Structural Study of the Lower Scarp of the Inner Eastern Nankai Accretionary Wedge

Marc FOURNIER　　Jean-Paul CADET

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南海トラフ東部陸側付加プリズム下部急崖の構造的研究

マルク・フルニエ*1　ジャンポール・カデ*2

「しんかい6500」の第116及び117潜航では，南海トラフ東部陸側付加プリズム下部急崖の構造的研究が行われ，走向N60°Eをもつ長さ30kmの崖錐を，北緯33°53′東経137°45′の地点において水深2,500から2,000mの間で調べた。地層はその斜面に平行で，崖錐は全体として走向N60°Eの水平軸をもつゆるやかな褶曲構造を示している。地層は，崖錐の基部と頂部でほぼ水平で，その傾斜は斜面中部に向かって規則的に増加し，最大はSEに向かって40°に達する。いくつかの急崖が斜面中部で観察され，水深2,260mでは比高40mの急崖が識別された。新しい崖錐，漂移性落下岩塊及び侵食小谷（ガリ）はこの急崖に沿って広く存在し，活構造を示唆する強力な海底侵食の証拠となる。流体湧出の明確な証拠は，この陸側プリズムの中では見つけられなかった。すなわち，二枚貝の群集は1つも観察されなかった。しかし，ハオリムシ及びそれに伴うトウヨウコシオリエビは，大きな崖の基部（水深2,260m）において各潜航中に観察された。ハオリムシ及びトウヨウコシオリエビは一般に，付加プリズム外側において二枚貝の群集と関連づけられ，また流体湧出の標識であると言えるかもしれない。もしそうならば，陸側に向かってゆるやかに傾斜し，水深2,260mで海底に現われている衝上断層が，この斜面の形成及び発達を左右しているのかもしれないし，また間欠的な流体湧出に関係しているかも知れない。地層は，このプリズム外側に見られる基部堆積層の原組織とみなし得るものと類似した直交節理網の影響を受けている。

キーワード：南海トラフ，付加プリズム，冷湧水，衝上断層，底棲生物群集

Structural Study of the Lower Scarp of the Inner Eastern Nankai Accretionary Wedge

Marc FOURNIER*3　Jean-Paul CADET*4

Dive 116 and 117 of “Shinkai 6500” were devoted to the structural study of the lower scarp of the inner eastern Nankai accretionary wedge. A 30km long talus trending N060 E was studied at 33°53′N-137°45′E between 2,500 and 2,000m. With strata parallel to the slope, the overall structure of the talus is that of a gentle fold with a N060E trending horizontal axis. Strata are nearly horizontal at the base and at the top of the talus and their dip increases regularly to reach 40° toward the SE at mid-slope. Several steep

＊1　東京大学海洋研究所
＊2　パリ・ピエールマリキュリー大学構造地質学科
＊3　Ocean Research Institute, University of Tokyo
＊4　Département de Géotectonique, Université Pierre et Marie Curie, Paris

scarps were observed at mid-slope, a 40m high scarp being identified at the depth of 2,260 m. Fresh talus, erratic fallen blocks, and erosional gullies are common along the scarps, evidencing a strong submarine erosion which suggests active tectonics. No clear evidence of fluid venting were found in the inner prism : we did not observe any clams colony. Yet, Vestimentiferan Tube Worms and associated Galatheids were observed during each dive at the base of the major scarp (2,260m). Tube Worms and Galatheids are generally associated with clams colonies in the outer accretionary wedge, and might be an indicator of fluid outlet. If so, a landward gently dipping thrust fault merging at the depth of 2,260m might control the formation and evolution of the scarp and be related to sporadic fluid outlets. Strata are affected by a network of orthogonal joints similar to that observed in the outer prism and interpreted as an original fabric of sediments in the basin.

Key words : Nankai Trough, Accretinary Prism, Cold Seepage, Thrust Fault, Benthic Biological Colony

1. Introduction

We report the results of dives 116 and 117 of "Shinkai 6500" in the inner part of the Nankai accretionary wedge. The accretionary wedge is progressively built in the Nankai trough at the expense of trench turbidities (Le Pichon et al., 1987) above the Philippine Sea plate slab which subducts under SW Japan. Direction and rate of convergence deduced from earthquake focal mechanisms are N305E (Ishibashi, 1981) and $1.3cm \cdot a^{-1}$ (Ranken et al., 1987) to $3.9cm \cdot a^{-1}$ (De Mets et al., 1990), respectively. From geodetic data inversion, Yoshioka et al. (1993) deduced a direction of convergence N 330E and an associated rate greater than $3.0cm \cdot a^{-1}$. Part of the convergence results in crustal shortening within the Philippine Sea plate taken up by thrust faulting along the Zenisu Ridge (Lallement et al., 1989 ; Chamot-Rooke et al., 1989). The remaining convergence is taken up at the Nankai trough. The easternmost portion of the Nankai trough (see the insert in Fig. 1) is seismically inactive since 1854 and is expected to be ruptured by the impending Tokai earthquake (Ishibashi, 1981 ; Yoshioka, 1993). This area is surveyed since 1984 by the Kaiko project (Le Pichon et al., 1987).

Fig. 1 shows the Seabeam bathymetric map of the outer accretionary wedge and its structural interpretation (Le Pichon, Kobayashi et al., 1992). The lower part of the outer prism results of the seaward propagation of thrusts within the turbiditic trench fill, and the upper part consists in a ridge (Yuki ridge) bounded by thrusts and backthrusts and interpreted as a pop-up structure. During dives 116 and 117 we surveyed the first large talus northwest of the Yuki ridge (the studied area is located in Fig. 1). This talus trends N060E parallel to the trench, it is more than 30km long, and is 500m high between 2,500 and 2,000m. Such a large structure, similar to the main talus of the outer prism, is likely to be controlled by tectonics.

2. Structural observations

Fig. 2 shows the detailed Seabeam map of the studied area and the main observations. Dive 116 cut across the whole talus with a N330 trend and dive 117 was devoted to detailed observations at mid-slope.

The talus as a whole is a regular structure with strata parallel to the slope, like a large cylindric gentle fold. Strata are nearly horizontal at the bottom and at the top of the talus, and their dip increases regularly to reach about 40° at mid-slope. Strata are typically 10 to 20cm thick, possibly thicker along scarps at mid-slope though it remains unclear. The lower and upper plateaus are similar monotonous gentle slopes covered with muddy sediments where very few outcrops could be observed.

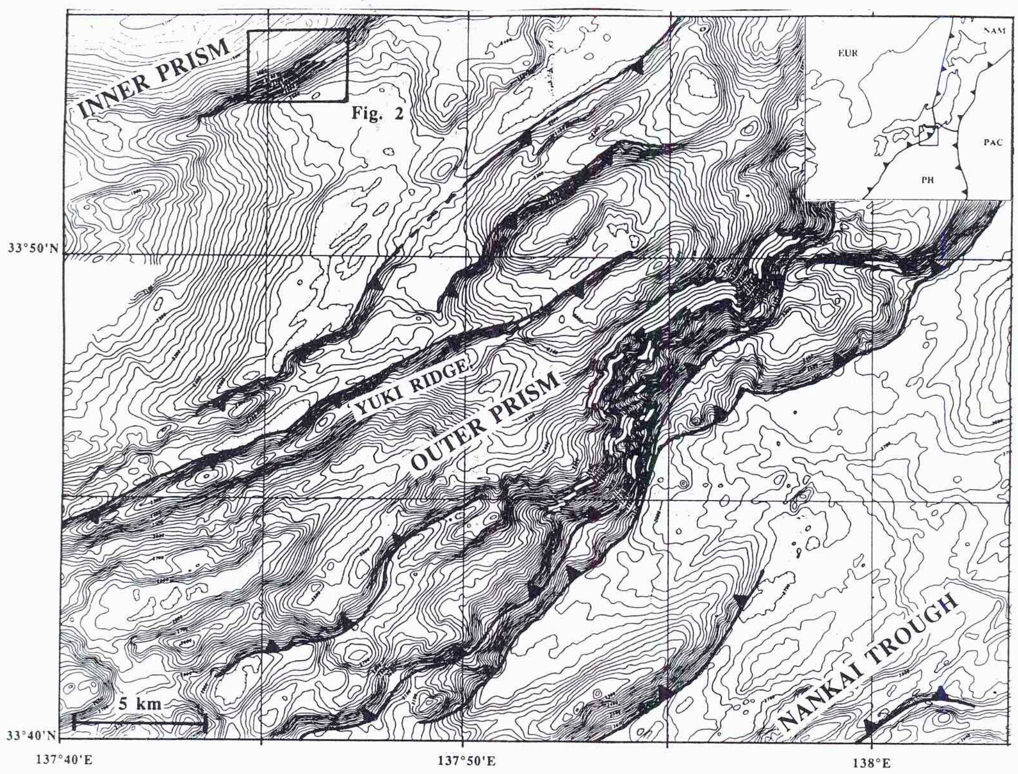

Fig. 1 Seabeam map with its structural interpretation of the Nankai outer accretionary wedge, and location of the studied area along the lower talus of the inner wedge (Fig. 2). The insert shows the tectonic framework of the studied area. EUR is Eurasia, NAM is North America, PAC is Pacific plate, PH is Philippine Sea plate.

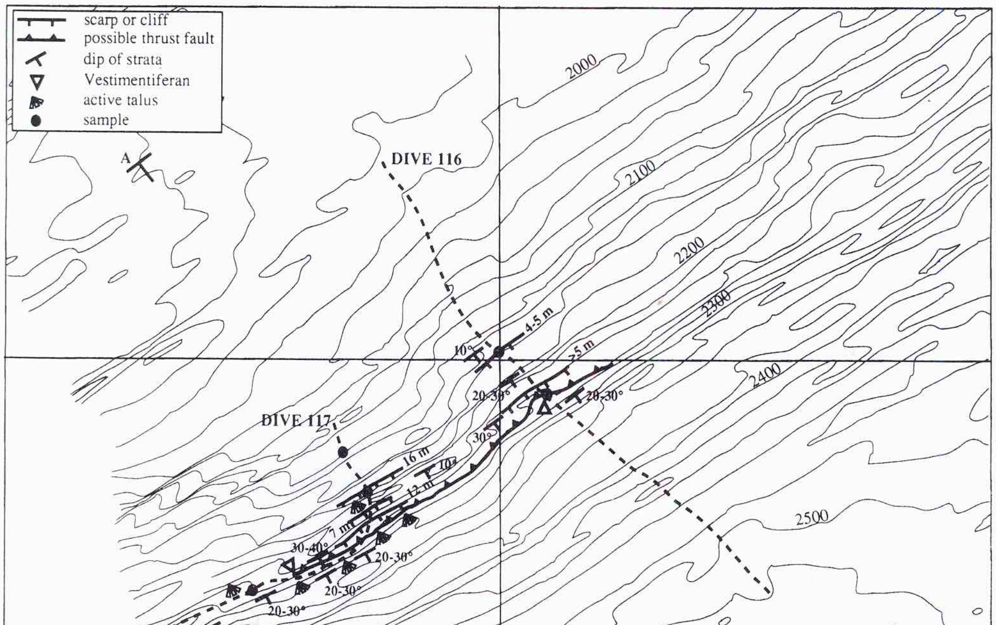

Fig. 2 Seabeam map of the diving area, main observations, and structural interpretation.

Burrows and bioturbations are common in these sediments, and many animals were observed living on the sea-floor : fishes, schrimps, starfishes, holothurias, seas anemones, and gorgonians. We did not observed any significant outcrop during each dive until the depth of 2,260m. From this depth to the depth of 2,140m we observed a succession of scarps or cliffs displaying fresh outcrops. Two and three main scarps were observed during dive 116 and 117, respectively. During dive 116, the first scarp was observed between depths of 2,227 and 2,213m (scarp 1=14m) and the second scarp at 2,140m. During dive 117, the first scarp was observed between 2,260 and 2,248m (scarp 1=12m), the second scarp between 2,223 and 2,216m (scarp 2=7m), and the third scarp between 2,171 and 2,155m (scarp 3=16m) (Fig. 2). During dive 117 we followedthe talus at the depth of 2,260m over 500m and observed that scarp 1 is not continuous. Nevertheless, fallen blocks and erosional gullies are regularly observed at 2,260m, evidencing the base of a steep slope. A steep slope was also observed between scarp 1 and scarp 2, i. e., between 2,240m and 2,226m, making scarps 1 and 2,244m high cliff, almost continuous, whose base is at the depth of 2,260m. This cliff is likely to be 700m long as it was also partly observed during dive 116 (scarp 1).

Trends of scarp are parallel to the trend of the talus, i. e. N060E. Scarps cconsistently display fresh outcrops and fallen blocks or erosional gullies at their base, evidencing a strong submarine erosion which suggests locally active tectonics (Photo 1). Along scarps, strata are roughly parallel to the slope and affected by subvertical joints (Photos 1 and 2). We did not observed neither small-scale fold nor

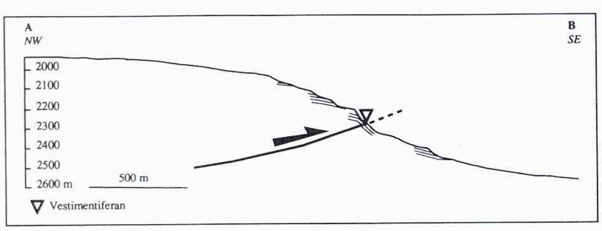

Fig. 3 Simple cross-section of the diving area. A and B are located in Fig. 2. No vertical exaggeration.

fault along these outcrops. Strata are made of non-indurated mudstones. Five samples were collected which did not yet provide a stratigraphic age. We cannot exclude that these strata consist in a thick layer of recent deposits covering the tectonic units of the accretionary wedge or its backstop, and sealing the deformation. However, because the rocks are consistently affected by joints with directions similar to joints observed in the lower units of the accretionary wedge (Lallemant, pers. comm.), we would rather consider these are not superficial deposits. On the other hand, indurated basement rocks would be expected in the backstop of the accretionary wedge. Then, it seems reasonable to consider that the studied talus is part of the Quaternary accretionary wedge.

3. Rare evidence of fluid venting

Indications of fluid venting were seldom observed. We did not find any clam colonies unlike in the outer accretionary wedge (e.g., Kobayashi et al., 1992). We twice observed Vestimentiferan tube worms and Galatheids only. These animals are often associated with clam colonies and fluid outlets in the outer prism. Each observation, the first one during dive 116 and the second one during dive 117, 1.2km far (Fig. 2), was made at 2,260m at the base of the major scarp. Hence, three facts suggest that a flat lying landward dipping decollement could merge at the depth of 2,260m, as shown on the structural cross-

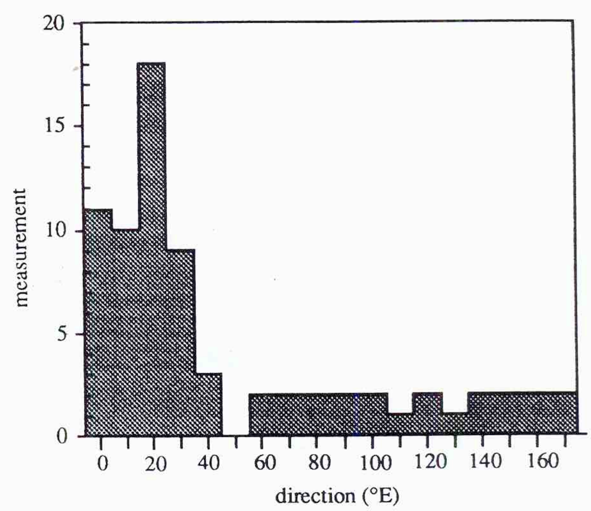

Fig. 4 Joint strike statistics.

section in Fig. 3. First, a major scarp 44m high and possibly 700m long is observed at mid-slope, the base of which is at the depth of 2,260m. Second, the strong erosion evidenced along this scarp suggests active tectonics. Third, fluid venting can be suspected only at the base of this scarp at 2,260m. A flat thrust fault at 2,260m might control the formation and the evolution of the scarp and be associated with sporadic fluid outlets. It had been demonstrated in the lower part of the accretionary wedge that fluid venting is often related to active faulting, faults providing channels for fluid migration (Chamot-Rooke et al., 1992). The same phenomenon is likely to be observed in the inner part of the prism. High-resolution seismic data are needed to verify this hypothesis.

4. Network of joints

Strata are affected by joints and a network of orthogonal joints was several times described (Photo 3). A first family of joints trending about N020E was often observed. In some places, joints are about 1cm spaced and strata actually seem to be affected by a schistosity. The orthogonal family of joints is less developed, joints being 20 to 50cm spaced. Joint strike statistics on 42 measurements show a peak between N000E and N030E centered on N020E (Fig. 4). This direction corresponds to the first family of joints. The perpendicular joints do not emerge from statistics. A similar network of orthogonal joints had been described in the outer accretionary wedge (Chamot-Rooke et al., 1992). Because trends of joints have no obvious link with the direction of convergence between Eurasia and the Philippine Sea Plate, joints were interpreted as the original fabric of sediments in the basin before being integrated in the accretionary wedge.

Joints sometimes consist in opened cracks filled with black crust (Photo 4). These hard black crusts, about 1cm thick, are often preserved from erosion when the surrounding soft sediment is not. They could be related to fluid outlets, joints providing channels for fluid percolation across strata.

5. Conclusion

The studied talus is partially covered with recent deposits, and outcrops are restricted to its central part between 2,260m and 2,140m. This prevents the observation of any structure at the base of the talus. Moreover, no clams colonies were observed in the inner prism, which implies that fluid outlets are not as intense as in the outer prism. Nevertheless, mid-slope observations suggest that a thrust fault merging at 2,260m may locally control the deformation and eventual fluid outlets. Similar networks of joint along this talus and in the lower prism lead us to consider that the studied talus belongs to the Quaternary accretionary wedge. In order to understand the structural relations between the prism and its backstop, to complete the mapping of sites of fluid outlets, and possibly to localize the fault of the soon-to-occur Tokai earthquake, dives are still required along the upper talus of the inner prism.

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(Notice) Photos are given on the following page.

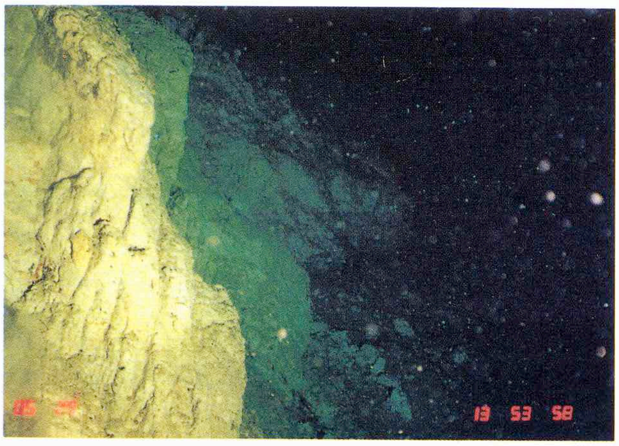

Photo 1 Scarp 3 (dive 117) at the depth of 2,170m. Fallen blocks are observed at the base of the scarp. Vertical planes are interpreted as joints. Heading of the camera is about N060E.

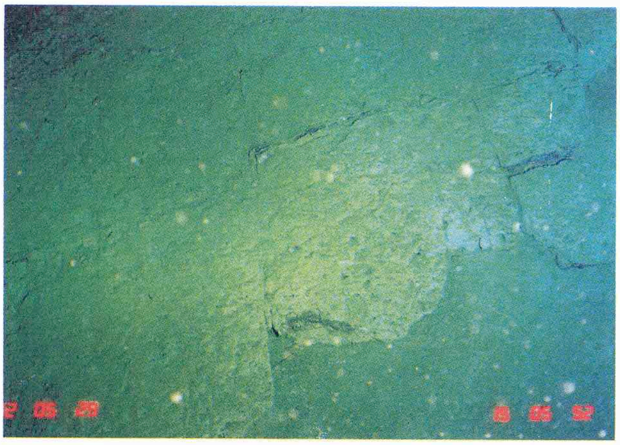

Photo 3 Upper plateau (dive 117) at the depth of 2,087m. A network of orthogonal joints is observed. Heading of the camera is about N020E.

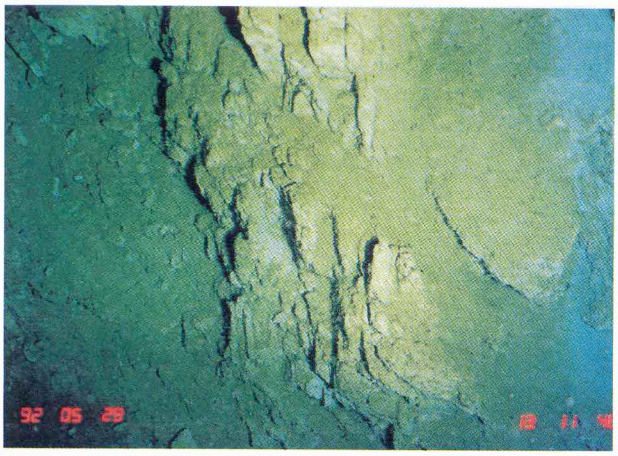

Photo 2 Scarp 1 (dive 117) at the depth of 2,257m. Few centimeters thick strata made of soft sediments are observed.

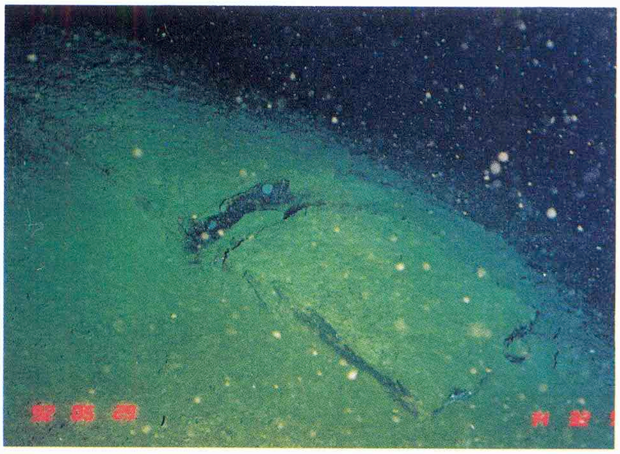

Photo 4 Upper plateau (dive 117) at the depth of 2,115m. Orthogonal joints filled with black crust.