LATE CENOZOIC NORMAL AND STRIKE-SLIP FAULTING IN NORTH PERUVIAN WESTERN CORDILLERA : AN EXAMPLE OF ALTERNATE EXTENSIONAL AND COMPRESSIONAL TECTONIC REGIMES IN HIGH ANDES

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RESUME

Au cours du Miocène, des demi-grabens s'organisent parallèlement aux accidents majeurs de la Cordillère Occidentale du Nord Pérou. Il s'y accumulent des dépôts fluvio-lacustres au cours d'une phase d'extension ENE-WSW. Au Néogène sup. et au Quaternaire inf., la région est alors soumise à deux régimes décrochants dont les directions de compression sont WNW-ESE puis N-S. Depuis le Pléistocène moyen, le régime est caractérisé par une extension de direction N-S. Ces régimes tectoniques sont interprétés comme la conséquence des forces de volume liées à la haute topographie et des forces de bordure liées à la convergence des plaques Nazca-Amérique du Sud.

Key Words : Half-graben, Extension, Compression, Tectonic regimes, Western Cordillera, Northern Peru.

I - INTRODUCTION

The Peruvian Andes is a cordilleran margin where the subduction is active since the Jurassic. The period from Early Miocene to Present-day is characterized by a high convergence rate between the oceanic Nazca and the continental South American plates; convergence direction being nearly orthogonal to the Peruvian trench. Sébrier and Soler (1989) have reported 4 compressional tectonic pulses which affect the Central Andes after the Eocene and Oligocene main deformation phases (i.e; 42 Ma and 26-28 Ma dated phases). These pulses are dated: lower Miocene (15-17 Ma), middle Miocene (10 Ma), upper Miocene (7 Ma) and early Quaternary (2.5 Ma). The lower and middle Miocene pulses correspond to locally deformational crisis. After the main upper Eocene shortening (Incaic phase) that affects the High Andes, several basins have been initiated along major faults in the Western Cordillera of northern Peru as for examples the Cajabamba, San Marcos, and Namora basins (fig.1). These ones were half-grabens infilled by Miocene fluvio-lacustrine deposits and bordered by normal faults that reactivated old compressional structures. The Cajabamba basin is situated in the western edge of the NNW-SSE trending Marañon Thrust and Fold Belt (see Mégard, 1984), the Namora basin is within the E-W Cajamarca deflection and the San Marcos basin, situated between the Cajamarca deflection and the Marañon Thrust and Fold Belt, is bordered by NW-SE trending structures. The mean altitude of this studied region is 3100 m (calculated on an area of 10 000 km2 [Bellier, 1989]). The study of the sedimentary and tectonic evolution of these basins, constraint by radiometric and paleontologic ages, permit to show evidence for longer periods of moderated and localized extensional deformation separated by short periods of compressional deformation.

II - MIOCENE SEDIMENTARY EVOLUTION

The Cajabamba and San Marcos basins were filled by a thick fluvio-lacustrine sedimentary Group (fig.2). This group is characterized by a mean 350 m thick lacustrine formation termed the Cajabamba fm and constituted by alternated shales, marls, lignited shales, gypsum, diatomits, silts and sandstones deposits which are overlying little conglomeratic fluvial series. In this lacustrine formation we observed volcanic-loam facies and synsedimentary normal faults indicating that volcanism and tectonics were active during the basin evolution. This lacustrine formation is overlaped by a mean 500 m thick fanglomerate formation termed the Condebamba fm. This one, is constituted by mud-flow and fluvial sequences at the bottom and coarser torrential sequences toward the top. The age of this group was estimated early to middle Miocene thanks to diatom assemblages exposed in the lacustrine deposits (Bellier et al., 1989a; Fourtanier et al, in preparation). The tectonic framework permit to estimate the age of this Group probably ranging between 15-17 Ma and 10 Ma; i.e., between the lower and middle Miocene tectonic pulses. The Condebamba fm indicate that a climatic change had occured between the Cajabamba fm and the

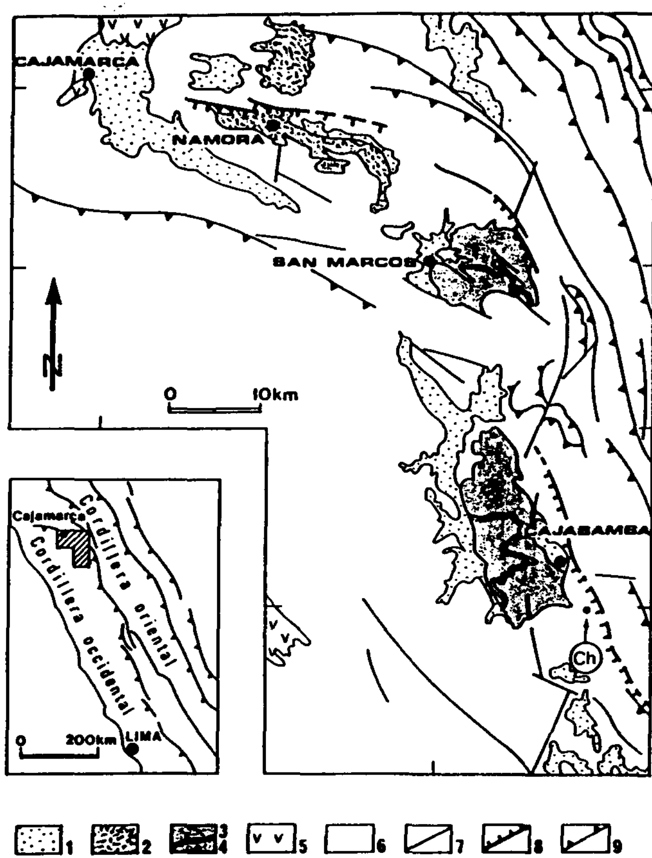

Fig. 1. - Strucural map of the Namora, San Marcos and Cajabamba basins.

(1): Plio-Quaternary sediments; (2): Namora Formation; (3): Condebamba Formation; (4): Cajabamba Formation; (5): Cenozoic volcanism; (6): Mesozoic bedrock; (7): Faults; (8): Miocene normal faults; (9): Late Eocene reverse faults and thrusts of the Marañon Thrust and Fold Belt and of the Cajamarca deflexion. CH: location of the Chaquilbamba active fault.

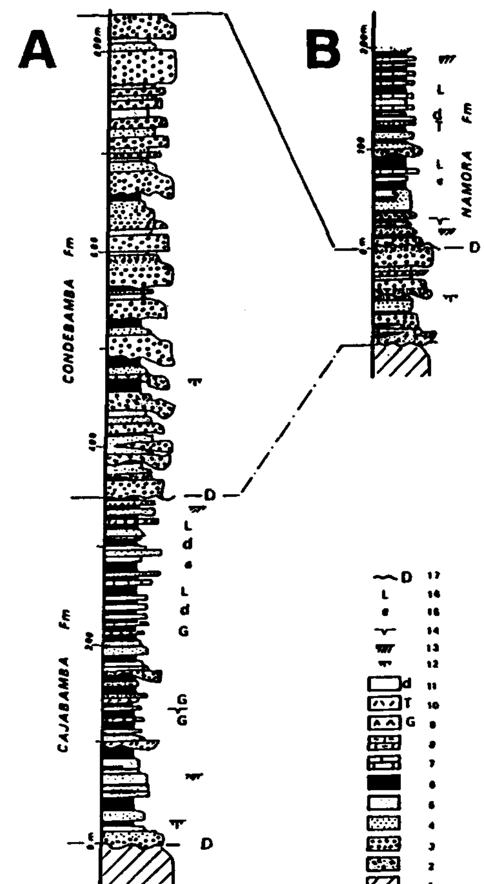

Fig. 2 - Synthetic stratigraphic logs of the intracordilleran Namora, San Marcos and Cajabamba basin filling.

(1) Cretaceous bedrock; (2) mudflood; (3) conglomerates; (4) sands; (5) loam and sandy-clay loam; (6) shales; (7) lacustrine limestones; (8) carbonated banks; (9) Gypsum; (10) tuffs; (11) diatomites; (12) Paleosols; (13) cross-bedding; (14) dessication trace (15) Planorbis and other lacustrine fossils; (16) lignited shale beds; (17) discordance.

Condebamba fm fillings. In addition, the catastrophic coaser conglomeratic facies of this group probably marked the closing of the basins associated to the middle Miocene tectonic pulse. We can estimate a mean deposit rate and consequently a mean subsidence rate in the basins during this period: taking into account the decompaction parameters we can estimate a mean 1000 m thick, decompacted sedimentary column which has been deposited during 6-7 Ma. This permit to calculate a mean subsidence rate is moderate 0.17±0.03 mm/yr.

The Namora basin is filled by a 180-200m thick fluvio-lacustrine formation termed the Namora fm locally overlying the Condebamba fm with a slight unconformity. This formation was characterized by elementary fluvial sequences which passed progressively toward the top to lacustine sequences made of sands, silts, shales, diatomits, lignited shales, carbonated concretions and limestones. In the middle part of the lacustrine sequence, some dacitic tuffs were interbedded within diatom beds. This indicate a volcanic activity contemporaneous to the basin filling. On the other hand, synsedimentary normal faults indicate a Normal faulting activity. The paleontological analysis of diatom sample gives a upper Miocene age (Bellier et al., 1989b; Fourtanier et al., in preparation). Recently, radiometric analyses of the Namora dacitic tuffs (K/Ar analyses by M.G. Bonhomme) give an age of 7.2±0.6 Ma for the middle-upper part cf the Namorafm. This is in agreement with ages of the Namora fm ranging between the middle and upper Miocene tectonic phases; i.e., between 10 and 7-8 Ma. We have estimated a maximum 300 m thick, decompacted sedimentary column of the Namora fm which has been deposited during 2-3 Ma. This permit to calculate a subsidence rate of 0.12±0.03 mm/yr.

III - MIOCENE TO QUATERNARY TECTONIC REGIMES

The Miocene to Quaternary tectonic evolution of northern Peru intra-cordilleran basins shows extensional periods separated by compressional deformation crisis. This evolution was investigated using tectonic analysis and fault kinematics analysis. Analysis of these fault kinematics in terms of stress was developed using the computer-aided method proposed by Carey (1979). This analysis show evidence for 5 successive geodynamic states (Bellier, 1989):

1 : The San Marcos and Cajabamba half-grabens were developed during the middle Miocene contemporaneously with the Western Cordillera uplift end. This Miocene basinal evolution was coeval with an extensional tectonic regime (1-fig.3) characterized by a dominant ENE-WSW trending tension exposed by synsedimentary normal fault affecting the Cajabamba fm. This ENE-WSW trending extension predate a minor NE-SW trending extension (2-fig.3) which affects all the rocks prior to the Namora fm. The Fanglomerate Condebamba fm seems to indicate a tectonic change which may correspond to the 10 Ma compressional pulse. This pulse may have produced the closing of the basins.

2 : Then, the Namora basins was formed, between 10 and 8 Ma, along WNW-ESE trending and S dipping major faults. The Namora fm was affected by synsedimentary normal faults which indicate a ENE-WSW extensional tectonics (1-fig.3). This synsedimentary faulting deformed the dacitic tuff levels indicating that volcanism, extensional tectonics, and the Namora filling were coeval.

Then, the Namora, San Marcos and Cajabamba basins were affected by WNW-ESE and N-S shortenings (3 and 4-fig.3). Structural observations show that the N-S trending compression postdates the WNW-ESE trending one.

3 : The WNW-ESE trending compression (3-fig.3) produce folds, reverse and strike-slip faults affecting all the Miocene deposits. This deformation phase may be considered: first, as the late Miocene pulse dated at 7 Ma in other Central Andes part; then, as an other compressional pulse, probably late Neogene too; i.e., younger than the Namora fm.

4 : The N-S trending compression (4-fig.3) appears major with respect to the WNW-ESE one and mainly in the Cajamarca deflection. It produced regional flexuration, folds, faulted overfolds, reverse and strike-slip faults as well as isolated and "en echelon" tensional gashes. These deformations were the effect of the Early Quaternary pulse.

The kinematics analysis demonstrates that the main (WNW-ESE and N-S) compressional deformations were produced with strike-slip regimes.

5 : The Early Pleistocene compressional pulse is followed by a nearly N-S trending extensional tectonics (5-fig.3). This tectonics is marked by minor normal faults which affects the Mesozoic bed-rock, the Neogene basin filling and the Quaternary fluvial terraces as well as by a normal active fault: the Chaquilbamba normal fault. This one was reactivated in 1937, and shows 10 m high vertical displacement of glacial moraine crests of the Last Glaciation (Bellier et al., 1989c) indicating that the N-S extension is the present-day state of stress.

IV - DISCUSSION AND CONCLUSION

In conclusion, this study shows a close relationship between tectonic, sedimentary and volcanic activities during the Miocene to Present-day evolution of the Western Cordillera in Northern Peru. This region is characterized by 4 major tectonic regimes: a Miocene extensional regime having a mainly ENE-WSW trending tension coeval with intracordilleran basins evolution and volcanism; Late Neogene and Early Pleistocene compressional tectonic regimes having WNW-ESE and N-S trending shortening; and, a Mid-Pleistocene to Present-day extensional tectonics having a N-S trending tension.

This analysis shows that the Late Cenozoic stress directions are homogeneous both in the NNW-SSE striking Cordilleran segment and in the E-W striking Cajamarca deflection. This suggests that since the early Miocene there was no significant differential rotation between the E-W Cajamarca deflection and the NNW-SSE striking northern Peruvian Andean Belt.

As it has been proposed in southern and central Peruvian Andes (Sébrier et al., 1985, 1988), the variations of Late Cenozoic state of stress in northern Peru appear to be related to the interaction between the boundary forces due to the convergence plates and the body forces due to the high topography. The variations of the state of stress are due to modifications of the boundary forces because the topography has not drastically changed during the considered time period. The changes of boundary forces may be the effect of modifications either in the convergence rate (Sébrier et al., 1985; 1988) and, in the slab-pull force (Sorel et al., 1988) or in the slab-retreat (Sébrier and Soler; 1989). The Mid-Pleistocene and active N-S trending extensional tectonics orthogonal to convergence direction, is explained by relative balance between the boundary forces and body forces. The late Miocene and early Pleistocene compressional tectonics seems to be related to an increase of the boundary forces due either to a high convergence rate or to a slab rupture (Bellier, 1989; Sébrier and Soler, 1989). The Late Miocene ENE-WSW trending extensional tectonics, is associated with predominant gravitational body forces due to the high topography and diminution of the boundary forces being due either to diminution of convergence rate, or to strong slab-pull or slab-retreat induced by a long slab. Moreover, the analyzed region illustrates that the increase of the vertical stress is sufficient to produce extensional deformations even if the mean topography is not very high (nearly 3100 m).

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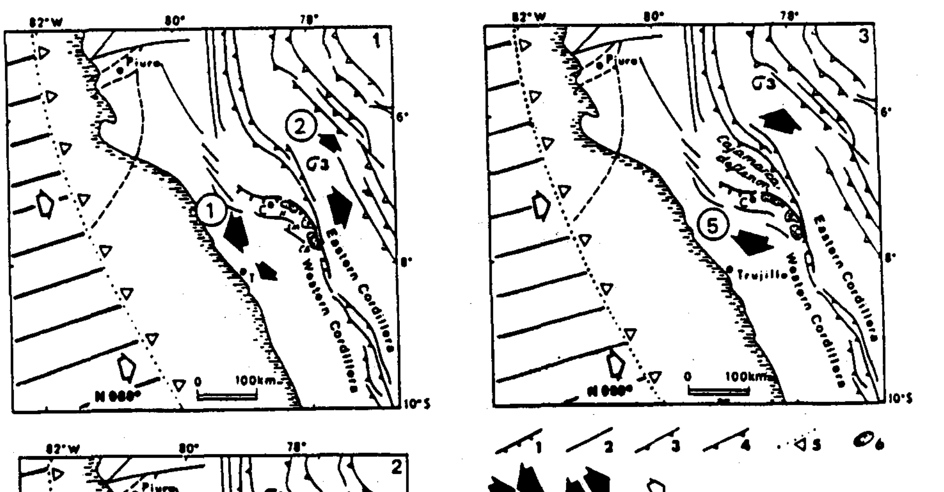

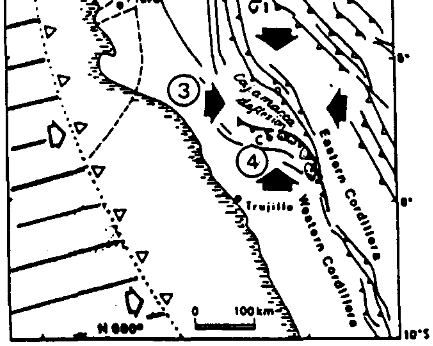

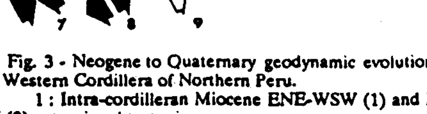

Fig. 3 - Neogene to Quaternary geodynamic evolution in the Western Cordillera of Northern Peru.

1 : Intra-cordilleran Miocene ENE-WSW (1) and NE-SW (2) extensional tectonics

2 : Intra-cordilleran Late Neogene-Early Pleistocene WNW-ESE (3) and N-S (4) compressional tectonics

3 : Intra-cordilleran Quaternary N-S extensional tectonics (5)

Boxes are : (1) Miocene normal faults; (2) regional faults; (3) Marañon Thrust and Fold Belt; (4) Subandean Thrust and Fold Belt; (5) Subduction trench; (6) studied basins: (N) Namora , (SM) San Marcos and (CA) Cajabamba basins; (7) compressional direction; (8) Miocene extensional direction; (9) Nazca plate convergence direction