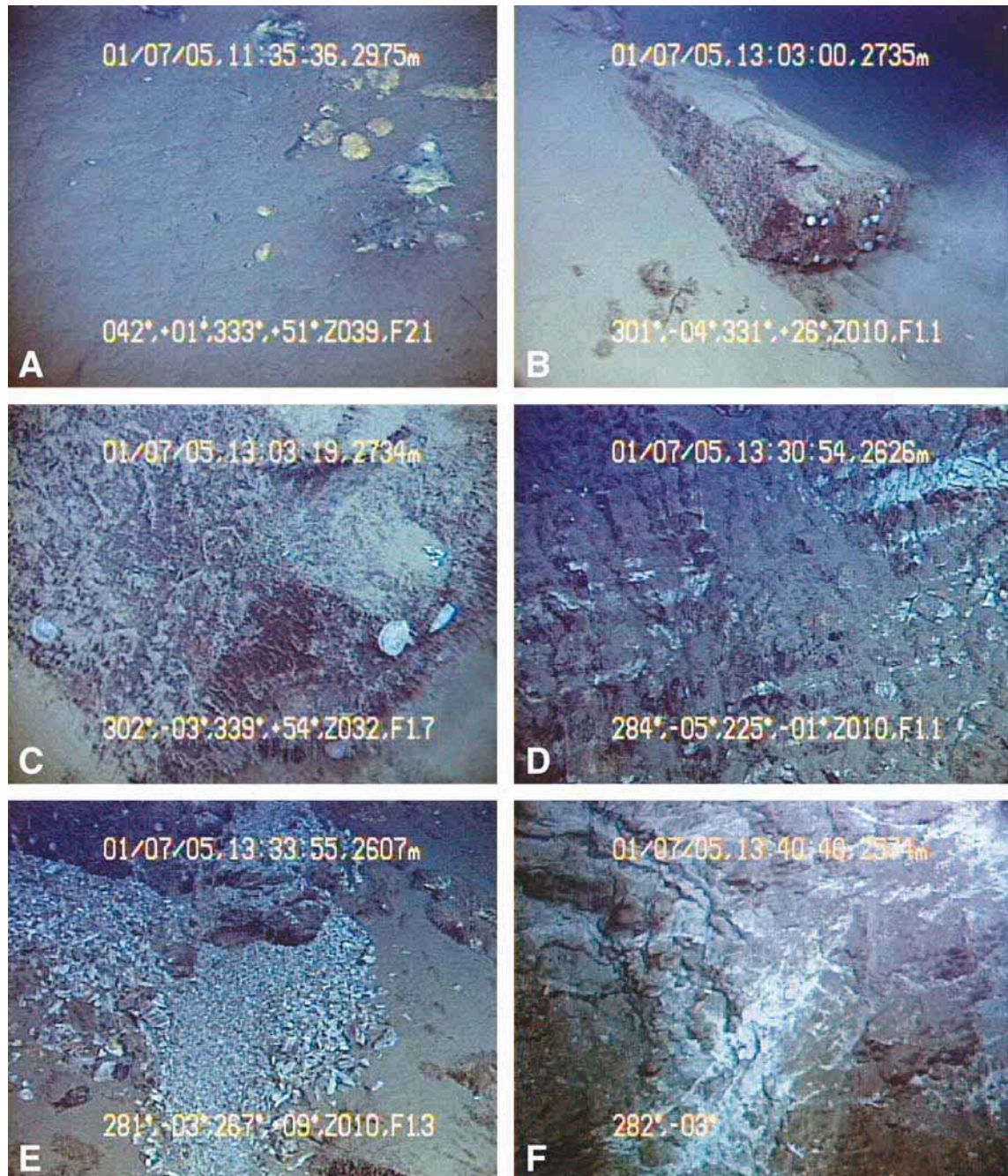


Fig. 17 Seabottom photos of dive #627. (A) Seabottom near the landing point. Rock fragments are scattered on the muddy sediments. (B) Boulder of mudstone on the lower slope. (C) Close up of mudstone boulder. Surface of the rock is covered by shells and unknown hair-like living things. (D) Cliff of mudstone showing horizontal stratification clearly. (E) Small-scale recent debris. (F) Small-scale recent collapse of cliff.

and narrow terraces. Stratification of mudstone is clearly observed on the outcrops (Fig. 17D). Most part of the outcrop is covered by mud, shells and unknown hair-like living things, and they are dark brownish gray in color (Fig. 17C and 17D). Small-scale recent collapses and debris less than 1 meter wide were observed (Fig. 17E and 17F), they show light gray in color. Two mudstone were sampled on the narrow terrace (R003).

The large-scale cliff observed by this dive indicates that the eastern slope of the Minami Shiribeshi Knoll collapsed again and again, but the age of the last collapse is not known. Mud cover and colonies on the outcrops and blocks suggest that most parts of the slope have been stable for more than tens of years.

## 2.5. Dive #628 : Okushiri Ridge, west of Minami Shiribeshi Knoll (A. Takeuchi)

We aimed to investigate one of the faults, along the eastern slope of north-central Okushiri ridge (Figs. 1, 2 and 18), west of the Minami-Shiribeshi knoll in order to examine paleoseismic events by this fault including the most recent earthquakes off western Hokkaido in 1940 and 1993. Our objectives of the dive were to make visu-

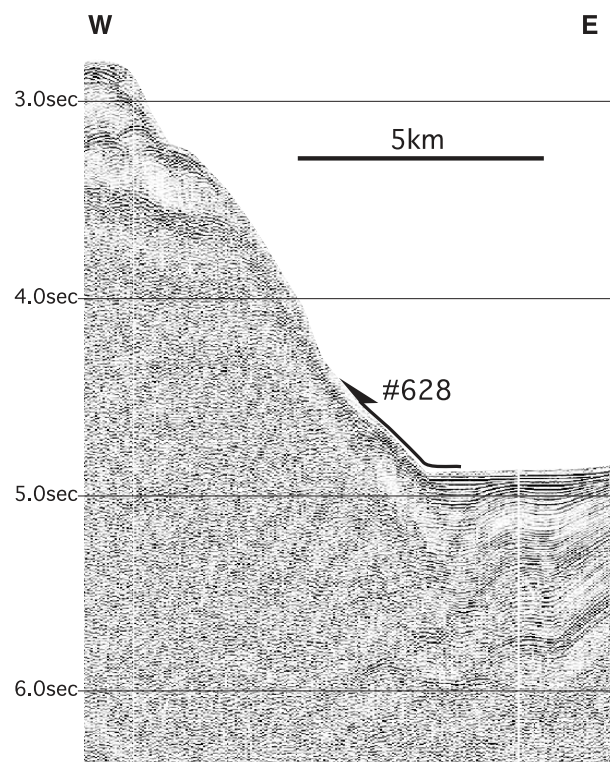


Fig. 18 Seismic profile of eastern slope of the Okushiri Ridge near the dive route #628.

al observation and camera recording of the seabed; samplings for sediments, water, organism, and rocks; investigation for seepage through the branching faults on the hanging wall and associated biological communities.

The eastern slope of north-central Okushiri ridge has two terraces, the lower (about 3,560m in water depth, w.d.) and the higher (around 3,440m w.d.) (Fig. 19 and 20). The dive began at the edge of the lowermost slope (43°17.6310'N, 139°19.8461'E; 3,622m w.d), where no outcrops and debris was distributed, and got two push-cores of sediments, one for X-ray CT analysis and one for reference (blank sample) of geochemistry. Just before the landing, we made water sampling by a Niskin sampler.

The dive #628 proceeded westward on the slope for more remarkable fault landforms, although we had missed the basin flat in front of the slope edge.

The lower slope was accompanied with shallow collapses (debris avalanche) and narrow outcrops of layered slope-sediments (Fig. 21A). Land slides seemed to

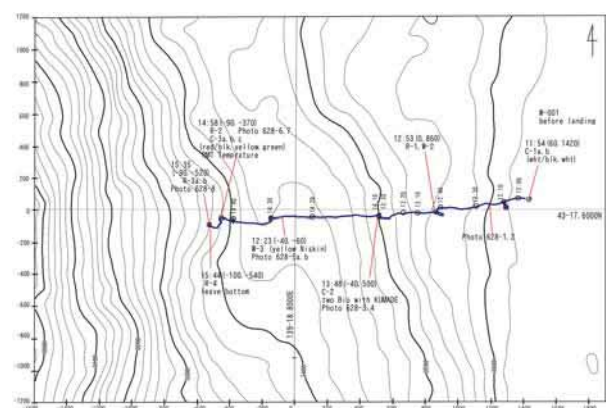


Fig. 19 Route map of Shinkai 6500 dive #628. Locations for rock (R) and core (C) samples and bottom geology are shown.

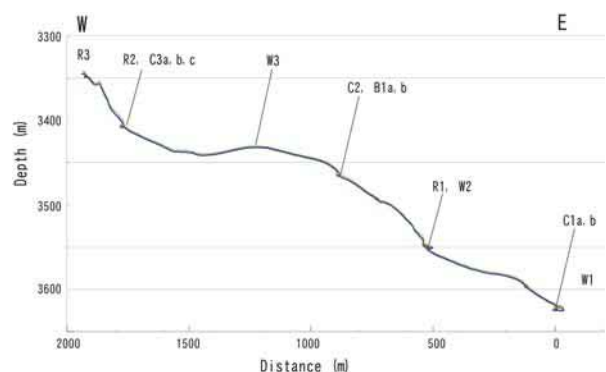


Fig. 20 Cross section of the dive route. Sampling points for rock (R) and core (C) as well as bottom geology are shown.

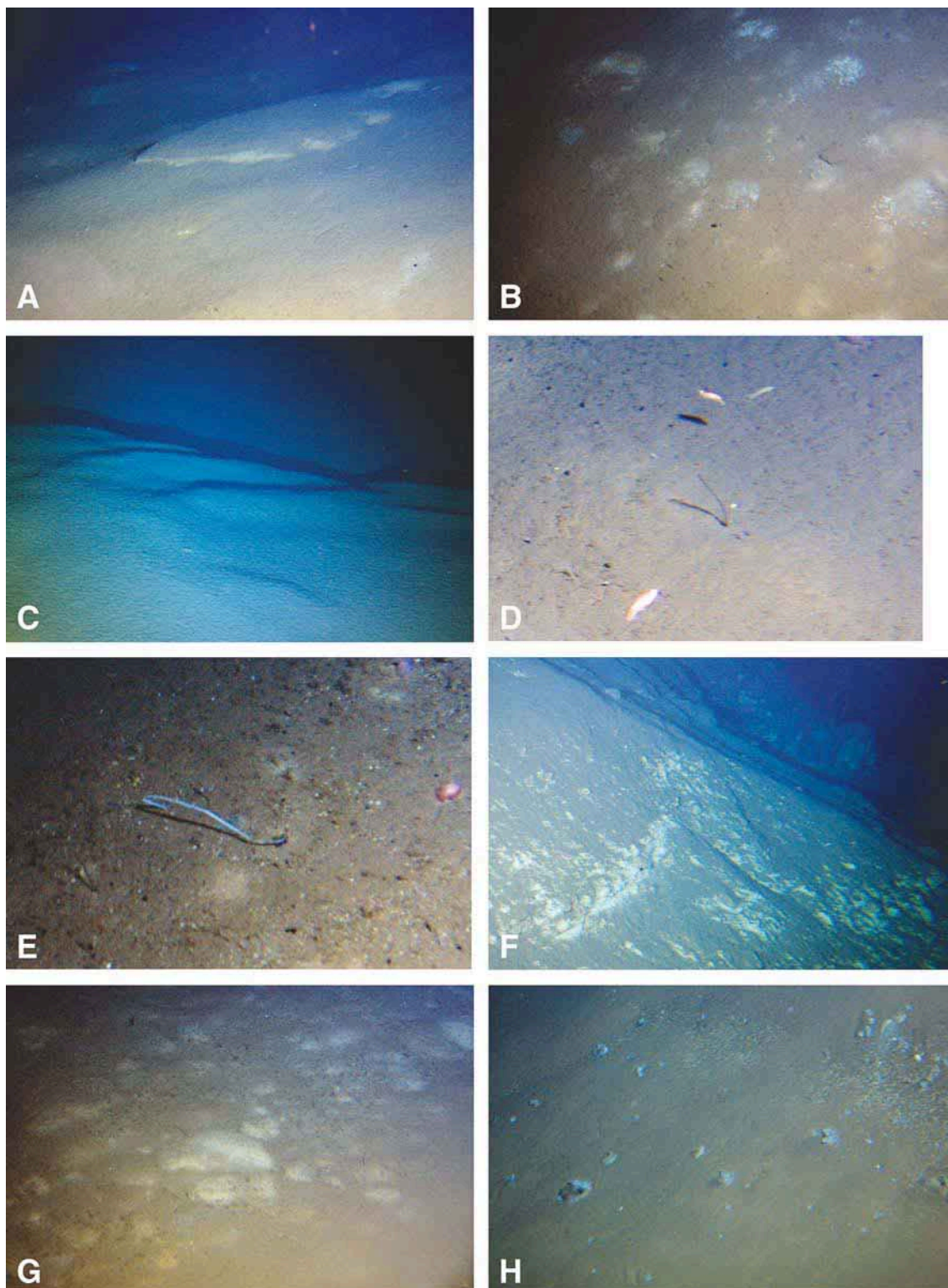


Fig. 21 Sea-bottom photos of dive #628.

(A) Slope failure on the first scarplet (12:12, 3,596m). (B) Buried talus with white patches (12:20, 3,597m). (C) Looking down a gullied scarplet of step fault (14:03 3463m). (D) A brownish string worms (13:47 3,463m). (E) A tube worm (14:28 3,440m). (F) Layered slope sediments and the basement (14:55, 3,405m). (G) Hummocky landscape of buried talus (14:25). (H) Fine-grained talus and spotted bacterial mats (15:15, 3,357m).

occur using bedding planes of the surface cover, more or less 10cm in thickness, which were slipped down away with resting small tables of remains on the slope. However, such micro landforms and debris were covered and buried by fragile blanket of mud, several centimeters in thickness (Fig. 21B), and no outcrop of surface break sub-parallel to the fault trace was found. Upon muddy floor, scaled polychaete, string worms and tiny bivalves were frequently observed.

At a central point of upward convex (top of steepest incline) in the middle slope, string worms were observed to form colonies associated with pale colored mats. Those mats are located just below a 2m high step of the slope (Fig. 21C), suggesting cold seeps along an active fault or toe of slid mass. On the apex of anticlinal convex, thin tube worms were found, and water sampling W2 was conducted for seepage geochemistry (Fig. 21D and 21E; 3,440m w.d.).

The later route of dive #628 met outcrops of layered mudstone (Fig. 21F) as well as slope slides with buried trace of avalanches (Fig. 21G), which is very similar to that of the lower slope (Fig. 21B) mentioned above. Finally, the dive reached the steeper slope with an apron belt of fine-grained debris (Fig. 21H), where RMT thermometer measurement of a basement mudstone through the sediments demonstrated an interesting temperature 0.17 degrees higher than the near bottom water (3,405m w.d.; Fig. 22).

The dive deployed marker buoys, no.38 to 40, at 3,546m w.d. on the boundary slope between the terraces, and at 3406 and 3,342m w.d. on the eastern slope of Okushiri ridge proper. In spite of sampling demands, no starfish or bacterial mat was observed through the

dive. The dive left bottom at 43°17.5496'N, 139°18.4120'E, and 3,342m w.d.

#### Summary of dive #628

- (1) No signs of present-day fault activity were found along the eastern slope of the north-central Okushiri Ridge in the seismic gap between the recent earthquake (tsunami source) areas.
- (2) Buried debris of slope avalanches found often in the dive route, indicating manifestation of the latest co-seismic event. Consolidated layered mudstones cropped out only in the uppermost dive route to form steep wall.
- (3) Two individuals of a thin type of tube worm were recognized on the apex of anticlinal slope. This is the first observation of living tube worms in the Japan Sea area, although sampling was not successful. Similarly, string worms on the step scarplet of the convex slope seemed accompanied with microbial activity in the field of soft debris (buried).

#### 2.6. Dive #629 : eastern slope of the Minami Shiribeshi Knoll, revisit of dive site #627 (Y. Sasayama)

This dive revisited the eastern slope of the Minami Shiribeshi Knoll, which was surveyed by dive #627 (Figs. 2 and 15) to collect the Pogonophora. It is generally accepted that the Pogonophora, that is, the beard worm, has a peculiar life style, since it lacks a mouth and digestive tract and has many tentacles, which are regarded as a beard. Therefore, this worm has been noted from the viewpoint of animal physiology. Usually, this worm inhabits deep-sea areas, including various areas of Japan such as the Sagami bay in the Pacific Ocean side and the Toyama bay in the Japan Sea side. Therefore, we expected to find this worm in this expedition. To our regret, however, we could not find any specimens, at least around the Minami Shiribeshi Knoll at a depth of 3,000m.

As we were diving in search for animals on the sea bottom, we found some kinds of sea cucumbers, and succeeded once in catching some using a Kumade sampler. Nevertheless, when we got back to the sea surface, sea cucumbers were no longer in the sampling box, as they easily drift in the seawater because their density is similar to that of seawater.

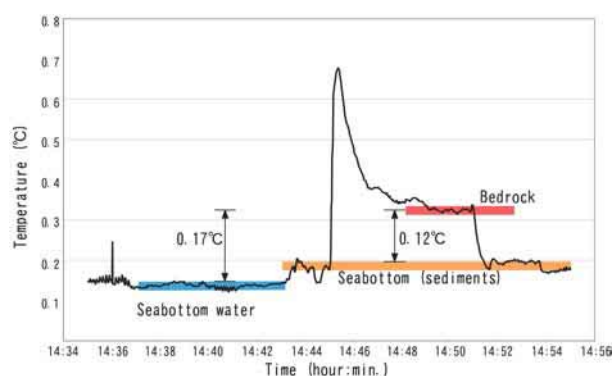


Fig. 22 Result of RMT thermometer measurement at the inflection between the upper and middle slopes.

Thanks to the pilots' efforts, however, we could get about 20 more species of invertebrates, although the number of intact samples was small. One species of amphipoda (crustaceans, Arthropoda) was collected by a trap that had been newly devised by Mr. Imai. The size of this shrimp was around 2cm in body length, and its color looked pinkish in the deep-sea. As soon as we arrived at the sea bottom, having a trap with fish meat inside, these shrimp rushed immediately to the trap and entered it. The number of individuals we could catch was very high, approximately two hundred. Therefore, the biomass of this amphipoda seems to be extremely large even at the depth of 3,000m. Furthermore, all species of shells and snails (Mollusk) were obtained using a Kumade sampler. One species of large-sized polychaeta (polynoidae or amphiomida, Annelida) was collected by utilizing a core sampler and a Kumade sampler.

Besides collecting animals, large-scale bacterial mats were discovered on the foot of the slope. The mats were not observed by dive #627, which has passed about 300m north of the mats.

## **2.7. Dive #630 : Okushiri Ridge, west of the Shiribeshi Seamount, revisit of dive site #626 (T. Gamo)**

Main Purpose of the dive was geochemical studies of cold seepage associated with bacterial mat-like white material on the seafloor in the northeastern Japan Sea.

Little is known on the chemical characteristics of cold fluid venting in the eastern margin of the Japan Sea. Previous works have found bacterial mats at and around the Okushiri Ridge area. Such biological communities strongly suggest the existence of cold seepage, which may supply hydrogen sulfide for chemosynthetic bacteria. It is probable that upward migration of methane, possibly derived from gas hydrate layers, should play an important role as an electron donor in producing hydrogen sulfide via sulfate reduction process. Oxidized methane (i.e. carbon dioxide) is expected to form carbonate concretion as previously observed in the eastern Nankai Trough cold seepage zones.

This dive aimed at obtaining much information of chemical characteristics of the cold seepage in the eastern margin of the Japan Sea, in a close collaboration with the chemistry group of Toyama University. Seawater samples just above the bacterial mats as well

as pore fluid samples below the mats were taken, in order to elucidate the concentration of chemical components (particularly  $\text{CH}_4$  and hydrocarbons) and their isotope compositions. Carbon cycles across the seawater-sediment interface will be discussed in association with bacterial activity (chemosynthetic bacteria, sulfate reducing bacteria, etc.), crustal deformation due to tectonic stress, formation of carbonate crusts, and gas hydrate at deeper depth.

As shown in Fig. 10 and 23, we landed on the eastern slope of the Okushiri Ridge (43°36.06'N, 139°18.24'E; 3,176m depth), ~11 miles westward from the top of the Shiribeshi Seamount. We climbed the slope just westward for the bacterial mat site (D=3,029m) located by the shinkai 6500 dive #626 a week ago (3<sup>rd</sup> of July). The distance between the landing point and the mat site is about 500 meters. During the ascent of the slope, rock outcrops and falling rocks were observed. Many of them are covered with communities of tiny semi-transparent bivalves.

We stayed at the #626 bacterial mat site about an hour, conducting water sampling just above the mat (with a Niskin bottle and with the ORI pump sampling system), push core sampling, and surface material sampling with a *Kumade* sampler (a rake made of stainless steel). Sediment samples taken with push corers were used for the extraction of pore fluids on board Yokosuka after the dive.

Additional surveys were performed to the northern (<~100m) and the southern (<~200m) directions from the #626 mat site (see Fig. 23). While little bacterial mats were observed in the northern area, distinct white patches of bacterial mats were observed to extend southward along the depth range of 3,027-3,037m. Additional samplings were conducted at two locations with bacterial mats (Fig. 24).

It is commonly observed that some hard material (probably carbonate concretion) exists just below the bacterial mat, which hindered the penetration of tube corers. In case that hard concretion material was broken by the shock of tube corers or removed by the *Kumade* sampler, black sediment (possibly containing sulfide particles) was appeared below the concretion.

No community of the tiny bivalves was observed just on the bacterial white patches. It seems that the bivalves form communities on the rocks which are appropriately away from a bacterial mat zone. It is probable that the

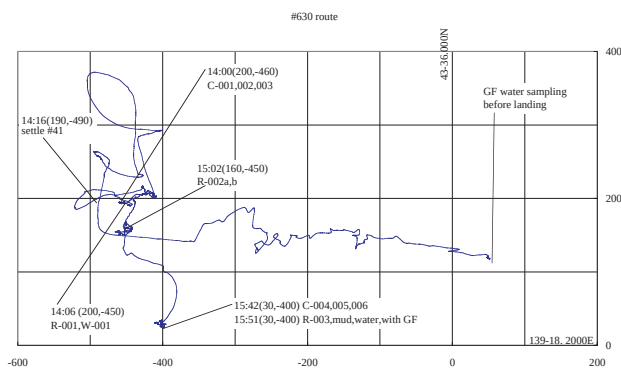


Fig. 23 A route map of the Shinkai 6500 dive #630.

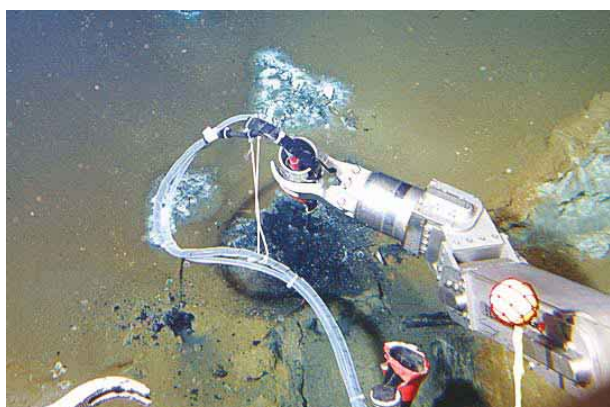


Fig. 24 Sampling of seawater just above the bottom using the ORI pump sampler.

environment in touch with the bacterial mats is unsuitable (or too severe possibly due to high concentration of hydrogen sulfide?) for the habitation of the tiny bivalves. In fact, the sediment samples from the bacterial patches have strong smell of hydrogen sulfide. The tiny bivalve community may be a good indicator for locating cold seepage zones, as similar to sea anemones around hydrothermal active zones.

## 2.8. Dive #631 : West of the Cape Motsuta, bacterial mat field (A. Takeuchi)

A wide-spreading field of bacterial mats found in 1999 by the dive #485 of Submersible Shinkai 6500 has surveyed by dive #624 to get a bacteria sample by utilizing a pressure-retaining sampler ( $42^{\circ}42.0634'N$ ,  $139^{\circ}40.0857'E$ , 3,135m) (Fig. 4). However, neither geological observation nor systematic sampling of water has been done.

To analyze the geochemical environment of the bacterial mats related to the cold seep activity and the geolog-

ical setting, we planned to complete this series of submersible investigation, mainly by mapping of spatial distribution of bacterial mats and by sampling of bottom-water and sediments. Detailed objectives are as follows;

- (1) Mapping of spatial distribution of the bacterial mats.
- (2) Analysis of the geochemical environment of the mat field.
- (3) Geological aspect for the origin of cold seep; structural, tectonic or volcanic?
- (4) Evaluation of effects by the 1993 Off-Southwestern Hokkaido earthquake ( $M7.8$ ,  $42^{\circ}47'N$ - $139^{\circ}12'E$ ) to the formation and/or existing of bacterial field.

The dive #631 began near the pressure-retaining sampler site of dive #624 (Fig.4, 25 and 26), referring to the marker buoy No.36. About 900m northward away from the #485 (and #624) site, isobathymetric traverse could locate the northern termination of the prominent microbial field where we deployed No.42 marker buoy (Fig. 4). Dimension of the field reach 40m in depth, 350m in east-west distance, and at least 900m in north-south distance,

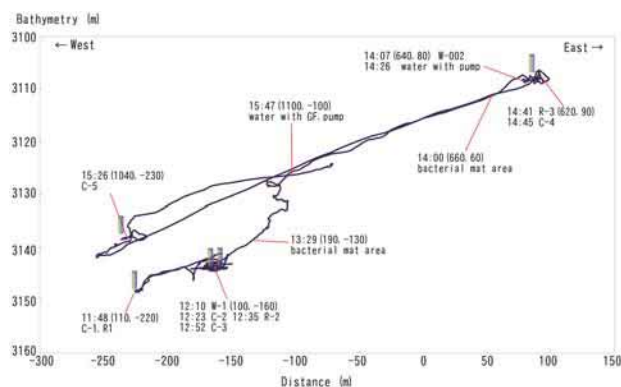


Fig. 25 E-W Profile of Dive #631.

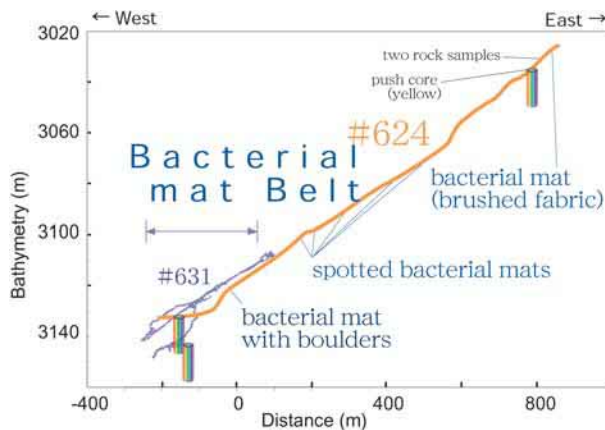


Fig. 26 Distribution of bacterial mats on E-W Profile of Dive #624 and #631.

and area exceeds 315,000 square meters. The mat field was situated at the edge of boulder zone where rounded block of metric size and boulders occupies and the extent is recognizable by the upward convex of bathymetric contours (Fig. 26). Most microbial mats were formed on horizontally flat places within the boulder zone.

We got near-bottom water sample by Niskin samplers just above a thick bacterial mats (Fig. 27A). Apparently, different types of bacterial mats are classified: 'panther hatched' (Fig. 27B), 'attaching' (Fig.

28A), and so on. Within the 'panther hatched' type several degrees of vividness are recognizable, 'super' (Fig. 27B), 'good', 'fair' (Fig. 27C), 'poor' (Fig. 27D), and 'lack' (Fig. 27E). Bacterial mats were developed on the surface of muddy sea-bottom, while attaching type of mats seemed to be formed directly by blowing-up seepage under some controls of screw current besides boulders (Fig. 28A and 28B). No chimney but a sink-hole type of mat was observed.

A linear array of black colored 'poor mats' and 'bro-

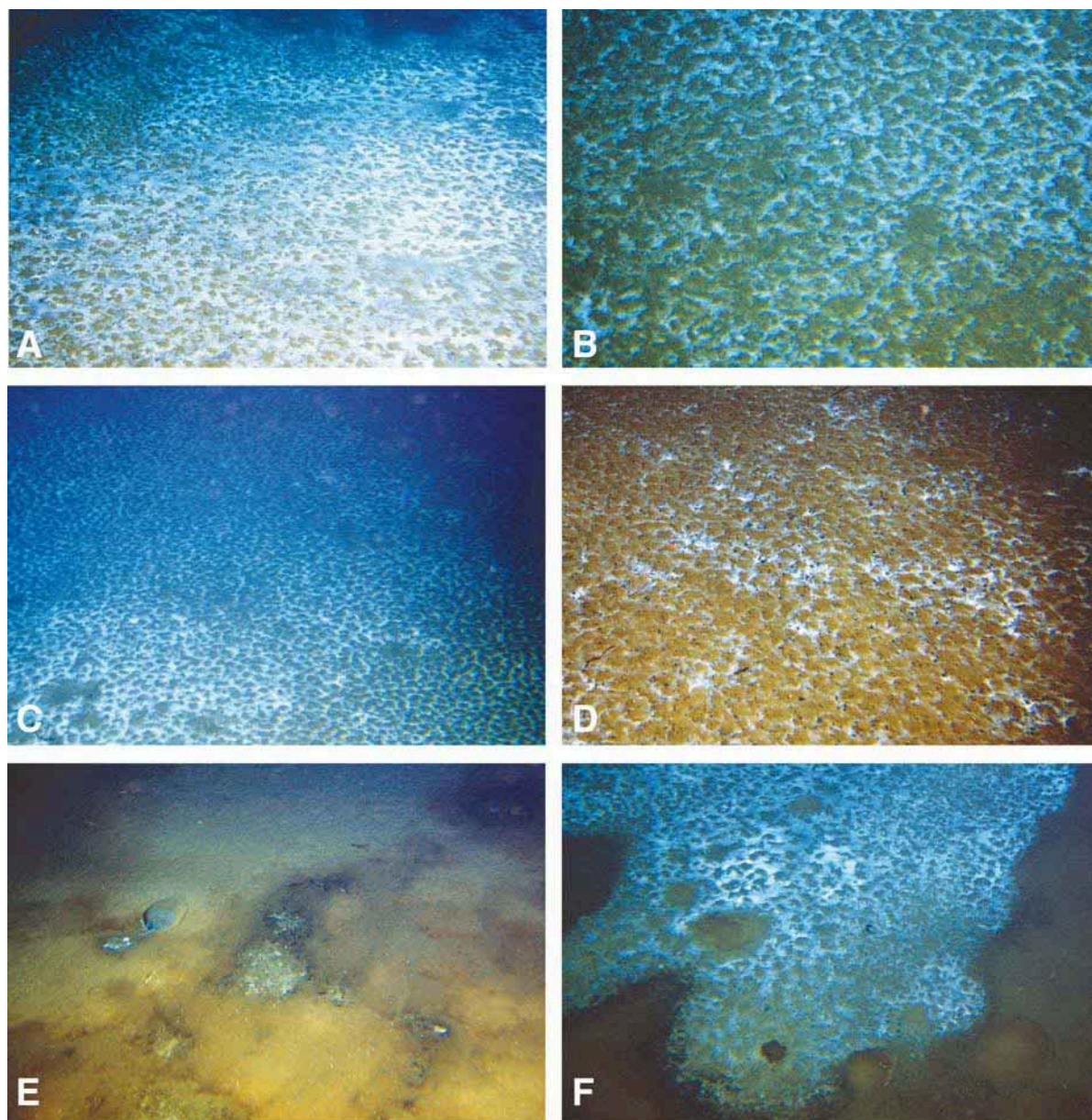


Fig. 27 Photos of bacterial mats

(A) Thick bacterial mat of 'panther hatch' at 3,115m. (B) Rich in bacterial mat with hummocky topography. (C) 'Fair' distribution pattern of bacterial mat. (D) Poor bacterial mat of 'panther hatched' hummocky topography. (E) almost lack of bacterial mat. (F) A thick bacterial mat and its margin.

ken or damaged mats' may be correlative to underground fissuring and/or strong seepage due to the 1993 SW off Hokkaido Earthquake (Figs. 28C and 28D).

We performed sediment sampling by push-cores and then collected bottom water by pumping units from each site of 'panther hatched' and 'attaching' types and from the outside. Inside, however, no push coring was successful because of coarse-grained sediments underlying the mats. Outside of the northern border of microbial field, yellowish deposits (perhaps jelly of iron hydroxide) spotted on the muddy floor (Fig. 28E).

#### Summary of dive

- 1) Dimension of the microbial field reach 40m in depth, less than 350m in dipping distance, and at least 900m in isobathymetric distance around 3,140m, and occupies an area more than 315,000 square meters.
- 2) The prominent microbial field was situated at the lowest margin of debris zone of metric sized boulders. A few degrees of maturity of a bacterial mat are proposed.
- 3) A linear array of 'poor mat' and 'damaged mats' might correspond to strong seepage due to fissuring by the 1993 SW off Hokkaido Earthquake.

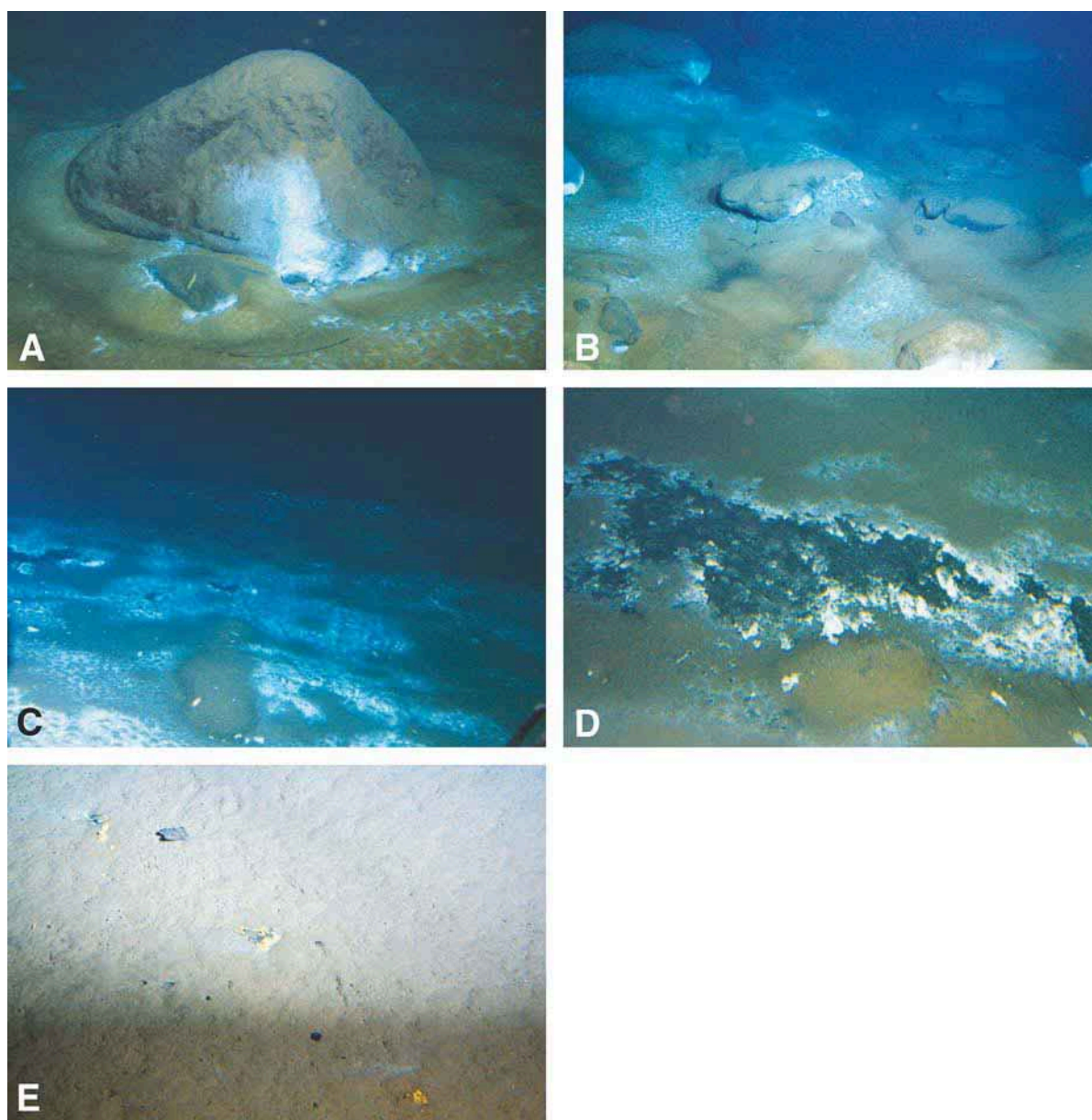


Fig. 28 Photos of sea-bottom and bacterial mats

(A) A boulder attached with a flush of bacterial mat. (B) Boulders attached with bacterial mats. (C) Linear alignment of amaged bacterial mat. (D) A Closed-up of damaged bacterial mat (3,143m). (E) Yellowish deposits on muddy floor.

## 2.9. Dive #632 : Western slope of the Okushiri Ridge, west of the Tsugaru Peninsula (Y. Okamura)

The source area of the 1983 Japan Sea Earthquake is located along the western margin of the Okushiri Ridge to the west of the Tsugaru Peninsula (Fig. 29). Seismological studies indicated that the ridge was not the source of the earthquake.

Detailed studies of the earthquake indicated that the source fault of the earthquake was about 120km long and dipping east. This fault is considered to expose along the western margin of the source area, where small-scale, discontinuous faults are recognized by seismic profiles. It is inferred that large-scale faults in the Okushiri Ridge have not broken and small-scale faults to the west of the ridge have broken, which suggests two possibilities. The first is that the 1983 earthquake is very rare earthquake, of which recurrence period is very long, more than several tens of thousand years. The other possibility is that the activity of the Okushiri Ridge is decreasing and faults to the west become active recently. This dive was planned to investigate the recent activity of the Okushiri Ridge near the source area of 1983 earthquake.

Detailed bathymetric chart and seismic profiles indicate that the target slope is composed of two terraces in the lower part, upper steep slope and a flat summit (Figs 30-32). Landing point is the lower terrace and is covered with muddy sediments. Before landing about 1.5m high from the bottom, a Niskin water sampler has triggered. Sea anemones are living on waste, rock frag-

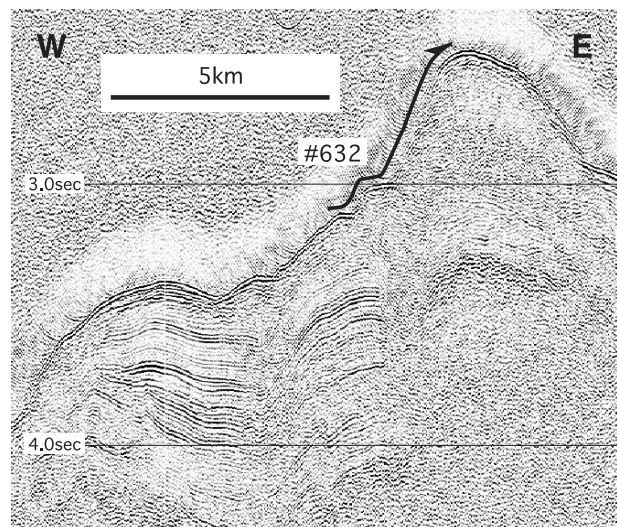


Fig. 30 Seismic profile across the Okushiri Ridge near the dive sites #632.

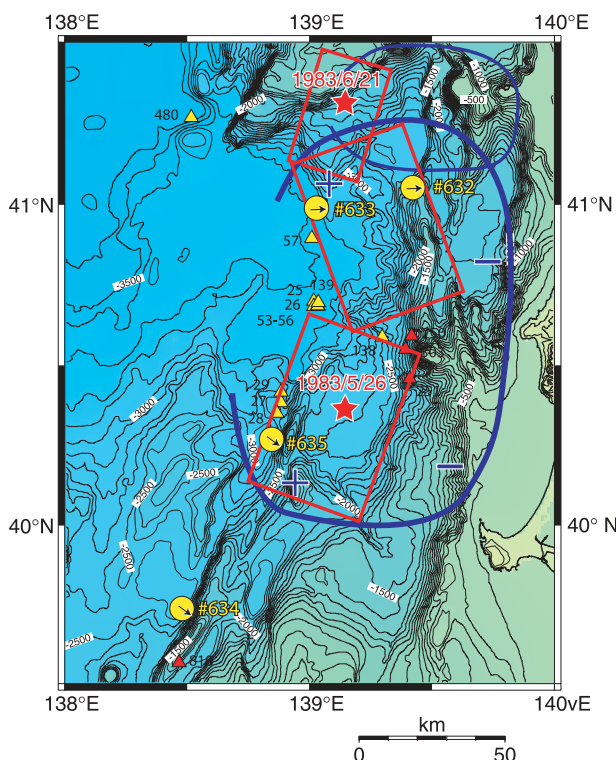


Fig. 29 Fault model and tsunami source areas of 1983 earthquakes. Dive sites of this cruise and previous cruises were shown.

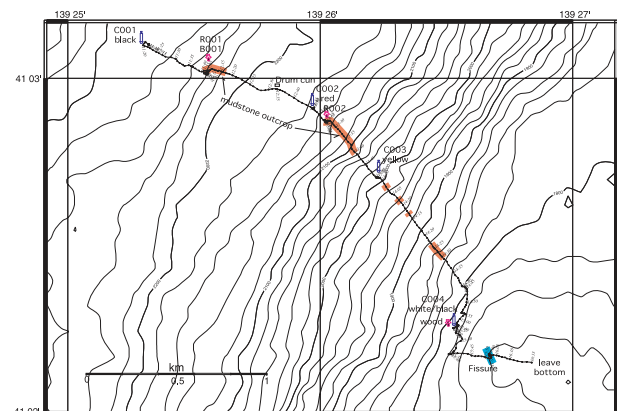


Fig. 31 Route map of Shinkai 6500 dive #632. Locations for rock (R) and core (R) samples and bottom geology are shown.

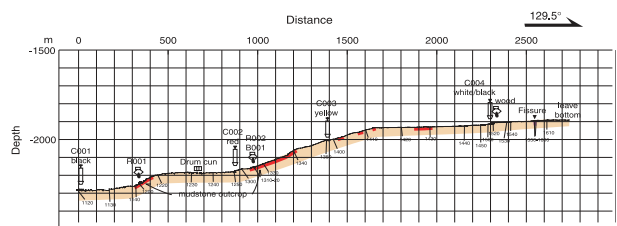


Fig. 32 Cross section of the dive route. Sampling points for rock (R) and core (R) as well as bottom geology are shown.

ments and other solid material (Fig. 33A), and crabs are often observed. A push cores was collected at the landing point (C-001, black). A slope between the terrace is characterized small-scale outcrops of mudstone which has stratification nearly parallel to the slope surface (Fig. 33B). The outcrops are covered with thin muddy sediments. A mudstone sample (R-001) and a sea

anemone have collected on this slope. The upper terrace is also covered with muddy sediments. A push core (C-002, red) has got near the eastern margin of the terrace. The top of this core is sandy silt indicating recent gravitational sediments.

Steep and gentle parts repeated on the upper slope. Mudstone outcrops and blocks are scattered on the steep

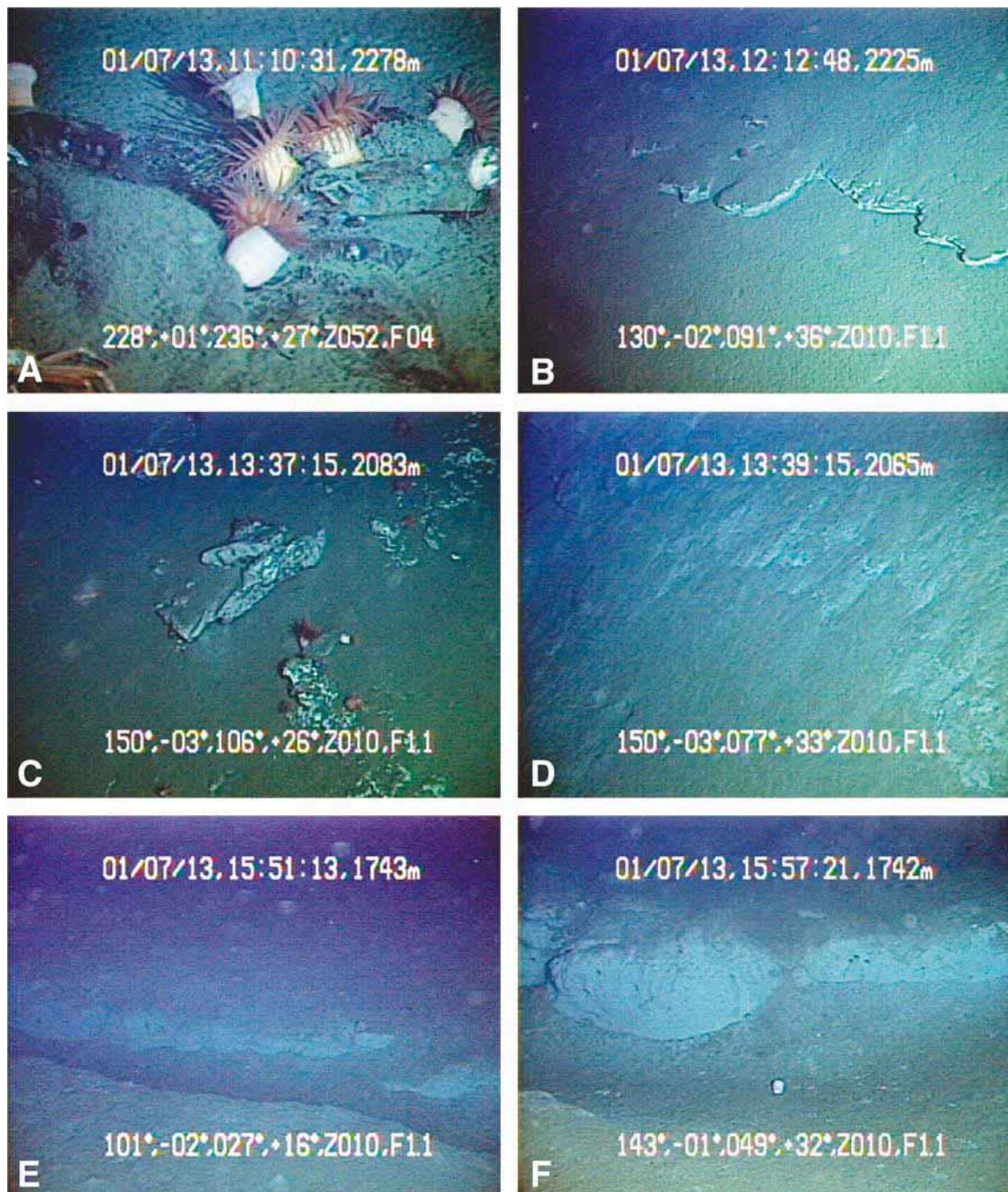


Fig. 33 Sea-bottom photos of dive #632.

(A) Sea anemones living on waste, rock fragments. (B) small-scale outcrops of mudstone dipping parallel to the slope surface. (C) Mudstone outcrops and blocks scattered on the steep slope. (D) Small-scale scarps of surface sediments falls. (E) Fissure near the top of the Okushiri Ridge. (F) The fissure is partly buried and wall of the fissure has collapsed, suggesting it is old.

part (Fig. 33C), while muddy sediments completely cover the gentle parts. Small-scale scarps of surface sediments falls (Fig. 33D) are sometimes observed on the steep slopes. A mudstone sample (R-002) was collected on the steep part and a push core (C-003, yellow) was taken on the gentle part. Cover of soft sediments on the outcrops and blocks are generally less than a few centimeters. As we close to the summit, gentle parts become predominant. Near the top of the slope, we collected a wood fragment on which sea anemones and other life are living.

At the western margin of the flat summit, we found several fissures (Figs. 33E and 33F). They are a few meters in width and a few tens of centimeters in depth. The wall of the fissure is partly collapsed and rounded, and their floor was buried by muddy sediments, suggesting that the fissure is old. Their lengths are less than a few tens of meter and distribution is limited in the narrow zone. The flat summit is covered with muddy sediments without disruption.

We have observed no large-scale collapse of the slope, indicating that the slope has been inactive recently. But sandy silt at the top of the push core and thin mud cover of mudstone outcrops and blocks indicate that surface sediments on the slope have fallen down by the 1983 earthquake.

## 2.10. Dive #633 : South of Matsumae Plateau, source area of the 1983 Nihonkai-Chubu Earthquake (A. Takeuchi)

The target of dive #633 was the western slope of small ridge (Figs. 29 and 34-36), which have formed at the boundary between the embayment of Japan Basin and the continental slope edge on the inner zone of Northeast Japan Arc (Fig. 1). The dive started at the base of the slope with obtaining near-bottom water sample by a Niskin sampler.

We landed on a gentle slope at 40°59.2785'N, 139°01.7598'E, depth of 3,313m, at a point 450m away from the foot of western slope of the first (Fig. 35 and 36), the lowest terrace (>3,260m), where no outcrop and debris was distributed. We got two push-core samples, one for X-ray CT analysis and one for reference (blank sample) of geochemistry (Figs. 35 and 36).

Recognizing a linear zone of strong reflection on the sonar screen of Shinkai 6500, we proceeded southeast

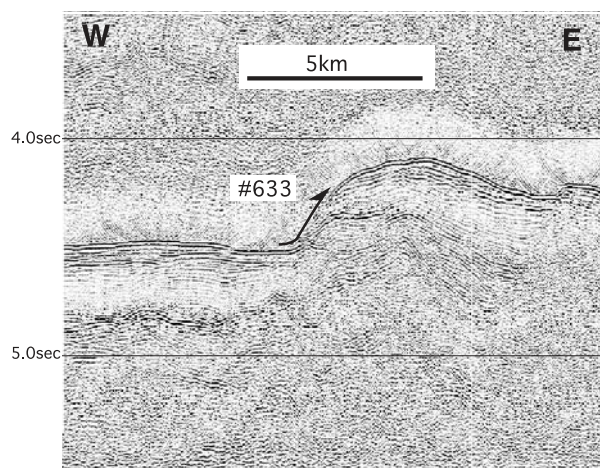


Fig. 34 Seismic profile crossing the ridge near the dive #633 site.

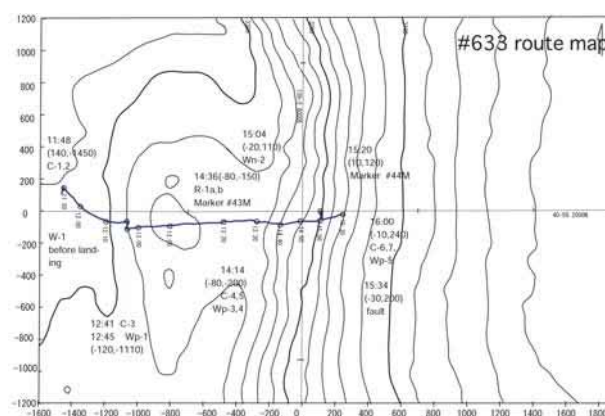


Fig. 35 Route map of the dive #633.

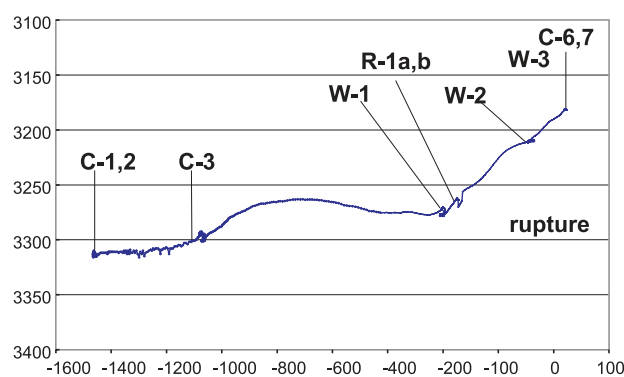


Fig. 36 E-W route profile of the dive #633.

and discovered a fault trace (inflection line), which bounds the sedimentary flat and the edge of west-faced slope of first terrace at a point 40°59.1373'N, 138°02.0379'E, depth of 3,300m. The slope was decorated with fresh collapses (debris avalanche) of slope and small outcrops of layered mudstone (Fig. 37A).

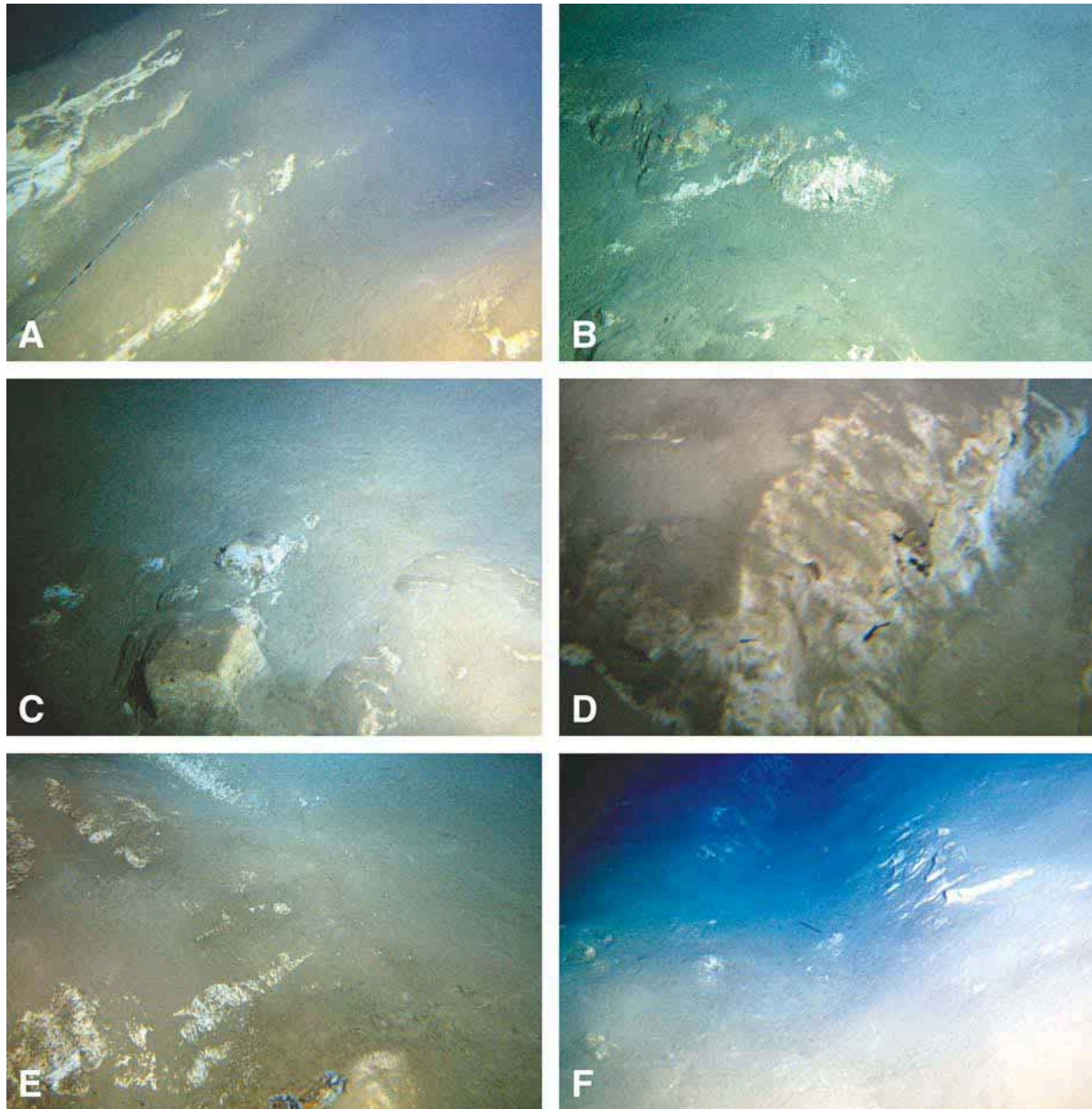


Fig.37 Sea-bottom photos of dive #633.

(A) Parallel narrow grooves due to slope failure (3,300m). (B) Corrugated surface (3,276m). (C) Pop-up rubble (3,274m). (D) Crossed gash (3,268m). (E) Buried grooves and talus (3,262m). (F) Cracked groove-wall (3,264m)

Slope failures seemed to occur within the surface cover, about 10cm in thickness, which were partly slipped down to make small cirques on the slope. The zone of slope failure paralleled the fault trace and was as narrow as several meters. However, no outcrop of surface break sub-parallel to the fault trace was found.

Then the dive proceeded on the planned course of 90°, while pale pink colored, small sea cucumber and large scaled polychaeta are frequently observed on the gentle, muddy bottom of an anticline hill.

Also according to the similar reflection of steep slope on the sonar screen as of the first slope, we discovered another inflection line, that is a fault trace, which bounds the flat bottom of the first terrace and the slope of second terrace at a point 40°59.1582'N, 138°02.6560'E, depth of 3,276m. The second slope was again decorated with fresh collapses and narrow outcrops of mudstone. Some outcrops of mudstone bedrock were corrugated probably by land-sliding (Fig. 37B). Pop-up rubble accompanied with buried fissures was

observed at the top edge of the slope (Fig. 37C).

On the midway of survey route, at a point around 40°59.2014'N, 138°02.8813'E and 3,209m depth, the dive met a spectacular zone of fracturing, demonstrated by wide gashes, narrow fissures, and other irregular cracks along the edge of a flat step within the west-faced slope of second terrace, where we set No.44 marker buoy. It is undoubting that most fractures in this place are of a co-seismic origin (Fig. 37C-F, 38A-C).

In spite of pre-dive sampling demand, no starfish was observed through the dive, and sea cucumbers were too small and light to be sampled. A couple of scaled polychaete and tens of small bivalves were obtained with rocks samples. The dive left bottom at 40°59.1942'N, 138°02.9745'E, 3,180m.

#### Summary of dive #633

- (1) Active fault traces of the deformation front were confirmed at water depths of 3298 and 3,276m along the west margin of 1983 earthquake/tsunami source area.

- (2) Severe fracturing found on a mid-slope step at 3,209m was so fresh as a distinct manifestation of the latest co-seismic event.
- (3) Fresh slope failures such as surface avalanches were observed widespread on the slopes of two terraces.
- (4) Irregular dispersions shown in sub-bottom profile may correspond to the zones of open gashes and slope failures.

#### **2.11. Dive #634 : Western slope of Sado Ridge (K. Satake)**

The location of the proposed plate boundary (or active fault zones) is not clear to the south of the 1983 Japan Sea earthquake source. Bathymetry and mapped active faults indicate that the boundary runs west of Sado Island toward Toyama submarine canyon, while the 1833 Shonai and 1964 Niigata earthquakes occurred further east near the coast.

In this dive, we visited the western slope of the Sado ridge (Figs. 2 and 39), where an active fault has been mapped by Okamura et al (1998), to examine the past

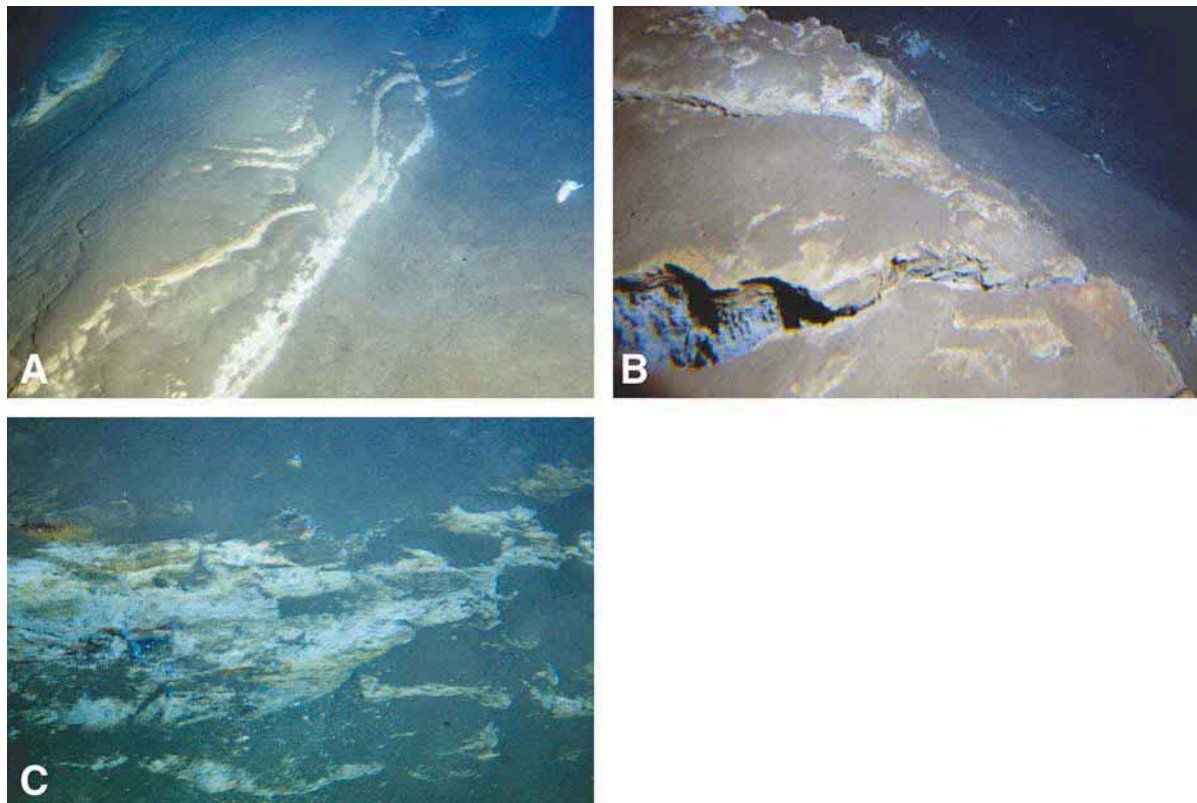


Fig. 38 Sea-bottom photos of dive #633.  
(A) closed-up of grooved wall (3,232m). (B) Open gashes on the terrace-edge (3,213m). (C) Open gash cropped stratified mudstone (3,209m)

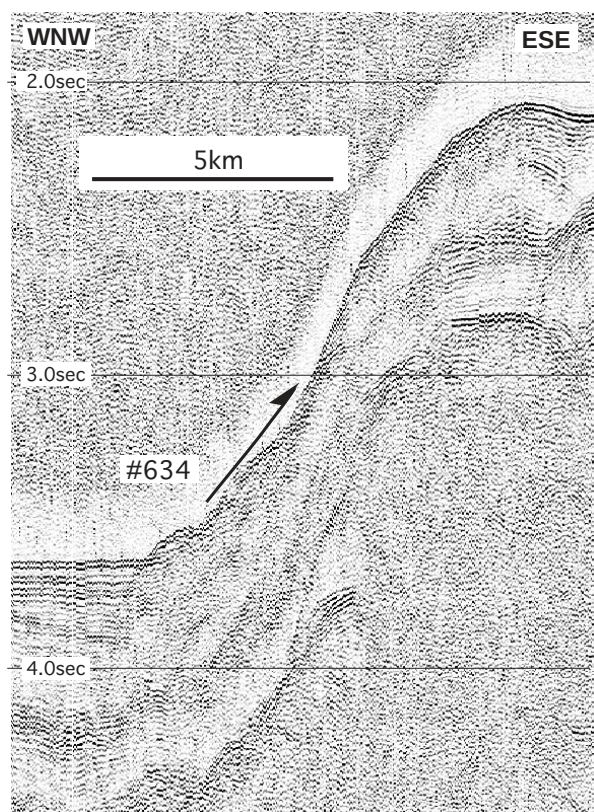


Fig. 39 Seismic profile of the western slope of the Sado ridge near the dive route #634.

earthquake activity. We made visual observation of the ocean bottom and sampled push-cores. The payload included 2 sample boxes, 3 markers, 7 push-corers, 2 Niskin water samplers, the ORI-type pump water sampler and the Kumade sampler. We obtained 5 cores, 4 rocks (mudstone and volcanic rock), water, driftwood, and biological samples (Figs. 40 and 41). Rock samples were first examined for attached biological samples. We collected numerous (about 100) small semi-transparent bivalves, Polychaeta and brittle star for biological and chemical analyses.

The dive started from the slope foot toward the east in a valley. From the valley center, we traversed the valley to the north, then we climbed the slope toward the southeast (Fig. 40). The dive route can be separated into 3 segments: ascent in the valley (11:30 through 12:40), traverse toward the slope foot (from 12:40 to 13:52) and climb of steep slope (13:52 through 16:01). The approximate height differences in the respective segments are 60m, nearly zero, and 300m (Fig. 41).

We landed on a flat bottom below the valley on the western slope of the ridge. Just before landing, we sam-

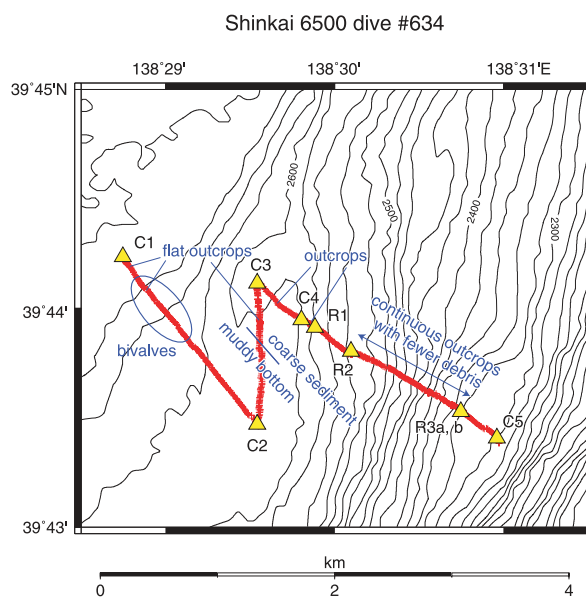


Fig. 40 Route map of Shinkai 6500 dive #634. Locations for rock (R) and core (C) samples and bottom geology are shown.

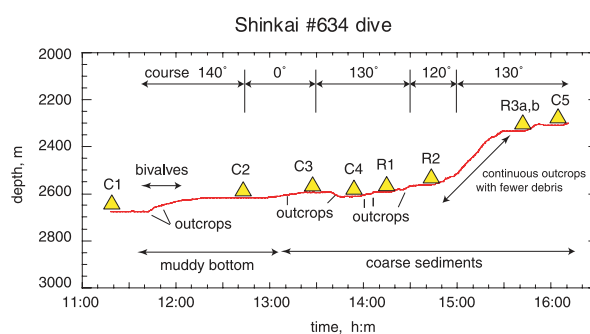


Fig. 41 Time-depth section of the dive route. Sampling points for rock (R) and core (C) as well as bottom geology are shown.

pled water by using one of the Niskin samplers (green). The bottom is covered with mud. We obtained push-core sample (C1, white/black), and started to ascend in the valley toward the southeast (140°). Soon after, we found two holes created by our own ballasts. The mud was so thick that the ballast themselves could not be seen. From around 11:40 (depth 2,676m), numerous small semi-transparent bivalve shells were observed on the muddy bottom (Fig. 42A). At 11:43 and 11:49, small outcrops (mudstone?) were observed. From around 12:00 (2,630m), the density of the bivalves became lower. Jellyfish swimming and brittle stars half-buried in mud were occasionally observed. At 12:40, we reached the center of the valley. We collected a push-core sample (C2, black) at this point, and changed the course toward the north.

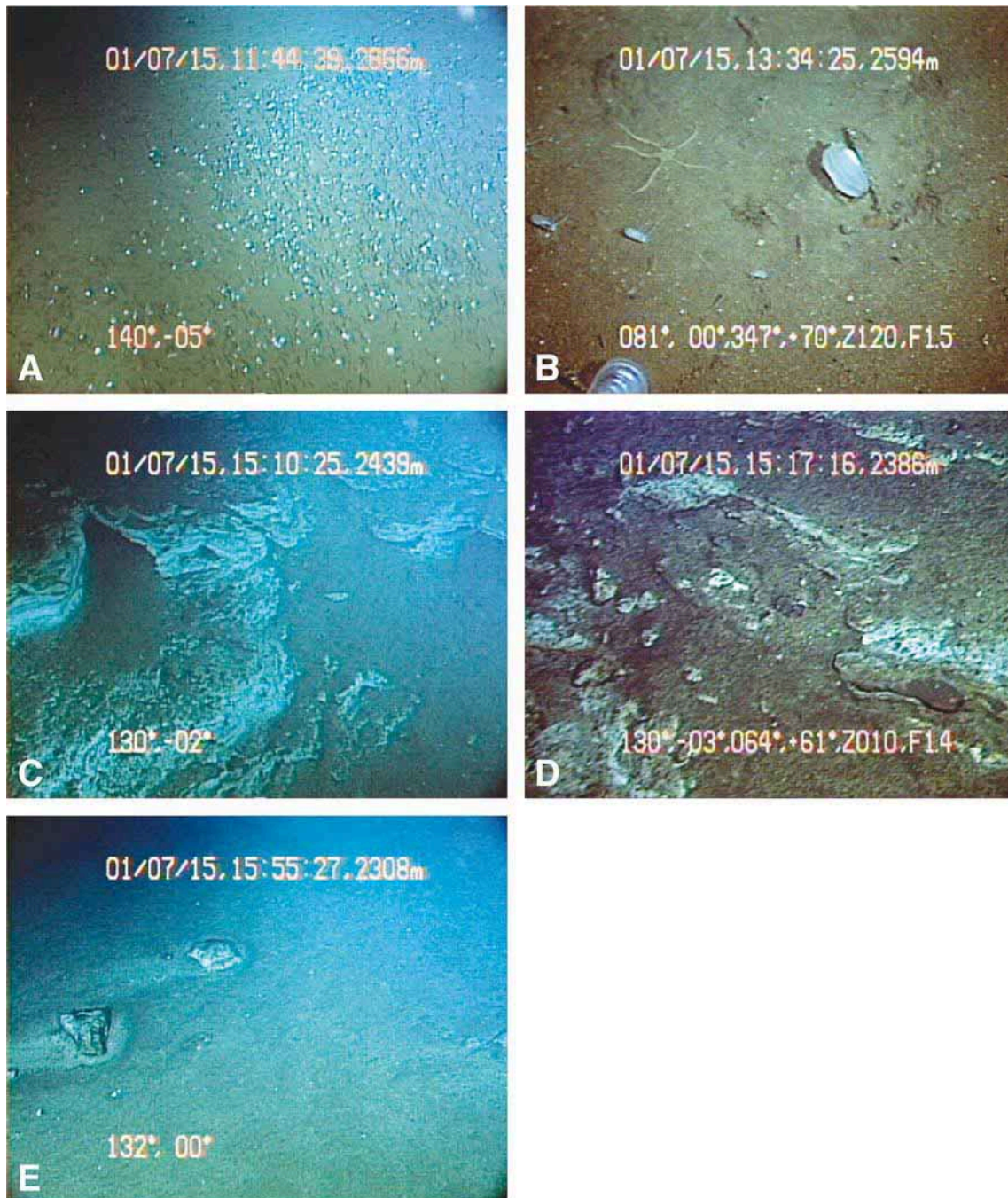


Fig. 42 Sea-bottom photos of dive #634.

(A) Numerous small semi-transparent bivalves are seen on the flat muddy bottom. (B) Close-up view of semi-transparent bivalves and a brittle star on coarse sediments. (C) Eroded headwall indicating that the collapse was not recent. (D) Collapse headwall and debris blocks. While the debris blocks are not covered with mud, the headwall is partially eroded. (E) Current crescent marks around the debris blocks indicating strong bottom current. The current direction is about 210°, parallel to the slope.

During the traverse of the valley, the bottom sediment became coarser and a few mudstone outcrops were observed. On a ridge crest at 2,595m depth, we sampled push-core (C3, yellow). Bivalves and brittle stars were

observed and video-taped (Fig. 42B). We then changed the course back to 130°, more or less parallel to the original course. We went down a gentle slope with occasional white outcrops. At a saddle point at 2,613m,

we made another push-core sampling (C4, green).

The last part of the dive route was a climb of steep slope of the ridge. Outcrops started to appear and continued for the entire slope. The bottom is covered with coarse sediments, probably brought by turbidite. At around 14:15, we sampled a rock (it turns out to be a piece of coal cinders) with many bivalves attached (R1). Slope covered with coarse sediments and outcrops continued. At 14:32, we changed the course to 120°. Similar slope with outcrops and coarse sediments continued. Angular blocks were occasionally observed, but the slope collapse did not seem to be fresh. At around 14:40, we sampled mudstone with bivalves attached (R2) at the depth of 2,563m.

The steep slope consisting continuous outcrops, debris blocks and coarse sediments continued from 14:50 (2,540m depth) through 15:30 (2,330m). The collapse headwalls are partially eroded and covered by thin sediments (Fig. 42C). Compared with the size of headwalls, much fewer debris deposits were observed. Only few of them seem to be fresh without sediment cover (Fig. 42D). On the way, we changed the course to 130° at around 15:00. On a gentle part of the slope, we sampled two rocks (R3 a and b) at 15:35 (2,334m). Sample R3a is a dark volcanic rock with brittle stars attached. Sample R3b is a white mudstone. After this point, sandy bottom with scattered debris blocks (including volcanic rocks) continued. From 15:53 (2,304m), the slope became gentle. Current crescent marks parallel to the slope were observed around the debris blocks (Fig. 42E), indicating strong bottom current. On the foot of next steep slope, we sampled push-core (C5; red) and a piece of drift wood. The core mostly consists of coarse mud clast fragments. We left the bottom at 16:11, after we sampled water using the other Niskin sampler (yellow).

Continuous collapse headwalls and turbidite sediments indicate that an earthquake occurrence in this region. The date of the most recent event is unknown, but does not seem to be recent. Because of the strong bottom current, the sedimentation rate on the upper slope may be very small. This means that the small amount of mud cover on the debris blocks or outcrops does not necessarily indicate the recent occurrence.

## 2.12. Dive #635 : Northern end of the Sado Ridge, near the southern margin of the source area of 1983 Nihonkai-Chubu Earthquake (A. Takeuchi)

In co-operation with the previous dives #632 and #633, the protocol of dive #635 was to search any seabed breaks (faults) due to 1983 Nihonkai-Chubu Earthquake (Fig. 29) and to observe sea-bottom disturbances with geochemical and ecological aspects as well as seismotectonic viewpoints.

According to the previous seismotectonic investigations (e.g. Satake 1985; 1989), remarkable dislocation is inferred along west margin of the southern segment of fault planes. Dive #635 aimed to observe the seabed faults directly related to the 1983 earthquake and tsunamigenic crustal movement, and to confirm the southern termination of the source area.

The dive #635 began in the northern portion of N-S trending straight valley, west of the northernmost Sado ridge (Figs. 2 and 43), getting near bottom water by a Niskin sampler.

We landed on a horizontal flat at 40°16.1049'N, 138°50.7223'E and depth of 3,049m, at a point 150m away from the edge of gentle slope below the steep western wall of the northern Sado Ridge (Figs. 44 and 45), where no outcrop and debris but narrow troughs subpar-

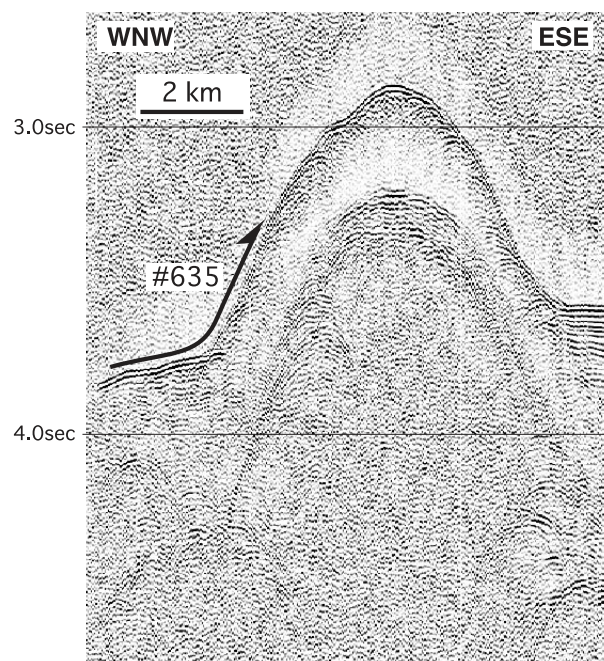


Fig. 43 Seismic profile across Sado ridge near the dive route #635.

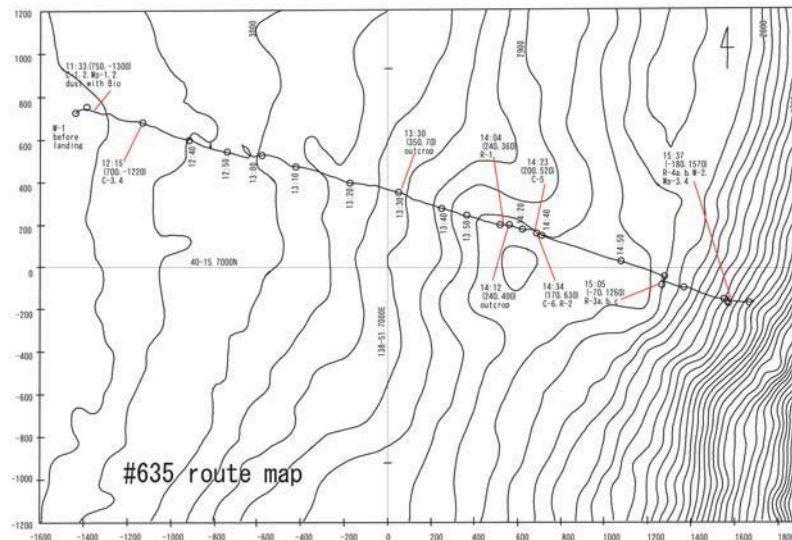


Fig. 44 Track chart of dive #635. Bathymetric contours are acquired by SeaBeam 2021 system on R/V Yokosuka.

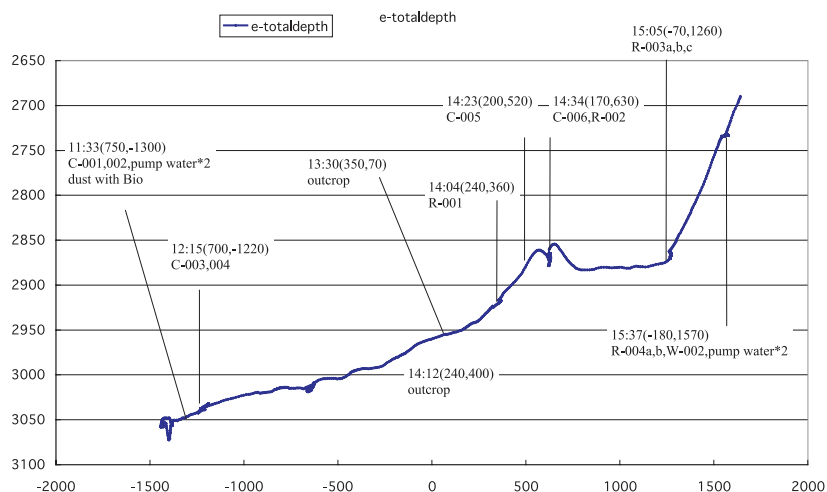


Fig. 45 E-W route profile of the dive #635.

allel to the slope edge were distributed. We got two push-core samples from one of the deeper trough, in (green core) and out (yellow), where many shells of pecten (scallop) were resident on plastic bags and other artificial materials (Fig. 46A).

After we collected pectinid samples, the dive proceeded in the planned course of  $110^\circ$  of East. Pale pink colored, small sea cucumber and large scaled polychaeta are frequently observed on the muddy floor.

Recognizing clear image of a step as a linear zone of strong reflection on the sonar screen of Shinkai 6500, we discovered a fault scarplet, about 2m high, with fresh collapses (debris avalanche) of slope (Fig. 46B)

and small outcrops of layered mudstone (Fig. 46C) at a point  $40^\circ 16.0765'N$ ,  $138^\circ 50.8403'E$ , depth of 3,037m, just along the edge of gentle slope. As was observed during the dive #633 in the northernmost source area of the 1983 earthquake, small slope failures affected the surface cover, about a few tens of centimeters in thickness, which were partly slipped down to make small cirques on the scarplet (Fig. 46D). However, no outcrop of surface faulting was found along the first scarplet.

Upon the gentle slope, we often observe narrow depressions fringed by cracks and angular rubble due to in-situ brecciation and falls, where, sometime, pale colored mudstone (otherwise, tuffs) were recognizable. On

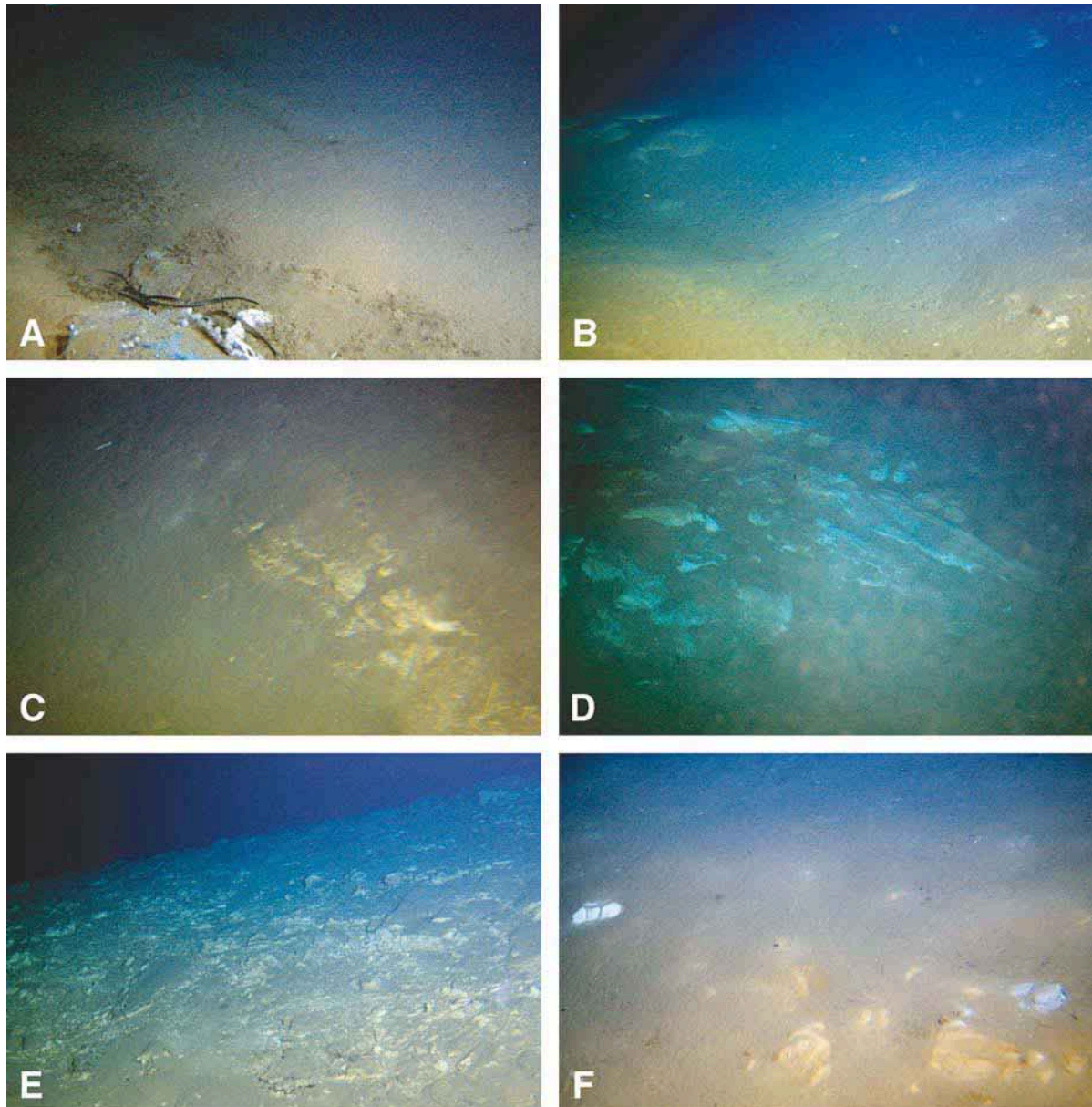


Fig. 46 Sea-bottom photos of dive #635.

(A) Parallel narrow grooves with plastic bags appended by pectinid shells. (B) The first fault-scarplet. (C) Mudstone outcrop. (D) In-situ fracturing along the upper edge of scarplet. (E) Mudstone ridge. Relative height is 8m from 2,995m. (F) Rubble due to in-situ brecciation or fall.

the midway of dive route at a point of 2,995m depth, a larger outcrop of mudstone was observed to form a narrow ridge with a relative height of 8m. The crest was free from dusty cover but fractures and rubble were recognizable (Fig. 46E). Although the origin was unclear, it is still possible that such fracturing is of a co-seismic origin. We picked up a talus-stone sample of volcanic rock on the scarp of the second terrace at 40°15.8268'N, 138°51.9563'E, 2,916m (Fig. 46F), from where the slope

became steeper and talus increased in number. Hereafter, mudstone outcrops were visible on the western edge of the second terrace. We obtained two rock samples and two push cores from the sedimentary flat near the small hill formed on the second terrace at 40°15.7919'N, 138°52.1430'E, 2,851m (Fig. 47A). Passing through the sedimentary flat of the second terrace, we met the foot line of the steeper wall of Sado Rigde, where we collected three rock samples at 40°15.6629'N, 138°52.5959'E,

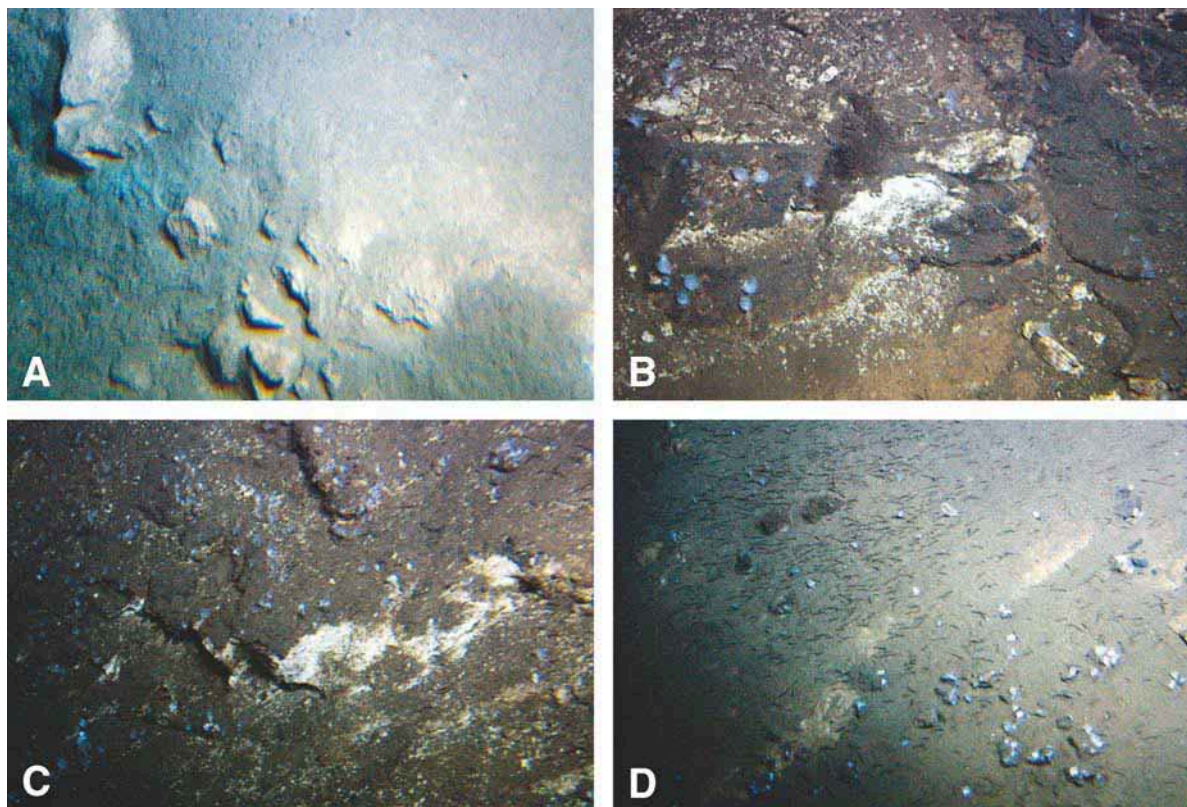


Fig. 47 Sea-bottom photos of dive #635.

(A) Older debris (breccia formation). (B) Outcrop of mudstone. West side cliff of 2,850m hill (2,915m). (C) Outcrop of mudstone. (D) String worms and small pectinids.

2,861m (Fig. 47B). This operation started the later half of the dive from 2873 to 2,734m.

Climbing the west-faced slope of the ridge, the wall was almost paved with fresh talus, but we could observe the underlying mudstone through the slid windows of talus (Fig. 47C), where string worms (clam worms) as well as tiny transparent bivalves (pectinids) were observed (Fig. 47D).

Debris stones on the lower talus were fully covered by 'algal' specula and looked older, while others were bared but occupied by such tiny bivalves. Therefore, at least, such talus full of pectinids clearly indicate recent event of rock fall or collapse of the shallower and steeper part of Sado Ridge, possibly due to co-seismic disturbance by the 1983 earthquake. After observation and Photography of their dense distribution in the shell field at a final site of the dive (40°15.6052'N, 138°52.8028'E, 2,733m), we collected a Niskin bottle and two pump-bottles of water sample and two rock samples with attached shells of pectinids. The no.45 marker was also

deployed on this site for the future dives.

The dive left bottom at 40°15.6089'N, 138°52.8757'E, 2,682m, where the talus pavement was still thick, including larger rounded blocks.

In spite of sampling demand from biologists, no starfish was observed through the dive, and sea cucumbers were too small and light to be sampled. At the landed point and, depth of 3,049 and 2,733m, a scaled polychaete and tens of were obtained with rocks and plastic bags.

#### Summary of dive #635

- (1) A distinct scarplet of active fault along the west margin of the 1983 earthquake and tsunami source area, discovered at a water depth of 3,037m.
- (2) The latest event of high-speed failure of unconsolidated strata by the co-seismic ground-motion on the hanging wall of the frontal thrust, observed.
- (3) A widespread, vivid settlement of enormous numbers of bivalves and spicular animal, also discovered. High energy is necessary for the dense biomass.

*SeaBeam* 2112 is a multibeam survey system built by L-3 Communications Sea Beam Instruments, Inc. for producing wide-swath contour maps and acoustic backscatter images of the seafloor. Two main subsystems compose the hardware: a 12 kHz transmitter and a receiver. The sonar beams, with a narrow  $2^\circ$  beam angle fore/aft, are projected as a swath and travel through the water column to the sea floor and are reflected off the bottom. An array of hydrophones mounted across the bottom of the ship receives the reflected sonar signals. This receiver array detects and processes the returning echoes through multiple stabilized narrow athwartship beams ( $2^\circ \times 2^\circ$ ) in a fan shape. The swath width varies from  $120^\circ$  to  $90^\circ$ , decreasing with increasing water depth. The system electronics process the signals, and based on the travel time of the received signals and signal intensity, calculates the bottom depth and other characteristics for echoes received across the swath. The bathymetry data represents a maximum of 120 data points per sonar ping, while the acoustic backscatter data contains up to 2000 pixels per ping. Swath location is based on navigation from the Global Positioning System satellites, using a differential GPS system, and ship motion input from an onboard vertical reference unit.

or better. One important parameter for accuracy of depth and position of the bathymetric survey is the sound velocity profile. Data quality also depends greatly on the sea state. Favorable sea conditions during YK01-06 cruise allowed for surveying at speeds from 12 to 15 knots, though at times ship speed was reduced on windy transects. The typical swath width for this system is 2-3 times the depth.

Post-processing includes editing of the cross track and navigation data (deletion of bad data, correction of position, etc.), making grid files, and bathymetry and backscatter plots. The software used for post-processing includes MB-System [Caress and Chayes, 1996] and the GMT-System [Wessel and Smith, 1995]. Bathymetry processing for all survey lines was performed onboard using the MB-System interactive program *mbedit*. Preliminary amplitude and acoustic backscatter imaging were also carried out using other MB-System. After all processing is complete, the remaining points are gridded or mosaicked and various maps are produced. The grid cell interval for regional survey is typically 100m.

During -YK01-06 cruise-, detailed SeaBeam surveys were conducted in three areas (Fig. 48).



a. Kuril Trench

Extended site-surveys for dives #622 and 623 were carried out around the corner of Kuril and Japan trenches. The detailed bathymetry map shows a steep inner wall associated with the subduction of a seamount. The dive points #622 and 623 were actually on this steep

wall. Another peculiar feature is a rhombic basin located landward the steep inner wall, just north of the bulge created by the subducted seamount.

b. Oshoro Seamount (Fig. 49)

Hydrographic department of Japan Coast Guard had

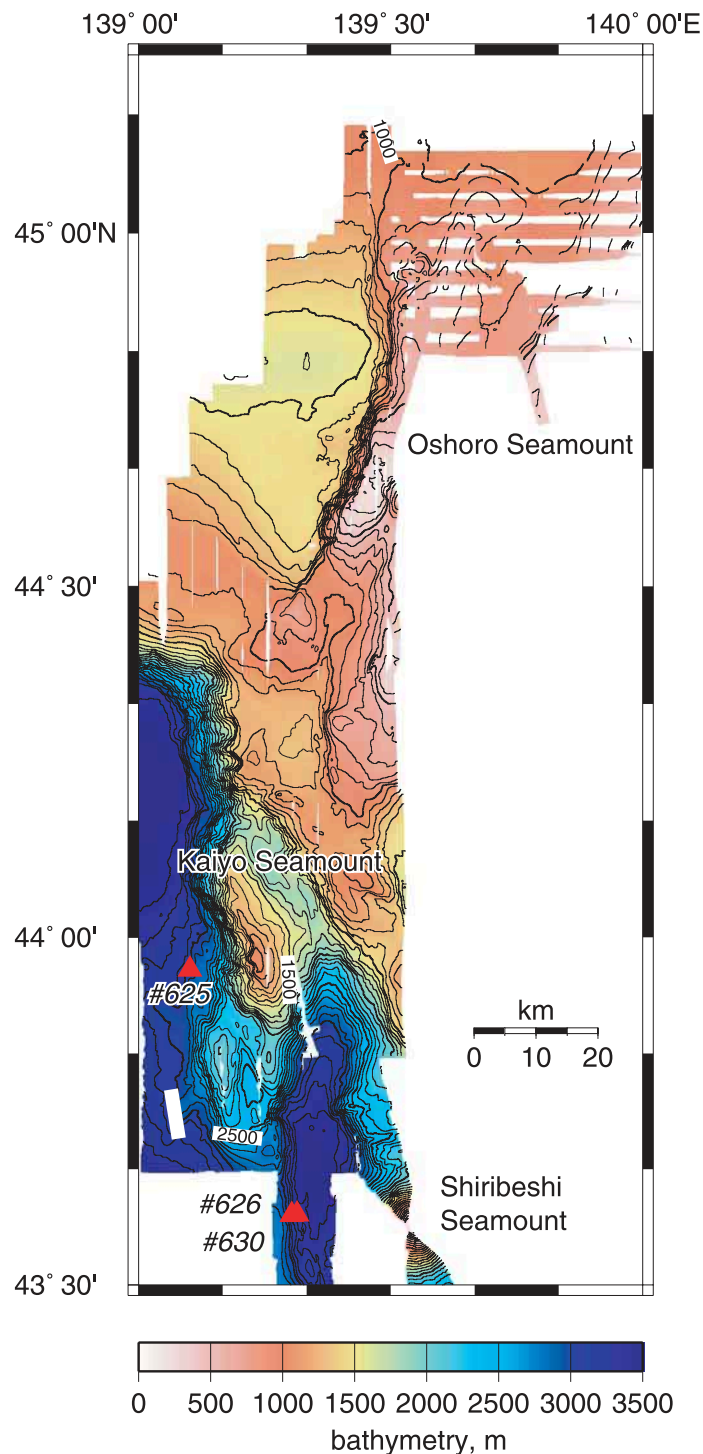


Fig. 49 Seabeam map of the Kaiyo and Oshoro seamount west of Hokkaido.

surveyed and published the detailed bathymetry map for the eastern slope of the Oshoro seamount. The western slope, below which an active fault is inferred, and the northern end of the seamount has not been previously mapped. During the YK01-06 cruise, we attempted to map the northern and western slopes as wide and detail as possible.

For the northern end, because of the shallow depth (less than 1,000m), swath coverage was limited. We therefore decided to map along the EW lines at 2 mile intervals. Although we could not completely cover the area, the topographic features of NS running seamount are roughly mapped. The Oshoro seamount appears to be branched at 44°56'N, and the main ridge continues to approximately 45°05'N, longer than previously mapped.

The new bathymetry map shows that the western slope of the Oshoro Seamount is very steep. Furthermore, there is a large (~10km wide) slump fea-

ture at around 44°42'N. Debris deposits are clearly mapped in both bathymetry and backscatter images. Another interesting feature is a NE-SW linearment offsetting the ridge at around 44°30'N. These features indicate that the inferred fault beneath the western slope of Oshoro seamount is active.

#### c. Mouth of Toyama Deep-sea Channel (Fig. 50)

Roughly 6,600km<sup>2</sup> of seafloor to the northeast of Yamato Rise was mapped after all the dives were completed. The new bathymetry map shows the mouth of Toyama deep-sea channel, nearly 500km from the Toyama bay. In the southern end of the mapped area, the channel wall is nearly 100m high, though it becomes smaller to the northwest. Sediment waves parallel to the channel are clearly seen in both topography and backscatter images.

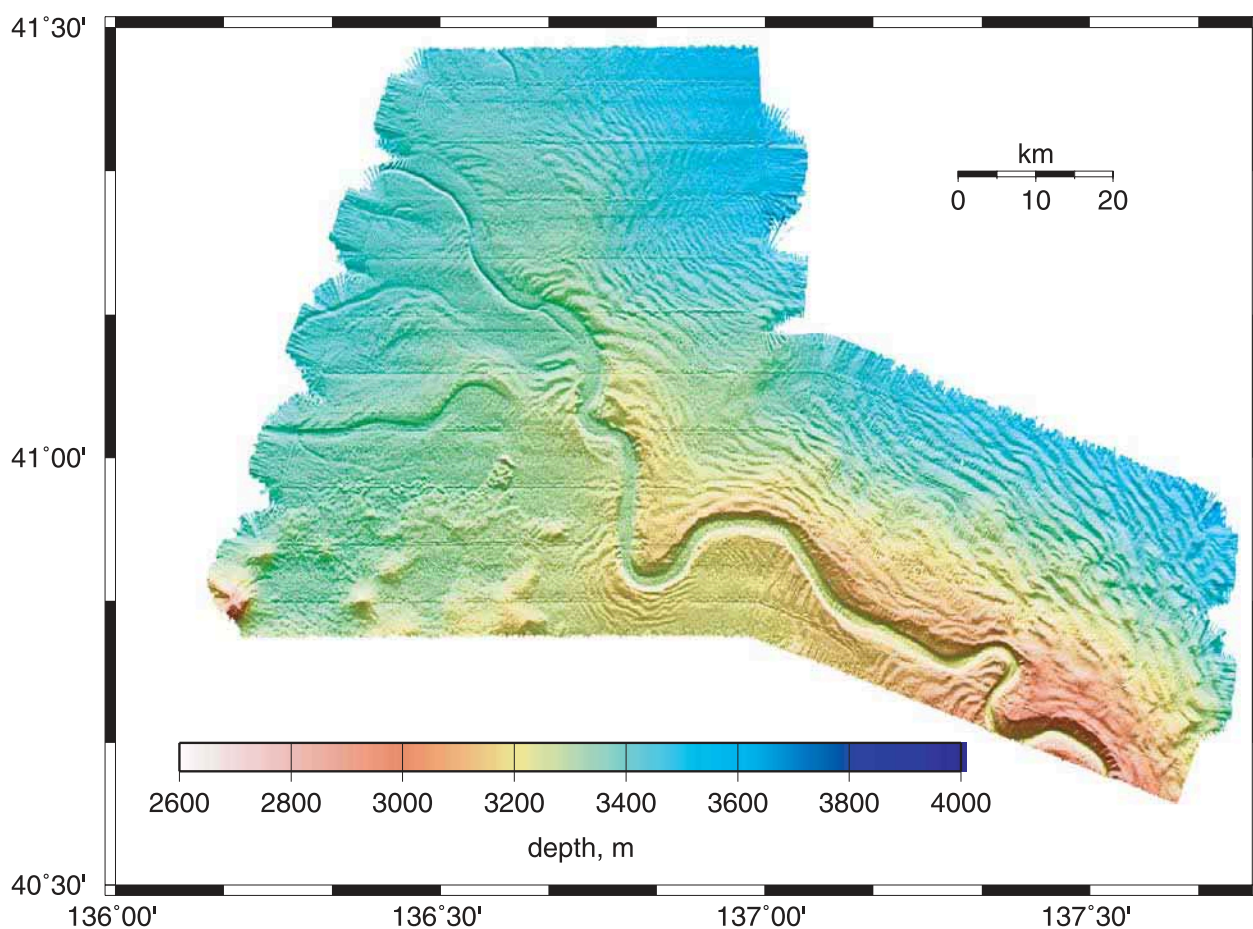


Fig. 50 Seabeam map of northern end of the Toyama Deep Sea Channel in the Japan Basin.

## 4. Post Cruise Analysis

### 4.1. Sediment core

Visual description and X-CT imaging was conducted for 33 sediment core samples collected during 9 dives. Most of them are composed of hemipelagic mud, but gravity flow deposits are recognized in 7 cores (Fig. 51).

Wavy laminated clayey silt was obtained by Core #625 C-4 with thin hemipelagic mud cover from the western slope of Kaiyo Seamount. X-CT image of the core indicated the occurrence of sand grains in laminated silt. A glaucony grain was found in the lower part of the core suggesting the grain supply from the upper part of the slope where modern sediment accumulation rate is nil or very little. Thin but clear turbidite sand with parallel lamination was found in Core #626 C-2 from the eastern slope of the northern Okushiri Ridge (Fig. 51-1). No or little hemipelagic mud cover on the turbidite suggests the occurrence of recent slope failure near the coring site.

Clear turbidite layers were observed in three cores (Cores #627 C-1, #629 C-1 and #629 C-2) from the northern Shiribeshi Trough (eastern foot of the Minami Shiribeshi Knoll). Upper turbidite layer has the same

characters through three cores. It shows sharp base contact, upward fining graded structure, and thin (0.5-1cm thick) hemipelagic mud cover (Fig. 51-2 and 52). Very thin hemipelagic mud cover indicates very recent deposition of the turbidite layer. Turbidite layer with the same characters was reported from the Shiribeshi Trough, Okushiri Basin and eastern margin of the Japan Basin, west of Okushiri Island, and was thought to be the seismo-turbidite by the 1993 Hokkaido-nansei-oki Earthquake (Ikehara and Inouchi, 1998; Shimokawa and Ikehara, in press). Then, the turbidite layers found in the present cores are also thought to be formed by the same event. In Cores #629 C-1 and #629 C-2, another turbidite layer was recognized. Hemipelagic mud of 4-5cm in thickness occurred between two turbidites. Benthic foraminiferal tests were found in lower turbidite in Core #629 C-2. It suggests the turbidite sand might be transported from the upper slope shallower than at least 1,000m. Similar occurrence of turbidite was reported from the Shiribeshi Trough and eastern Japan Basin

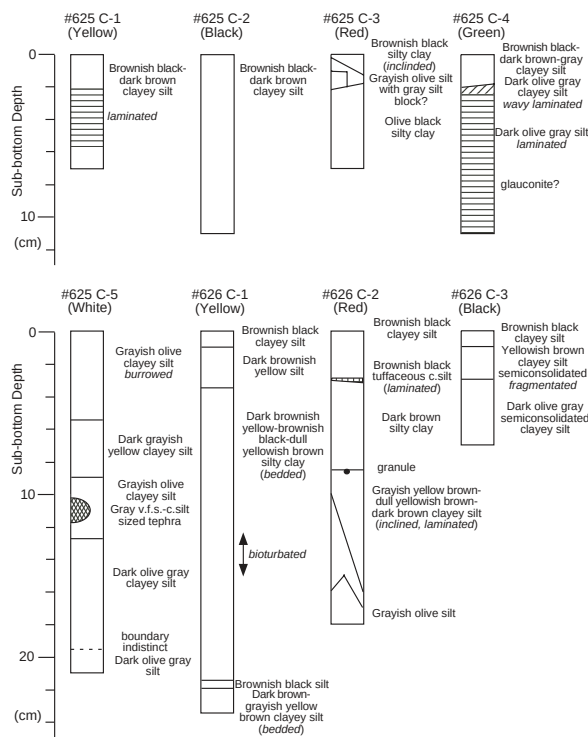


Fig. 51-1 Columnar section of collected sediment samples.

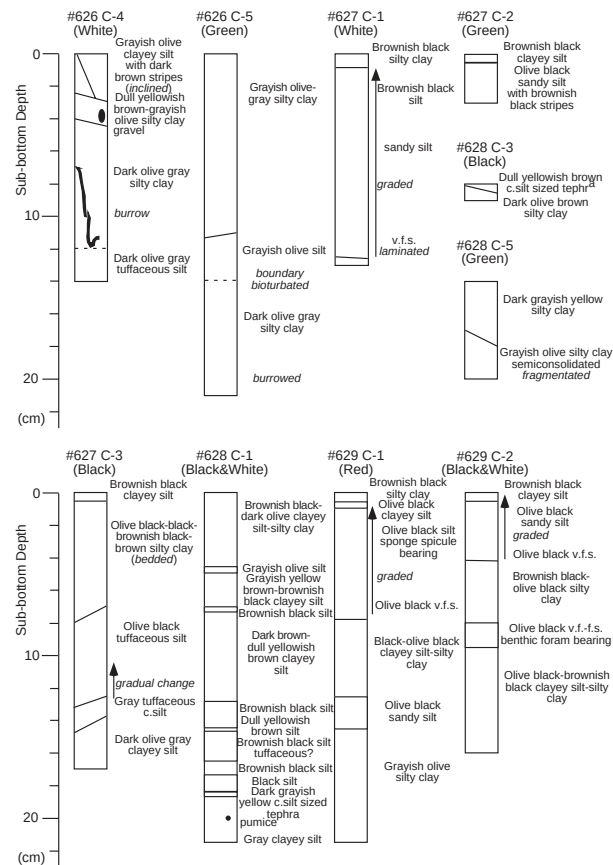


Fig. 51-2 (continued)

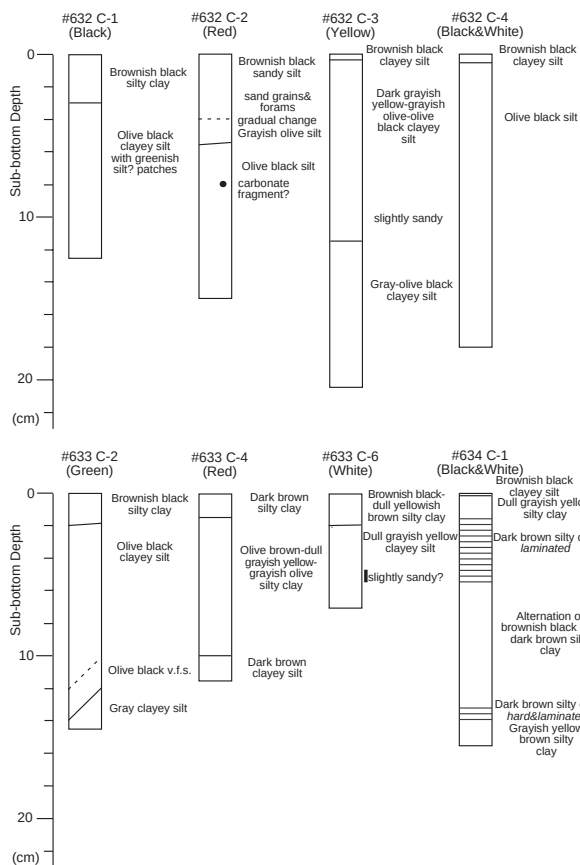


Fig. 51-3 (continued)

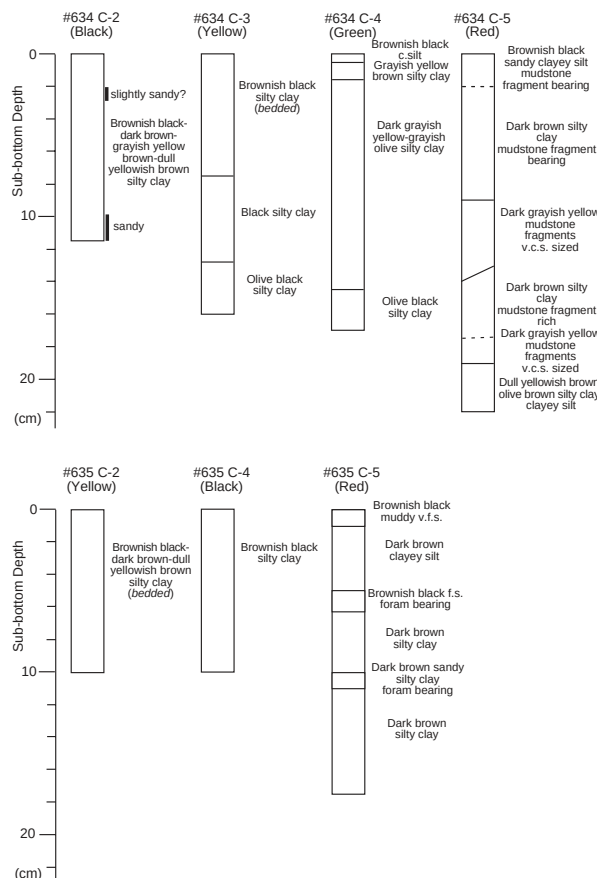


Fig. 51-4 (continued)

(Ikehara and Inouchi, 1998), and the event forming the turbidite was thought to be the collapse of Oshima-Oshima Island in 1741 (Shimokawa and Ikehara, in press). It is hard to correlate each other at present, because of the difference of grain composition, and no occurrence of volcanic ash layer (Ko-d from Hokkaido Komagatake), which found in the samples reported by Ikehara and Inouchi (1998), in the present cores.

Evidences on down slope sediment transport were recognized in four cores around the source area of the 1983 Nihonkai Chubu Earthquake. Sandy silt with foraminiferal tests found in 1.5-4cm deep of Core #632 C-2 suggesting the grain supply from shallower water along the slope. A small piece of carbonate (?) grain with high x-ray absorption, which has the similar character of "carbonate chimney" collected from the western slope of Matsumae Plateau by submersible Shinkai 6500 dive 480, was occurred from olive black silt with sub-bottom depth of 8cm. A relatively thick turbidite with upward fining graded structure was found in Core #633 C-2 from south of Matsumae Plateau. A lot of

mudstone fragments occurred in the upper to middle part of Core #634 C-5. Based on the concentration of mudstone fragments, this is divided into two sedimentary unit. Each unit shows the higher concentration of the fragment at the basal part. Because many berrecia (debris block) and outcrops of mudstone were observed around the coring site, mudstone fragments were supplied from the nearby outcrops by the earthquake events. Age of the event, however, is unclear, because of no age assignment and the possible bottom erosion by strong bottom currents along the slope forming obstacle scours around the debris blocks. An obvious turbidite and two sandy parts were recognized in Core #635 C-5 (Fig. 52) from the eastern slope of the northernmost Sado Ridge near the epicenter of 1983 Nihonkai Chubu Earthquake. Foraminiferal tests were observed in the three horizons. The uppermost sand occurs at surface indicating very recent event which might be correlated to the 1983 Nihonkai Chubu Earthquake.

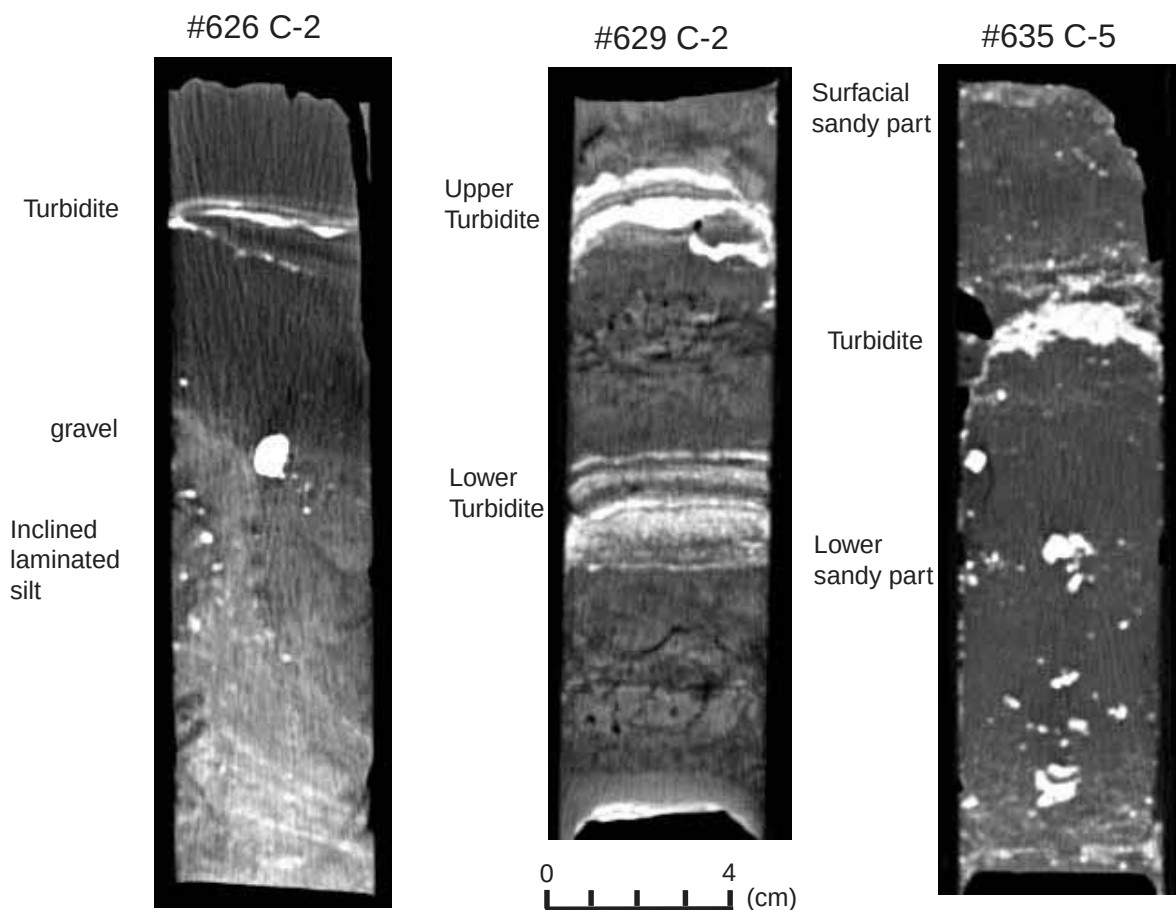


Fig. 52 X-CT images of three cores.

#### 4.2. Slope failure

Large-scale slope failures have been observed during the four dives in the seismic gaps between the source area of the 1940 Shakotan and 1993 off SW-Hokkaido earthquakes. They are covered by thin muddy sediments, suggesting that events were not recent. Taking into account the sedimentation rates in this area as around 10cm/ky, these observations strongly suggest that faults are active while no earthquake has occurred recently. There is a possibility that earthquake potential in this area is higher than surrounding areas.

Fresh slope failures were widely observed in dive # 633, while small-scale surface fall were observed on the slope during the dive #632. Buried slope failures are predominant at dive #635. These dives strongly suggest that the earthquake fault of 1983 Japan Sea earthquake is located near the small ridge to the west of the Okushiri Ridge.

Another seismic gap to the south of the 1983 Japan Sea earthquake was surveyed by dive #634 on the active

fault along the western margin of the Sado ridge. Upper part of the slope is widely covered by broken rocks and coarse sediments, while lower slope was covered by muddy sediments. Current crescent marks on the upper slope suggest that strong currents have swept away muddy sediments and exposed old debris. These observations support that this area is a seismic gap.

#### 4.3. Cold seepage

Bottom seawater and/or pore fluid samplings were performed during the dives #628, 629, 630, 631, 632, 633, 634 and 635. From these samples, we have detected high content of  $\text{CH}_4$  (up to  $340\mu\text{mol kg}^{-1}$ ) with extremely low  $\delta^{13}\text{C}$  values of -75 to -84‰. These data confirmed for the first time that a great quantity of bacterial  $\text{CH}_4$  is emanating from the bottom of the eastern Japan Sea. It is strongly suggested that some of the  $\text{CH}_4$  comes from gas hydrate layers below the seafloor.

We will elucidate the mechanism of fluid circulation in the eastern Japan Sea bottom, using the  $\text{CH}_4$  data

together with pore fluid geochemical data. Comparative studies will be done for the cold seepage in the eastern margin of the Japan Sea with that of the Nankai Trough accretionary prism. Chemical flux due to the cold seepage will also be estimated using more detailed data and in situ seepage meter observations in the near future.

#### 4.4. Bacteria

The plenary studies for microbial diversity analyses showed that no piezophilic microorganisms were found in these sediments obtained by the pressure-retaining sampler cultivated using the DEEPBATH system during dive #624. Kato and Nogi (2001) reviewed that the diversity of piezophilic *Shewanella* in the deep-ocean should be co-related with deep-ocean current from the polar area. Therefore the deep-ocean current is not flowing to Japan Sea, because of the depth of its gates, so the results shown above may be proofed the co-relations between the diversity of piezophiles and the deep-ocean current.

Another important finding is that no epsilon Proteobacteria were not detected in the mat sediments, which usually identified in the cold seep sediment (Li and Kato, 1999). We do not have enough data to explain this result, so we need more samples to realized the features of the microbial structure in Japan Sea cold seep sediment.

#### 4.5. Bivalve

In this cruise, many tiny semi-transparent bivalves were collected. Studies in our laboratory after the trip indicated that the species name of these bivalves was known as the *Delectopecten vitreus macrocheiricolus*. We examined the gonads of this species in detail using a microscopy to determine whether cyclic changes are present or not, even in the deep-sea environment. Furthermore, we examined growth curve of their shells and the number of individuals in each size. As a result, we could determine that these bivalves breed cyclically even in the deep-sea environment without seasonal changes. Also results of histological observation supported this conclusion.

#### 5. SUMMARY

1) Visual observation of slope and push cores on the terraces under the steep slopes provide strong evi-

dence of paleo-seismicity during the last thousands years. Ten dives along active faults strongly suggested the presence of two major seismic gap between the 1940 and 1993 earthquakes to the west of Hokkaido and between the 1983 and 1964 earthquakes along the western margin of the Sado Ridge.

- 2) New bacterial mats have discovered at two sites. Most of the bacterial mats are located on the slope along the active faults, while the largest bacterial mat field off Cape Motsuta spread on the marginal slope of the Shiribeshi Trough where no active faults is identified. High content of CH<sub>4</sub> has detected from seabottom, which suggests that the CH<sub>4</sub> comes from gas hydrate layers below the seafloor.
- 3) Sea-bottom sediments around bacterial mats were obtained by the pressure-retaining sampler. Microbial diversity analyses of the sediments strongly suggested that deep-sea water from polar area has not flow into Japan Sea.

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