Tectonic implications of tomographic images of subducted lithosphere beneath northwestern South America

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ABSTRACT

We used seismic tomography to investigate the complex structure of the upper mantle below northwestern South America. Images of slab structure not delineated by previous seismicity studies help us to refine existing tectonic models of subducted Caribbean-Pacific lithosphere beneath the study area. Beneath western Venezuela and Colombia we distinguish two slabs: a Maracaibo and a (redefined) Bucaramanga slab. The Maracaibo slab, coinciding with most of the Bucaramanga slab previously defined by W. D. Pennington, dips in a direction of 150° at an angle of 17° to a depth of 275 km and correlates to the subducted Late Cretaceous oceanic plateau of the Caribbean plate. Farther south, a second slab dips at an angle of 50° in a direction of 125° to a depth of at least 500 km and correlates to the subducted oceanic crust of the Nazca plate and the downdip extension of the Panama island arc. We refer to this slab as the redefined Bucaramanga slab, because it is different from the Bucaramanga slab segment defined by Pennington. The area of the South American plate overriding both slabs is characterized by the absence of an active volcanic arc, an anomalously wide topographically uplifted and tectonically active area, and the northward escape of the Maracaibo block along active strike-slip faults. In support of earlier studies, we attribute this to the underthrusting of the Caribbean oceanic plateau (our shallowly dipping Maracaibo slab) along the base of the South American lithosphere and to the recent collision of the Panama island arc rafted in on more steeply dipping crust of the Nazca plate (our redefined Bucaramanga slab).

INTRODUCTION

No simple plate boundary can be drawn connecting island-arc systems along the Pacific margin of Central and South America to the strike-slip boundary along the Caribbean coast of South America (Dewey, 1972) (Fig. 1). In northern Colombia and Venezuela deformation and shallow seismicity is diffuse, and the Andean Mountains are two to three times wider than in southern Colombia and Ecuador. Major tectonic elements in the study area include (1) the South American plate (Precambrian); (2) the Maracaibo block, a triangular piece of the South American plate that is advancing toward the north along active strike-slip faults (Mann and Burke, 1984); (3) the Caribbean plate (Late Cretaceous oceanic plateau crust and Jurassic[?] oceanic crust; Bowland and Rosencrantz, 1988); (4) the Panama island arc (Late Cretaceous and Tertiary), sutured to South America in late Miocene to Pliocene time (Mann and Corrigan, 1990); and (5) Oligocene-Miocene oceanic crust of the Nazca plate.

Dewey (1972) and Pennington (1981) used relocated earthquakes and their focal mechanisms to identify segments of subducted lithosphere of the Caribbean and Nazca plates beneath northwestern South America. Pennington (1981) identified the Bucaramanga slab, correlated to Caribbean lithosphere subducted at the South Caribbean deformed belt (Ladd et al., 1984), and the Cauca and Ecuador slabs, continuous with Nazca plate lithosphere and subducted at the Colombian trench (Fig. 1B). Pennington (1981) proposed that slab boundaries could correspond to subducted, buoyant bathymetric features.

The precise delineation of subducted slabs and their tectonic interpretation are difficult because the regional earthquakes with hypocenters below 70 km depth are not located in well-defined seismic zones. We used seismic tomography to improve the mapping of the seismic structure of the upper mantle below the study area and, in par-

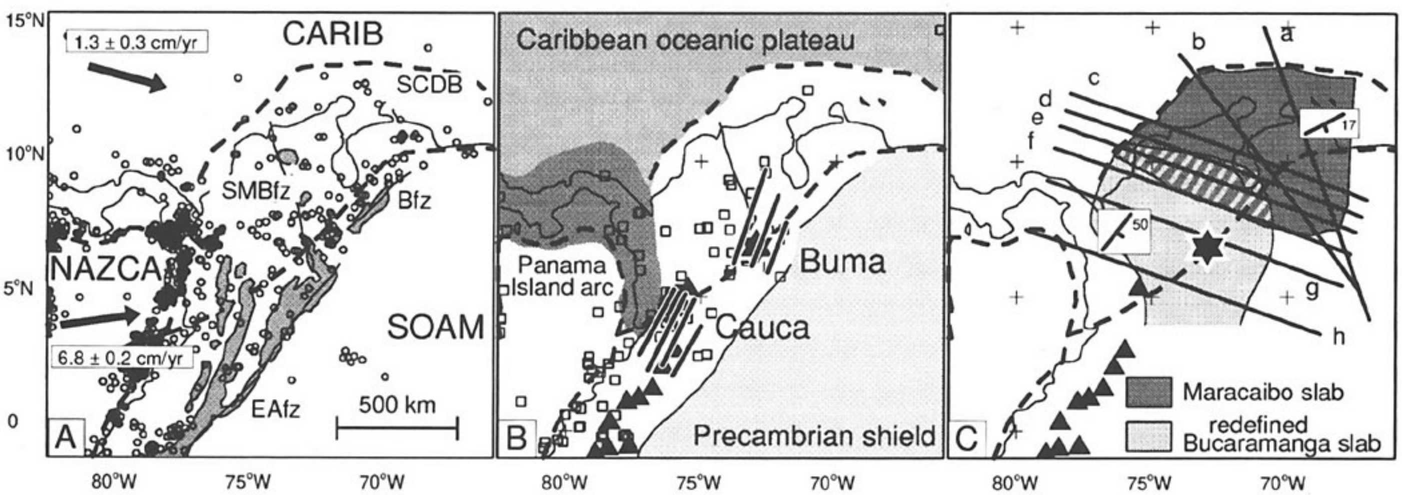

Figure 1. Location maps and crustal tectonic features of study area. A: Seismo-tectonic map. Plate boundaries and directions and velocities of plate motion are from NUVEL-1 (DeMets et al., 1990); circles—epicenters of shallow earthquakes (focal depths <75 km) and Richter scale magnitudes >4.5 from International Seismological Centre catalogue. Bfz = Bocono fault zone, CARIB = Caribbean plate; EAfz = East Andean fault zone (Pennington, 1981); SCDB = South Caribbean deformed belt; SMBfz = Santa Marta–Bucaramanga fault zone; SOAM = South American plate. B: Map showing earthquake epicenters (squares) of intermediate depth and magnitude >4.5 earthquakes. Contours to Benioff zones and segment names are from Pennington (1981). Buma = Bucaramanga segment; Cauca = Cauca segment. C: Map showing lines of cross sections of Figure 3 and extent of Maracaibo and redefined Bucaramanga slabs as determined from images (shaded areas). Numbers at dip symbols indicate dip angle of slab inferred from images. Large areas of subducted slab mapped with tomography are aseismic and are not detectable by traditional seismicity studies. Solid triangles in B and C depict volcano locations; star depicts location of Bucaramanga cluster of intermediate depth earthquakes.

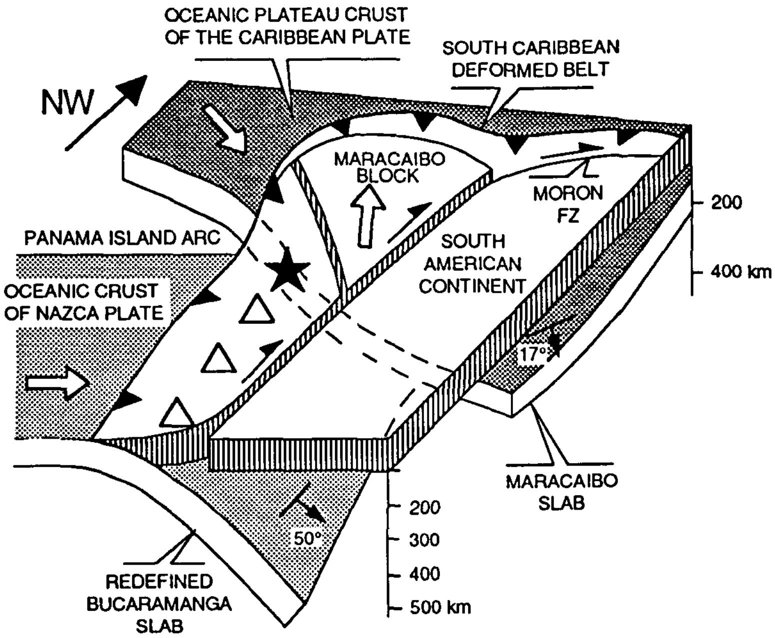

Figure 4. Schematic block diagram summarizing geometry and extent of subducted slabs inferred from Pennington (1981), using traditional seismology and tomographic inversion. FZ—fracture zone.

acaibo slab at the South Caribbean deformed belt and the compressive stress due to the collision of young lithosphere west of the redefined Bucaramanga slab can combine to drive northwestern South America toward the northeast along the East Andean–Bocono and Santa Marta–Bucaramanga strike-slip systems. This tectonic escape was discussed by, for example, Mann and Burke (1984). The southern part of the redefined Bucaramanga slab is offset from the high seismic activity at the site of present-day subduction of normal Nazca sea floor at the Colombia-Equador trench (Fig. 3H), which marks the northernmost part of Pennington's (1981) Cauca segment. The right-lateral offset was discussed by Pennington (1981) and is consistent with focal mechanisms (e.g., no. 48 of Pennington, 1981) in the boundary region between the slab segments.

The limited spatial resolution in the images renders tentative the following discussion of the implications of the overlap of the steep redefined Bucaramanga slab and the shallower Maracaibo slab (Fig. 3, D and E). The overlap could explain two important observations. First, the absence of a volcanic arc above the northern part of the redefined Bucaramanga slab may be due to a blocking effect by the Maracaibo slab at higher levels in the mantle. Second, the relatively low attenuation of seismic waves (Shih et al., 1991) above the Bucaramanga seismic nest and the northern part of the redefined Bucaramanga slab may be due to the passage of the waves through the overlying Maracaibo slab rather than through an asthenosphere with high attenuation of seismic waves.

The Bucaramanga cluster of intermediate depth earthquakes appears to be located within the redefined Bucaramanga slab, just south of the overlap. In the images (Fig. 3G), the cluster is at the top of the slab where the upper mantle wedge is marked by P-wave velocities that are >2.5% lower than the average velocity at that depth. This low-velocity wedge becomes less pronounced toward the north because of the presence of the shallow Maracaibo slab segment. This observation could support the hypothesis that the Bucaramanga earthquakes are being produced by partial melt and the rise of magma accompanying the formation of a volcanic arc (Schneider et al., 1987; Shih et al., 1991). However, we cannot reject the possibility that the nest is produced by a complex stress field near the contact of the Maracaibo and Bucaramanga slabs in the upper mantle.

ACKNOWLEDGMENTS

The tomographic images were obtained when van der Hilst was at the University of Utrecht, The Netherlands, using inversion software modified from the code by W. Spakman. We thank W. D. Pennington for suggestions to improve the manuscript. University of Texas Institute for Geophysics contribution no. 1045.

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Manuscript received October 14, 1993
Revised manuscript received February 16, 1994
Manuscript accepted February 21, 1994