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Shear partitioning in the eastern Nankai Trough: evidence from submersible dives

X. Le Pichon [a], S. Lallemant [a], M. Fournier [a], J.P. Cadet [b], K. Kobayashi [c]

[a] *Laboratoire de Géologie, Collège de France et Ecole Normale Supérieure, URA-CNRS 1316, 24 rue Lhomond 75231 Paris Cédex 05, France*

[b] *Département de Géotectonique, Université P. et M. Curie, URA-CNRS 1759, Paris, France*

[c] *Japan Marine Science and Technology Center, Yokosuka, Japan*

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Abstract

Submersible dives over the wedge of the easternmost Nankai Trough demonstrate the existence of a left-lateral strike-slip system parallel to the subduction zone. This system develops as the trench, turning northward toward land, becomes highly oblique to the motion. Although shear partitioning is well known in other subduction zones, the process here has the peculiarity of continuing northward into land.

1. Kinematic background

The Philippine Sea plate is subducting below southwest Japan along the Nankai Trough. The 305–310° direction of motion was well established by the great Tonankai earthquake of 1944 [1,2], which ruptured the eastern portion of the trough. This earthquake was used as the basis for kinematic models, which give a velocity of 2–4 cm/yr [3,4]. Recently, Yoshioka et al. [5] have proposed that the direction of convergence inferred from geodetic data inversion analysis may be closer to 330° along the easternmost portion, which would then belong to the North American plate. Seno et al. [6] also put the limit between the Eurasia and North American plates in the vicinity of the Izu peninsula. Following Yoshioka et al., the limit of the North American plate system would be along the eastern limit of the Tonankai rupture zone (Fig. 1). We conclude that the subduction motion is frontal along the Tonankai rupture zone but becomes highly oblique along the N–S trending Suruga trough (Fig. 1).

2. Structural background

The main characteristic of the eastern portion of the Nankai Trough is that the subduction boundary shallows progressively along the Suruga Trough. It extends on land, where it transforms into a collision zone north of the Izu peninsula, before re-entering the sea along the Sagami Trough (Fig. 1). The accretionary wedge was studied in detail during the Kaiko Nankai program [7–10]. A synthetic structural map, incorporating the results of the Kaiko Nankai dives as well as a later submersible survey [Lallemant et al., in prep.], based mainly on a detailed Seabeam map from the Japan Hydrographic office and a

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few multichannel seismic sections [11], is shown in Fig. 2.

The outer portion of the accretionary wedge consists of a 20–40 km wide belt of highly shortened thrust units limited by a major landward-verging thrust. Landward of this backthrust, the middle slope, which is less deformed, is characterized by a major, rectilinear, N60°E trending scarp which can be followed for over 60 km. The scarp ends to the northeast within a small depression trending N–S, which has the morphology of a graben. A major unknown was the tectonic nature of the large, rectilinear scarp. We explored it during two dives of the Shinkai 2000, in October, 1993 (Figs. 2 and 4).

3. Observations from the dives

The scarp trending N60°E is oblique with respect to the isobaths. Dive 705 (observer: J.P.C.) climbed the cliff between 1500 and 1300 m,

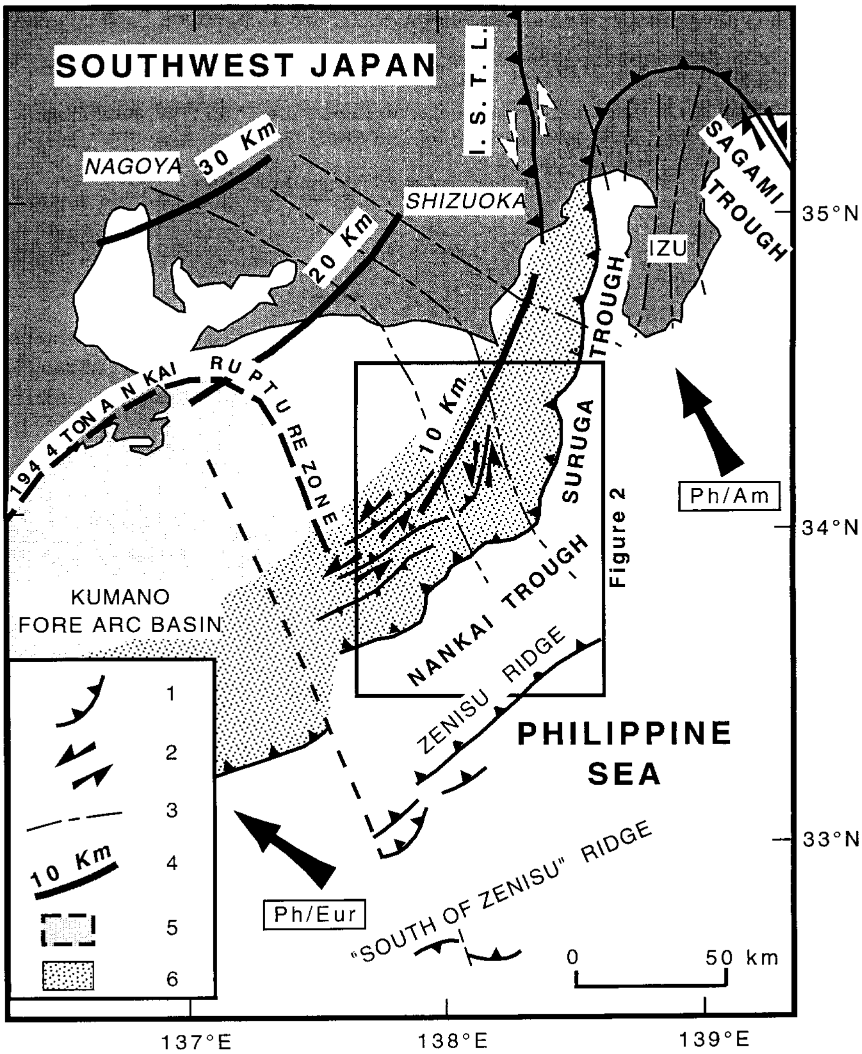

Fig. 1. Geodynamic setting of the eastern Nankai area. *1* = major thrusts; *2* = strike-slip component along active faults; *3* = maximum horizontal compressive stress trajectories ($s_{h\ max}$); *4* = isodepth lines for the subducting Philippine Sea plate; *5* = rupture zone of the 1944 Tonankai earthquake (magnitude 8.3); *6* = Eastern Nankai accretionary complex.

whereas dive 706 (observer: X.L.P.), 20 km to the northeast of it, crossed it between 800 and 600 m. In both cases, the main scarp appears to be the limb of a large fold because the stratification is parallel to the slope (Fig. 3). The adjacent plateau, which was crossed during dive 706, is formed by the top of the fold. It is affected by intensive erosion, with frequent fluid seeps, as evidenced by tube worms. A broad talus, covered with debris and cut by numerous fresh scarps, occupies the base of the cliff.

The material forming both the cliff and the talus consists of weakly indurated mudstone, based on Foraminifera [G. Glaçon, pers. commun., 1993] its age is younger than 600,000 yr. In spite of the poor consolidation, the scarps are fresh and unaffected by erosion; the debris on the talus are not covered with sediments. The evi-

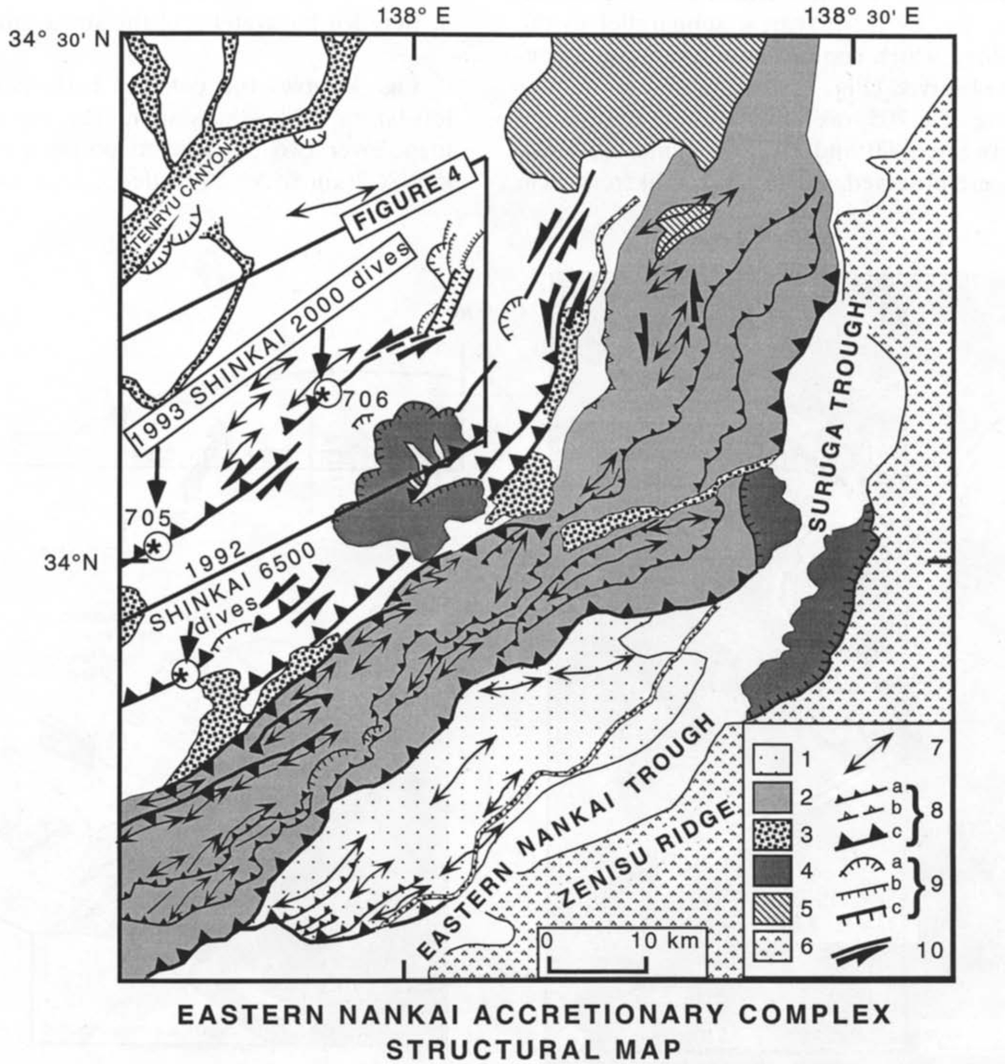

Fig. 2. Structural map of the eastern Nankai accretionary complex. *1* = recently deformed trench fill; *2* = main body of the active accretionary prism; *3* = ponded slope basins; *4* = areas of massive slope failure; *5* = terraces; *6* = Zenisu ridge reliefs; *7* = major anticline axes; *8* = thrust faults, *a* = minor, *b* = inferred, *c* = major; *9* = extensional and erosive structures, *a* = slump scars; *b* = linear scarps; *c* = probable normal faults; *10* = strike-slip faults.

dence thus points to active tectonics along this feature.

We have observed several diagnostic structures which lead us to believe that this large, rectilinear lineament is the surface expression of a fault with a predominant left-lateral strike-slip component. Starting from the base, metric folds, oriented 290–320°, were observed within the talus during dive 706 and are interpreted as drag folds. These broad (4 m) smooth undulations were observed over a length of 300 m, between 800 and 750 m. They are cut by fresh scarps, subparallel to the slope, along which conformable layers can sometime be observed (Fig. 3).

During dive 705, over the steepest part of the cliff, between 1400 and 1300 m, numerous small scarps were observed, varying in height from 5 cm to 1 m, oriented N30°E and facing east. These are associated with drag traces compatible with left-lateral motion. Numerous joints trending N30°E and a few open cracks with the same orientation are compatible with the same stress system. We conclude that these rectilinear scarps are left-lateral faults, although the broad steep asymmetrical fold suggests the existence of a present or past component of transpressive motion.

4. Detailed bathymetry of the strike-slip system

Fig. 4 shows the detailed bathymetry of this left-lateral strike-slip system. The two dives were made over two en échelon portions offset by 2 km. A 2 km wide, 20 m deep, depression lies at

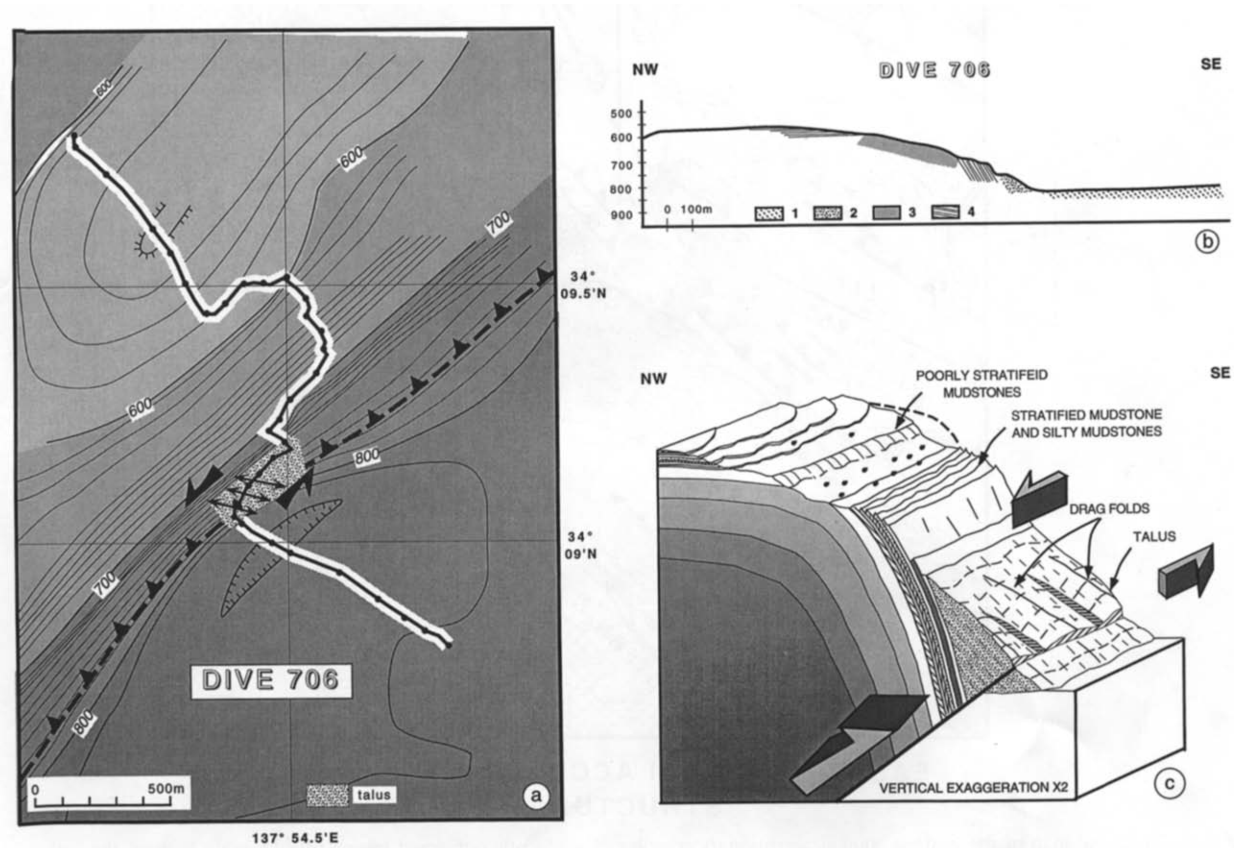

Fig. 3. Geological observations along dive 706. (a) Dive track with location of drag folds and talus. (b) Schematic cross section with sedimentary facies observed: *1* = hemipelagics; *2* = talus; *3* = massive and poorly stratified mudstones; *4* = thin bedded stratified mudstones and silty mudstones. (c) Synthetic block diagram of the scarp.

the foot of the northeastern portion along the prolongation of the offset. It was crossed during dive 706 and appears to be filled by quiet sedimentation without any evidence of tectonic activity. Its general geometry suggests a pull-apart mechanism.

The northeastern segment terminates at the location of the previously mentioned N–S trend-

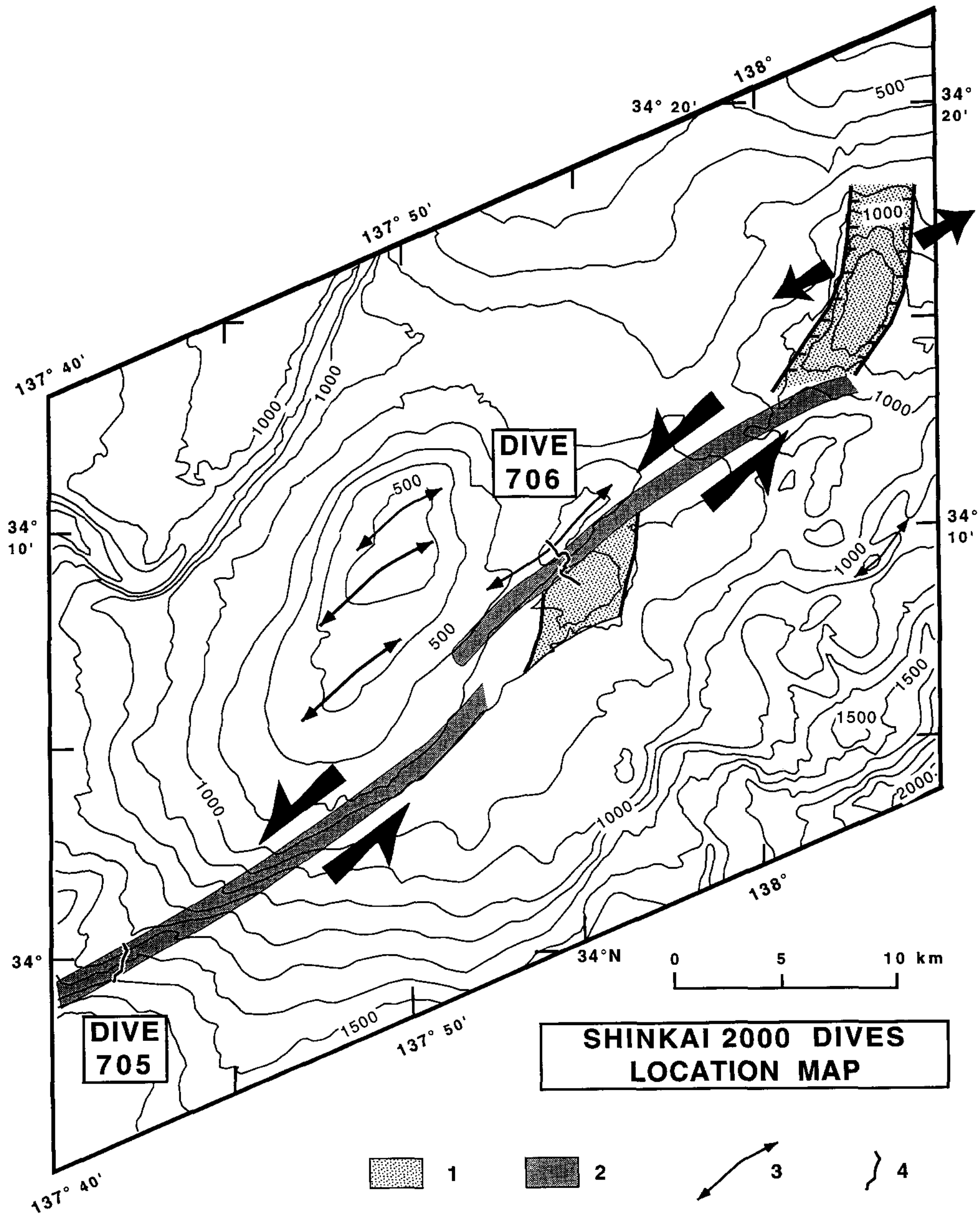

Fig. 4. Detailed multibeam bathymetric map of the scarp investigated during the 1993 SHINKAI dives. *1* = ponded probable 'pull-apart' basins; *2* = area of maximum slope; *3* = anticline axes; *4* = SHINKAI dive tracks.

ing, 3 km wide, 100–200 m deep, linear depression, limited by two steep scarps trending N to N10°E (Figs. 2 and 4). We interpret this structure as a pull-apart graben.

From the geometry of these two pull-apart grabens bounding the segments of the main scarp, we infer the existence of a large-scale left lateral strike-slip system.

5. Significance of the left-lateral system: shear partitioning

During two dives of the submersible Shinkai 6500 in 1992, we explored a 600 m high N060°E scarp, at depths ranging between 2500 and 2000 m and located 20 km seaward (Fig. 2) [Fournier et al., in prep.]. The evidence was interpreted as indicating an active oblique thrust with a significant left-lateral component, as shown in particular by the direction of minimum stress (numerous joints trending N to N30°E).

On this basis, we have interpreted the structural map (Fig. 2) as a left-lateral system, progressively curving counterclockwise toward the north, parallel to the toe of the subduction zone. The system appears to die out toward the west before it reaches the eastern limit of the Tonankai earthquake (Fig. 1).

Thus, this structural pattern reflects a shear partitioning phenomenon (that is, the partitioning of the oblique motion into a pure thrust component in the frontal trench system and a pure strike-slip component landward) related to the 30° angle made by the subduction motion with the N–S trending plate boundary along the Suruga Trough. In our study area (Fig. 2), west of 138°E, the 60°E direction of the strike-slip fault we have discovered is perpendicular to the direction of subduction, whereas east of it the N–S to NNE–SSW direction is clearly oblique. We interpret the southwestward prolongation along a 60°E direction as a tail of this system. However, further west, outside our study area, the trench is again oblique to the direction of subduction but with a right-lateral component, which produces the well known right-lateral motion of the Median Tectonic Line (MTL) on land [12].

The part of the outer wedge which is moving to the north with respect to the inner wedge is less than 10 km thick, as the 10 km isobath of the surface of the plunging plate, after Ishida [13], approximately coincides with the main left-lateral fault (Fig. 1).

The strike-slip system can be followed northward to the continental shelf but its extension within the shelf is not obvious. Further north, the ISTL (Itoigawa Shizuoka Tectonic Line), which is interpreted as a left-lateral fault acting now mostly as a thrust fault [14], appears to be a direct prolongation of the accretionary wedge left-lateral strike-slip system. However, the system is probably quite complex, especially if the motion is not parallel to the isobaths of the plunging plate: we are not able to discuss it here.

6. Conclusion and discussion

As in the classical examples of Sumatra, the Philippines [12] and the western Aleutians [15], the Eastern Nankai Trough shows a clear case for shear partitioning as the trench becomes very oblique to the motion. The difference with other well known cases is that the laterally moving portion of the wedge abuts against the continental shelf. This appears to be a unique case, the implications of which are not yet understood.

We suggest that the large vertical fault limiting the outer wedge to the west isolates the fluid circulation of the outer shallow wedge from the inner margin. Thus, any fluid circulating within this wedge must originate either within the wedge or laterally from the northern shelf. The Kaiko–Nankai studies have shown a very large amount of fluid expulsion at the toe of this wedge. This amount implies a source of fluids much larger than the amount of water produced by simple compaction [16]. However, the existence of the strike-slip system should drain to the surface any deep fluids coming from the inner portion of the margin and thus prevent any significant lateral flow from the inner margin to the outer wedge. The source of the fluid from the toe must be found within the outer wedge or along the strike-slip system. For example, meteoric water coming from the continent or fluid resulting from high temperature (> 100°) metamorphic transformations would be prevented from reaching the outer wedge.

Platt [17] has recently discussed the mechanics of oblique convergence and shown that the partitioning is distributed throughout the wedge for a viscous material, whereas a plastic or Coulomb wedge moves coherently without internal deformation, the partitioning depending on the obliquity of convergence. Our study indicates that the strike-slip deformation is concentrated near the limit of the backstop. Thus, the material behaves as a plastic or Coulomb material, in spite of the fact that the wedge here is quite thin and formed of Neogene sediments.

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