Trans-Andean mega-regional seismic reflection line extending from the Caribbean coast to Cordillera Oriental of Colombia: implications for hydrocarbon exploration

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Abstract

During 2007-2008, the Colombian government working through the National Hydrocarbons Agency (ANH) collected a 383 km-long, triaxial high-resolution seismic reflection line using active sources that were recorded to depths of 20 seconds two-way time. Several types of supporting data were collected along the same transect that included surface geology, gravity, magnetics, and geochemistry of hydrocarbons. The purpose of the study was to constrain 1) the deep structure and stratigraphy of the Sinú -San Jacinto belt - the onland late Cretaceous accretionary prism; 2) the tectonic boundary separating these accreted oceanic rocks from the South American continental margin (Romeral fault zone); 3) the Eocene-Oligocene unconformity of the Lower (LMB) and Middle Magdalena basins (MMB) and 4) the tectonic boundary between the Cordillera Oriental and the MMB. Features best imaged in the study include the unconformity and overlying sedimentary fill of the San Jorge and Middle Magdalena basins. Both gently folded, synclinal basins have been shortened in the east-west direction by much less than estimates of 110-115 km based on previous balanced cross sections. Geochemistry of hydrocarbons in the San Jorge and Middle Magdalena basins show that all source rocks are contained within these gently deformed synclines.

Sub-vertical, active strike-slip faults of northern extension of the La Salina fault zone are seen crossing the eastern part of the line in the MMB. Seismic penetration into the sub-unconformity section was disappointing but more recent seismic processing shows the general eastward dip of thrust-imbricated strata of the Sinú-San Jacinto belt. In this area, the Eocene-Oligocene unconformity at the base of the western margin of the LMB may act as a trap for hydrocarbons for known source rocks of the Sinú -San Jacinto belt. The boundary between the Cordillera Oriental and MMB is defined by the Cambao – La Salina thrust system that dips 25 degrees to the east beneath the Cordillera Oriental.

Data and acknowledgements

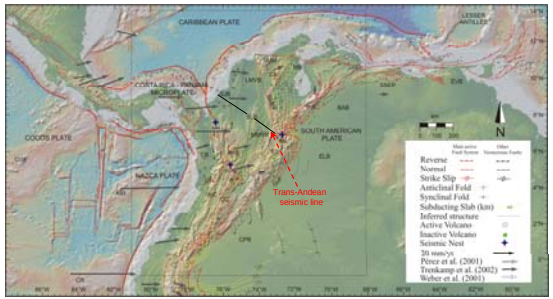
The acquisition, processing, analysis and interpretation of the Trans-Andean transect has involved the support and assistance of three institutions:

1. ANH - Colombia: ANH acquired the 383-km-long line that was divided into two segments. Data acquisition by Sismopetrol, Ltd., included 800 triaxial accelerometers, shots at 50-m spacing, and receivers at 25-m spacing. Processing of seismic data was completed by Inforpetrol, Ltd. Complementary data collected along the seismic line included: gravity, magnetic, geochemical, and geologic map data.

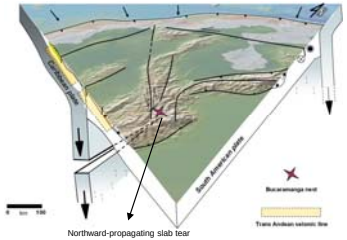
2. University of Texas, Institute for Geophysics (UTIG) and Departamento de Geociencias, Universidad Nacional de Colombia: UTIG and Universidad Nacional provided support for further processing of the seismic line and computer assistance for tomographic study based on attenuation of coda waves of 1674 Colombian earthquakes.

3. INGEOMINAS (Colombia): Ingeominas made available to the study the Colombian earthquake catalogue, a geothermal gradient map of Colombia, and a national geologic map.

Extent of subducted slabs beneath northwestern South America based on previous studies of Benioff zone

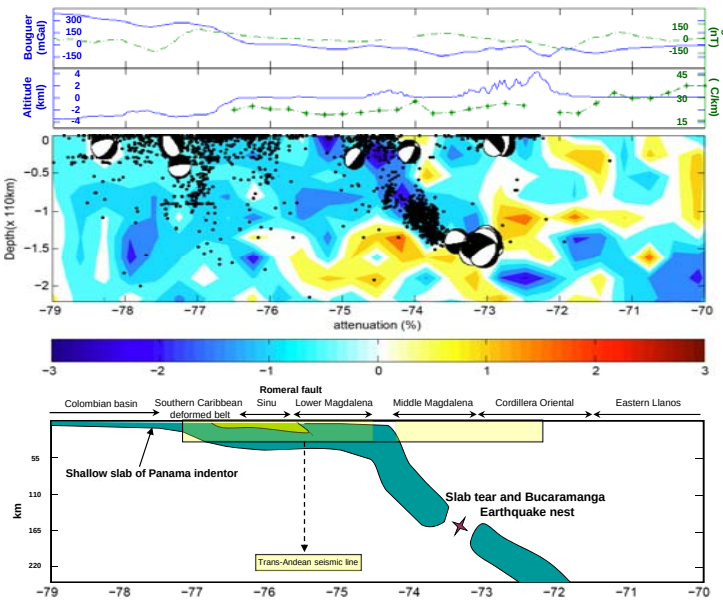


Model for slab breakoff beneath NW Colombia based on seismic tomographic data parallel to Trans-Anden seismic reflection line



Tomographic data indicates flat, eastward subduction of the Panama block beneath Colombia as the result of the thicker crust of the subducted and colliding Panama arc. Flat subduction produces uplift and subaerial exposure of the overriding late Cretaceous to recent accretionary prism of western Colombia (Sinu basin and San Jacinto belt). Tomographic and earthquake data indicate that the downdip extension of the flat subduction is tearing at a depth of 160 km. The slab tear is propagating northward.

Seismic tomographic constraints on lithospheric structure and subducted slab underlaying the Trans-Andean seismic reflection line



Estimates of observed attenuation of coda wave (Q_c) over large regions using earthquakes data sets are described in detail by Vargas et al. (2004). We use this same method for imaging the subsurface of Colombia to mantle depths of 240 km based on assumption that the volume sampled by the observed coda wave at an instant t is an ellipsoid whose foci are located at the hypocenter and the station:

$$\frac{x^2}{\left(vt/2\right)^2}+\frac{y^2}{\left(vt/2\right)^2}+\frac{z^2}{\left(\left(vt/2\right)^2-R^2/4\right)}=1$$

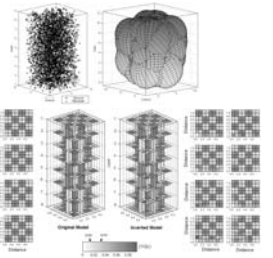
This ellipsoid represents the geometric location of the points whose sum of distances to foci is constant and equal to vt, with v being the S-waves velocity, t the time interval of coda from the origin and R is the distance source–receiving. The ellipsoid's volume is function of the time and allows the establishment a relation with Q_c:

$$\frac{V_{TOTAL}}{Q_{av}}=\sum_j\frac{V_{Block-j}}{Q_j}$$

where, V_{TOTAL} is the sampled total volume and each value of Q_c measurement is an estimated average value Q_{av} (or $Q_{apparent}$) for the sampled volume. $V_{Block-j}$ is the discrete volume fractions whose true quality factor values are represented by Q_j.

$$\frac{1}{Q_{av}}=\frac{1}{Q_1}\frac{V_{Block-1}}{V_{TOTAL}}+\ldots+\frac{1}{Q_j}\frac{V_{Block-j}}{V_{TOTAL}}+\ldots+\frac{1}{Q_n}\frac{V_{Block-n}}{V_{TOTAL}}$$

A solution of this system can be obtained by means of the damped least squares method (Crosson, 1976). Several 3D tests were done to verify the accuracy of this technique using both real and synthetic data.



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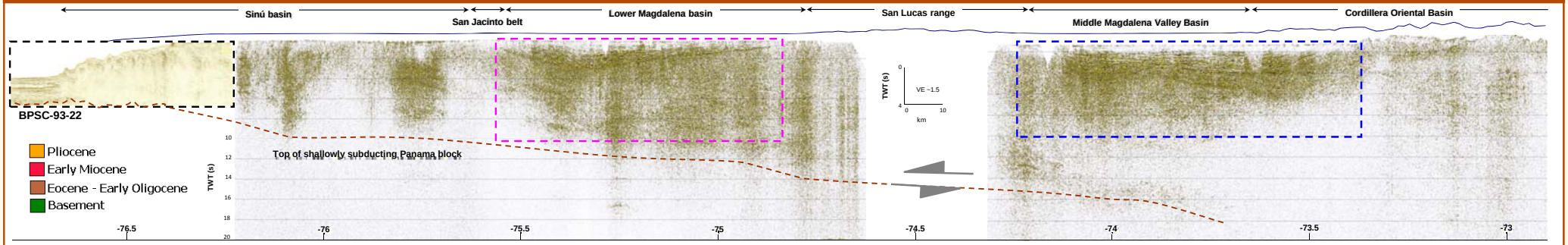
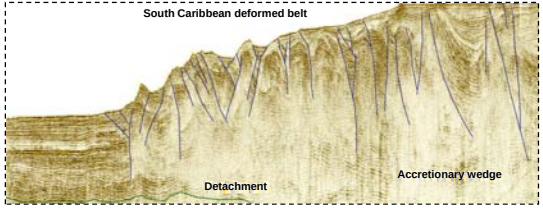
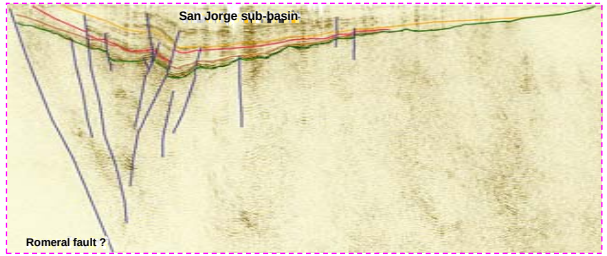
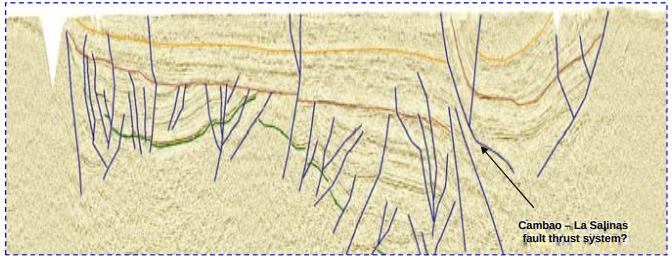
Trans-Andean seismic reflection line showing relationship between shallow subduction of Panama block and overlying accretionary wedge and hydrocarbons basins









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Trans-Andean seismic reflection line showing depth of inferred source rocks, composition of surface hydrocarbons, possible migration pathways, and Golden Zone of optimal depth for hydrocarbon preservation