LARGE SCALE POLYPHASED SUBMARINE SLOPE FAILURE INDUCED BY SUBSIDENCE ALONG THE NORTHERN PERUVIAN MARGIN

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RESUME : Une récente compilation de données Seabeam et Hydrosweep, acquises de 5°15'S à 6°10'S le long de la marge nord-péruvienne, a permis la mise en évidence d'un méga glissement sous-marin, se développant en plusieurs étapes. 1) La principale étape du glissement est un "debris-avalanche", dont le matériel s'est accumulé sur la pente inférieure et en partie dans la fosse. 2) la deuxième phase d'instabilité correspond au glissement de deux blocs en voie de détachement. 3) Etant donné que la pente moyenne se bombe le long du plan de glissement d'une faille normale majeure, un méga-glissement de la pente est à prévoir dans un avenir proche.

KEY WORDS : Peru, active margin, submarine slide, debris avalanche, subsidence, subduction erosion.

INTRODUCTION

A morphological analysis realised from the bathymetric compilation of Seabeam and Hydrosweep data acquired along the northern margin of Peru, shows the occurence of polyphased mega-submarine slides. The surveyed area is located offshore Paita from 5°15'S to 6°10'S. At this location, the continental shelf is flat and narrow, the continental slope is steeper than to the south of the margin and the subduction of the Nazca Plate triggers a great seismic activity. Therefore, the area presents a typical profile of East Pacific active margin.

STRUCTURAL SCHEME OF THE CONTINENTAL MARGIN

From the continent to the trench, the continental slope is characterized by three distincts domains:
1) The upper slope, with a continuous slope gradient of 7°, which is incised by deep parallel E-W canyons. 2) The middle slope, which presents curved directions in the central part of the area. 3) The lower slope characterized by a rough topography, which represents a debris-slide deposit (Bourgois *et al.*, 1988).
The main morphological features of the area are three curved scarps respectively named from upslope to the trench : the upper slope scarp (USS), the middle slope scarp (MSS) and the lower slope scarp (LSS).
The USS represents the limit between the upper slope and the middle slope area. It is a curved scarp with an average slope gradient of 25°. As shown by a seismic profile, this scarp corresponds to the emergence of a listric normal fault, dipping seaward (Bourgois *et al.*, 1986, 1988). At the base of the USS, the middle slope shows a dome-shape deformation combined with a structural pattern roughly parallel to the curvature of the USS.
The main structure of the area is the MSS. It extends for 30 km along the middle slope and presents an average slope gradient varying from 10 to 30° over a distance of 1 km. The MSS shows a typical shape of debris-slide breakaway.
The LSS appears as an amphitheater shaped scar along which an entire 500 m height block has glided down. These three curved scarps results from different stages of polyphased mega-submarine slides.

THE POLYPHASED MEGA-SUBMARINE SLIDE

The main stage of failure of this active margin is characterized by a debris avalanche, which has let on the slope a breakaway named MSS. This feature is regarded as a scar along which an important volume of rocks has slid down towards the trench (Bourgois *et al.*, 1986, Von Huene *et al.*, 1988, Bourgois *et al.*, in press).
Sixteen deep-sea dives with the submersible *Nautile* were performed along the MSS, during the NAUTIPERC cruise in 1991. The MSS appears to be composed of a succession of small cliffs exposing dominant mudstones and siltstones bounded by steps covered with recent pelagic sediments. Fresh outcrops are frequent and screes are often observed at the foot of the steepest slopes. Generally, the freshness of the outcrops suggests that rock falls and others gravity flows are still active along the scarp.
Micropaleontological results obtained from samples collected during the dives indicate that the sediments are from Quaternary to Miocene in age. The scarp exposes deep strata of the middle slope thus confirming that this feature can be considered as the scar of a major slide.
The debris slide deposit covers the entire lower slope and in-fills a part of the trench. The deposit is characterized by a succession of isolated blocks without specific trends. The chaotic topography observed at the toe of the continental margin is indicative of a debris-avalanche deposit, which originated most probably from the MSS.
At the base of the MSS, the middle slope is characterized by a flat terrace. As shown by seismic profile, this area presents a chaotic seismic facies. This feature is characteristic of a smooth debris-flow deposit, which could represent the fine grained part of the debris avalanche. These deposits are burying the main slide plane.

The second stage of failure is characterized by two glided blocks. They appear as amphitheater shaped scars, that showing the same trend. The first, occured along the middle slope scarp. The second is one of the major feature of the slope and was named LSS. It is located in the flat area of debris-flow deposit created by the main debris avalanche. Both features are aligned along a N80 direction, roughly parallel to the direction of the subducting Nazca Plate.
These blocks have glided down after the main debris avalanche. They are indicative of a secondary stage of failure probably induced by the debris avalanche. This second stage of slope failure would be less catastrophic than the first one.

The dome-shape deformation of the middle slope is combined with a peculiar structural fabric, characterized by the developement of small ridges and valleys. They are roughly parallell to the curvature of the USS. As shown by this structural pattern, the deformation of the middle slope along the listric normal fault could be always active. The continuation of the deformation could able to produce a second giant submarine slide, which would affect the whole middle slope and which would occur along the seaward dipping normal fault.
The upward progression of slope unstability is actually stopped at the location of the main normal fault of the margin (USS), because the upper slope is incised by deep parallel which doesn't progress downward the USS.

ORIGIN OF SLOPE FAILURE

These giant polyphased submarine slides result from a peculiar state of stress of the continental slope in relation with the subduction of the Nazca Pate. For instance, another similar case of great scale slope failure has been recognized along the northern Chile continental slope, offshore Iquique (Li and Clark, 1991).
Slope unstabilities occur generally within unconsolidated materials and are favoured by a supply of sediments inducing an increase in slope gradient. It is not the case here. Because at this location, the continental margin is characterized by a lack of sedimentary supply coming from the land. Moreover, from the *in situ* observations of the submersible *Nautile* along the MSS, the sediments involved in the slope failure are predominantly consolidated. The initiation of this great-scale slope failure are consequently mostly originated from the subduction of Nazca Plate. Obviously, the great seismic activity observed in this area prepare favorable condition for the slope failure.
In such a context of active margin, several processes are able to produce the slope failure :
The main stage of slope failure is assumed to come from the oversteepening of the slope, which is induced by a roll-over deformation of the middle slope along a seaward dipping listric normal fault (USS) (Bourgois *et al.*, in press). The debris avalanche occured for slope gradient greater than 13° (Duperret *et al.*, 1993).
The deep sea dives realised along the MSS, have revealed the occurence of numerous clams fields and associated biological colonies related to fluid vents. Bourgois *et al.*, (in press) assumed that the fluid vents is the result of the unloading create by the failure of the slope. Such emergences could also be induced by an increase of pore pressure fluids along the subduction plane. They could significantly reduce the shear strenght in the upper plate and generate a sedimentary mobility along a minimum shear zone.

Then, the slope failure occurs within consolidated rocks by an oversteepening of the slope. The high seismicity of the area and the circulation of fluids have probably greatly contributed to initiate the failure.

The debris avalanche deposit covers the entire lower slope and extends to the trench axis. In the trench, the topography of the mass-wasting is smoother than on the lower slope ; but the inner trench wall is completely buried by the debris-avalanche. By comparison with northern and southern undisturbed slope profile of the margin, the area covered by the deposit shows a relative topographic low of about 200 m. The topographic low is partially in-filled by the debris avalanche deposit and it is located just below the three main curved scarps of the slope. Therefore, this feature within the Nazca Plate is probably responsible for the initiation of the detachement faulting and the subsequent polyphased submarine slides. The origin of such a depression must be discussed.
1) It could be explain by a process of subduction erosion along the base of the continental margin. 2) It could also result from a change in the dip angle of the subducting Nazca Plate, which could originate from a change in the Nazca Plate motion. This hypothesis must be correlated with a change of the kinematic organisation of the Nazca Plate versus South American Plate. 3) The occurence of topographic asperities within the subducting plate is able to increase locally the process of subduction erosion (Lallemand *et al.*, 1992). These asperities could be representated by horsts and grabens or by a volcanic seamount.
Now, the respective influence of these various processes needs to be clarified.

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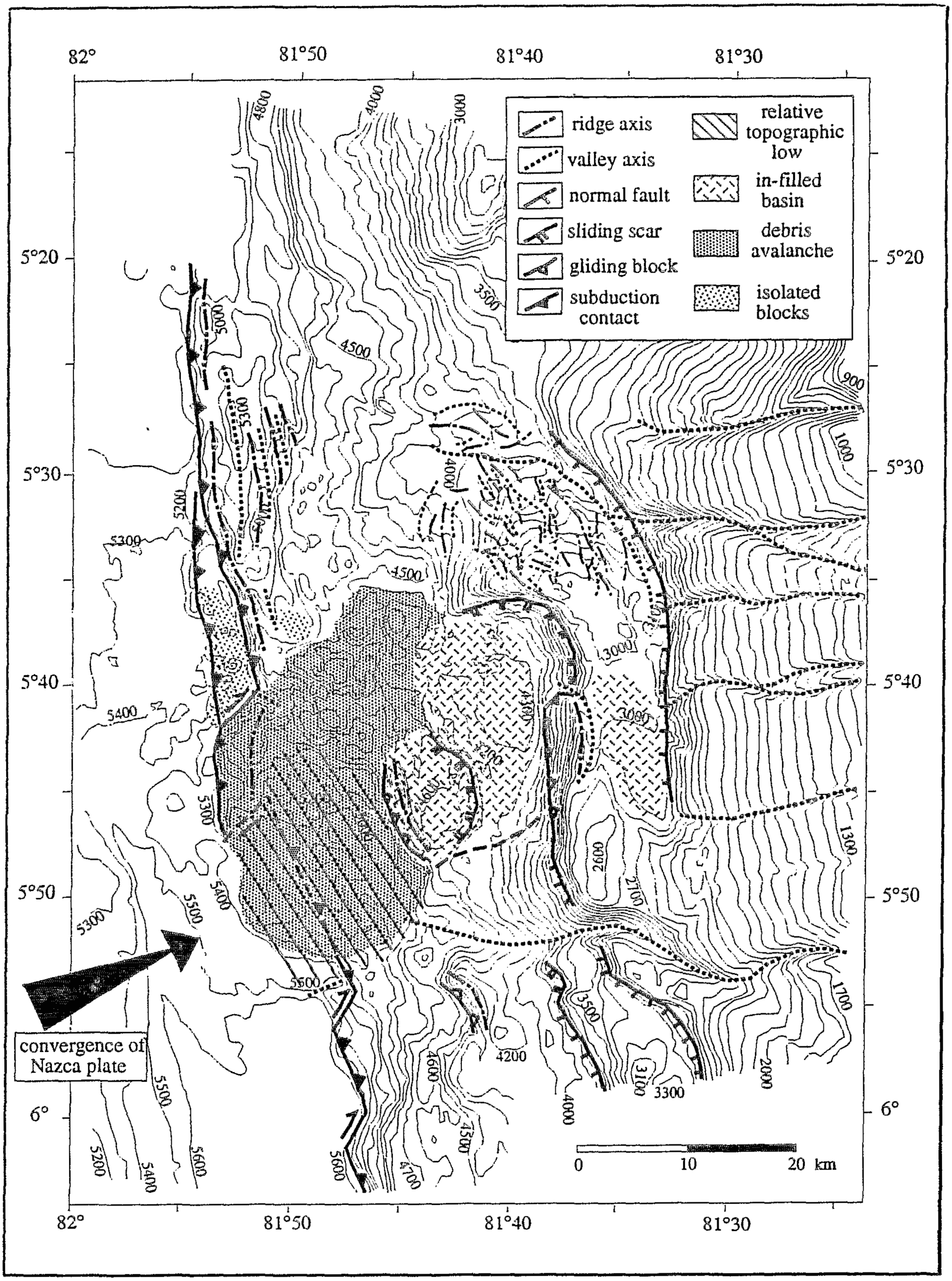

82°
81°50
81°40
81°30
5°20
5°30
5°40
5°50
6°
ridge axis
valley axis
normal fault
sliding scar
gliding block
subduction contact
relative topographic low
in-filled basin
debris avalanche
isolated blocks
convergence of Nazca plate
0
10
20 km