

Tectonics of the Eastern Nankai Accretionary Prism, in Situ Study of the Kodaiba Fault Central Scarp (October 1995, "Shinkai 2000" Dive Report)

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Dives 823 and 824 of the "Shinkai 2000" submersible (October 1995) were held on the upper part of the Eastern Nankai accretionary prism. These two dives were devoted to the study of the Kodaiba fault at 34°00'N, 137°40'E, where the central scarp, trending N 060°E and about 400 meters high, intersects the Tenryu Canyon. We describe tectonic, stratigraphic and biological observations made along both the southern flank of the talus and the eastern slope of the Canyon. Although few active scarps were identified, we could notice, during dive 823, a series of four to five scarps which might be the surface expression of the fault. Animal life was quite important all along the dive tracks. During dive 824, numerous dead *Calyptogena* shells, but also a few living clams, were found in a major erosional corridor perpendicular to the slope. This avalanche-like canyon was followed up to 1,760m depth and continues upward. Such a high quantity of clams must be related to an important fluid outlet, probably located at the mid-slope of the talus (by 1,600m). From these evidences, we conclude that the Kodaiba central talus is the expression of an active fault. Unfortunately, none of these few tectonic features observed enable us to characterise unambiguously the type of faulting.

Key words : Accretionary prism, Kodaiba fault, Active faulting, Clams colony, "Avalanche-like" erosion

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1. Introduction and geodynamic background

We present the results of the "Shinkai 2000" dives 823 and 824, conducted in October 1995, as part of the French-Japanese Kaiko-Tokai Project. This dive survey was devoted to the study of the upper part of the Eastern Nankai accretionary wedge.

Fig. 1 shows a bathymetric and tectonic map of the Eastern Nankai prism compiled from the various cruises held in this area since 1984 (cf. Le Pichon *et al.*, 1987; Le Pichon *et al.*, 1992). The plate tectonic setting is exposed in the inset in Fig. 1. The Philippine Sea Plate subducts under south-western Japan along the Nankai Trough and the Suruga Trough,

then passes eastward to inland collision north of the Izu Peninsula. West of the collision zone, the convergence is partly accommodated by plate subduction along the troughs, and partly by intra-plate deformation along the Zenisu Ridge (Lallemand *et al.*, 1989). Assuming that the boundary between the Eurasia and the North-America plates runs east of the Izu Peninsula, Seno *et al.* estimated the Philippine/Eurasia motion vector at the Nankai Trough to be 50mm/y to N308°E (Seno *et al.*, 1993). Geodetic measurements (Yoshioka *et al.*, 1993) suggest a rate and direction of motion (30mm/y to N330°E) quite different from the plate tectonic inversion. This

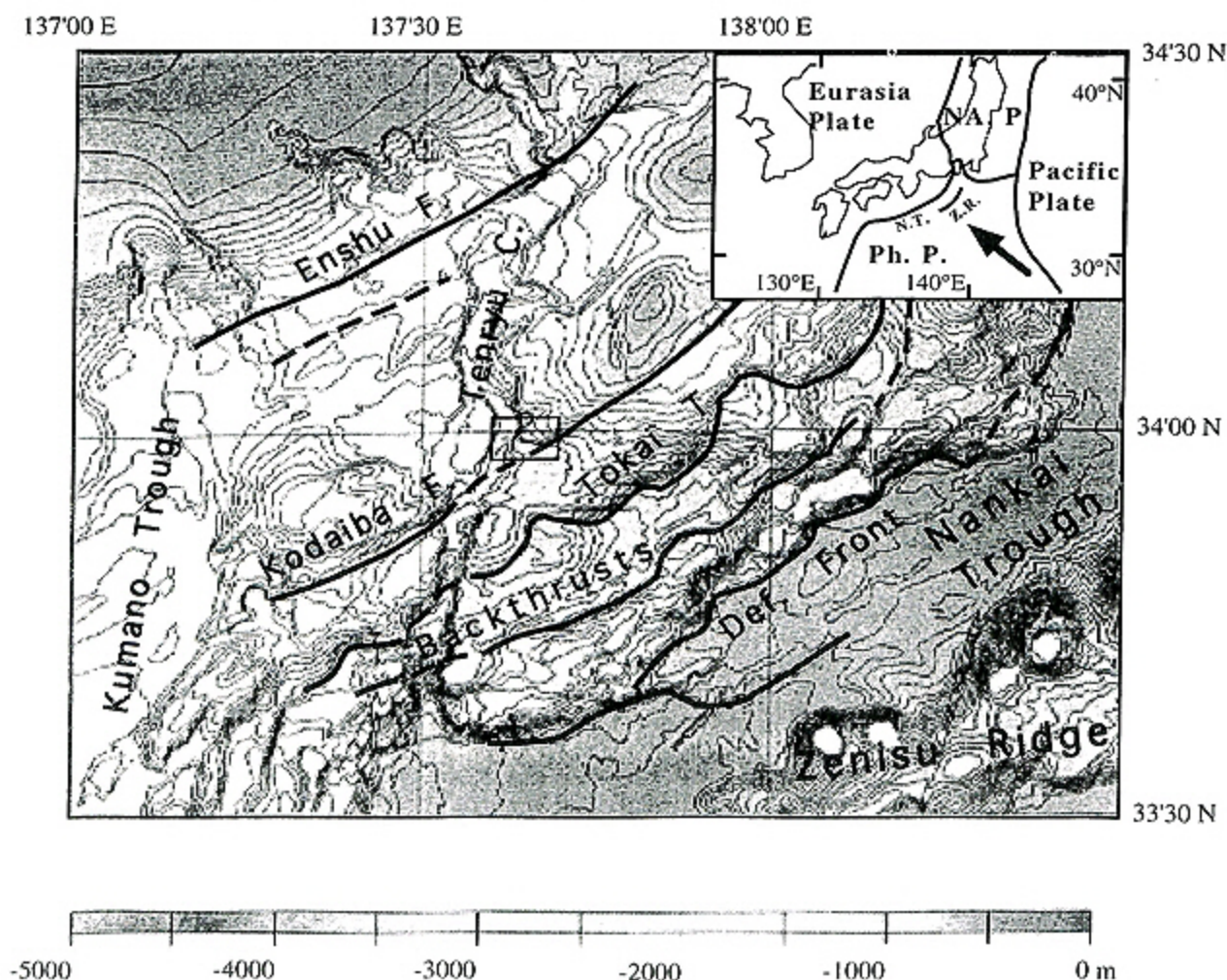


Fig. 1 Bathymetric and tectonics map of the Eastern Nankai accretionary complex. Bold lines: major faults on the low and upper prism (Enshu fault, Kodaiba fault, Tokai thrust, backthrusts system, Deformation Front). Central inset: location of Fig. 2. Upper right inset: plate tectonics setting around Japan (Ph. P.: Philippine Sea Plate; NA. P.: North American Plate; N.T.: Nankai Trough; Z.R.: Zenisu Ridge), the arrow shows the relative motion of the Philippine Sea Plate with respect to the Eurasia Plate (cf. text).

difference is partially due to the complexity of the convergence partitioning between the Zenisu Ridge thrusts, the accretionary prism and the Central Japan deformation systems (cf. Le Pichon *et al.*, 1996).

The main objectives of the Kaiko-Tokai Project is to study the offshore tectonic features in order to understand this partitioning and its relationship with the soon-to-occur great Tokai earthquake (e.g. Ando, 1975; Ishibashi, 1981; Le Pichon *et al.*, 1996 (submitted)).

The dives 823 and 824 were devoted to the survey of one of the major fault of the upper prism (cf. Fig. 1 for tectonic setting and dive locations). The upper prism is characterised by localised deformation mainly concentrated along linear faults trending N 060°E to N070°E, parallel to the Nankai Trough. These morphotectonic features run from the Kumano Basin eastern boundary (137°15'E) to 138°10'E, where the general trend of the prism changes abruptly to north-south, parallel to the Suruga Trough. The scarp studied during both dives is the surface expression of the Kodaiba fault. It is more than 70km long and consists of three en-echelon segments, about 300 to 400m high. Through seismic reflection lines, dive surveys and other geophysical means, the Kodaiba fault has been identified as a major active thrust dipping northward (e.g. Chamot-Rooke *et al.*, 1992; Moore *et al.*, 1990), with an important strike-slip component. However, whether the strike-slip is left-lateral or right-lateral is still a matter of debate (cf. Thoué *et al.*, 1995; Le Pichon *et al.*, 1994). The motion on this fault is thus an important issue, as it would bring a good constrain on the type of deformation accommodated in the upper prism.

2. Observations

During both dives, we studied the Kodaiba fault central talus, where it intersects the Tenryu Canyon. Fig. 2 shows a detailed bathymetric map with the dive tracks. The main observations are also reported.

2.1 The southern slope of the talus

Dive 823 (observer X. Le Pichon) was located at the edge of the southern flank of the Kodaiba fault scarp.

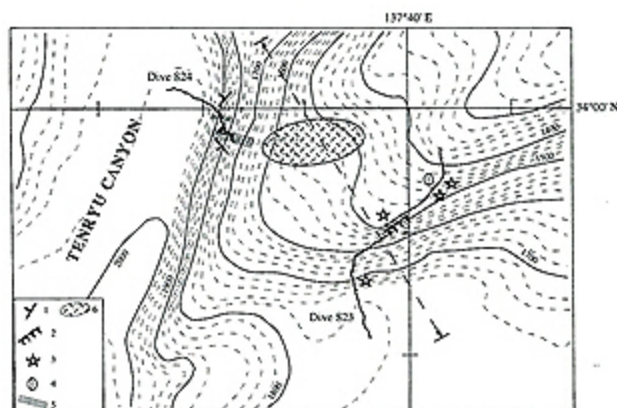


Fig. 2 Detailed bathymetric map of the dive survey area. Bold lines: tracks of the dives 823 and 824 (October 1995). 1=general dip and strike of strata; 2=major scarp zone; 3="Sea-stars field"; 4=bivalves; 5=location of the main erosional gullies; 6=probable location of the clams colony site (cf. text). Dashed line: position of Fig. 4 the cross-section.

between 1,770 and 1,350m depth. It climbed a talus trending locally N070°E, covered by a poorly indurated mudstone, and with an average slope about 15° steep. The talus is divided into two parts by a small plateau located between 1,490 and 1,470m depth.

The only scarps encountered during the dive are located at the top of the first talus, at the front of the plateau. A series of four to five small scarps, concentrated on 200 meters between 1,520 and 1,480m depth, forms a quite continuous scarp striking N050°E on average (Fig. 2). Each outcrop is more or less conformable to the slope (trend N040°E to N060°E, except one N010°E), facing SW, few tens of centimetres high, and quite fresh (with fallen blocks at the front). No layering was clearly identified on the scarps. The material forming the talus was sampled on the second encountered scarp. It consists of a soft, bioturbated mudstone (probably talus fill formation) dated by nannofossils (CN14a) at 0.46 to 0.88 Ma (J. Ashi, personal communication, June 1996).

Animal life was quite important all along the dive, especially on three different spots: many star-fishes were found at the foot of the talus, in the scarps area and at the top of the talus (Fig. 2). Numerous sea-fans were established on the top of the outcrops

around 1,500m depth. Few bivalve shells were found from 1,430m depth up to the end of the dive, some of them might have been alive.

As stated previously, the scarps affecting the talus are relatively parallel to the talus trend and thus might be interpreted as scars of gravity slumps. However, considering that they are located at the top of the talus, on the border of the plateau (one might expect gravity slumps on the main slope of the talus), that they seem to form a continuous scarp more than 300m long, and that their trending is consistent with the general N060°E direction of the Kodaiba fault, these scarps may as well be regarded as the surface expression of the Kodaiba fault.

2. 2 The western extremity of the talus

Dive 824 (observer S. Lallemand) ran across the slope on the eastern side of the Tenryu Canyon, where it intersects the Kodaiba fault, from 1,970m to 1,760m depth (cf. Fig. 2 and 3). The slope increases from 15° at its base to 35° average from 1,920m depth. Its strike is about N010°E, consistent with the main direction of the canyon.

At the base of the talus (1,970 to 1,960m depth), the channel bottom is covered by an extremely soft mud affected by ripple marks oriented N020°E to north-south. These ripples are thus oblique to the current which runs from N250°E in this area, and most of

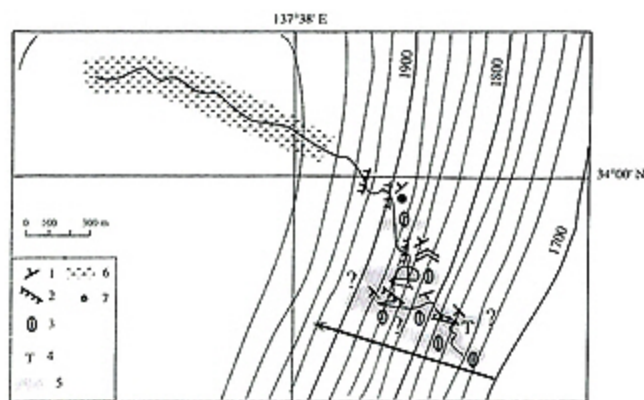


Fig. 3 Observations along the track of dive 823. 1=dip and strike of strata; 2=main scarps; 3=living or dead clams; 4=tube worms; 5=erosional gullies and canyons, with possible extent (marked by a "?"); 6=bottom of the channel affected by ripple marks; 7=sample site dated between 5.6 and 8.2 Ma; thick arrow: main direction of the avalanche flows.

them show an asymmetrical shape, their steepest flank facing East.

The first part of the slope (1,960 to 1,920m depth) consists of a talus made of semi-indurated mudstone, outcropping locally in the upper part. These outcrops are conformable to the slope, from a few tens of centimetres to one metre high. The layers are 10 to 30cm thick, with a stratification averaging N030°E, 40°NW, thus slightly oblique to the canyon talus. However, the strike of the strata is consistent with the general trend of the main N060°E talus (cf. Fig. 2). The mudstone was sampled at 1,940m depth and nannofossils study (CN9 nanno-facies) reveals an age between 5.6 and 8.2Ma (J. Ashi, personal communication, June 1996).

From 1,930m depth, the slope gets steeper, and large erosional gullies and transverse canyons cut through the strata. These gullies are a few metres large and erode the layers over a 0.5 to 2m height. Most of them are filled with debris of mudstone and pebbles, witnessing an active erosion through "avalanche-like" processes. From 1,909m depth, dead *Calyplogena* clams are also present in the canyons. They are concentrated in a large transverse canyon running mainly east-west, where their density reaches a maximum of 10 to 20 shells per square metre. The shells are part of the avalanche flows that partly filled the canyon as they are aligned along the steepest slope line (average direction N100°E) and more or less buried inside the debris. From there, erosional gullies that belong to the same canyon system were followed. However, their evolution along the slope was quite chaotic and many ramifications appeared as the submersible climbed the talus up to 1,757m (cf. Fig. 3 for locations of the main gullies). Clam shells are present from spot to spot all along the avalanches and show quite regular east-west alignment. From 1,880m depth, a few irregular trails in the mud suggested that some of the clams might be alive. At two different spots, vestimentiferan tube worms appeared to be alive. A poorly indurated mudstone (no datation) and one dead tube worm were sampled at 1,815m depth. Some *Calyplogena* clam shells were also sampled, but

no specification has been obtained yet.

Fig. 3 shows the numerous outcrops, mostly parallel to the slope, created by the erosional gullies cutting through the strata. The stratification observed consists of 10 to 30cm thick, indurated mudstone layers oblique to the local slope, on average N140°E, 30°SW.

No clear evidence of active tectonics could be observed on any part of the talus, except at the slope rupture area (1,920m depth), where a large erosional corridor exposes features in the strata that may be interpreted as a series of small folds with angular hinges striking N060°E, parallel to the trend of the Kodaiba talus. The folded strata are cut by a few sets of joints, two to three metres long, with a roughly north-south trend. However, the joints are parallel to the local trend of the slope and thus might be only related to gravity slides. In this area, the stratification appears to be N030°E, 40°W, consistent with estimations on the lower part of the talus (cf. Fig. 3). The implications of these observations are discussed in the next section.

3. Interpretation / discussion

The Kodaiba fault talus has been the subject of previous "Shinkai 2000" surveys. Dives 762 to 764 were located at the easternmost extremity of the eastern segment of the fault, and dives 705 and 706 took place on the eastern and central segment. These two dives showed that the talus is the expression of an active thrust, with a typical anticline forelimb forming the plateau and the 400 meters high cliff observed all across the upper prism (Le Pichon *et al.*, 1994). On its central segment, the base of the talus is affected by numerous fresh scarps as well as sets of joints and folds. Tube worms (but no clams) located around the scarps show frequent fluid outlets, symptomatic of the activity of the fault. The depression at the easternmost section of the Kodaiba talus was studied during dives 762 to 764. In this area, active faulting was also evidenced by scarps and other tectonic features on the northwestern wall of the depression (Thoué *et al.*, 1995).

Some similar features were observed during dives

823 and 824. The strata and the probable folds described along the western flank of the talus might be regarded as the outcrop of an anticline, striking roughly WNW-ESE (cf. Fig. 3 and 4). The inner sedimentary layers of this anticline would correspond to the rocks sampled by 1,940m depth on the western flank of the talus and dated between 5.6 and 8.2Ma, bringing a rather good constrain on the age of the deformation related to the Kodaiba fault (at least Upper Miocene). The trend of the anticline does not match exactly the general trend of the Kodaiba talus (N060°E), but the local estimations of the stratification are probably biased by the very important erosion, through the Tenryu Canyon as well as the transverse gullies.

Fig. 4 shows a cross-section of the Kodaiba talus in the dives area (cf. Fig. 2 for location of the section), with the main observations reported by projection. The first two-thirds of the section are based on the bathymetric data recorded during the dive 823. As it appears on the Figs. 2 and 4, the scarps described on the southern flank of the talus are located at the front of a small terrace. Furthermore, the tube worms and the huge quantity of dead clams found in the avalanches on the western slope of the talus are most probably coming down from the small plateau situated near 1,650 meters depth (cf. Fig. 3 and 4) directly above the scarps, themselves associated with numerous sea-fans. This suggests that important fluid seepage is related to the scarps. These observations, associated with the anticline form described earlier lead us to conclude that active faulting occurs along the Kodaiba talus.



Fig. 4 Cross-section along the eastern-central Kodaiba talus based on bathymetry from dive 823 (cf. Fig. 2 for location). Observations from both dives 823 and 824 are reported. 1=location of the main scarp site (dive 823); 2=probable major Kodaiba thrust fault, not outcropping; 3=secondary surface expression of the Kodaiba thrust fault; 4=probable location of the clams colony; 5=stratification of the observed strata.

The morphology of the talus, as well as observations made during previous dives on its central part, strongly suggest that the Kodaiba fault has an important reverse component (Le Pichon *et al.*, 1994). The features described during dives 823 and 824 are consistent with this thrust fault interpretation.

However, few direct evidences of tectonic activity could be clearly spotted during both dives 823 and 824. This could be partly explained by the high sedimentation rate due to the proximity of the Tenryu Canyon. We believe that the talus deposits have buried most of the latest surface expressions of the Kodaiba fault, leaving only a few fresh scarps or outcrops. Considering the thickness of the talus fill and the poor induration of the strata on the southern flank, these scarps are consistent with the expression of a fault within a very soft mudstone.

4. Conclusion

The Kodaiba scarp in the study area is a highly sedimented talus, covered by recent (Pleistocene to Holocene) deposits. The abundance of clams and the presence of tube worms on the western slope of the talus evidence some intense fluid outlets related to the activity of the fault. Tectonic markers of this activity are not well expressed but the observations made are concordant with faulting along a N050°E direction.

The type of deformation affecting the Eastern Nankai subduction system is presently an important issue of the scientific researches in Japan. In order to understand the mechanism of earthquake ruptures in this area, the study of the tectonic features of the prism is of high interest. Questions as whether shear partitioning occurs or not between the deformation front and the inner prism system, what is the relation between the prism and the backstop, may be resolved by dive surveys. Results from the October 1995 "Shinkai 2000" survey confirmed that the Kodaiba scarp corresponds to a major fault but did not bring any discriminating evidences about the strike-slip motion on the fault, or the lateral extension of its activity. Thus, some dive observations are still required along the upper prism.

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