Influence of Caribbean tectonics across the Eastern Venezuela petroleum basins

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Abstract

Venezuelan industrial oil exploration has been improving our knowledge of the petroleum systems in the septentrional region of the South American plate.

Hydrocarbon generation and structural deformation are closely related over the "Ensenada de Barcelona" area. This fact, together with the complex structural styles, resulting of the frontal collisions between Caribbean and South-American plates, originated the most complex oil and gas traps present in the area.

The objective of this study is to integrate the petroleum systems and the structural styles from the Southeast (Serranía del Interior Oriental) to the Northwestern offshore area. 756 Km of 2D seismic lines were interpreted and compared with previous studies. Duplex structures with four repetitions and shortening between 38% and 44% were identified. A cutoff ramp of 18 degrees (2 degrees higher than the "Serrania") was recognized. Through "Ensenada" area the deformation is older than Pliocene (5.3 m.y), but the detachment level (Lower Cretaceous) is the same as in the "Serrania" fold and thrust belt.

Additionally, a younger extensional fault system was recognized, with a principal fault to the North identified as "Coast Fault" dipping to the South, and a secondary normal fault system dipping to the North not present to the East. Petroleum traps are Cretaceous duplexes shallower and better-preserved reservoirs, than the Serrania.

Timing between the processes of petroleum generation-expulsion-trapping in the "Ensenada" area has higher probabilities to occur, because this deformation is older than in the Southeastern part of the study area. The expulsion time was estimated as around 8-16,6 m.y.

Resumen

Los sistemas petrolíferos asociados al norte de la placa Suramericana son aún objeto de controversia en el mundo de la exploración petrolífera Venezolana. El complicado esquema de estilos estructurales presentes en el norte de Venezuela como resultado del choque frontal de la placa Caribe contra la placa Sudamericana, permitió generar los más exóticos estilos estructurales, que hoy son capaces de almacenar petróleo y gas.

El objetivo de este estudio es contribuir al conocimiento de las estructuras y de los sistemas petrolíferos presentes en el área de "Ensenada de Barcelona", ubicada al noroeste de la "Serranía del Interior Venezolana".

Fueron interpretados un total de 756 kilómetros lineales de datos sísmicos 2D, y los mismos se compararon con estudios previos, encontrando acortamientos asociados a la fase compresiva en el rango de 38-45% lo que coincide con todos los trabajos anteriores. Además fue determinado un ángulo de rampa de 18 grados, 2 grados más que los calculados para la Cuenca Oriental de Venezuela y edad de deformación más antigua que 5.3 m.a, edad esta basada en que la secuencia Pliocena no está deformada. Por otra parte, se determino que las estructuras están mucho más someras en función de que en el área de "Ensenada de Barcelona" los pliegues superiores están bien conservados.

El área, luego de la compresión fue sometida a efectos extensivos generando dos grandes fallas, la primera de ellas asociada al sistema de extensión principal con buzamiento al sur denominada "Falla de Costa", y un segundo sistema con buzamiento al norte ya sin expresión hacia el este. Finalmente, se concluye que el sistema compresivo del norte coincide en edad y características con el sistema compresivo que generó los campos petrolíferos aún en exploración de la Serranía; y se deduce que el sistema extensional de edad reciente debe haberse iniciado no antes de 5 millones de años atrás, con posibilidad de presentar movimiento en la actualidad.

Al contrario que en la Serranía, las estructuras presentan mayor prospectividad a nivel del Cretáceo que del Terciario, ya que en esta área todavía está cuestionada la presencia de una roca almacén Terciaria con la calidad de la Formación Naricual (roca almacén por excelencia en el Oriente de Venezuela).

Se estima una mejor sincronización entre los procesos de generación-expulsión-entrampamiento de hidrocarburos para los sistemas petrolíferos del área de "Ensenada" que para los de la "Serranía", ya que la edad de expulsión estimada en 8-16,6 m.a. en la "Serranía" es casi simultánea con la formación de las estructuras compresivas.

Introduction

Caribbean tectonics has been forming a complex puzzle of structural styles since the Oligocene, in the Northeast coast of Venezuela (figure 1). Actually, we know that these styles are responsible for the oil reserves of the area, but how they can impact the petroleum reservoirs is still unknown.

Since 1970, geologists and geophysics are studying the mechanical deformation of rocks along the "Serrania" folding. Therefore, this study tries to identify the structural behavior in the north of the visible folding (Figure 2), at the "Ensenada de Barcelona" area.

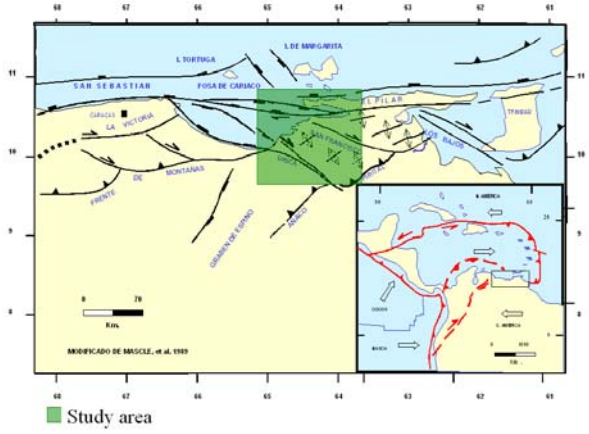

Figure 1. Study area (Eastern Venezuelan Basin)

This study investigate the relationship between oil traps present in the southeast and the northwest of the basin, as a result of the richest association of structural styles, combining compression, transpressive and extensional tectonics.

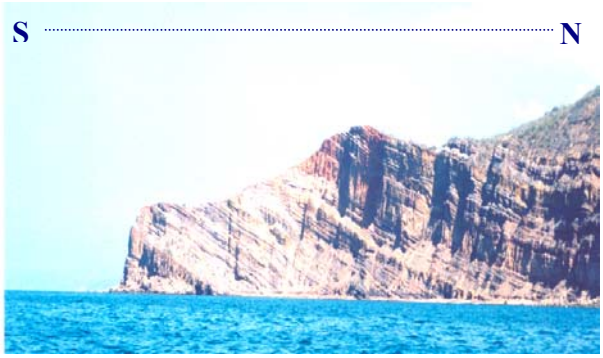

Figure 2. "Borracha", island (February, 2004)

In this area petroleum accumulations depend on a combination of structural styles, and a negative inversion of contractional fault system was recognized at the north of a fold and thrust belt. The structural style identified here was defined by Williams, Powell and Cooper (1993), which concluded that this kind of system is less common than positive inversion, and that extension faults cut through the thrust system, and detach at a deeper level.

Based on the Serranía analyses, Roeder (2001) and, Castillo and Morales (2002) assumed two main kinematics stages of deformation, the first one related to the emplacement of the frontal thrust (Pirital) onto undeformed foredeep fill, along the Oligocene; and the second one as a compression and transport of the foredeep and its Cretaceous sediments to the south, with a shortening estimation between 36% e 44%. The period of deformation dated by Castillo (2004) is as old as 8 million years.

The authors are looking for an explanation about what happened with the structural styles from the hinterland to the foreland in the basin and how these styles are related. This study is based on the interpretation of two seismic northwest - southeast cross-sections (Figure 3, northwest region), interpreted with the Dahlstromian-Suppe method and their comparison with Castillo's (2004-A) regional results (Figure 3, southeast region).

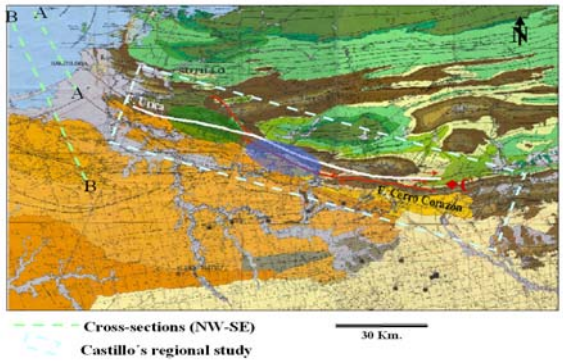

Figure 3. Geologic map (cross-sections AA´and BB´, and Castillo's regional study positions)

Methodology

Seismic data was calibrated using Castillo (2004-A) study along the "Serranía del Interior Venezolana". 636 Km of 2D seismic lines and 120 km² of 3D seismic were interpreted. Two of the most representative cross-sections through "Ensenada de Barcelona" area are shown here.

Because seismic data is limited and have a poor signal/noise ratio, the Dahlstromian-Suppe interpretation method was used. This method requires the depth conversion of the time section in order to work with the depth structural model, and to adjust the vertical and horizontal scale in a 1:1 proportion.

For the time-depth conversion the following interval velocities for each sedimentary layer were used:

Stratigraphic Level	Interval Velocity (m/s)
molasse	2000
Tertiary	3879
Paleocene	3955
Upper Cretaceous	4420
Lower Cretaceous	4820

Table 1. - Interval velocities for the stratigraphic levels in the Ensenada de Barcelona Area[1]

[1] Velocities of molasse, Upper Cretaceous and Lower Cretaceous were calculate by Castillo and Morales, 2002; and velocities of the Tertiary and Paleocene were generated in this study, based on VSP profiles.

Special attention was given to the Lower and Upper Cretaceous sections, as they are considered good levels to evaluate the structural sedimentary deformation. This sedimentary section is regarded as a passive margin since Jurassic to Oligocene.

Finally the structural model was retro-deformed (restored) to get a balanced cross-section. In the Tearpock and Bischke (1991) opinion “a section which does not balance cannot be geologically reasonable on simple geometric grounds”.

Results

Two interpreted cross-sections of the total area will be presented as a result. The first one is in depth scale (Figure 4). In this case, the structural model was interpreted in time scale and seismic-depth converted with Depth Team Express using the velocity table model (table 1). The second cross-section was interpreted in time (figure 5) and depth converted using the point-to-point method (figure 6).

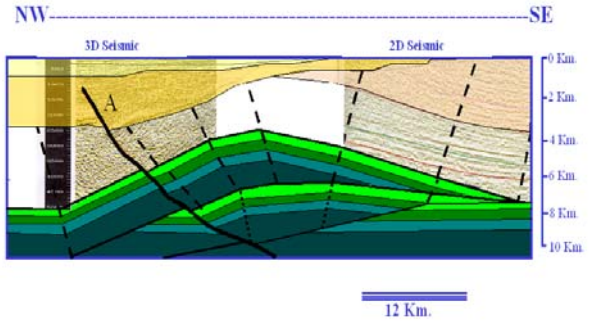

Figure 4. Cross-section A-A´ (depth scale)

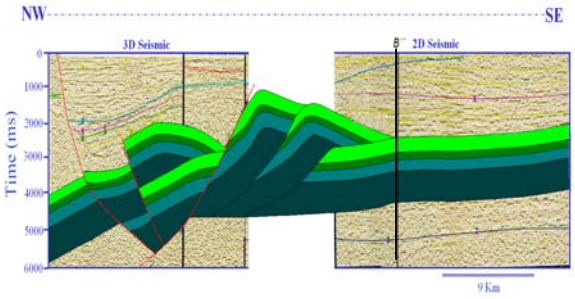

Figure 5. Cross-section B-B´ (time scale)

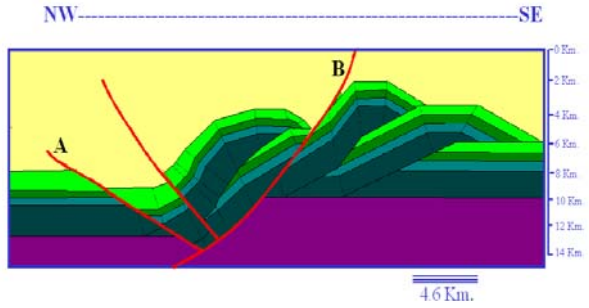

Figure 6. Cross-section B-B´´ (depth scale)

Duplex structures were interpreted with a cutoff ramp of 18 degrees and a lower detachment in the Lower Cretaceous (Barranquin Formation base, dark green level). The upper detachment was located over the Guayuta Group (light green level), implying that the stratigraphic levels involved in the deformation range from the Lower Cretaceous to the Upper Cretaceous.

Deformation is older than 5.3 m.a because the Pliocene level (dark yellow) is not deformed by the fold and thrust belt; therefore, this level was sedimented after the compressional deformation.

An extensional fault system from the Pliocene to the Recent was recognized (Figure 4 and 6, letter A) along the northern part of the coast. Sedimentation was concurrent with fault movement. Another fault system dipping to the South was generated at the same time.

The last normal fault system studied was developed in the second hanging wall ramp (Figure 6, letter B). Figure 7 shows two stages in the progressive negative inversion of the thrust-fold.

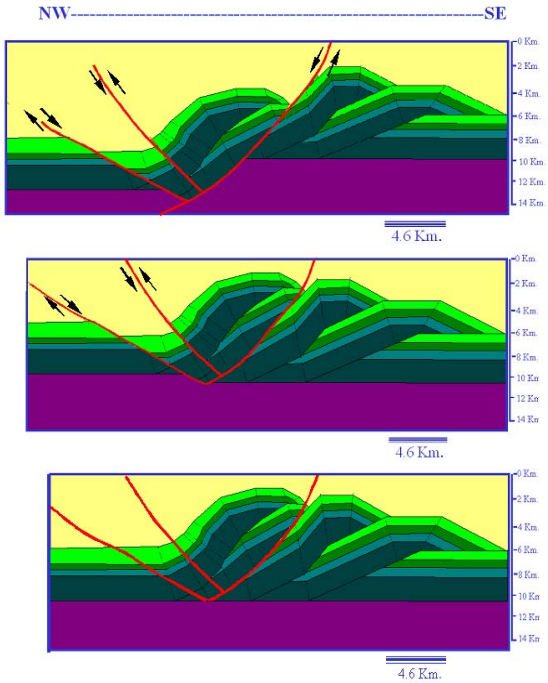

Figure 7. Extensional event restored until 5.3 m.y. of the Cross-Section B-B´.

After removing the extensional reactivation 1.6 kilometers of elongation for the cross-section A-A´, and 3.4 kilometers for the cross-section B-B´ were found. As a final result, when the compressive event was removed the shortening calculated was 46.5 kilometers for the cross-section A-A´ (Figure 8) and 21.3 kilometers for the cross-section B-B´ (Figure 9). This represents 43.7% of shortening for the first section and 38% for the last one.

Discussion.

Next, the results obtained in this study will be compared with studies over “Serrania del Interior” area (De La Peña,

1999; Roeder, 2001; Castillo and Morales, 2002; Castillo, 2004-B; Hung, 1997; Martinez, 1995; among others), mainly with Castillo's (2004-A) research; who identified and proposed structural oil and gas plays along Urica and Tala faults (Figure 3) to the southeast of the "Ensenada" area.

The principal Lower Cretaceous (Barranquin Formation) detachment is the same along both areas. The main difference found between the previous studies and this one is the cutoff ramp of 16 degrees (previous studies) and 18 degrees in this project. This can be explained by the poor velocities control used to convert the model from time to depth. This difference has a minimum impact on the duplex model interpreted.

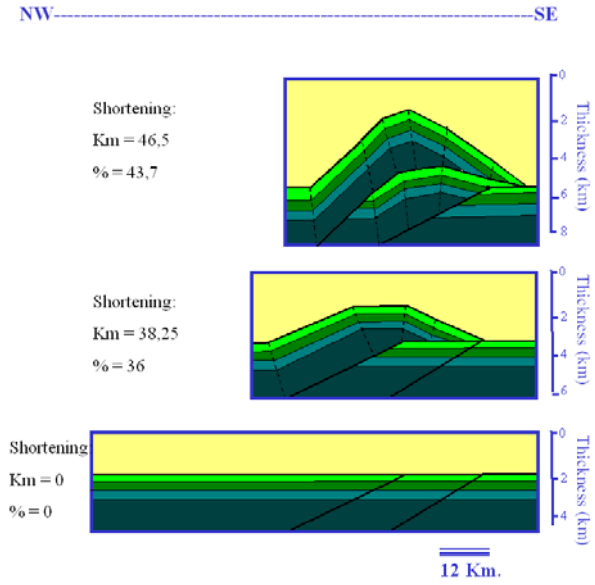

Figure 8. Compressional event restore until 23.7 Cross-Section A-A´.

The stratigraphic sections over the reservoir level (Barranquin formation) in this area are basically Pliocene and Pleistocene sediments. In contrast with the Paleocene and Cretaceous sediments that are emplaced over the autochthones "Serrania" terrains, this area was also deformed by the Caribbean and South American collisions along the Oligocene.

Two reservoirs rocks were tested by PDVSA in the "Serrania" area: Naricual Formation (Tertiary) and Barranquin Formation (Cretaceous). The first one presents high exploratory risk because it has been eroded in all the area and do not have a regional seal. In "Ensenada" area the only reservoir level identified is Cretaceous, even though it has not been tested yet.

The duplex structures interpreted along "Ensenada" area are older than those of the southeast area. The prospective structures in the South are interpreted in the deeper part of the duplex structure, because the shallower part was eroded. As a matter of fact, the younger (8 m.y approximately) deformation was responsible for the generation of oil and gas traps at the "Serranía", in contrast with "Ensenada" area where all the duplex structures were preserved, and trap age is between 8 and 16.6 m.y. This last statement was based on the age of the foreland basin sedimentary deposits and their relationship to the thrust and fold belt.

The Querecual formation (source rock) entered the oil windows around 16.6 m.y (Intevep, 2000); therefore, it is estimated that deformation was contemporaneously with the hydrocarbon expulsion. Because the "Ensenada" traps are older than the "Serrania" traps the exploratory risk in "Serranía" is higher than in the study area.

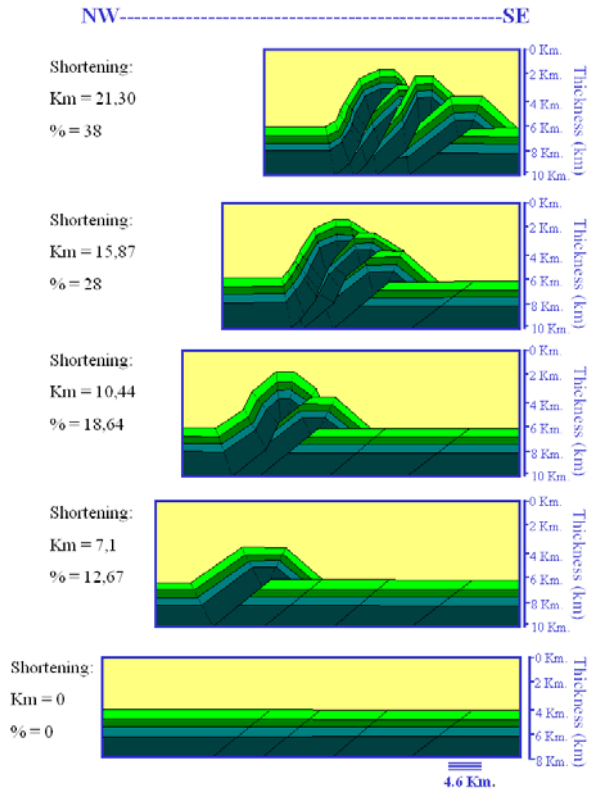

Figure 9 Compressional event restore until 23.7 Cross-Section B-B´.

Finally, it is estimated that prospective oil and gas traps in "Ensenada" area are around 1 and 3.5 kilometers shallower than in "Serranía", with a hydrocarbon prospective level between 3 and 4 Kms. depth.

In order to determine if the deformation mechanism of "Ensenada" fold thrusting have any relationship with the "Serranía" thrust and fold belt, analyses of structure types (Duplex) and restorations results (shortening value and cutoff ramp) were performed. These comparisons allow to conclude that the mechanism of compressive deformation was the collision between both plates, but it cannot be established if this deformation has the same age. The extensional event is only observed in the northwest area and they are related to a negative inversion of the compressional fault system.

Conclusions:

It is concluded that "Ensenada" is a hydrocarbon prospective area, with good timing for hydrocarbons

entrapment. The structural styles are duplexes with a cutoff ramp of 18 degrees, and shortening between 38-44%. As a consequence of the negative inversion, new oil and gas traps in the deeper part of the duplex were generated, associated with the extensional recent faulting and conditioned by the existence of a Tertiary source rock to the North of the area.

References

Castillo, M. G, 2004-A, Interpretación sismo-tectonica y construcción de un modelo tridimensional integrado en el Norte del Estado Monagas Venezuela: M. Sc. Thesis, Universidad Central de Venezuela, Caracas.

Castillo, M. G, 2004-B, Análisis Regional Estructural de la Serranía del Interior Venezolana: XII Congreso Venezolano de Geofísica, Caracas. In CD ROM.

Castillo, M. G, and Morales, M., 2002, Modelo tridimensional y reconstrucción tectónica en el Norte de Anzoátegui: XI Congreso Venezolano de Geofísica, Caracas. In CD ROM.

De La Peña, B. M., 1999, Análisis tectono estructural del área del piedemonte del corrimiento mayor de Tala: Trabajo especial de grado. Universidad Central de Venezuela, Caracas.

Hung, E. J., 1997, Foredeep and Thrust Belt Interpretation of the Maturín Sub-Basin, Eastern Venezuela Basin: Ph.D Thesis, Rice University. Houston-Texas P. 1-125.

Intevep, 2000, Estudio del sistema petrolífero sobre un perfil de la Serranía del Interior: PDVSA´s internal note.

Martinez, J.A., 1995, A geological and geophysical study of structural style along a transect of the Maturin subbasin, eastern Venezuela Basin: M. Sc. Thesis University of South Carolina.

Roeder, D.,2001, Eastern Venezuela and Cutufito Fold – Thrust Belts: Serie of structure Cross sections: Report of a regional structural review. Subsurface Consultants and Associates. Denver-Colorado. PDVSA´s internal note.

Tearpock and Bischke, R.,1991, Applied subsurface geological mapping. Prentice may, New Jersey. 648p.

Williams G. D., Powell, C. M and Cooper, M. A., 1993, Some geometrical characteristics of inversion: Inversion tectonics. Edited by M.A Cooper y G.D Williams. Geological Society. London. P 3-15