

東部南海トラフ付加プリズムの断層崖における 冷湧水の分布

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「しんかい 6500」第 321 潜航では、東海沖南海トラフ陸側斜面の断層崖において地質構造と生物群集の調査を行った。この断層崖は、付加プリズム斜面中部に連続して分布し落差 300 m 以上に達する。潜航は、断層崖の前面（海側）に形成された堆積盆から斜面にほぼ直交して行なわれた。堆積盆底は、泥質堆積物で覆われており構造運動による変形は認められない。崖の麓は泥質の崖錐堆積物で完全に覆われており、断層からの湧水が妨げられているものとみられる。崖錐堆積物の最上部には、バクテリアによる白色の変色域とハオリムシが認められた。流体湧出は崖錐の被覆の薄化によるものと考えられる。中部～上部斜面は、多数の炭酸塩クラストによって特徴づけられ、炭酸塩で固められた地層が約 500 m に渡って分布する。炭酸塩クラストのこのような広い分布は、かつてメタンを含んだ流体の湧出が活発であったことを示す。わずかではあるがチューブワームの生息から、現在もメタンを伴った流体湧出が存在することが示される。断層崖の上部斜面は、緩傾斜となっており泥質堆積物で完全に覆われている。生きたシロウリガイが多数認められ、遠距離を移動した跡が残っている。シロウリガイはコロニーを形成せず孤立して生息しており、メタンを含んだ流体が集中して湧き出すのではなく、分散して斜面全体に湧出していることを示している。断層系が表層に達しておらず、比較的厚い堆積層中に流体が分散して流出しているものと考えられる。

キーワード：断層崖，生物群集，冷湧水，付加プリズム，炭酸塩クラスト

Distribution of cold seepage at the fault scarp of the eastern Nankai accretionary prism

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Dive 321 of "Shinkai 6500" was performed at a continuous fault scarp in the eastern Nankai accretionary prism. A well-developed slope basin seaward of the scarp is covered by muddy sediments and shows no tectonic deformation structure. The scarp base is completely covered by muddy talus deposits preventing fluid expulsion through a fault plane. White patches probably caused by bacteria and living tube worms were scattered around the upper part of the talus. This seepage may be associated with upward thinning of talus deposit cover. The middle to the upper scarp is characterized by exposure of carbonate crusts. Completely carbonate-cemented strata, so called "carbonate pavements" were distributed for about 500 meters. Such wide distribution of carbonate crust indicates that pervasive expulsion of methane bearing fluids oc-

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curred previously. Present seepage is also suggested by a small number of living tube worms within the carbonate pavement. A large number of *Calyptogena* sp. clams were observed on muddy terrace sediments above the scarp. Their long traces and isolation without forming colonies suggest that fluid flow from the prism is not channelized but diffusive. Such dispersion of methane bearing fluid is probably caused by lack of major conduit within relatively thick surface sediments that cover the hanging wall of the thrust fault.

Key words : Fault scarp, Biological community, Cold seepage, Accretionary prism, Carbonate crust

1. Introduction

Subduction settings yield active fluid expulsion due to rapid dewatering by tectonic compaction and development of fluid conduits such as faults and/or dipping permeable strata. Fluid chemistry of such seepage informs us diagenetic contexts and sources of fluid/gas (*e.g.*, Kulm *et al.*, 1986). Studies of fluid venting provide information about not only fluids themselves but also geological structures: distributions of vents correspond to regions where active faults or permeable layers crop out or reach the near surface of the sea bottom (*e.g.*, Moore *et al.*, 1990). Distribution of porosity and pore fluid pressure controlled by these dewatering processes, moreover, has strong effects on mechanical properties of landward wedges of subduction zones during their deformations (Davis *et al.*, 1993).

The eastern part of the Nankai Trough is one of the areas where cold seepage is well-investigated. Since 1984, the French-Japanese KAIKO Project has found several cold seep sites in the prism by submersibles (*e.g.*, Le Pichon *et al.*, 1987). During dive surveys, chemosynthesis-based biological communities were useful makers on mapping of seep sites because anomalies of temperature and geochemistry of cold seeps are more hardly detected than those in hydrothermal area. An accretionary prism is developed in this area due to an incoming thick sedimentary section on the Philippine Sea Plate converging to west-northwest or northwest (Ishibashi, 1981; Yoshioka *et al.*, 1993). A large number of active faults are recognized by bathymetric and seismic reflection surveys (The Research Group for the Active Faults of Japan, 1991; Le Pichon *et al.*, 1992; Huchon *et al.*, in press). In the outer prism, a thin-tapered prism toe and a pop-up structural ridge 20 km

landward of it, active fluid venting was revealed by distributions of biological communities during dense submersible surveys (Chamot-Rooke *et al.*, 1992; Lallemant *et al.*, 1994). In the inner prism, cold seepage has been detected along the two faults named "Tokai Thrust" and "Kodaiba Fault" (see the locations of dives 116 and 117, and dives 706, 762, 763 and 824 in Fig. 1, Fournier and Cadet, 1994; Le Pichon *et al.*, 1994; Ashi *et al.*, 1995; Thoué *et al.*, 1995; Mazzotti *et al.*, 1996), and the Ryuyo Canyon (see the location of dive 821 in Fig. 1, Ashi *et al.*, 1996).

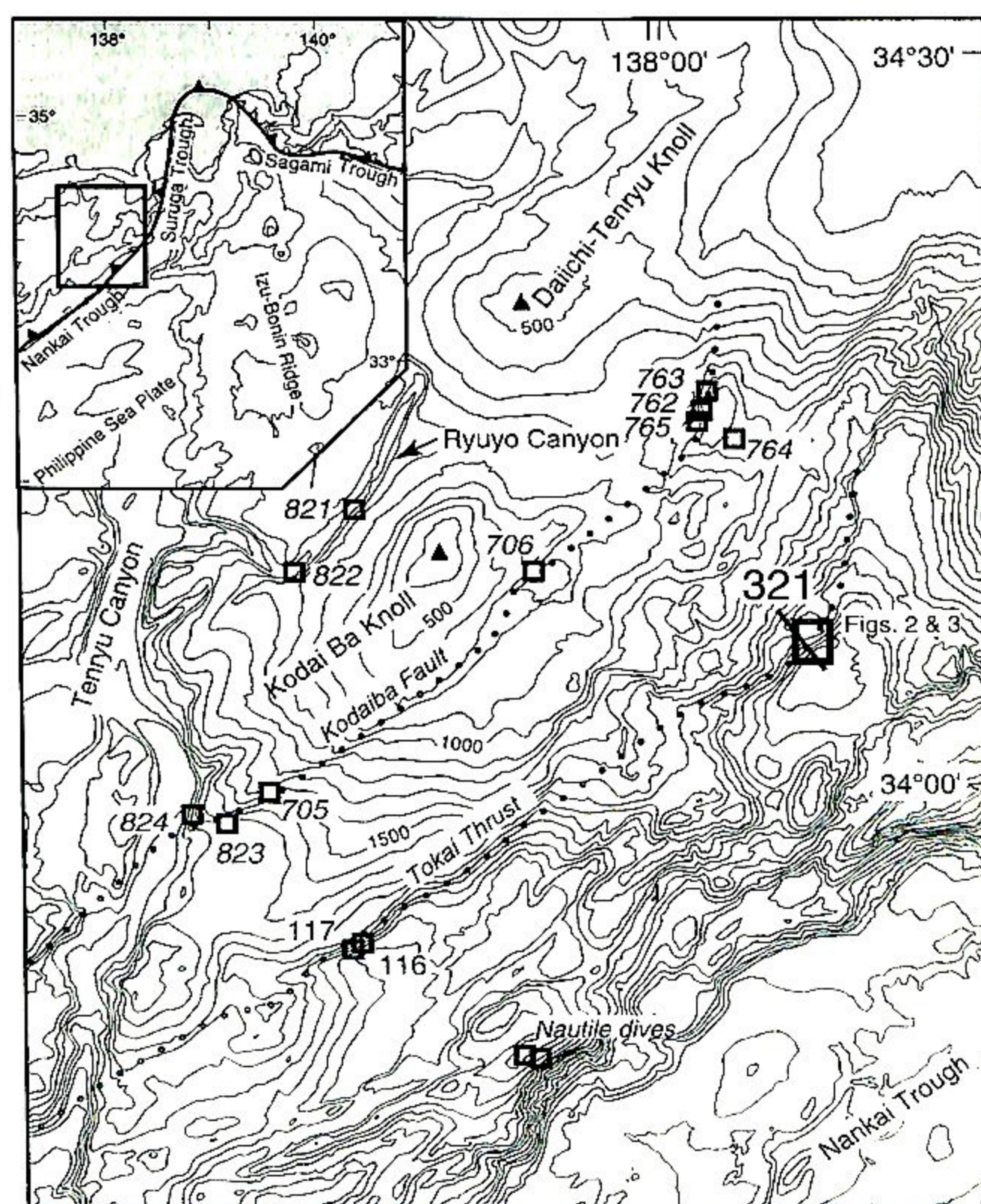


Fig. 1 Bathymetric map with dive sites of the KAIKO project. Rectangle indicates the study area (see detail map in Fig. 2).

This study, "Shinkai 6500" dive 321, was conducted in the Tokai Thrust that has the well-continuous large scarp at the depth of about, 2,400m. During previous dives 116 and 117 along this thrust fault (Fig. 1), active crustal movements and fluid venting were suggested by existence of fresh talus, tube worms and dead clams (Fournier and Cadet, 1994). In this study, the dive location with less sedimentary cover is carefully selected using deep-towed sidescan sonar images and seismic reflection profiles obtained during the 1996 L'Atlante cruise (Huchon *et al.*, in press). The main objective of this dive is to investigate structures of a large scarp probably associated with large earthquakes and to find evidences of cold seepage along the fault. Ages of rock samples from the scarp are also important for discussion about prism growth.

2. Dive observations

This dive was performed from a slope basin of 2,419 m to an upper terrace of the scarp of 2,024m in depth (Figs. 2 and 3). The landing point is located at the foot of the scarp within the well-developed piggy-back basin (Figs. 1 and 2). The seafloor was covered by muddy sediments and characterized by high-amplitude, irregular-shaped current ripples. The depth of the basin was constant along the dive track. A deformation structure such as a step or a fracture was not detected on the basin floor.

The base of the scarp is completely covered by muddy talus deposits without any fallen block. Apparently, no deformation structure was observed on the talus. White discolored patches with living Vestimentiferen tube worms were scattered on the upper most part of the talus deposit between the depths of 2,360 and 2,325 meters (Figs. 2, 3 and Photo 1). A short core sample obtained from a white patch exhibits that surface sediments consist of black sandy silt with hydrogen sulfide smell. The upper boundary of the talus deposit is not clear. At the depth shallower than 2,330m, various sized sedimentary blocks, ranging from several centimeters to one meter in diameter, were observed among muddy sediment cover. Collected blocks consist of calcareous sandy siltstone and show elongated shapes probably parallel to the bedding planes and well-rounded edges

(Photos 4 and 5). Block sizes of carbonate crusts gradually increase and carbonate cemented strata are predominant toward the shallow depth (Photos 2 and 6). At the depth between 2,305 and 2,165 meters, the seafloor is widely covered by carbonate crusts and become to be so called "carbonate pavement". Most of the carbonate cemented strata are gently dipping toward the down-slope directions, although the strata at the depth of 2,178m were vertically dipping. Biostratigraphy using calcareous nannofossil were examined in these strata. Ages of all rock samples collected from 2327, 2245 and 2162 meters, however, were not determined due to poor preservation of fossils. A few tube worms were observed at the upper part of the carbonate pavement (Figs. 2 and 3). The seafloor shallower than 2,165m was covered by fine grained sediments with scattered shell fragments and dead bivalves. At the depth shallower than 2,120m a large number of tracks by clams were distributed on the seafloor (Photo 3). Living bivalves were often observed at the ends of the tracks.

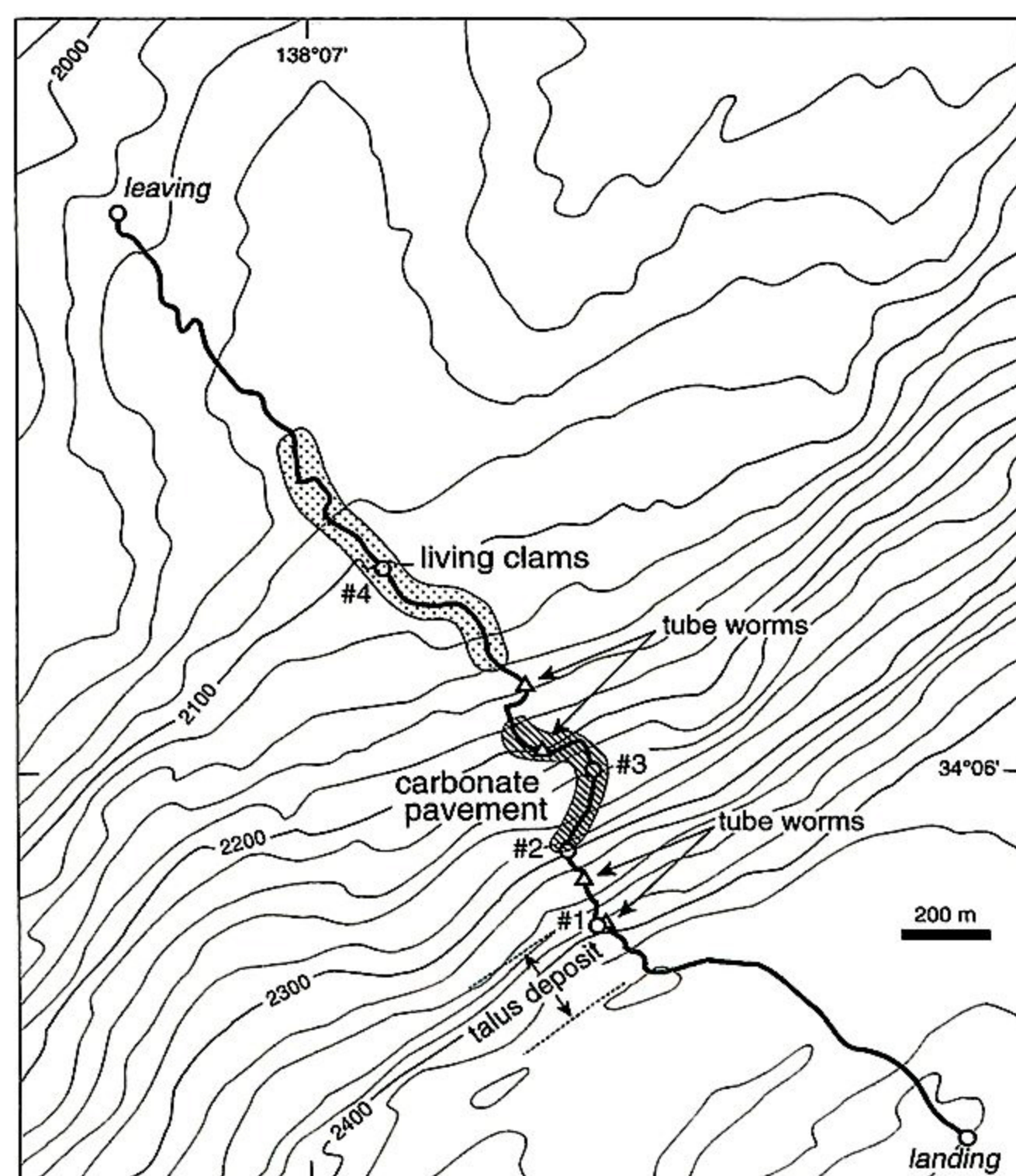


Fig. 2 Track chart of dive 321 of "Shinkai 6500" on a detailed Seabeam map. Carbonate pavement and a living clam area are shown in the scarp and the terrace, respectively. Numerals indicate sampling localities of sediments (#1), rocks (#2 and #3) and living clams (#4).

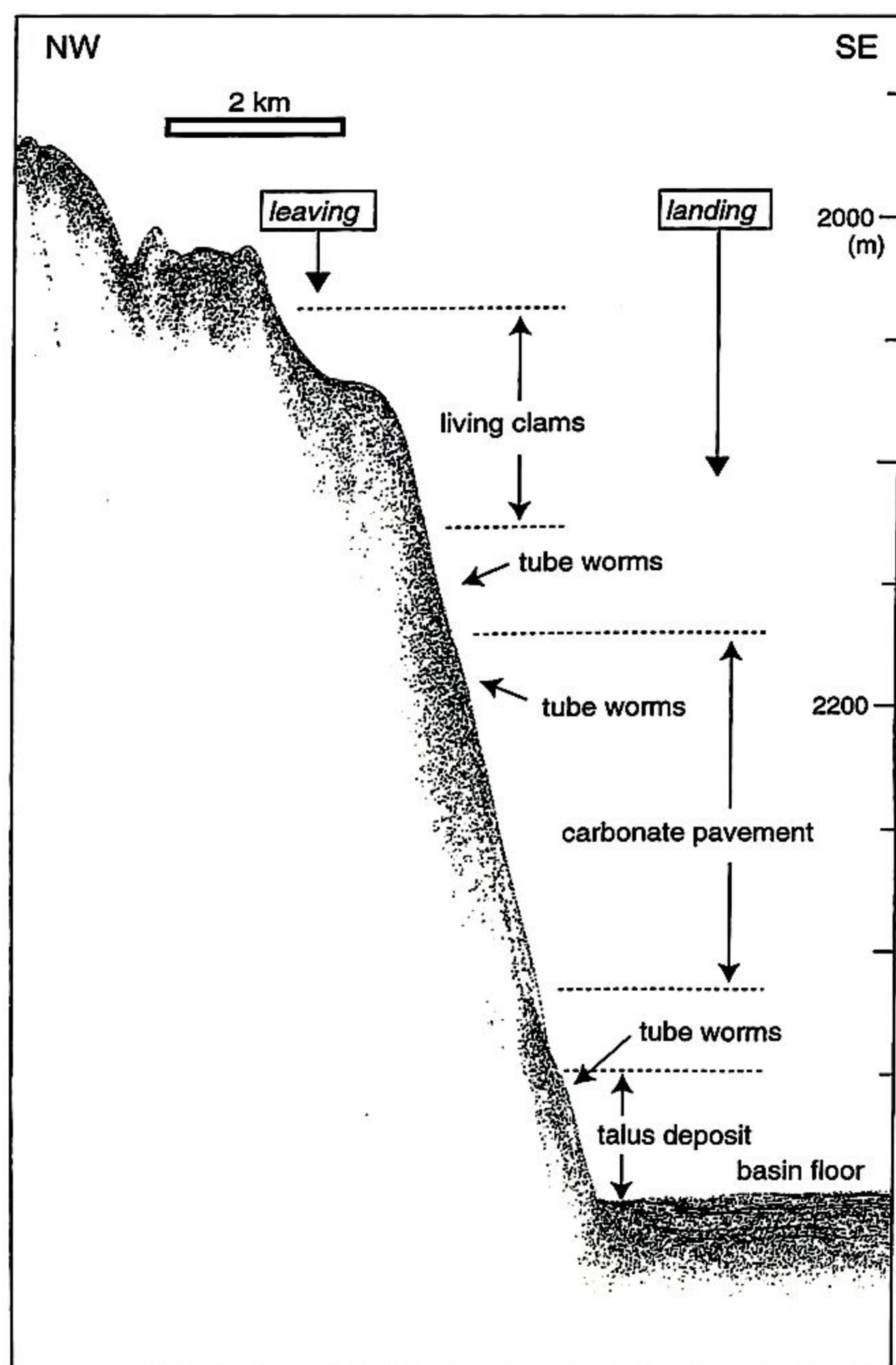


Fig. 3 Deep-towed 3.5 kHz subbottom profile obtained during the 1996 L'Atlante cruise (Huchon *et al.*, in press) and dive observations. The track line of this profile (shown in Fig. 1) is about 500 m west of the dive track.

Most of the bivalves are supposed to be *Calyptogena* sp. on the basis of two samples collected from the depth of 2,084m. These bivalves are reported as a new species (Okutani *et al.*, in press). Divergent distributions of living bivalves with long tracks indicate their active movements without forming colonies. Such bivalve distribution was recognized for more than 800m interval on the gentle slope. There is not any remarkable deformation structure on the muddy sediment cover. At the upper terrace shallower than 2,070m in depth, the bottom consists of flat muddy sediments without clams and partly shows undulations regarded as distal parts of erosional canyons.

3. Discussion

No cold seepage at the base of the slope, where a thrust fault is recognized in a multichannel seismic profile (Kato *et al.*, 1983), suggests that thick talus deposits prevent fluid venting. At the upper part of the talus, distributions of both white patches (probably bacterial mats) and living tube worms may be due to thinning of the talus sediment cover. A large amount of carbonate crusts suggest methane oxidation of up-welling fluids within the sub-surface sediment. Small fractures, most of which were filled by calcite veins, occurred in carbonate crusts (Photo 4). Preliminary study of stable isotopes indicates that carbon and oxygen isotope values of calcite veins are -34 to -38‰ and $+4.0$ to $+4.8\text{‰}$ PDB, respectively. Preservation of fragile parts of the crusts suggests in-situ bottom current erosion after carbonate concretion.

The carbonate pavement seems to be formed by removal of surface sediments above carbonate crusts. Inactive fluid venting is supposed from a small number of living tube worms in this region, although steep slope and exposures of hard rocks are not appropriate environments for *Calyptogena* sp. clams even if venting is active.

According to the previous dive results around fault scarps, cold seepage was well developed in upper terraces rather than steep slopes where faults emerge at seafloors (*e.g.*, Moore *et al.*, 1990; Le Pichon *et al.*, 1992). During this dive, dispersed small white patches with tube worms were observed in the lower part of the scarp mentioned above. In contrast, the terrace above the scarp is characterized by widely distributed living *Calyptogena* sp. clams (Fig. 2). These results are generally consistent with the previous observation. Isolative living clams in the terrace are, however, quite different from general clam distributions in seep sites. This suggests that fluid flow from the prism is not channelized but dispersed within the relatively thick surface sediment. Such dispersion of methane bearing fluid is probably caused by lack of major conduit within the surface sediment. Wide distribution of living clams may indicate a large amount of fluids escaping from the prism through the hanging wall of the thrust fault.

4. Summary

Dive 321 of "Shinkai 6500" was conducted on the large fault scarp named "Tokai Thrust". The following are the main results from this dive observation.

1) No direct evidence of tectonic deformation was detected along the dive track.

2) Existence of cold seepage is suggested by white patches (probably caused by bacteria) and living tube worms distributed at the upper part of the talus.

3) Carbonate crusts are widely distributed in the upper slope. This indicates previous seepage of methane bearing fluids and recent active surface erosion.

4) A large number of living bivalves including *Calyptogena* sp. clams are distributed in the terrace above the fault scarp. Fluid flow from the prism is not channelized but dispersed within the surface sediment on the hanging wall of the thrust fault.

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(Notice) Photos are given on the following page.

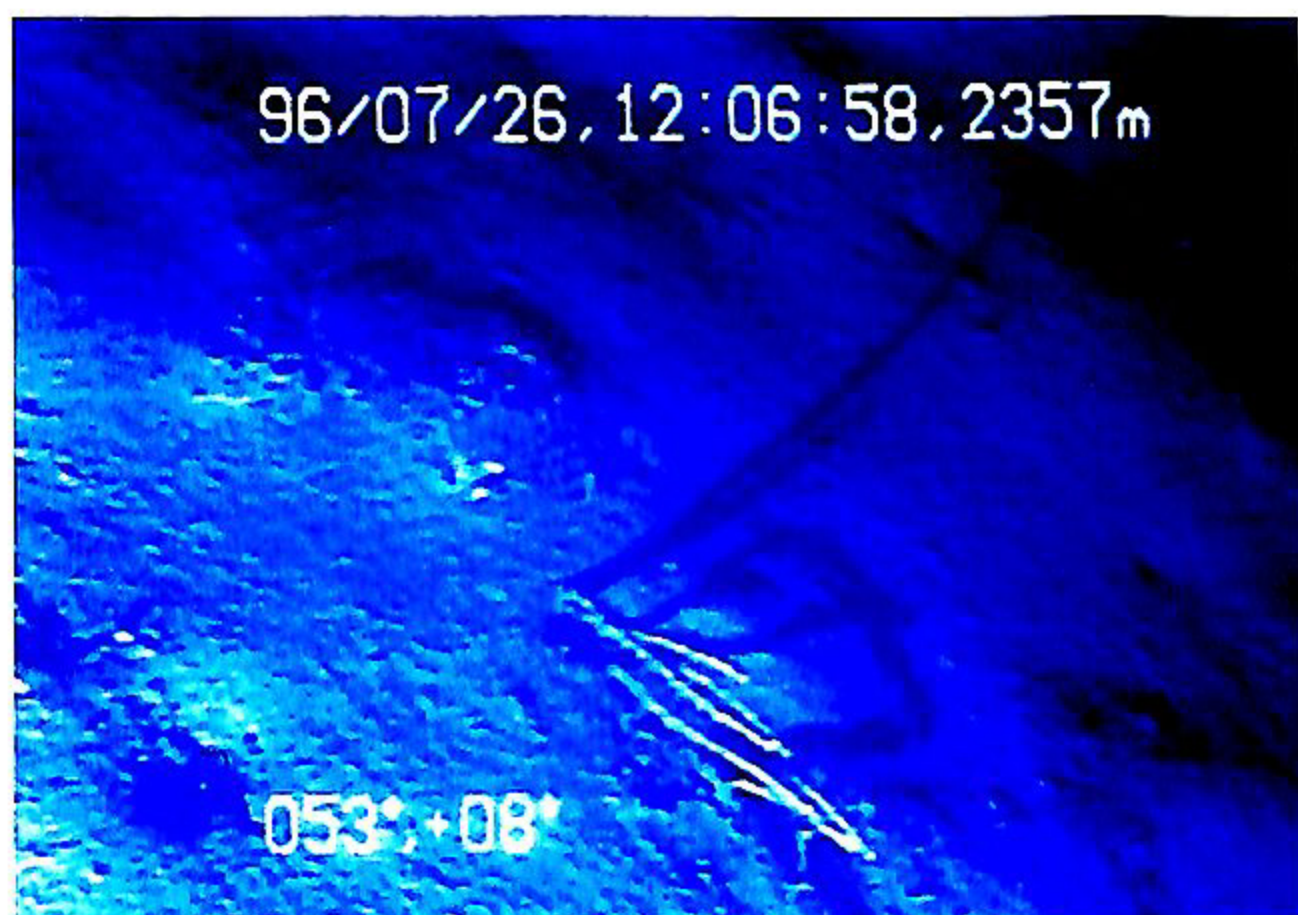


Photo 1 Vestimentiferan tube worms and white patches at the upper part of the muddy talus deposit. Water depth 2,357m.

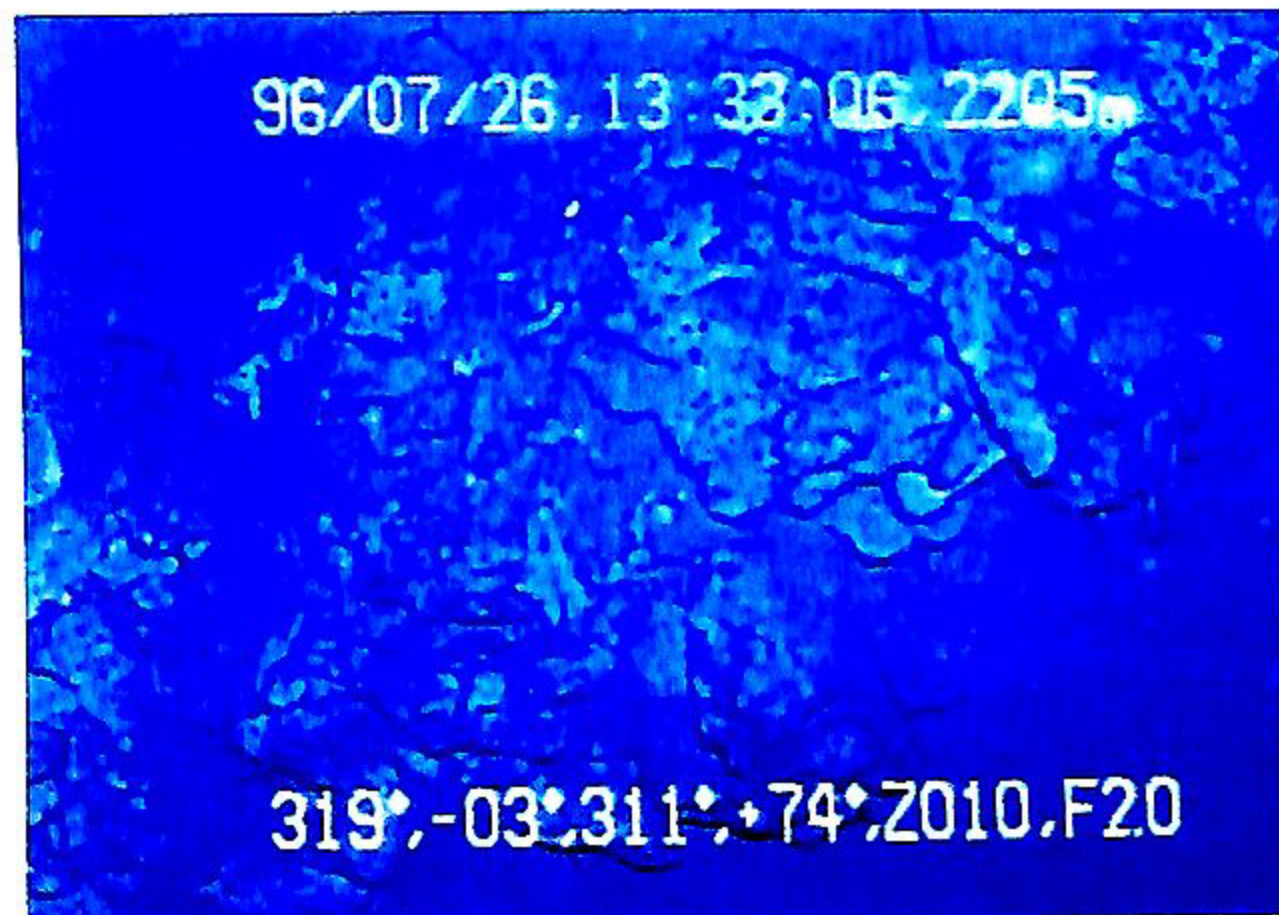


Photo 2 Carbonate crusts at the upper scarp. Water depth 2,205m.



Photo 3 *Calyptogenia* sp. clams on muddy terrace sediments with their tracks showing active movement.



Photo 4 Closed-up photo of cutting surface of the carbonate crust obtained from the outcrop #2 in Fig. 3. Small fractures are filled by calcite.



Photo 5 Carbonate crusts with rounded edges collected from the sampling locality #2 in Fig. 3.

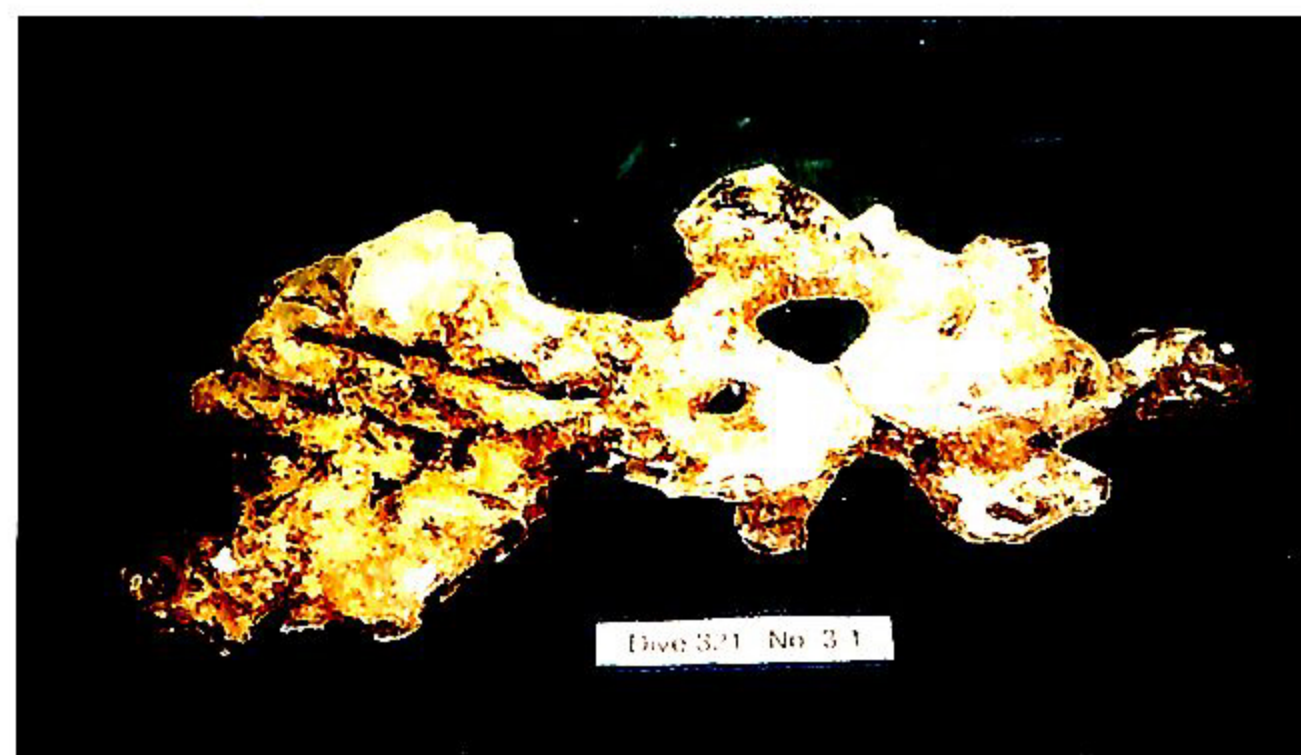


Photo 6 Carbonate crust elongated parallel to the bedding. The sample (about 65 cm in length) was collected from the sampling locality #3 in Fig. 3.