QUATERNARY STATE OF STRESS IN THE NORTHERN ANDES AND THE RESTRAINING BEND MODEL FOR THE ECUADORIAN ANDES

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Résumé : L'inversion des mécanismes au foyer superficiels des Andes septentrionales, et l'analyse néotectonique des Andes d'Equateur, montrent un champ de contrainte homogène ($\sigma_1 \pm$ E-W). Celui-ci induit un mouvement dextre sur les failles N30-35°E et du raccourcissement sur les failles N-S, (relais compressif nord équatorien). Les vitesses de déplacement des failles dextres majeures sont calculées et discutées.

Key Words : Sismotectonics, State of Stress, Quaternary, Andes, Ecuador, Kinematics.

INTRODUCTION

The subduction of the Nazca Plate beneath South America results from a N80°E trending convergence (Fig. 1). This convergence is thus oblique along the N30°E, 1500-km long northern Andes. This obliquity is accommodated in the upper plate by NNE trending, active dextral faults. In Ecuador, two major active strike-slip faults are known. (1) The Pallatanga Fault (PF), that is located in the Cordillera Occidental of southern Ecuador, is well studied (Soulas, 1988; Winter, 1990; Soulas et al., 1991; Winter et al., 1993). (2) The Rio Chingual-la Sofia Fault (CSF), that is located in the Cordillera Real (CR) of northern Ecuador (Soulas et al., 1988; 1991; Tibaldi & Ferrari, 1992), is still poorly known. In addition, several Quaternary, N-S striking folds and reverse faults have been reported in northern Ecuador (Winter, 1990; Ego et al., 1993); They are interpreted as a restraining bend between the PF and the CSF (Ego et al., 1993). In order to address this problem, we have analyzed the stress pattern in northern Andes inverting shallow focal mechanism data. Then, we calculated slip rates on the major strike-slip and reverse faults.

INVERSION OF FOCAL MECHANISMS

In the literature, 113 shallow focal mechanisms, registered by world seismic networks, are available (e.g., Pennington 1981; CMTS by Dziewonski 1981-1992 and USGS catalog 1977-1988). They are mainly distributed along the Andean subduction zone and in the Sub-Andean region; in contrast, few events are located in the Andean mountains. We have defined 8 zones, each one corresponding to a specific structural province. Then, data inversion (same method as Carey-Gailhardis & Mercier, 1987) was performed in each zone in order to calculate its mean state of stress (Fig. 2). The most significant result is that the state of stress is quite homogeneous in northern Andes, σ_1 trending roughly E-W, except nearby the Caribbean.

CSF SLIP RATE DETERMINATION AND IAV SHORTENING ESTIMATE

In order to constrain the CSF slip rate, a detailed fault mapping was performed using LANDSAT imagery coupled with aerial photo analysis and field control. Numerous dextral offsets are seen along the 70 km long, N35°E striking trace of the CSF in Ecuador. The rio Chingual, a major river of the CR, exhibits a dextral offset ranging between 7.5km and 10.5km. Other streams of minor importance show offsets between 50m and 500m. All these offset streams, that are from different ages, allow us to conclude that the fault has been active in a dextral sense for a long time (>1My). These offsets could be used to calculate the slip rate of the fault; however, lacking of precise stream ages, we determined the CSF slip rate using the Soche lava

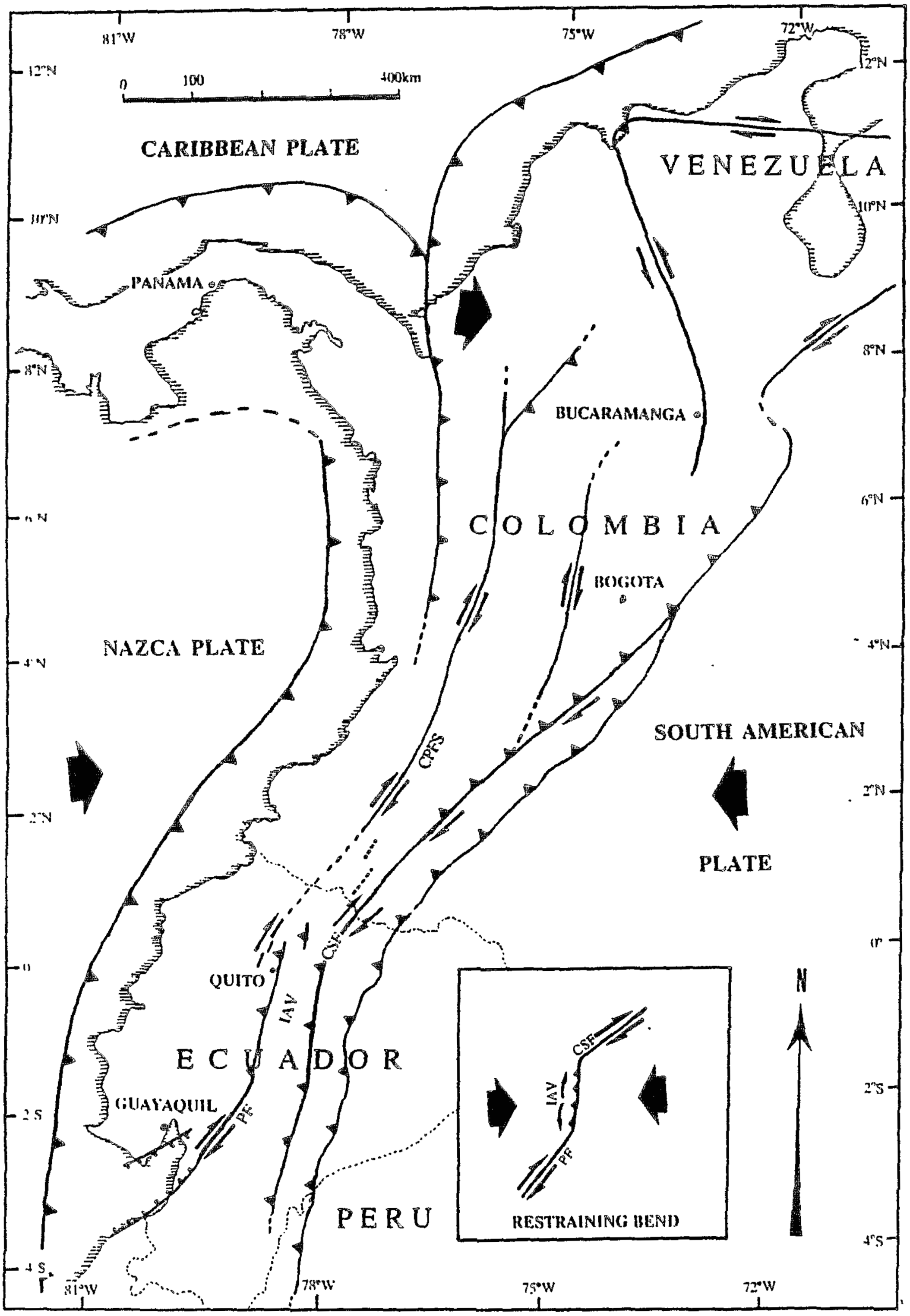

Figure 1: Geodynamic setting and major structures in northern Andes and restraining bend model for the northern Ecuadorian Andes. CSF: Rio Chingual-la Sofia Fault, CPFS: Cauca-Patia Fault System, IAV: Inter-Andean Valley and PF: Pallatanga Fault.

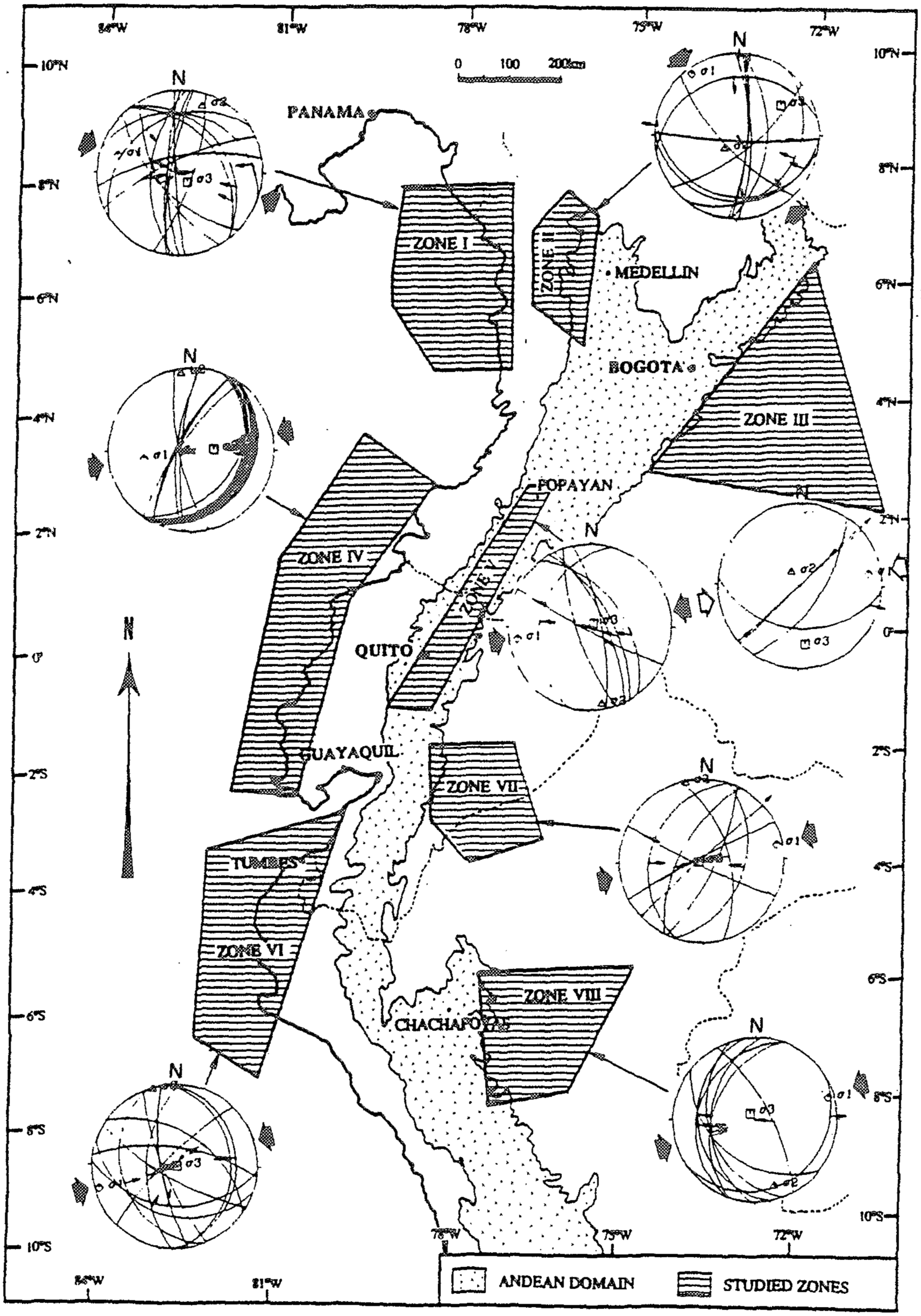

Figure 2: State of stress in northern Andes calculated by inversion from focal solutions. Due to few data, only a test has been performed for zone III. Solid black arrows: σ_1 orientation.

flow dated at 9670 yrBP (Hall & Beate, 1991). Since this lava flow exhibits an offset ranging between 60m and 70m, and assuming a 5% error on the age, the "long term" slip rate is 7 ± 1mm/yr. In contrast, the N30°E trending PF has a slip rate of 4 ± 1mm/yr (Winter (1990; Winter et al 1993). The marked difference in slip rate between PF and CSF suggests a northward increase in dextral slip rate along northern Andes. Assuming that the whole strike-slip motion of the N30°E striking PF is transmitted northward to the N-S striking restraining bend, we can estimate the order of the IAV shortening rate. This simple geometrical pattern yields an E-W shortening of 2 ± 1mm/yr. Conversely, if the whole 7 ± 1mm/yr slip rate of the CSF would be transferred southward to the restraining bend, its shortening rate would be thus 4 ± 1mm/yr. This theoretical calculation shows that there is a difference of 2 mm/yr of E-W shortening between the northern and southern ending points of the Ecuadorian restraining bend.

CONCLUSION

During the Quaternary period, northern Andes are submitted to an homogeneous state of stress. Moreover, the N-S striking Ecuadorian IAV is submitted to an E-W compression and the motion of the two NNE-striking, major dextral fault systems (PF and CSF), located North and South of the IAV, also agree with this regional state of stress. Slip rate calculations on the PF and CSF suggest a northward increase in dextral slip along Ecuadorian Andes. This increase should be the consequence of a northward increase in convergence obliquity. Indeed, the obliquity between the trench normal and the convergence is ±30° in Ecuador (from Guayaquil to Esmeraldas) while it is ±45°E in northernmost Ecuador-southern Colombia (from Esmeraldas to Buenaventura). Taking into account the 78mm/yr convergence rate and the convergence obliquities, there is 39mm/yr of dextral slip, parallel to the trench, to accommodate in Ecuador while this amounts to 60mm/yr in northernmost Ecuador-southern Colombia. In fact, the subduction slip is actually oblique (see zone IV on Fig. 2) and consequently accommodates most of the parallel to the trench component of convergence. A simple calculation shows that the subduction slip accommodates approximately 75-90% of the parallel to the trench component of convergence. The remaining 10-25 % are accommodated by the upper plate dextral faults so that the theoretical dextral slips are: 4-10 mm/yr in Ecuador and 6-13 mm/yr in northernmost Ecuador-southern Colombia, respectively. These theoretical values are of the same order than the PF and CSF calculated slip rates showing that other major dextral faults are unlikely. Finally, the 2 mm/yr excess in shortening rate existing to the North of the restraining bend should correspond to the CFS southward damping on the Reventador reverse fault zone.

REFERENCES

CAREY-GAILHARDIS E. & MERCIER J.L., 1987. A numerical model for determining the state of stress using focal mechanisms of earthquake population: application to Tibetan teleseims and microseismicity of Southern Perou. *Earth Planet. Sci. Lett.*, 82, 165-177.

DZIEWONSKI A.M. et al, from 1981 to 1992. Determination of CMTS in *Phys. Earth. Planet. Int.*

EGO F., SEBRIER M., LAVENU A., EGUEZ A., and YEPES H., 1993. A new geodynamical model for the Northern Ecuadorian Andes. EUG VII, 4-8 April 1993, *Terra abstract* 5 (1): 203.

HALL L.M. & BEATE B.,1991. El volcanismo plio-cuaternario en los Andes del Ecuador. *Estudios de Geografia* Vol 4, 5-17, Quito 1991.

PENNINGTON W.D., 1981. Subduction of the eastern Panama basin and seismotectonics of northwestern south America. *J. Geophy. Res.* , 86, B 11 : 10753-10770.

SOULAS J. P., 1988. Informe de misión en el Ecuador, Proyecto UNDRO-EPN. Programa de prevención y planificación para desastres en el Ecuador y países vecinos. UNDRO, Genève, Suisse, 21p.

SOULAS J. P., EGUEZ A., YEPES H. and PEREZ H., 1991. Tectónica activa y riesgo sismico en los Andes ecuatorianos y el extremo sur de Colombia. *Bol. Geol. Ecuat.* Vol 1, n°1, pp 3-9.

TIBALDI A. & FERRARI L. 1992. Lastest pleistocene-holocene tectonics of the ecuadorian Andes. *Tectonophysics.* 205, pp 109-125.

U.S.G.S., N.E.I.C., 1988. World Data Center_A for Seismology. Listing, 1977 to 1988. U.S. Dept. of the Interior.

WINTER T. 1990. Mécanismes de déformation récentes dans les Andes equatoriennes. *Thèse.* Paris-Sud, Orsay, 205 p.

WINTER T., AVOUAC J. P., and LAVENU A., 1993. Holocene Kinematics of the Pallatanga strike-slip fault (central Ecuador) from topographic measurements of displaced morphological features. *Geophys. J. Inter.* (accepted).