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Deep-tow survey in the KAIKO-Nankai cold seepage areas

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ABSTRACT

Deep-sea biological communities associated with cold venting were located within the eastern portion of the Nankai Trough using a deep-towed TV system. Five continuous lines (approximately 200 km long) were observed. Bivalve communities were found both in the Tenryu Canyon outlet region and at the outcrop of the frontal thrusts of the accretionary wedge off Cape Omaezaki. The former is a site at which biological communities had been found during the KAIKO dives in 1985. However, the second site appears to be associated with larger scale venting and was chosen for the 1989 KAIKO-Nankai submersible cruise. Three small mud volcanoes with diameters of several hundred meters and heights of several tens of meters are found in the Seabeam topography map, but the present survey showed neither evidence of recent venting nor biological communities.

1. Introduction

Detailed features of the deep-sea bottom surface at the toe of the landward slope of trench were observed by the manned research submersible *Nautile* in June 1985 under the auspices of the French-Japanese KAIKO Project [1,2]. Benthic communities including bivalves *Calyptogena* [3] were discovered at several sites: the northern and southern Japan Trench (40 and 36° N, $D = 5900$–5600 m) [4,5], the westernmost Kuril Trench (41° N, $D = 5700$ m) [4] and the eastern Nankai Trough (33° 37′ N, $D = 3800$ m) [6]. Bivalve communities in the eastern Nankai Trough were first found by the *Nautile* at the intersection of the frontal portion of Nankai accretionary prism with Tenryu Canyon. Temperatures a few centimeters below the surface within the benthic communities were higher than those in the surrounding areas, although the exact value of the vertical gradient of temperature within the sediments was not known. Chemical analyses of interstitial water and clams indicated advection of methane-rich water [7,8]. It was thus concluded that these benthic activities are related to venting of overpressure-driven fluid moving upward along tectonic zones with surface deformation [9].

As a reconnaissance survey of the target areas in the KAIKO-Nankai Project executed in 1989, a deep-towed TV system owned by the Japan Marine Science and Technology Center (JAMSTEC)

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was used to investigate the eastern Nankai Trough region including the Tenryu Canyon site. These instruments were loaded onboard the newly built research vessel *Hakuho-Maru* during cruise KH-89-1 [10] in a joint program by the Ocean Research Institute, University of Tokyo and JAMSTEC as a part of the KAIKO-Nankai Project.

The JAMSTEC deep-towed TV sled is equipped with color and monochromatic TV, operated alternately by a manual switch, together with two still cameras, a CTD set (a system continuously measuring chlorinity, temperature and depth), an altitude sonar and thermometer. A transponder installed on the towed system gave position relative to the ship with an accuracy of 2% of the distance to the sensor, e.g., errors of positions were within 80 m while it was towed with 4000 m long cable. Depths of sensor was obtained using a pressure gauge.

The camera was towed at speeds of 0.5 to 1 knots at 2 to 4 m above the sea floor. The color TV images were observed in real time on the ship. Still cameras were remotely activated. Five continuous lines composed of ten tracks (DT-1–7, -10–12) over the landward slopes of the eastern Nankai Trough (Figs. 1 and 2) were surveyed.

2. Observations

2.1. Back-thrust ridge to trough (DT-1)

The observations in DT-1 started on the crest of a shallow ridge (see Fig. 3). The structural setting of this ridge (later named Yukie Ridge) is shown on the seismic cross section of Fig. 5 near shotpoint 2450. Scattered living and dead *Calyptogena* clams were observed on the summit with meter-sized blocks and smaller gravels of mudstone and conglomerate on a gentle slope with small pockets and tunnels which presumably result from dissolution of cemented materials. Eastward, a steep cliff with debris limits the domain shallower than 2150 m, which is characterized by rough topography with irregular blocks of a meter in size. A NNE–SSW graben with steep walls is present at a depth of 2280 m. Gravel and mud layers outcrop on its southern wall. Between 2542 and 3129 m on the lower flank of the ridge steep eastward dipping cliffs were commonly observed. Gravel layers outcrop on the crests of high-angle faults.

At the foot of the ridge ($D = 3400$ m), the track turned to the SE, crossing an E–W trending channel. A small graben (5–10 cm wide) was seen at the axis of the channel. The bottom is otherwise quite smooth with ripple marks. Neither living shells nor outcrops were observed. These observations imply that repeated succession of intermittent deposition and erosion has predominated in the channel. The camera then reached the northern margin of the Enshu Deep-Sea Basin (Terrace), bound by a 300 m high scarp. Manganese-coated gravels and blocks are abundant, indicating an exposure of longer than 1000 years.

2.2. Tenryu Canyon to the deformation front (DT-4–6)

This track started on the eastern margin of the Tenryu Canyon (Fig. 4). The camera reached the sea floor in the canyon at a depth of 3508 m. Debris and blocks were scattered on a gently sloping sandy bottom. The depth increased slightly southward. Ripple marks were observed at a depth of 3560 m. Garbage, including plenty of empty cans and vinyl sheeting, was seen, indicating large recent supply of material from land through the canyon floor. A number of animals such as fish, shrimp and sea anemonae were

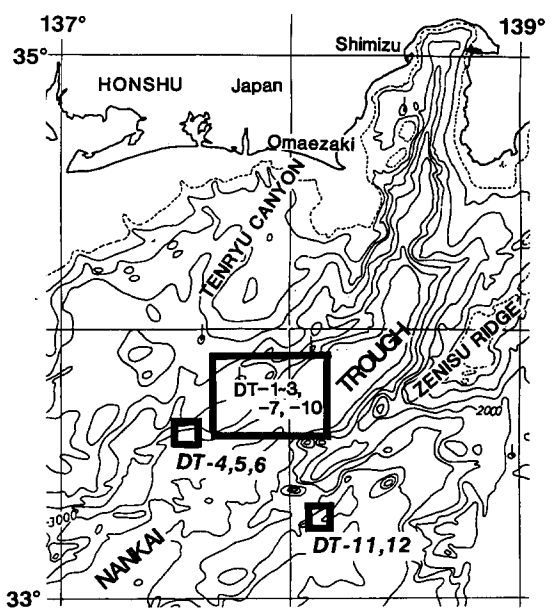

Fig. 1. Three boxes where deep-tow observations in the eastern Nankai Trough region were made. Contour interval 500 m.

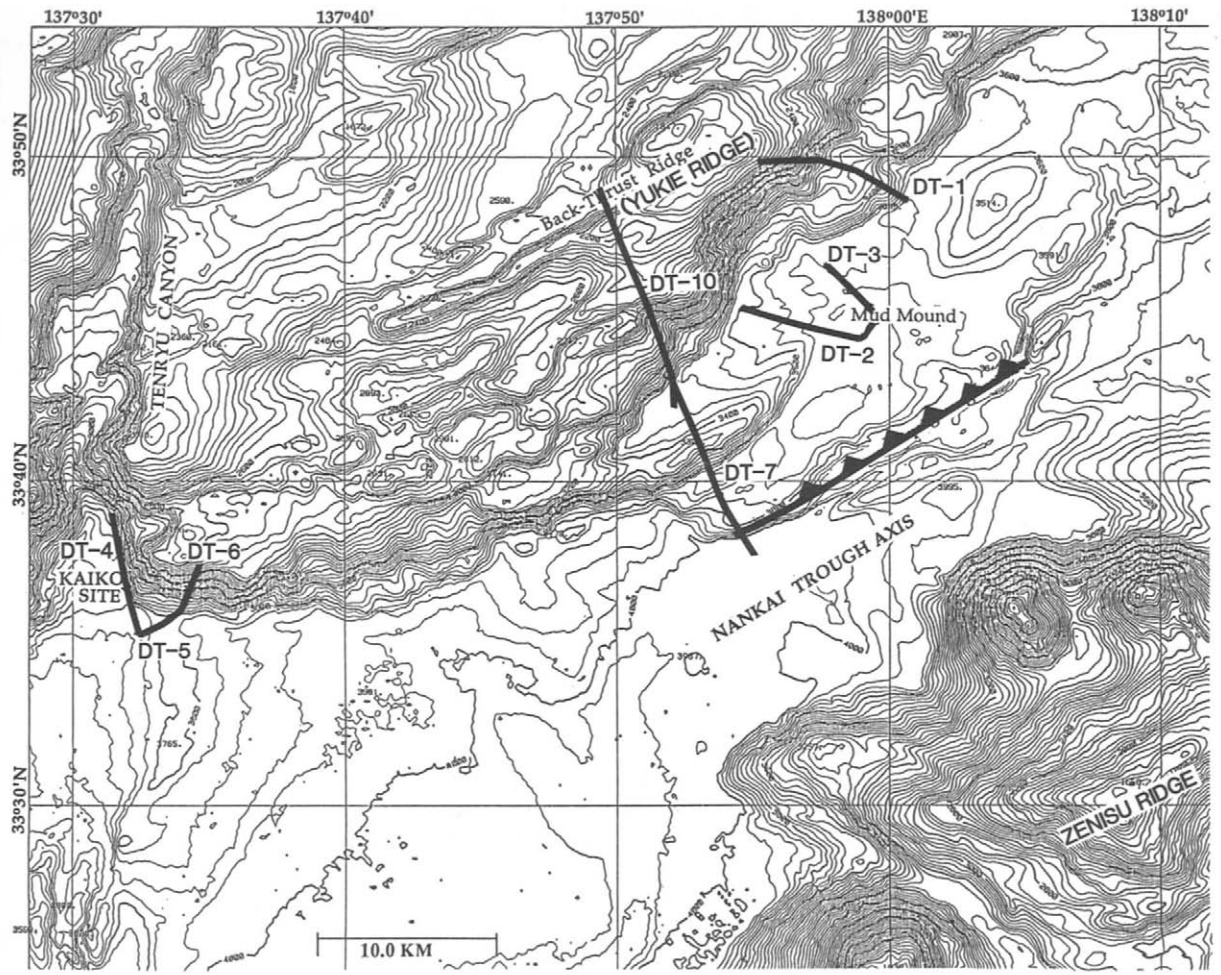

Fig. 2. Locations of deep-tow survey tracks DT-1–7 and DT-10 shown on a Seabeam map compiled based upon cruise KH-89-1 and the KAIKO I results. Contour interval 40 m. Note that DT-8 and -9 are tracks of side-scanning sonar survey which are not described in this article. Teeth indicate position of the first propagating thrust.

found, showing the existence of a sufficient amount of organic matter on the bottom surface, although they form no dense communities on the floor of the canyon.

Large communities of living and dead clams were found at 13:47 at a depth of 3822 m on the eastern bank of the canyon. Whether or not they were the same as observed during the *Nautile* dives in 1985 cannot be ascertained, since the positioning is not sufficiently accurate to confirm the coincidence of these two surveys. At the southernmost end of the eastern bank of the canyon, the camera turned to N40–45° E (DT-5) and later to 340 to 320° (DT-6) toward the deformation front. Steep scarps of a few meters to tens of meters in relief were repeatedly observed north of the first deformation front. They were covered by thin muddy sediments and were probably formed by faulting or slumping. A number of dense communities of *Calyptogena* were observed on the crest of the terraces at 16:00–16:40. The communities were chiefly composed of bivalve *Calyptogena*, sea slugs, sea cucumbers, shrimps and galateas together with many mounds and trails built by benthic animals. Sediments adjacent to the communities are black in color,

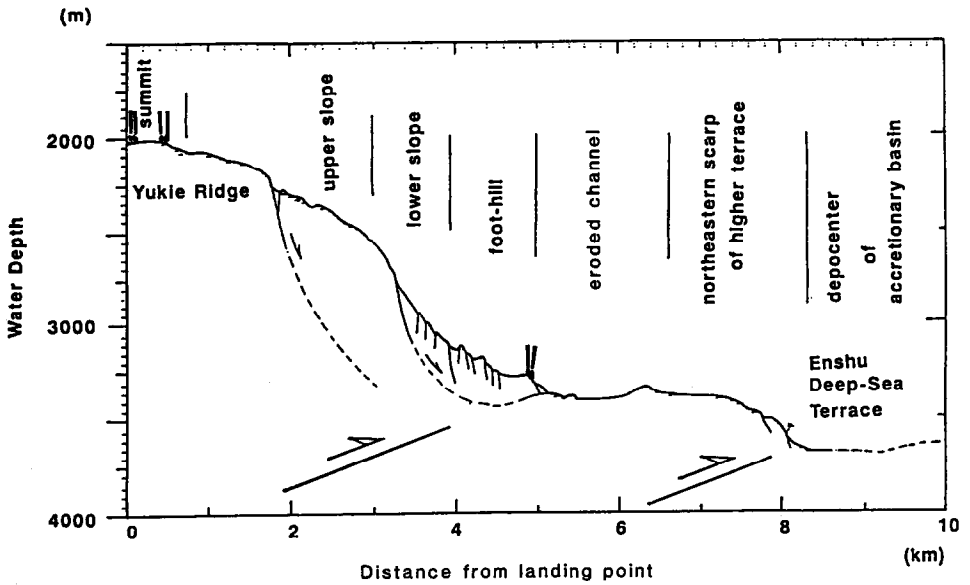

Fig. 3. E–W cross section of survey track DT-1. Observed clusters of living clams are indicated by stars. Exclamation marks denote positions of scattered bivalves.

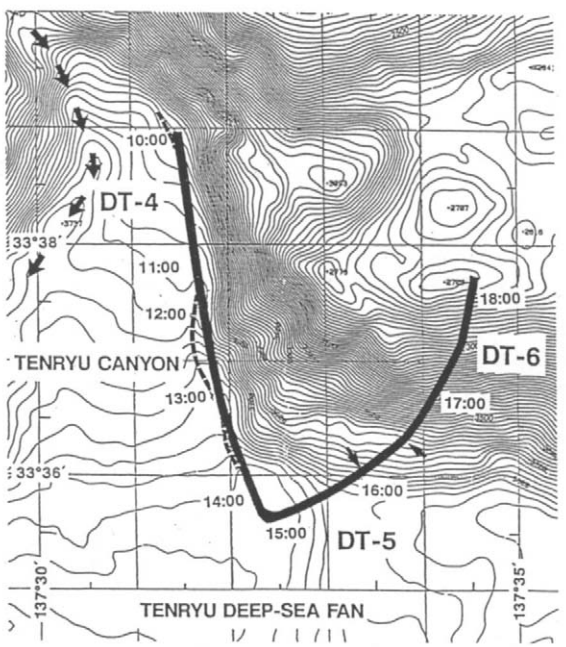

Fig. 4. Locations of tracks DT-4–6 in the Tenryu Canyon region with time. Thick arrows indicate the present erosional channel, whereas broken line shows eastern wall of a remnant channel. Bivalve communities first discovered by the *Nautile* in 1985 were found at point 13:47. Much larger bivalve communities were found along the deformation front at 16:10 and 16:38 indicated by small arrows.

suggesting anoxic conditions. Figure 6 shows two photographs of the clam communities with clear trails of living clams marked on the mud bottom.

2.3. Deformation front south off Cape Omaezaki (DT-7 and -10)

This NNW–SSE line is located about 60 km east of the Tenryu Canyon. Observations started at the trough floor at a depth of 4030 m and moved upward. A steep 300 m step formed the first deformation front of the accretionary prism. A seismic profile interpretation shown in Fig. 5 after [11] suggests that a thrust may outcrop near the top of the step. Communities of *Calyptogena* are most prominent there as shown in Fig. 7. Several tens to a hundred individuals of relatively small clams with a small number of large species are associated with sea anemonae (Fig. 7a). Many trails of bivalves and gastropods are seen. It is also seen in the upper left corner of Fig. 7b that the bottom sediment surrounded by clams is colored black, indicating anoxic conditions. Sporadic outcrops of hard mudstone are observed at some places nearby the communities.

The following relatively flat terrace (about 4 km wide) is devoid of clams, although many bio-

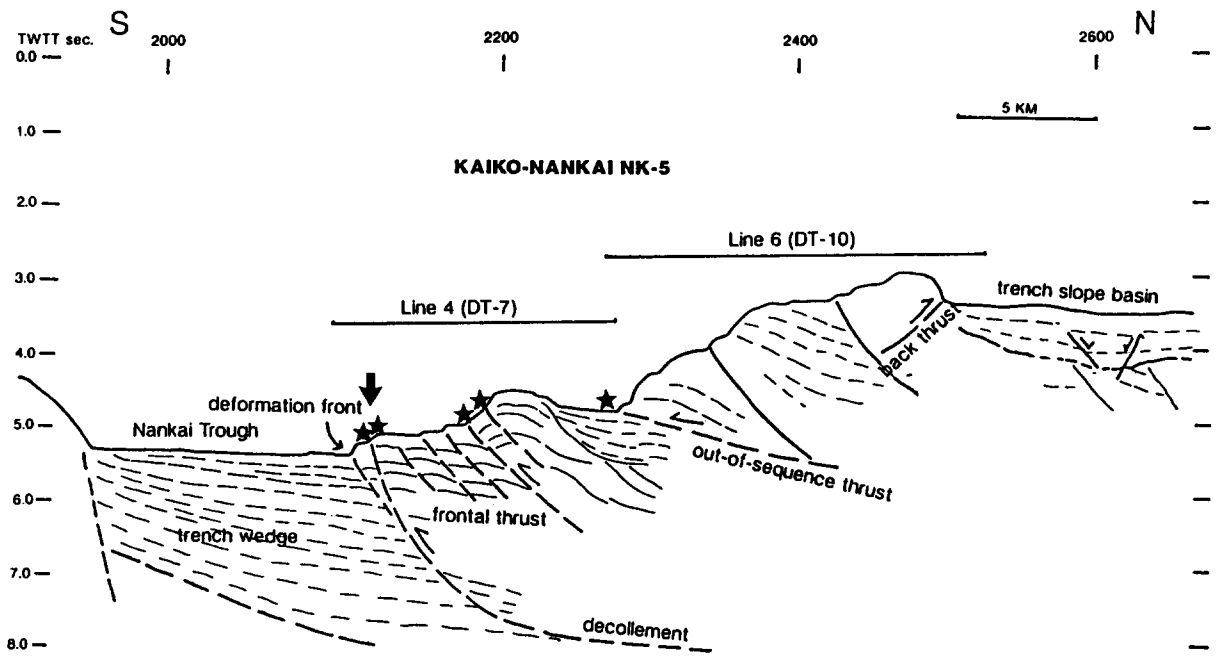

Fig. 5. Cross section of survey tracks DT-7 and -10 based on a seismic profile of Kaiko-Maru KN88 processed by Kuramoto [11]. Star denote sites of living *Calyptogena* communities found by deep-tow camera observation. A small arrow denotes position of photos shown in Fig. 7.

genic mounds are seen. Relatively small communities of *Calyptogena* were found over the second deformation front. DT-10 is an upper continuation of DT-7 and comprises steep scars representing sharp E–W thrusts. Altered beds of mudstone and sandstone outcrop on the cliff. On the crestal region a gentle floor is covered by pebbles scattered on muddy sediments with a few clams. The

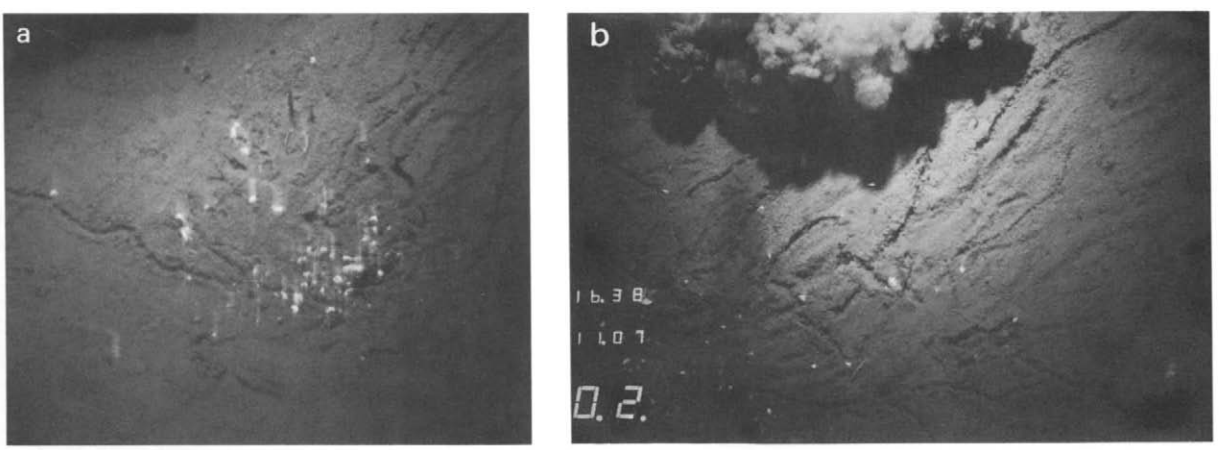

Fig. 6. Bottom photographs showing community of living clams and their trails on mud along DT-5–6 at a deformation front east off Tenryu Canyon outlet; (a) taken at 16:10 (D = 3719 m) and (b) at 16:38 (D = 3606 m), both in July 7, 1989. Smoke at the top of (b) was caused by a small dredge hauled by the deep-towed system.

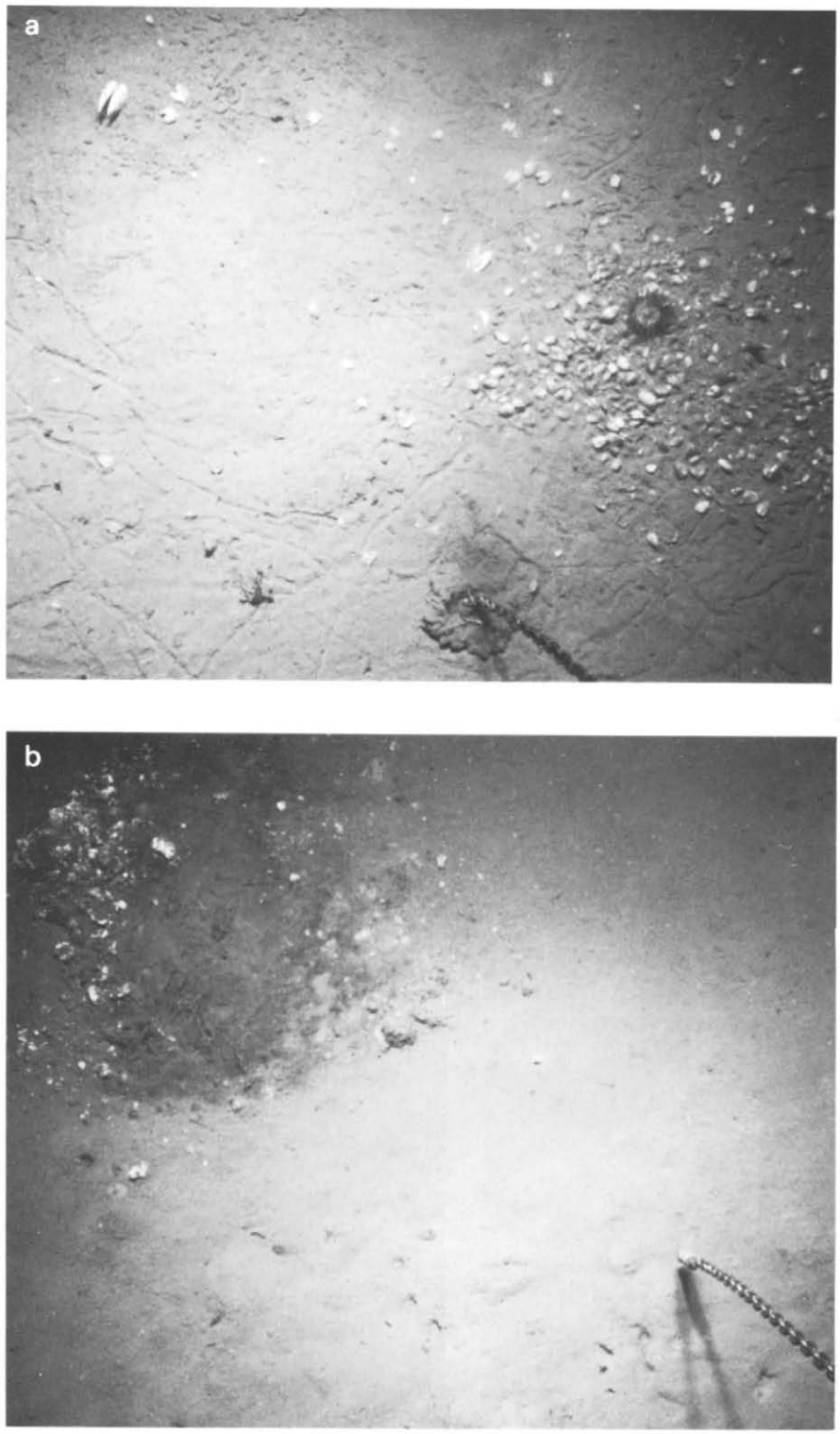

Fig. 7. Bottom photographs showing clam communities at the first deformation front along DT-7; (a) indicating circular colony of clams taken at 11:36 (D = 3784 m) and (b) showing black mud in a community taken at 13:46 (D = 3693 m), both on July 8, 1989.

most remarkable portions in this transect were surveyed by *Nautile* in much detail and no further discussion of our results is presented here.

2.4. Mud diapir in the Nankai Trough (DT-2–3 and -11, 12)

At least three small mud mounds have been recognized on the Seabeam map and on the IZANAGI side-looking sonar image near the deep-sea channel in the Nankai Trough [12]. An 80 m high mud mound was also recognized in the flat bottom a few kilometers south of a thrust fault immediately south of the East Zenisu Ridge, an outer ridge located south of the Nankai Trough axis. These mud mounds have a conical shape similar to mud diapirs found in Barbados region [13–15]. One TV track (DT-2) first went across an isolated mound situated close to a scarp over the deformation front soon after it reached the trough bottom. Later it traversed a chain of mounds located near the deep-sea channel in the trough. DT-3 cuts across the deep-sea channel extending north of a mound. A thick cover of bottom sediment indicates that the channel is now inactive and the site of hemipelagic deposition.

The DT-11–12 line is situated south of Zenisu Ridge (Fig. 8). It crossed a small mud mound but discovered no sign of venting activity, although the cliffs are steep and sharp and their fractured surface suggests relatively recent tectonic movement.

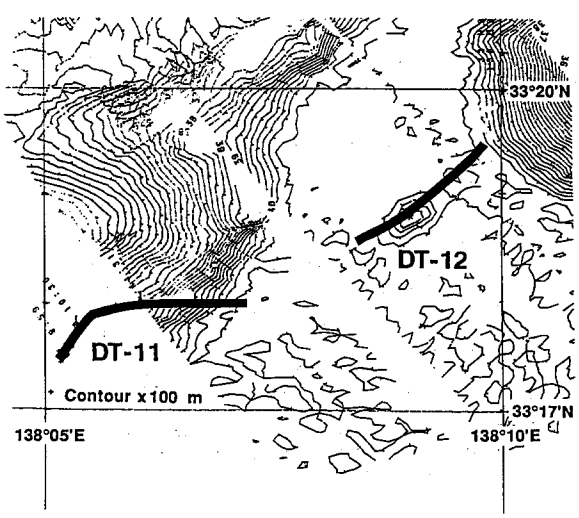

Fig. 8. Location of survey tracks DT-11 and -12 traversing a mud mound. No clams were found in any part of the area of this map. Contour interval 20 m.

3. Evidence for seepage on the sea floor

Large communities of *Calyptogena* sometimes accompanied by sea anemonae and sea cucumber appear to be associated with the crests of the first deformation fronts at both Tenryu Canyon East and south off the Omaezaki sites. Scattered clams of *Calyptogena* were also found on the upper terraces of the accretionary prism and on the crestal portions of the back-thrust ridges. Note that the occurrence of smaller *Calyptogena* communities on the crest of the back-thrust ridges had been unexpected until they were found by this deep-tow observation.

This was the rationale behind choosing the first deformation front as the first priority site of the *Nautile* dives in August–September, 1989. The back-thrust ridges were also adopted as a target of dives. A line south off Cape Omaezaki was preferred to the Tenryu Canyon East site, since the communities off Omaezaki appear denser and larger than any others surveyed by the present observation and the deformation front–back-thrust is aligned on one nearly straight line through DT-7 and -10.

In-situ studies with the *Nautile* indicated that venting of cold water with dissolved methane and sulfur is taking place at sites where bivalves are living. Detailed discussion of this problem is left to other articles on the dive results appearing in this issue.

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