CHANGES IN THE TECTONIC REGIME ABOVE A SUBDUCTION ZONE OF ANDEAN TYPE: THE ANDES OF PERU AND BOLIVIA DURING THE PLIOCENE-PLEISTOCENE

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Résumé

Une étude détaillée de la cinématique des failles pliocène-quaternaires des Andes du Pérou et de Bolivie montre une succession de trois états de contrainte. Cette succession se traduit dans les Hautes Andes par (1) une extension N-S au Quaternaire moyen à Récent, (2) une compression E-W ou N-S au Quaternaire ancien , (3) une extension E-W ou NE-SW au Pliocène. Ces variations du régime tectonique sont mises en relation avec des variations des forces aux limites dues probablement à un changement de géométrie de la plaque plongeante.

Key words : Andes, faulting, stress patterns, Pliocene, Quaternary

Introduction

The changes in the tectonic regime in the Peruvian and Bolivian Andes, analyzed in this paper, mainly concern the period subsequent to the upper Miocene. At that time, the High Andes had almost reached their present-day elevation above sea-level. The stress patterns are deduced essentially from a field study of fault kinematics and a numerical inversion of the slip vector data measured on the fault planes.

Geological data

The Cuzco fault system in southern Peru is chosen as an example to illustrate the used methodology. In this region, striations on both active and Holocene faults are in agreement with a N-S tension. But faults affecting Lower Pleistocene deposits exhibit two families of striations. The younger results from the previous N-S tension, the older, involving reverse motions, result from either an E-W, or a N-S compression. Faults affecting Pliocene formations, often show an oldest family of striations resulting from a NE-SW or an E-W trending tension. Thus, three tectonic regimes are demonstrated which are also supported by regional unconformities and sedimentological data : (1) a Pliocene extensional regime , (2) a Lower Pleistocene compressional regime (3) a Mid. Pleistocene-Present day extensional regime. Similar analyses conducted in the

Pacific and sub-Andean lowlands allow to sketch the successive Pliocene-Quaternary stress patterns in the Central Andes. The Quaternary and Present-day stress pattern is characterized by a N-S tension in the High Andes and in the Pacific lowlands and by an E-W compression in the sub-Andean lowlands and at the contact between the Nazca and South American plates (Fig. 1). This stress pattern is interpreted at a large wavelength (> 100 km) as an effect of compensated topography. This model, supposes that the vertical lithospheric stress σzz increases with the topography the crustal thickness and the low density mantle beneath and that the lithospheric maximum horizontal stress $\sigma Hmax$ trending E-W roughly parallel to the convergence, is fairly constant. On both edges of the Andes, tectonic being compressional, σzz is $\sigma 3$ and $\sigma Hmax$ is $\sigma 1$. In the High Andes, σzz becomes $\sigma 1$, then the E-W trending $\sigma Hmax$ is $\sigma 2$ and $\sigma Hmin$ trending N-S is $\sigma 3$, allowing extension to occur in this direction (Fig. 4D). The Pliocene stress pattern was characterized by a NE-SW or an E-W trending tension in the High Andes, in the Pacific lowlands and possibly in the sub-Andean lowlands (Fig. 3). This stress pattern was clearly different from the Present-day one because the E-W trending stress was $\sigma Hmin$. This required a weak push or eventually tractional boundary forces acting onto the South American lithosphere. This might result from a strong slab pull due to a long steep dipping slab which decreased the value of the σxx stress transmitted to the overriding plate (Fig. 4A, B). The Lower Pleistocene state of stress was compressional (Fig. 2A, B). As the elevation of the Andes had not markedly decreased during this period, this required an increase of the E-W trending stress value. This resulted from a strong coupling between the two lithospheres possibly due to a rupture of a long slab under its own weight (Fig. 4C). Other spatial changes in the stress pattern are related to the particular situation of the forearc, to the subduction of the buoyant Nazca ridge and to the different dips of the slab.

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Figure captions

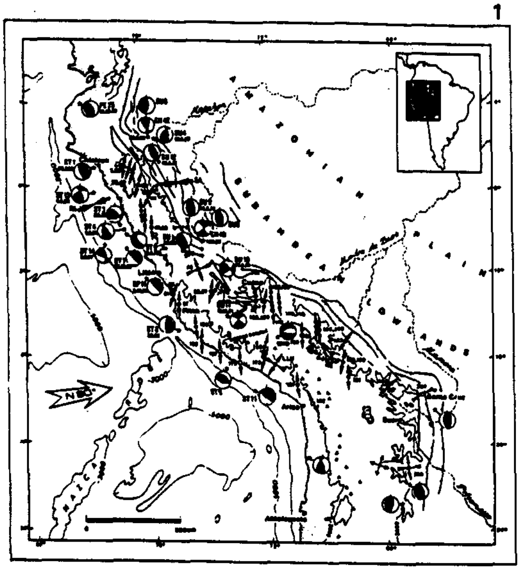
Fig. 1 Principal stress directions deduced from the analysis of Quaternary and active faults of Peru and Bolivia. Divergent arrows, tensional horizontal stress directions (σ_3) ; convergent arrows, compressional horizontal stress directions (σ_1) ; filled circles attached to the arrows, computed directions ; open circles, graphically defined directions ; balloons, focal mechanisms of earthquakes ; letters refer to authors, Ab : Abe (1972), St : Stauder (1975), Sp : Dewey and Spence (1979), Pe : Pennington (1981), Su : Suarez (1982) and Suarez et al. (1983), C : Chinn and Isacks (1983). Mechanism CHO is from Grange et al. (1984a). Compressional stress directions F.A and S.A are obtained from the inversion of these teleseismic focal mechanisms and LLU from the inversion of microseismic focal mechanisms (Grange et al., 1984b) ; large arrow, direction of the Nazca-South America plate convergence (Minster and Jordan, 1978).

Fig. 2 Principal compressional stress directions deduced from kinematics of reverse faults of Lower Pleistocene age. A, E-W trending compressional directions. B, N-S trending compressional directions.

Fig. 3 Principal tensional stress directions deduced from kinematics of normal faults of Late Miocene - Pliocene age.

Fig. 4 Qualitative scenario to interpret the changes in the Andean state of stress during the Pliocene - Pleistocene. VNA and VSOM, velocities of the Nazca and South America plates respectively ; VT, velocity of the westward slab retreat. This scenario is hypothesized for the evolution of the Andes of southern Peru during the Pliocene-Quaternary period.

1



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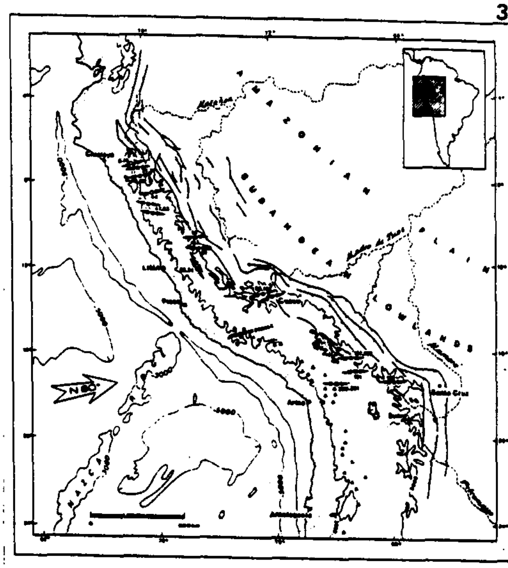

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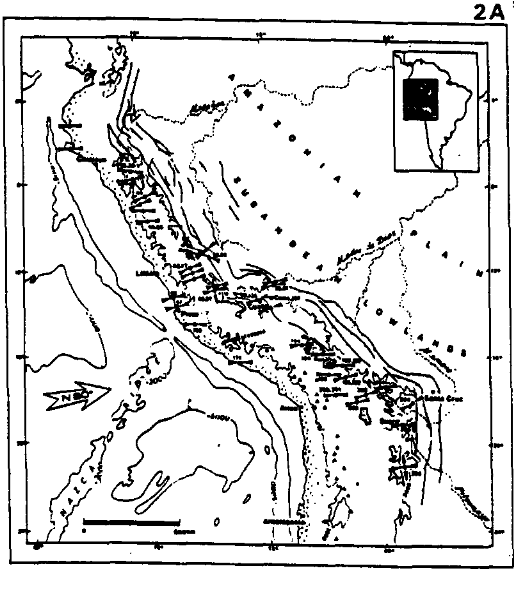

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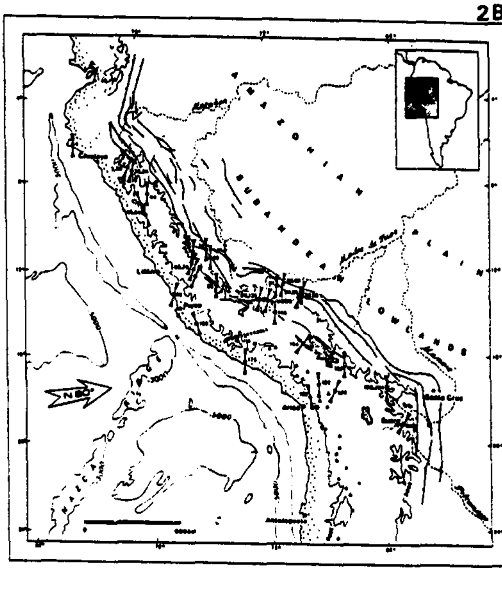

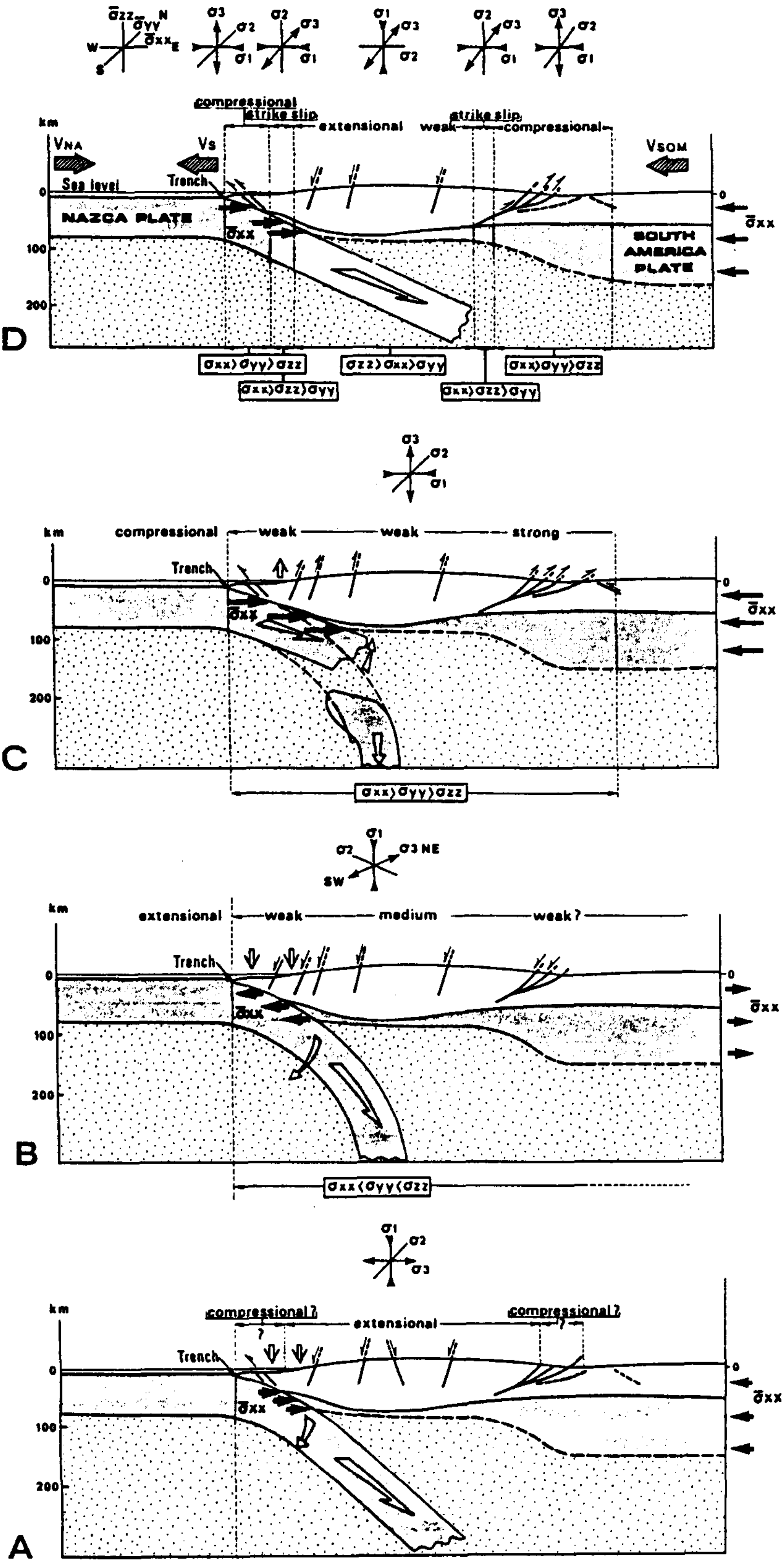
D
km
V_NA
Vs
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Sea level
Trench
NAZCA PLATE
SOUTH AMERICA PLATE
σxx
compressional
strike slip
extensional
weak
strike slip
compressional
σxx>σyy>σzz
σxx>σzz>σyy
σzz>σxx>σyy
σxx>σzz>σyy
σxx>σyy>σzz
C
compressional
weak
weak
strong
Trench
σxx>σyy>σzz
B
σ1
σ2
σ3 NE
SW
extensional
weak
medium
weak ?
Trench
σxx<σyy<σzz
A
compressional ?
extensional
compressional ?
Trench
σxx