CAMPAGNES KAIKO (legs 1 à 3) :
DIVERS ASPECTS DE LA SUBDUCTION DANS LES FOSSES JAPONAISES

KAIKO I

-1ère Partie-

Dates:

- Leg I (Fosse de Nankai - Ride de Zenisu) - 1er au 19 Juin 1984.
- Leg II (Dépressions de Suruga et Sagami - Point Triple) - 21 Juin au 9 Juillet 1984.
- Leg III (Fosse du Japon - Volcans Kashima et Erimo - Jonction Fosse des Kouriles) - 12 au 30 Juillet 1984.

Lieu: Japon

Participants:

Leg I:

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Opérations:

- Reconnaissance par méthodes indirectes des secteurs-clés des fosses japonaises à l'intérieur de 7 zones préalablement sélectionnées (Figure 1).

- Mise en oeuvre:
    - du sondeur multifaisceaux Seabeam
    - du sondeur à sédiments 3,5 KHz
    - de la sismique monotrace rapide
    - du magnétomètre
    - du gravimètre

- Des cartes Seabeam (couverture à 100%), magnétiques et gravimétriques ainsi que des jeux de profils sismiques sériés ont été obtenus pour 7 "boîtes":

    - Boîte 1: Partie nord de la fosse du Japon et sa jonction avec la fosse des Kouriles (leg 3)
    - Boîte 2: Partie sud de la fosse du Japon dans la région du volcan Kashima (leg 3)
    - Boîte 3: Escarpement de Boso dans la dépression de Sagami (leg 2)
    - Boîte 4: Région de la dépression de Suruga (leg 2)
    - Boîte 5: Fosse de Nankai - Canyon de Tenryu et Ride de Zenisu (leg 1)
    - Boîte 6: Fosse de Nankai et Ride fossile de Shikoku (leg 1)
    - Boîte 7: Fosse de Nankai et Ride de Palau-Kyushu (leg 1)

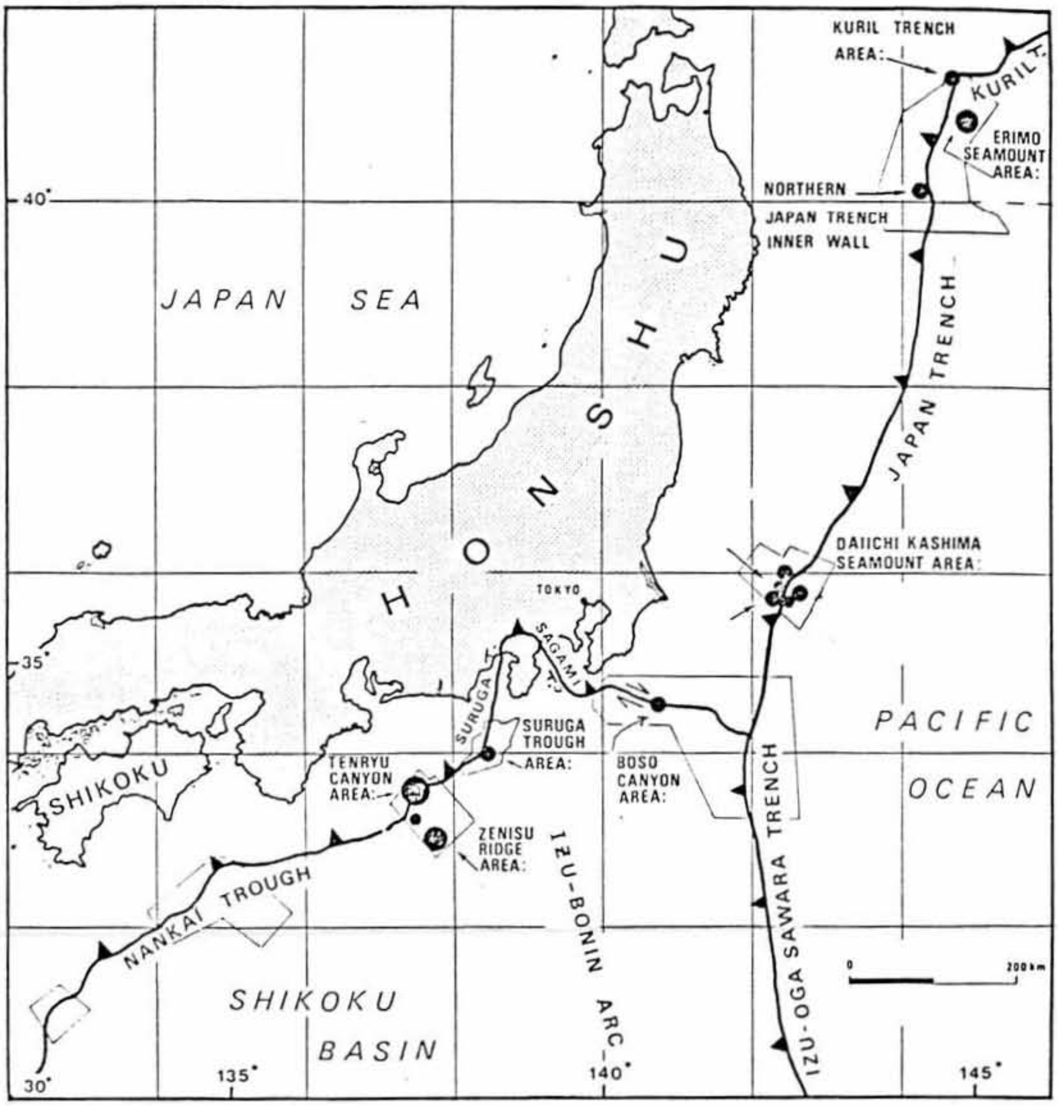

Fig 1 Localisation des campagnes KAIKO tire du receuil de donnees de plongees KAIKO edite par l IFREMER (1989, sous presse)

- 2ème partie -

Objectifs et méthodes:

Le but de cette série de campagnes, outre l'aspect imagerie du fond qui a livré de précieuses observations, était de définir des cibles de plongées (KAIKO II, été 1985). Les résultats de KAIKO II ne seront pas décrit dans le présent document bien qu'ils forment souvent un tout, car il ne s'agit plus du Tour du Monde du N/O J. Charcot.

L'intérêt était de comparer sur une courte distance 2 types de marges convergentes: l'une en construction (Nankai) avec un prisme d'accrétion actif bien développé et l'autre se consumant (Japon au sens strict) caractérisée par des glissements gravitaires importants et une fosse vide de sédiments. La dépression de Sagami semblant plutôt caractérisée par un coulissement dextre avec une faible composante convergente.

De plus, divers phénomènes viennent perturber cette vision simple et apportent des informations exceptionnelles sur la compréhension du processus de subduction. Il s'agit de la subduction d'édifices volcaniques à différents stades d'enfouissement (rides ou volcans sous-marins), de l'écaillage intraocéanique près de la fosse (ride de Zenisu), de la présence d'un point triple Fosse-Fosse-Décrochement (Dépression de Sagami-Fosse du Japon et d'Izu-Ogasawara) ainsi que d'une jonction de fosses (Fosses du Japon et des Kouriles).

La cartographie des anomalies magnétiques a permis en outre de préciser l'évolution du Bassin de Shikoku, l'allure des linéations au Nord de la Fosse du Japon et la présence d'un volcan enfoui sous la marge au niveau de la jonction Japon-Kouriles.

- 3ème partie -

Thèmes:

Prisme d'accrétion (fig.2)

La campagne KAIKO a fourni pour la première fois une image tridimensionnelle du prisme exemplaire de Nankai (sismique-Seabeam). Il apparaît que les turbidites venant du continent sont d'abord plissées avant de s'empiler, alors que la plus grande partie des boues fines qui recouvrent la croûte s'enfonce loin sous le prisme. Il existe donc un niveau de décollement le long duquel la partie superficielle des sédiments comprimés contre la marge se désolidarise des sédiments plus profonds qui entrent en subduction. Le décollement se produit dans des couches sédimentaires gorgées d'eau où la friction et donc la résistance au mouvement sont faibles.

Erosion tectonique (fig.3)

A l'inverse, la marge de la fosse du Japon ne montre pas ou peu d'accrétion, notamment dans sa partie septentrionale. Divers arguments tels que l'importance de la subsidence depuis le Miocène ou la troncation des réflecteurs du socle à la base du prisme suggèrent que le volume de la marge a fortement diminué au Néogène. L'examen des cartes Seabeam du secteur a révélé de nombreuses falaises parallèles à la fosse, dont la hauteur peut atteindre plus de 2 km. Il s'agit dans la plupart des cas de cicatrices d'arrachement. De manière simpliste, on peut penser que l'instabilité du rebord de la marge continentale induit des glissements en masse de sédiments. Ces derniers sont piégés dans les dépressions de la plaque océanique qui finalement s'enfonce sous la marge le long d'un plan lubréfié par l'eau en surpression qui se dégage des sédiments.

Subduction d'aspérités (fig.4)

La plaque Pacifique présente dans ce secteurs 2 types d'aspérités. Le premier, assimilable à des "touches de piano", correspond à la fracturation en horsts et grabens de la plaque océanique lors du ploiement de la lithosphère en avant de la fosse (relief vertical de l'ordre de 20 à 200 m). Ces failles continuent à être actives sous le prisme et guident la fracturation du front de la marge. Le second correspond aux volcans sous-marins portés par la plaque et arrivant en subduction (relief vertical pouvant atteindre 3 km). Par chance, tous les stades d'enfouissement sont représentés le long de la fosse du Japon: volcan Erimo (à peine enfoui), volcan Kashima (enfoui au tiers de sa surface) et un volcan totalement subduit à la jonction Japon-Kouriles. L'ensemble de ces observations a permis d'élaborer un scénario de tectogénèse de la marge et du volcan lors de l'enfouissement, le stade le plus avancé montrant que le volcan reste solidaire de la plaque océanique et que le front de la marge s'effondre massivement en arrière.

Point triple (fig.5)

La plaque Pacifique s'enfonce à la fois sous le rebord japonais et sous le bord de la plaque Philippines. De plus, cette dernière passe, elle aussi, en subduction sous le bord Japonais. Elle doit donc s'enfoncer sous le Japon tout en restant au dessus de la plaque Pacifique. Cela ne se produit pas sans difficulté car il n'y a pas assez de place entre le bord japonais et la plaque Pacifique pour que la plaque Philippines puisse s'enfoncer librement sans se déformer. KAIKO a fourni les preuves de l'existence de cette déformation en surface grâce à la carte Seabeam et aux profils sismiques. En effet, l'extrême bord de la plaque Philippines est affecté en surface par des plis et des chevauchements qui traduisent les déformations en profondeur de cette plaque.

Ecaillage intraocéanique (fig.6)

La ride de Zenisu apparaît comme une conséquence directede la collision-subduction d'Izu. La sismicité est active le long de la ride, indiquant que celle-ci est actuellement en processus de formation. KAIKO a fourni les arguments tectoniques et géophysiques (Seabeam, sismique, gravimétrie) en faveur d'un chevauchement intra-océanique au pied de Zenisu côté océnique. La déformation superficielle compressive est intense à la base de zenisu où les sédiments sont plissés et le socle est fracturé. La modélisation des linéations magnétiques démontre la nature océanique et l'âge miocène inférieur du socle de Zenisu. Une modélisation gravimétrique 2-D révèle un épaississement de la croûte océanique sous la ride, compatible avec une déformation profonde le long de chevauchements plats. Vers l'ouest, la ride s'amortit progressivement vers l'intérieur du bassin de Shikoku où elle meurt.

- 4ème partie -

Résumé anglais détaillé

First Leg: From Kochi to Shimizu

Subduction of a fossil island arc

The Palau-Kyushu volcanic ridge sinks beneath the Nankai trench. That ridge is an old island arc which has been extinct for over 30 MY. The survey has shown it was subsiding below the accretionary prism, generating rather moderate strain instead of the expected intense deformations. It seems that subduction can "swallow" fairly big "bones" without problems. Only when the island arc becomes quite wide and high like the Izu-Bonin arc is subduction made very difficult or even impossible.

The death of a rift valley

The Shikoku basin, an external portion of the Philippines marginal sea, was known to have been formed by an active rift valley from 23 to 15 MY. This survey was focused on the probable intersection zone of the Miocene fossil rift valley and the Nankai trench. It is indeed the area where tha plate being subducted is most recent and therefore, hotter and less resistant. The fossil rift was actually discovered during this expedition. It is offset by great transform faults, which are fractures generally normal to the rift valley, occuring along the plate sliding motion. To the great astonishment of the scientists, however, these fractures are not perpendicular to the rift valley (E-W) but, on the contrary, very oblique (N-S) to the latter. This implied that, immediately prior to its death, the rift opening had turned by 90° and become no longer parallel, but rather normal to the Nankai trench. this quite surprising behavior is probably related to the opening of the Japan sea which took place at the same time (15 to 12 MY ago), but the relation is poorly understood.

Anyway, it was also found that these great transform faults behave as mechanically weak zones which are reactivated upon the plate bending and sinking below the accretionary prism, as shown by the basement depth map.

The bending initially affects panels bounded by these great fractures. Later on, as the top of the plate reaches 8 or 9 kilometers in depth, the panels fit together and, probably due to the weight of the accretionary prism, the basement topographic features become obliterated. This complex scissorlike reactivation of these fractures is then likely to induce seismic activity.

Transition to the collision and uplift of the Zenisu ridge

The third survey covers the transition area from the Nankai trench to the Suruga trench, on the W border of the Izu collision. The first leg surveyed the eastern termination of the Nankai trench. It is featured by a pair of major structures. In the north, the Tenryu canyon cuts across the accretionary trench. It runs into the longitudinal canyon originating from the Suruga trench. These two canyons supply huge amounts of coarse muds which have accumulated over more than 4 kilometers on the floor of the trench and have provided materials to a very much developed accretionary prism. In the south, a volcanic ridge parallel to the trench, which is called Zenisu ridge, slowly climbs up to a more than one kilometer high steep scarp. The origin of Zenisu ridge was very much disputed.

During this expedition, it was established that Zenizu was **a piece of uplifted ocean floor**, the coming together of Japan and the Philippine plate taking place partly beneath the S Zenisu wall. Everything happens as if the subduction zone were split into two zones as it comes closer eastward to the Bonin island arc collsion. A second smaller accretionary prism is being formed at the foot of Zenisu. A well defined mud volcano, 40 meters high and 200 meters wide, could be observed there.

In the north, this survey shows that the Nankai prism, which is the main accretionary prism, is actually cut and offset by the Tenryu canyon which is established along a large strike slipe fault.

Second Leg : From Shimizu to Tokyo.

Whereas the other two legs mainly aimed at investigating relatively simple trenches where the Philippine and Pacific plates sink below the Japan arc through subduction, this leg was directed toward the much more complex region located not far off Tokyo where these two major systems meet together and interfere with another large subduction zone consisting of the Pacific plate being driven under the Philippine plate. This is the **triple junction** region, the meeting point of the three following sets of trenches :

- Ryuku trench and Nankai trench in the SW,
- Kurile trench and Japan trench in the NE,
- Mariana trench and Bonin trench in the S.

The triple Junction

The convergence at this point of three major plates (Pacific, Philippine and Eurasia) induces particular lithosphere deformations. Moreover, the situation of this region is complex, since the Izu-Bonin arc produced by the Pacific plate subduction beneath the Philippine plate (refer to the sketch) cannot readily sink under the Eurasiatic margin of Japan, in contrast with the thinner and denser surrounding ocean floors. Such a resistance to subduction has resulted in a collision between the Izu peninsula and Japan. The purpose of this expedition was therefore as follows : accurate mapping of the Nankai trench NE termination (Suruga trench) ; investigation of the triple junction proper ; determination of the way the triple junction is linked to the Izu collision region, i.e. the Sagami trench itself.

In such conditions, it could be observed that, on the E side of the Japan trench, the Pacific oceanic plate is cut by three sets of faults. The older ones, which follow a NE-SW strike (parallel with the ocean floor magnetic anomalies), were produced at the same time as the oceanic lithosphere and are independent of both subduction and existence of the triple junction. These faults themselves are crosscut by other faults directed NNW-SSE that are related to plate overstretching (they are the socalled normal faults). They probably correspond to the oceanic plate bending in the vicinity of the trench. This phenomenon may be compared with the formation of cracks at the surface of a thick hand-bent sheet of clay.

An outstanding feature, however, is the trend of these faults which are oblique to the subduction trench. The simplest interpretation for such an obliquity is the relatively old age of these faults which could have been formed while **the triple junction was located further northward** : they would correspond to the subsidence of the Pacific plate not below Japan, but rather bellow the Izu-Bonin arc whose trend is different. Such an interpretation is in agreement with the geological observations made on land, as well as with the kinematic analysis of the relative movements of Japan and the Pacific and Philippine plates.

The third set of faults observed on the external wall of the Japan trench (ocean side) is disputed. This is because the seismic reflection profiles are not sufficient to determine unquestionably whether they are normal faults indicating a stretching or, on the contrary, reverse faults indicating a compression. Both opinions were expressed in that respect by the scientists of the party.

In the triple junction area (refer to the sketch), a triangular depression of several ten kilometers could be observed in the inner trench wall, immediately to the south of the meeting point of the Sagami area (current limit between the Philippine plate and Japan) and the Japan trench. This triangle is a subsiding zone affected by intense deformations related to the operation of the triple junction and, possibly, to its southward migration as abovementioned. Sings of a south-eastward sliding of the Sagami trench could also be observed in this area.

The trench on either side of the Izu-Bonin Island arc.

The morphostructural and seismic reflection data collected in the Sagami area between the triple junction and the mainland at the outlet of Tokyo Bay indicate the existence of a network of faulted features corresponding to the southward motion of this region of Japan with respect to the Izu-Bonin arc. It might be an old subduction zone covered by a thick layer of much deformed sediments and recently reactivated by slumping. The interpretation of the data collected during this second leg corroborates the observations made on land on either side of Tokyo Bay, which have revealed faulted features configurated like those in the Sagami trench. Such faulting has initially functioned in the form of compressive movements, then as strikeslip faulting.

Lastly, on the other side of the Izu-Bonin arc, the investigation of the NE part of the Nankai trench, i.e. the deep Suruga trench, permits to define the structures of both the inner wall (overthrusting unit to the south) and the external wall of the trench. Once again, the interpretation from the morphological and seismic analysis and the data collected on land to the W of Suruga Bay are in good agreement : the direction of subduction-related stresses, as indicated by the faulting configuration of the inner wall (on the Japan side), seems to be the same.

Third Leg : From Tokyo to Shimizu

This first leg studied the subduction processes governing the Pacific plate sinking beneath the Japan arc. It considered the way the oceanic plate is bent prior to subsiding under the continental plate and the behaviour of submarine volcanoes. The other objectives consisted, on the one hand, in observing the continental flank of the trench (inner wall) so as to establish its structure and identify possible accretionary prisms and, on the other hand, in accurately analyzing the transition zone from the Kurile trench to the Japan trench.

Plate bending

It was found that the oceanic plate, which is covered by sediments, is cut by two sets of faults. The older one (inherited from the generation of the lithosphere) is oblique to the trench axis and parallel to the direction of the magnetic anomalies. The second fault set results from the plate bending on the trench border. It has given rise to a sequence of parallel trenches. These faults are very deep, since they affect the whole thickness of the oceanic crust.

Submarine volcanoes

The two submarine volcanoes which are the most interesting in this area are Daiichi Kashima, located on border of the Japan trench, and mount Erimo, located at the meeting point between the Kurile trench and the Japan trench. Daiichi Kashima, which is similar in size to mount Fuji, is cut into two parts by an over 100 km long great vertical fault which has induced the sliding of one volcano half over more than 1,500 meters into the trench. This fact is very interesting, as it happens quite exceptionally that a volcano is, so to speak, cut into two pieces by a knife. As a matter of fact, provided that erosion has not too much altered the fault plane, it should be possible to observe on the latter the internal volcano structure (lava flows, pipes and, perhaps, cooled magma chambers) and to sample rocks from them. This volcano had already been detected on less precise bathymetric maps than those prepared during this expedition. One of the questions to answer was whether this volcano constituted an obstacle strong enough to locally hinder the subduction. Actually, as shown by the detailed topographical study, the inner wall of the trench is gradually raised during the passage of the submarine mountain so that subduction does not seem to be hindered in any way. Mount Erimo is also cut by faults, but with less throw than those affecting Daiichi Kashima.

Trenches

Surprisingly, the Japan trench is quite narrow, its axis is sometimes hardly detectable and, compared with the Nankai trench or the Kurile trench, it contains lesser amounts of sediments. It consists of a sequence of small basins partly filled with gigantic submarine landslides rushing down the continentale trench flank. The Pacific and Eurasia plate convergence, though proceeding rapidly at a rate of about 9 to 10 cm/year, is not accompanied by the formation of an accretionary prism.

The analysis of the seismic reflection and bathymetric profiles shows that, to the north of the Japan trench, huge masses of sediment have slumped along the continental slope forming a major scarp, whereas most of the sediments on the Pacific plate are subducted with the plate, without any significant deformation, instead of accumulating at the base of the continental slope.

As for the Kurile trench, it is a wide valley filled by abundant sediments.

The transition zone between the two trenches is partly covered by a thick layer of sediment. Nevertheless, the topographic, magnetic and gravimetric studies altogether have permitted to outline some structural features. The abrupt changes in the trench width and trends are not related to the presence of Mount Erimo but to the occurence of strike-slip faults of significant extent in the prolongation of a zone of major faults that can be seen on land in Hokkaido. This zone might correspond to the limit between the America and Eurasia plates. The transition area from the Kurile trench to the Japan trench might then correspond to the boundary between these two plates.

As a conclusion

The observation made in 1984 show that the trenches around Japan exhibit a whole range of possible subduction processes, from deep and narrow, nearly sedimentless trenches with a continental border eroded by subduction to shallow, sediment-filled trenches with an active accretionary prism well lubricated by those fluids released by the compaction of water-saturated oozes.

It has been demonstrated that the subduction could fairly easily "swallow" as sharp-pointed fishbones as volcanoes of the same dimensions as Fuji Yama or even as big lumps as the Palau Kyushu fossil volcanic arc. On the other hand, subduction is not efficient where the island arc reaches the dimensions of, for example, the Bonin arc. The subduction then changes into collision and these surveys provide the first indications about the way, the transition from the Nankai trench to the Izu collision takes places. It has been demonstrated that such transition is accompanied by an oceanic lithosphere overthrust. This last phenomenon had been inferred from the study of mountain ranges on land but is clearly observed for the first time off-shore.

Lastly, it appears that scars exhibited by the oceanic lithospher in the form of fossil Rift Valleys and faults are reactivated upon the bending of the plate in the trench and play a key role in the determination of the network of seismically active faults.

- 5ème partie -

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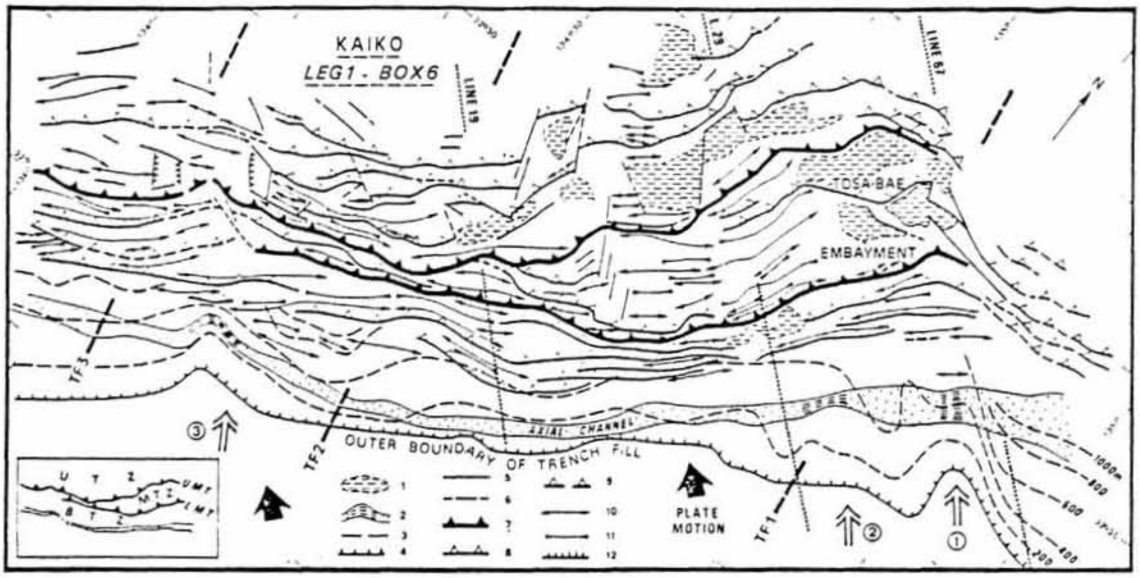

Fig. 2 d'après Le Pichon et al., 1987

Structural map of the accretionary prism, as revealed by Seabeam and seismic data over Box 6.1 = ponded basins and slope sediments : 2 = trench fill sediments ; 3 = lines of equal thickness of trench fill ; 4 = outer boundary of trench fill ; 5 = faults ; 6 = possible faults ; 7 = main thrust ; 8 = thrust ; 9 = possible thrusts ; 10 = anticlines ; 11 = synclines ; 12 = normal faults.

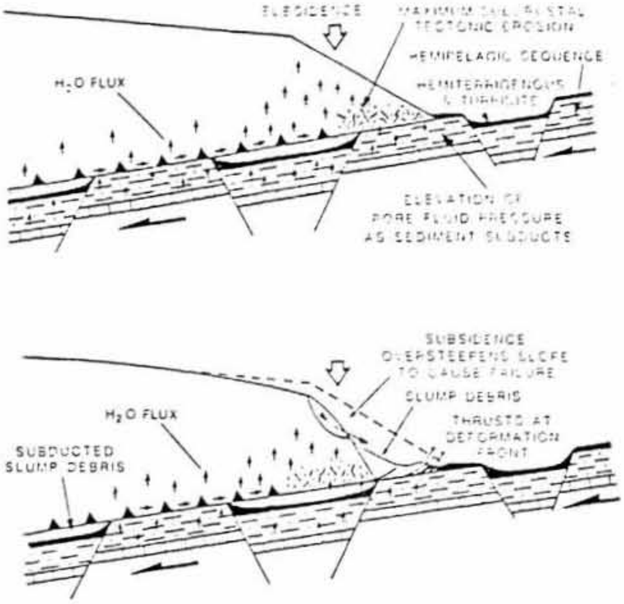

Figure 3 d'après von Huene et Culotta, 1989

Diagram of tectonic erosion at the front of the margin. Subcrustal erosion at the front of the margin causes subsidence and oversteepening of the lower slope. This erosion is facilitated by invasion of overpressured water (arrows) into fractures producing a slurry of many small fracture-bounded pieces that can be carried down the subduction zone. The oversteepened lower slope fails and slump debris accumulate at the foot of the slope. The upper part of these debris (stippled) are thrust and accreted like trench deposits ; the lower part is incorporated with the subducting oceanic sediment by filling lows such as graben. Note that the upper hemipelagic sediment sequence (dash-dot symbol) remains intact. Uppermost hemipelagic/turbidite sequence is darkened.

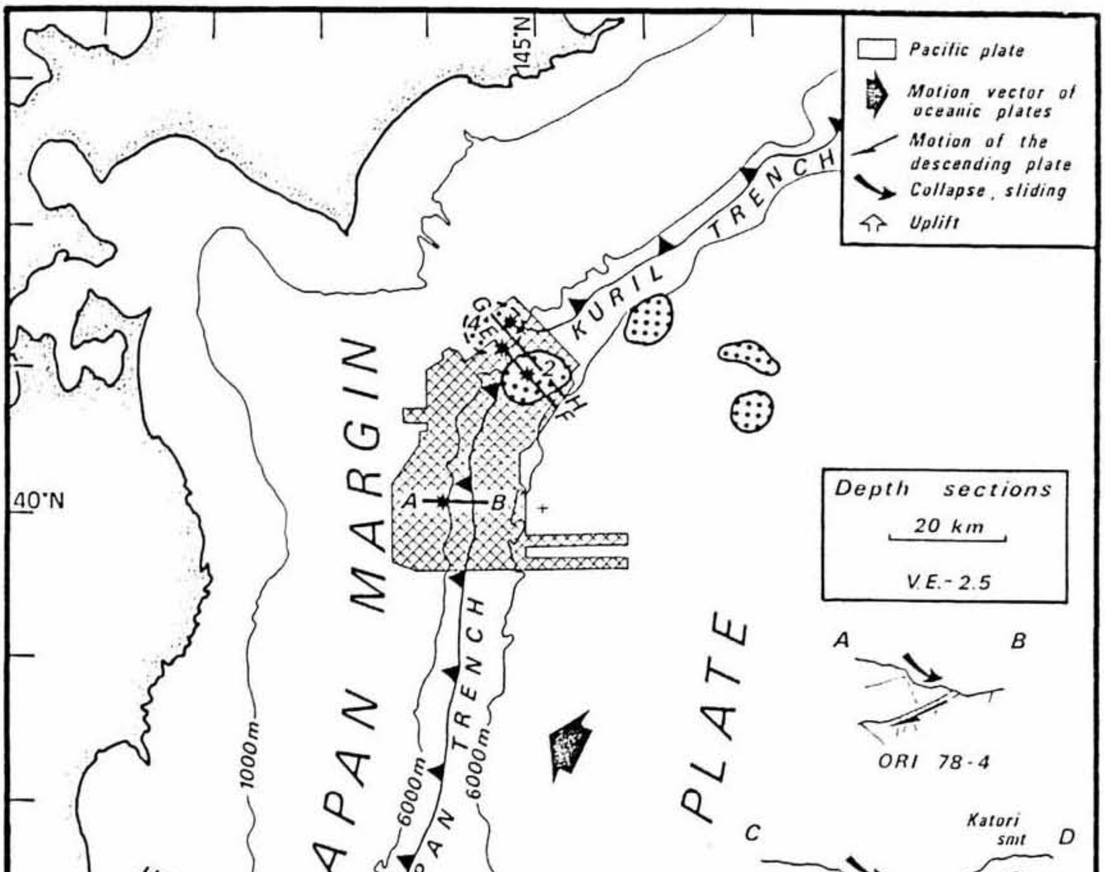

Fig. 4 .. Locations of seamounts near Japan Trench axis and simplified depth sections along some seismic lines at different stages of seamount subduction. ORI 78-4 and Shell P 844 are two processed multichannel seismic records. Kaiko P5, P9, and P20 are single-channel seismic lines recorded during Kaiko cruise in 1984. Shaded band represents area of seamount-chain subduction. Location of profile H.D.79 from Sakurai et al., 1981.

d'apres Lallemand et le Pichon (Geology, 1987)

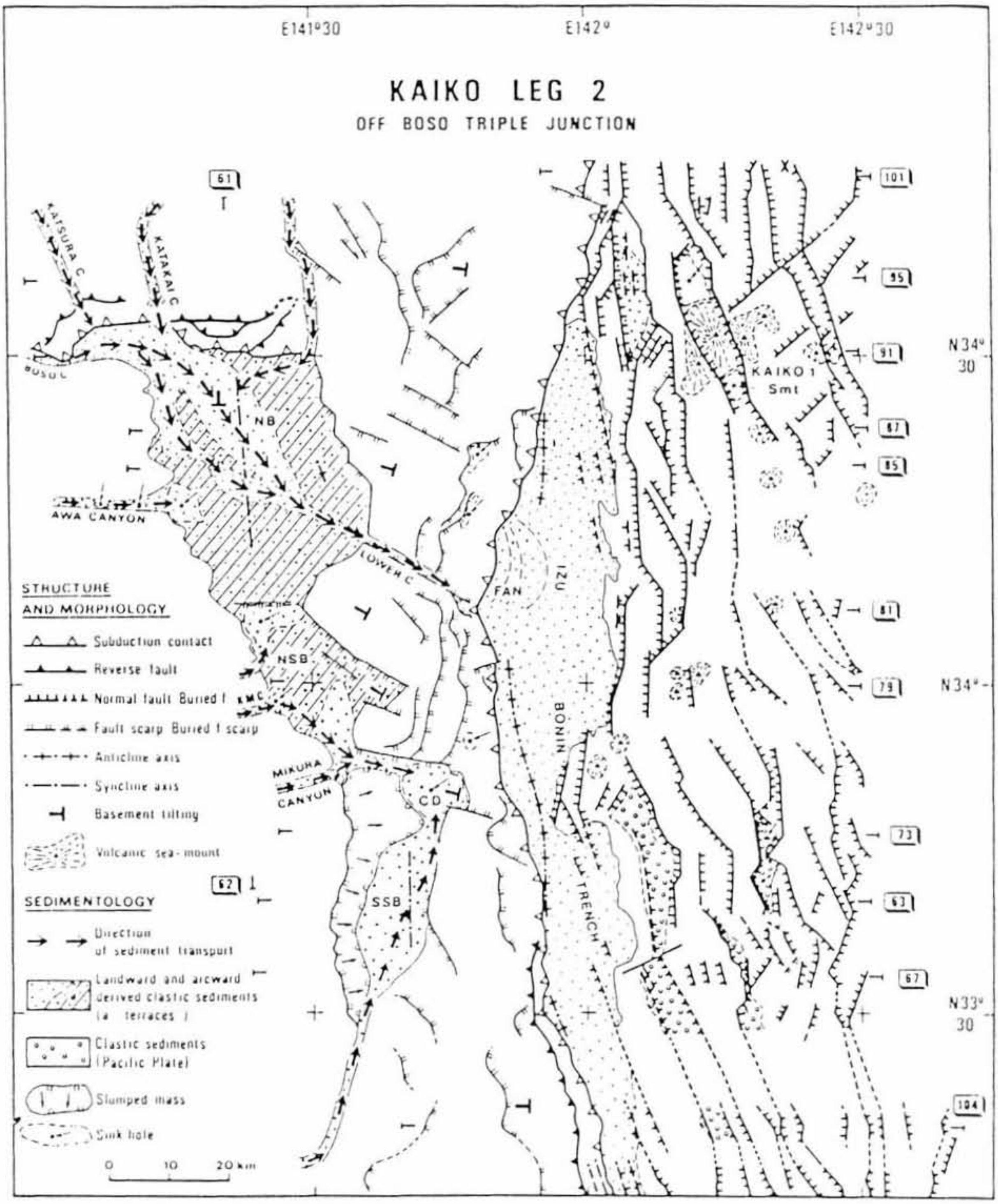
E141°30
E142°
E142°30
KAIKO LEG 2
OFF BOSO TRIPLE JUNCTION
N34° 30
N34°
N33° 30
KATSURA C.
KATAKAI C.
BOSO C.
NB
AWA CANYON
LOWER C.
NSB
KMC
MIKURA CANYON
CD
SSB
IZU
FAN
BONIN
TRENCH
KAIKO 1 Smt
61
62
101
95
91
87
85
81
79
73
63
67
104
STRUCTURE AND MORPHOLOGY
Subduction contact
Reverse fault
Normal fault Buried f.
Fault scarp Buried f. scarp
Anticline axis
Syncline axis
Basement tilting
Volcanic sea-mount
SEDIMENTOLOGY
Direction of sediment transport
Landward and arcward derived clastic sediments (a : terraces)
Clastic sediments (Pacific Plate)
Slumped mass
Sink hole
0
10
20 km

Figure 5

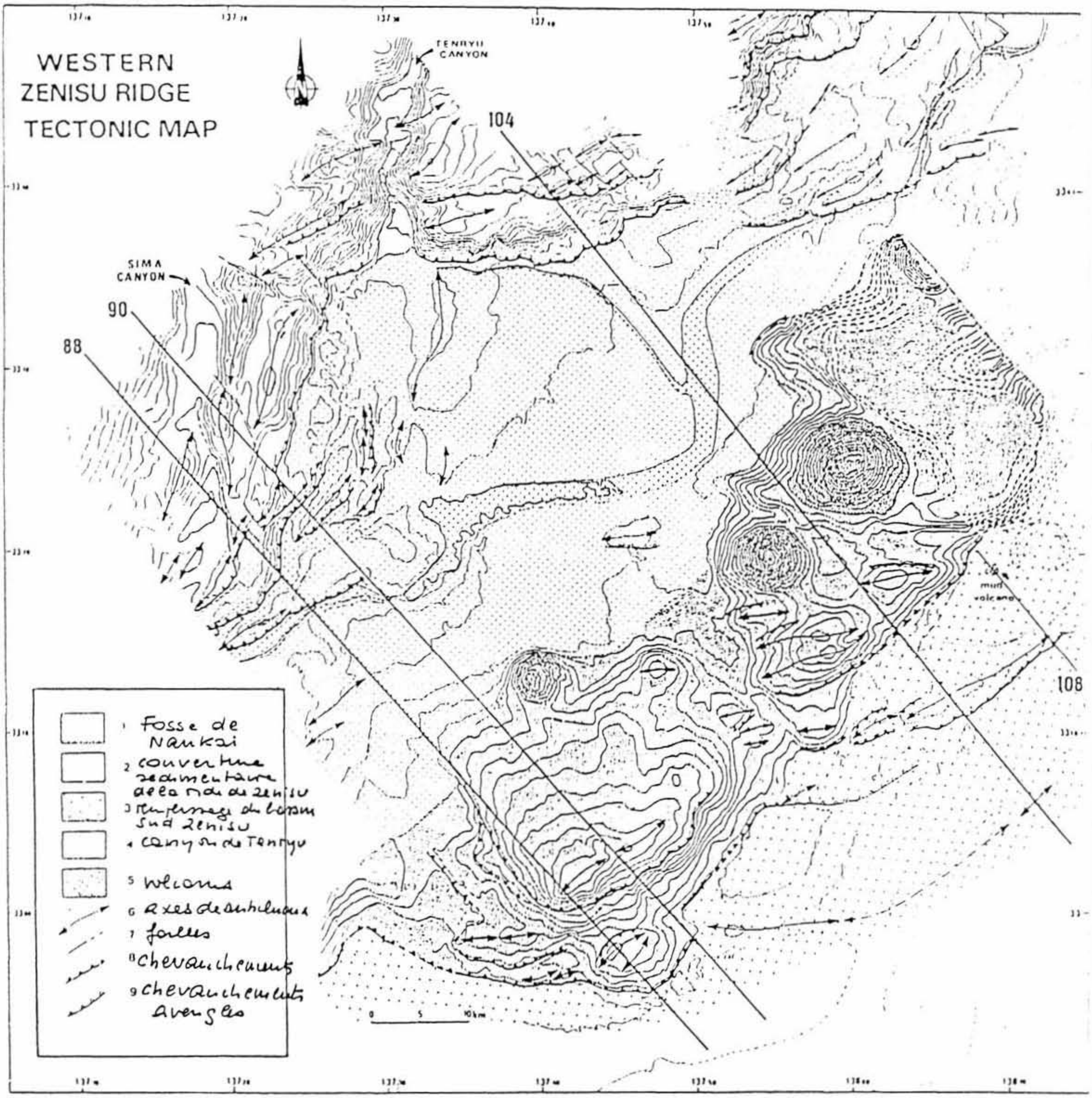
WESTERN ZENISU RIDGE TECTONIC MAP
TENRYU CANYON
SIMA CANYON
104
90
88
108
mud volcano
1 Fosse de Nankai
2 couverture sedimentaire de la ride de Zenisu
3 Remplissage du bassin Sud Zenisu
4 canyon de Tenryu
5 volcans
6 axes des anticlinaux
7 failles
8 chevauchements
9 chevauchements aveugles
0 5 10km

Figure 6