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# Pleistocene to Present North Andean "escape"

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ABSTRACT

This study compiles 20 published field geologic estimates of displacement rates for the northern Andes, such as displaced glacial moraines and offset pyroclastic flow, and compares them to published Global Positioning System (GPS) measurements. Dated displacements compiled in this study were obtained from the Gulf of Guayaquil, Pallatanga, Chingual-la Sofia, and Cayambe-Afiladores-Sibundoy fault systems in Ecuador and southern Colombia and the Boconó fault system in Venezuela. Right-lateral slip estimates on the individual fault segments range from 2 mm/a to 10 mm/a. The mean estimated geologic slip rate for the last 86,000 years is 7.6 mm/a. This estimate is very similar to the GPS measurements of Present day motion at the 2 sigma level. Published GPS results suggest that a large part of the northern Andes is "escaping" to the northeast relative to stable South America at a rate of 6 ± 2 mm/a. The GPS displacement rates of seven sites in Venezuela, Colombia, and Ecuador are statistically identical at the 95% confidence level. Four geologic estimates indicate that slip rates of 4 to 10 mm/a continued back to 1.8 Ma. No geologic slip estimates have been reported for Ecuador prior to that time period. The "escape" of the North Andes is believed to be a result of increased coupling between the obliquely subducting Nazca plate and the overriding South American plate due to the subduction of the Carnegie Ridge in the Ecuador–Colombia trench. If this is correct, the slip estimates for the North Andes suggest that the Carnegie Ridge arrived at the trench prior to 1.8 Ma. In the Eastern Cordillera of Colombia, strike-slip crustal earthquakes reflect slip partitioning on high angle faults located above crustal detachment ramps across a 200 km wide zone. Intermediate depth mantle earthquakes indicate that brittle shearing extends to the base of the lithosphere.



## 1. Introduction

Northwestern South America is a broad convergent plate boundary zone characterized by active seismicity, a volcanic arc, subduction, and an on-going arc–continent collision. The North Andes is bounded by the Colombian–Ecuador trench and the Panama block to the west, the South Caribbean deformed belt to the north, and the Boconó fault and East Andean fault zones to the east (Pennington, 1981; Kellogg and Vega, 1995). Cenozoic deformation in this broad zone has been produced by the converging Nazca, South American, and Caribbean plates, and the Panama microplate (Kellogg and Bonini, 1982). Geodetic measurements using GPS from the Central and South American (CASA) GPS project show that the Nazca oceanic plate is rapidly converging with stable South America (Freymueller et al., 1993; Trenkamp et al., 2002). The convergence direction is slightly oblique to the Colombia–Ecuador trench (Fig. 1). The aseismic Carnegie Ridge, produced by the passage of the Nazca plate over the Galapagos hotspot, is being subducted in the Ecuador–Colombia trench. CASA measurements also suggest that a large part of the northern Andes is "escaping" to the northeast relative to stable South America at a rate of 6 ± 2 mm/a. The relative northeastward motion of the northern Andes is also demonstrated by earthquake focal mechanism solutions (Fig. 2) as well as numerous geologic field measurements of dated offset glacial features and pyroclastic flow. Tapponnier et al. (1982), using plane indentation experiments on unilaterally confined blocks of plasticine were able to model intracontinental deformation and the evolution of strike-slip faults due to the collision of India and Asia. The faults that develop, allow the "escape" of the detached block in the direction of the free boundary. Proposed driving mechanisms for the "escape" of the North Andes include subduction of the Caribbean plate, collision with the Panama arc, rapid oblique subduction of the Nazca plate, and the subduction of the aseismic Carnegie Ridge at the Ecuador–Colombia trench. The geologic history of the "escape" might therefore shed light on the driving mechanisms. If subduction of the Carnegie Ridge is an important factor as has been proposed (Lonsdale, 1978; Pennington, 1981; Gutscher et al., 1999; Witt et al., 2006), then the initiation of northeastward displacement could indicate when the Ridge arrived at the trench.

This study provides the first compilation of published geologic estimates of displacements with reliable ages from the entire East Andean frontal fault zone. The results include 20 geologic estimates obtained from transverse faults underlying the pull-apart basin in the Lechuza depression, on Puna Island, and from the Zambapala Fault

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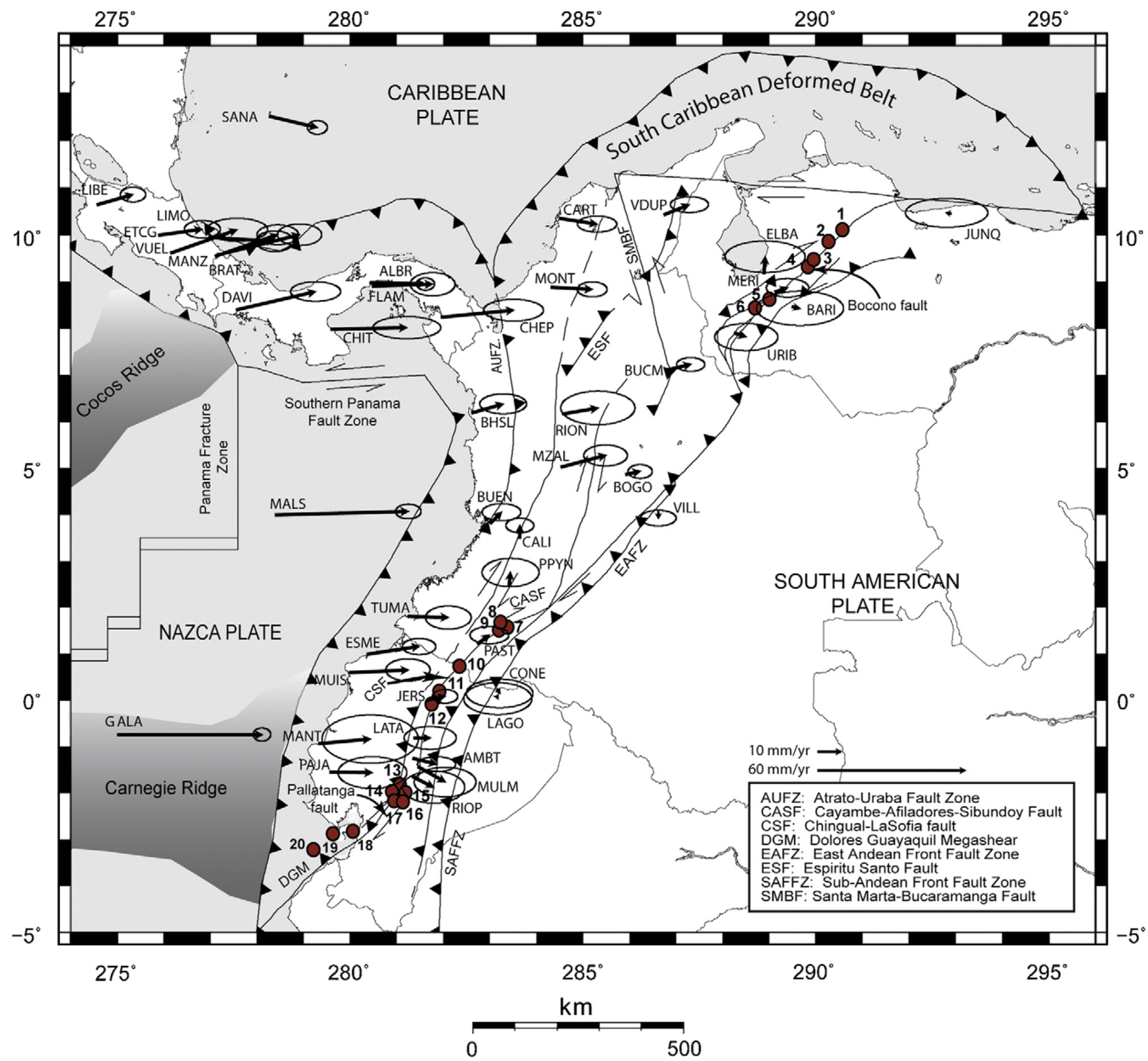


**Fig. 1.** Structural map of the North Andes. Numbers are the locations of geological displacement estimates (Table 2). CASA station GPS velocity vectors relative to stable South America are shown with 95% confidence error ellipses (Trenkamp et al., 2002). The Galapagos vector (GALA) has been relocated so that it is visible on this map. AUFZ: Atrato-Uraba fault zone; CASF: Cayambe-Afiladores-Sibundoy fault; CSF: Chingual-la Sofia fault; DGM: Dolores Guayaquil megashear; EAFZ: East Andean Frontal fault zone; ESF: Espiritu Santo fault; SAFFZ: Sub-Andean Frontal fault zone; SMBF: Santa Marta-Bucaramanga fault.

Zone, both in the Gulf of Guayaquil, as well as from the Pallantanga and Chingual-la Sofia faults in Ecuador, the Cayambe-Afiladores-Sibundoy fault in southern Colombia, and the Boconó fault system in northwestern Venezuela. These estimates were compared with the Present day displacement rate for the North Andes determined from CASA GPS measurements. The results were then used to make inferences regarding the driving forces for the northeastward "escape" of the North Andes as well as to attempt to explain the lack of geologic measurements of northeastward strike-slip motion in the Eastern Cordillera of Colombia.

### 1.1. GPS results for the North Andes

Space geodetic studies are now the primary method of studying the kinematics of plate boundary zones on land, because, since space geodetic measurements are in a global reference frame, they can be used to measure motions within the boundary zones as well as relative global motions of plate interiors (Stein and Sella, 2002). These measurements include coseismic, postseismic, and interseismic deformations associated with plate motion and crustal deformation at the plate boundaries. The demonstrated repeatability of horizontal position estimates for regional GPS networks is in the order of 1–5 mm (Jaldeha et al., 1996; Segall and Davis, 1997). The CASA GPS project measured plate motions and crustal deformation of the Nazca, Cocos, Caribbean, and South American plates. Fig. 1 includes velocity vectors from geodetic measurements conducted in the field from 1991 to 1998 in Venezuela, Colombia, and Ecuador (Trenkamp et al., 2002). The data was analyzed using GIPSY OASIS and GIPSY OASIS II software. Deformation vectors in the northern Andes reflect strain associated with convergence at the broad Nazca–South American plate boundary, Caribbean–South American plate boundary, and Panama arc–South America boundary. GPS measurements are consistent with rapid active subduction ($58 \pm 2$ mm/a) of the oceanic Nazca plate and the Carnegie aseismic ridge at the Ecuador–Colombia trench beneath stable South America (Trenkamp et al., 2002). Approximately 50% of the Nazca–South America convergence is locked at the subduction interface, causing elastic strain in the overriding plate