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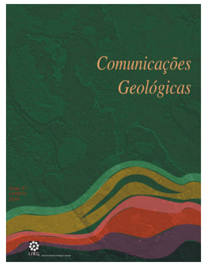

Diachronic Cenozoic wrenching in southwest of the Colombian Basin

Transcorrência diacrônica Cenozóica no sudoeste da Bacia Colombiana

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Abstract: We propose a major Eocene tectonic inversion related to an oblique convergence between Farallon (after Cocos plate) and Caribbean plates in the offshore of Colombian Caribbean. Between Eocene-Oligocene occurred an extension and another tectonic inversion since Oligocene to Pleistocene. By structural and stratigraphic evidence extracted from seismic, gravity and well data, we identified diverse diachronic Cenozoic deformations related to an important syndepositional wrenching event. Diachronic wrench system corresponds with Riedel structures and subordinated related-structures which have been growing progressively from north to south as result of convergence of Farallon (after Cocos plate) and Caribbean plates. Older basement-involved structures were inverted since Eocene. Tectonic inversions were interpreted from different strata geometries, relations of strata, growth strata and erosive truncations. A regional Eocene unconformity defined by erosional truncations reveals the timing of tectonic inversion and consequently closure of Colombian basin at northern boundary. The Eocene erosional unconformity becomes conformable toward the basin and should be an important correlative stratigraphic surface in the Caribbean offshore.

Keywords: offshore, Colombian Caribbean, Farallon plate, Cocos plate, wrenching, tectonic inversion, syndepositional, Colombian basin.

Resumo: Propõe-se que uma inversão tectónica maior tenha ocorrido durante o Eocénico associada à convergência oblíqua entre as placas Farallon (actual placa de Cocos) e Caribe no *offshore* do Caribe Colombiano. No período Eocénico-Oligocénico ocorreu extensão e do Oligocénico ao Pleistocénico ocorreu outra inversão tectónica. Foram ainda identificados diferentes eventos de deformação diacrónica no Cenozóico a partir de evidências estruturais e estratigráficas obtidas a partir de dados sísmicos, gravimétricos e de poço. As diferentes deformações estão associadas a um importante evento de transcorrência sin-deposicional. O sistema de transcorrência diacrónica é evidenciado em estruturas *riedel* e outras subordinadas que se desenvolveram progressivamente de norte para sul no seguimento da convergência das placas Farallon e Caribe. As estruturas antigas que afectaram o substrato foram invertidas a partir do Eocénico. As inversões tectónicas foram interpretadas a partir das diferentes relações geométricas dos estratos. A discordância regional eocénica, identificada a partir de superfícies erosivas, revela o período da inversão tectónica associada ao fecho da Bacia Colombiana no limite norte. A discordância erosiva do Eocénico passa a conformidade à medida que tende para o interior da bacia e deve ser uma importante superfície estratigráfica de correlação no *offshore* do Caribe.

Palavras-chave: *offshore*, Caribe Colombiano, placa Farallon, placa de Cocos, transcorrência, inversão tectônica, sin-deposicional, Bacia Colombiana.

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1. Introduction

The Caribbean plate is the centre of a heated debate that discusses about its origin; paleomagnetic data supports the allochthonous hypothesis proposed and defended by PINDELL and BARRETT, 1990; PINDELL and KENNAN, 2001; PINDELL et al., 2002; KERR, 2005; PINDELL and KENNAN, 2009. This hypothesis proposes that the Caribbean plate was formed in the Pacific Sea during Mesozoic. Then it was moving toward the northeast until present days. Other authors like as STAINFORTH, 1969 and JAMES, 2002, 2006, 2009; propose that the Caribbean plate was formed in-situ, due to a large extent between the North American and South American plates during the Early Triassic-Jurassic. This last event generated a severe extension of continental crust and serpentinization of mantle (SKVOR, 1969 and James, 2009). There are many studies about the geological evolution of NW corner of South America and its relationship with the Caribbean plate. The oblique convergence between South America Caribbean plates have been generating a variety of structural styles as normal faulting, compressive zones, contractional fault-related folds, fold belts, wrench systems and intense mud diapirism. A regional erosive event occurred during Eocene in the most of Colombian onshore basins. This event is clearly evident as a regional unconformity marked by erosive truncations in subsurface data. This observation has been interpreted as part of the Andean orogeny. The process of uplifting of Andean orogeny in NW of South America has been interpreted as a tectonic inversion of older Cretaceous marine basins. Although numerous studies of the tectonic framework of the Caribbean plate has been published, there a few studies about the structural style within the plate, particularly in the western zone of the Colombian basin. By structural and stratigraphic evidence found in a regional seismic line, we identified a diachronism of syndepositional wrenching in the western area of the Colombian basin during the Cenozoic. We identified two tectonic inversions in seismic data, which should be related to the convergence between the Caribbean and Cocos plates (and the old Farallon plate). According to growth strata, the first tectonic inversion was an important regional event occurred during Eocene. The occurrence of growth strata, erosive truncations, inversion faults and strata geometries reveals a second inversion during Oligocene-Pleistocene.

2. Localization

The study area corresponds to the western portion of the Colombian basin, Caribbean Sea (Figure 1). It is located in the south of Nicaragua Rise, to east of Arc of Panama and to west of the Mono Rise, in deep waters of the Caribbean Sea. The sea water can reach depths around 3000 to 4000m. The nearest places above the sea level are the San Andres and Providence islands, which are part of Colombian territory.

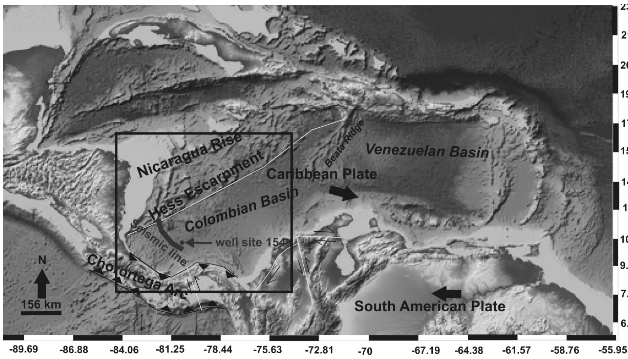

Fig.1. The study area corresponds to the boundary between the Colombian basin and the Nicaragua Rise (Modified from General World Bathymetric Chart of the Oceans, 2004). Arrows indicate plate motions. It is located in the west portion of the Colombian basin in the Caribbean Sea. The map shows diverse major tectonic features in the Caribbean plate.

Fig.1. A área de estudo corresponde ao limite entre a Bacia Colombiana e o Nicaragua Rise (Modificado de General World Bathymetric Chart of the Oceans, 2004). As setas indicam o sentido do movimento das placas. A área de estudo está localizada na zona oeste da Bacia Colombiana no mar do Caribe. O mapa mostra diferentes características tectônicas da placa Caribe.

3. Geological Setting

The structural and stratigraphic evolution of Caribbean plate has been controlled by the interaction between Cocos, Nazca, South American and North American plates, the Micro-plate of Panama and Andean Orogeny (KOLLA et al., 1984; MATTSON, 1984; MASCLE et al., 1985; VITALI et al., 1985; BOWLAND, 1993; GIUNTA et al., 2001; PINDELL and KENNAN, 2001; PINCE et al., 2002, FLINCH, 2003; PINDELL et al., 2005; LUZIEAUX et al., 2006). The tectonic evolution of southwest margin of Caribbean plate has been related to a rift-passive margin during Triassic-Paleogene, a Neogene compressive stage and recent transcurrent system. However, the east and west zones have been mainly dominated by a Cretaceous-Cenozoic compressive regime evidenced by the volcanic arc system of Panama, Cuba and Antilles. Towards the interior of the basin it has been developed a Jurassic-Cretaceous passive environment with generation of some rifting zones (JAMES, 2009). Plate reconstructions based in paleomagnetic data made by PINDELL and KENNAN, 2001, allow propose that during the Middle Miocene, the Caribbean plate changed in the azimuth orientation due to its interaction with the North American plate (Figure 2). This would be resulted in radical changes of its structural style mainly toward plate boundaries zones, evidenced by the occurrence of intense transcurrent tectonism in the Hess Escarpment area and the west and south Caribbean margin.

An oblique convergence between the Caribbean and South American plates during Cenozoic generated a variety of structural styles as normal faulting, compressive zones, contractional fault-related folds, fold belts and wrench systems (Figure 3). The origin of the Caribbean plate has been controversial and there are proposed two main hypotheses. The first hypotheses proposes that the Caribbean plate was formed in a hot spot in the Pacific Sea during Lower Cretaceous, and later was moving to the northeast until its current position (Figure 4a) (PINDELL and BARRET, 1990; PINDELL and KENNAN, 2001; PINDELL, et al., 2002; KERR, 2005; PINDELL and KENNAN, 2009). The second hypotheses proposes that the origin of the Caribbean plate has been autochthonous or in-situ, as the product of an intensive expansion and separation of South American and North American plates during Lower Triassic to Jurassic (Figure 4b) (STAINFORTH, 1969; JAMES, 2002, 2006, 2009). This last event generated a severe extension of continental crust and serpentinization of mantle (SKVOR, 1969 and James, 2009). The Miocene to Pleistocene deposits in the western of the Colombian basin, corresponds mainly with volcanic clays, calcareous clay, sandy siltstone and siltstone, as is illustrated in the stratigraphic column from the well DSDP site 154 (Figure 5). Older rocks corresponds with distal volcanogenic, carbonate turbidites, chalk, chert and siliceous clay of Paleogene to Miocene. Also are present basalts with interbedded sedimentary layers of Upper Cretaceous. Five seismic sequences (CB1, CB2, CB3, CB4 and CB5) and an acoustic basement were interpreted by BOWLAND, 1993, who presents a preliminary stratigraphy of Colombian basin (Figure 6).

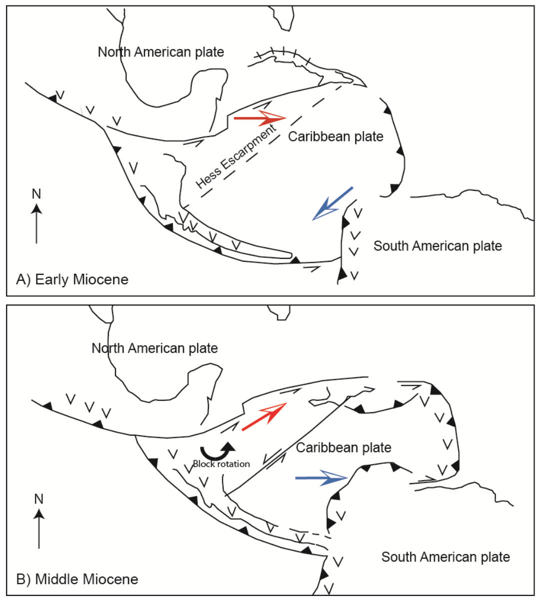

Fig.2. Changes in tectonic development in the north and south Caribbean plate boundary zones according to PINDELL and KENNAN, 2001. Red arrows indicate Caribbean - North American azimuth and blue arrows indicate Caribbean – South American azimuth. A) Plate motions during Early Miocene. B) Change in plate motions and strike-slip faulting related to counterclockwise rotation (circular arrow) of northern Central America relative to the Caribbean plate during Middle Miocene.

Fig.2. Mudanças dos movimentos tectônicos nos limites norte e sul da placa Caribe segundo PINDELL and KENNAN, 2001. As setas vermelhas indicam o azimute do movimento relativo das placas Caribe e América do Norte. As setas azuis indicam o azimute do movimento relativo das placas Caribe e América do Sul. A) Movimentos das placas durante o Mioceno Inferior. B) Mudanças no movimento das placas e falhamento de transcorrência associado à rotação anti-horária (seta circular) do norte da América Central relativo à placa Caribe durante o Mioceno Médio.

The more studied area in Colombian basin is the South Caribbean Deformed Belt which comprises a large tectonic province in the margin NW of South America in Colombian Caribbean Sea. The area is tectonically controlled by the interaction between Caribbean plate, South American plate and the Panamá Arch (KOLLA et al., 1984; MATTSON, 1984; MASCLE et al., 1985; VITALI et al., 1985; BOWLAND, 1993; GIUNTA et al., 2001; PINDELL and KENNAN, 2001; PINCE et al., 2002, FLINCH, 2003; PINDELL et al., 2005). The tectonic evolution of this zone is related to the regional Lower Triassic-Jurassic rifting-passive margin and to a Cenozoic inversion (ROSSELLO, 2007). The tectonic inversion formed major fold belts, thrust faulting, tight anticlines, wide synclines and intense mud diapirism in the southeast zone of Colombia, while the extension and transtension structures occurred mainly at northeastern zone of South America (MANTILLA-PIMIENTO et al., 2005; LINCH et al., 2003; ROSSELLO, 2007). Transpression also is present forming fold belts and relay structures which have been occurring until nowadays (ROSSELLO, 2007). South Colombian Caribbean basin is controlled by intense mud diapirism and major strike-slip structures dipping at SE (BERMUDEZ, et al., 2009). The sedimentary infill has been provided by major fluvial systems of Colombia as Magdalena and Sinú rivers. Sedimentation has been confined to wide synclines as piggy-back mini-basins (CORREDOR, et al., 2003; FLINCH, 2003). In the most of sedimentary basins of Colombian onshore, an important erosive event took place during Eocene. Geological evidence from Colombian onshore reveals an inversion of older marine Cretaceous basins and uplifting of cordilleras as part of Andean orogeny (COOPER et al., 1995; SARMIENTO et al., 2006). Consequently an Eocene erosive unconformity is present as a correlative stratigraphic surface in most of Colombian sedimentary basins.

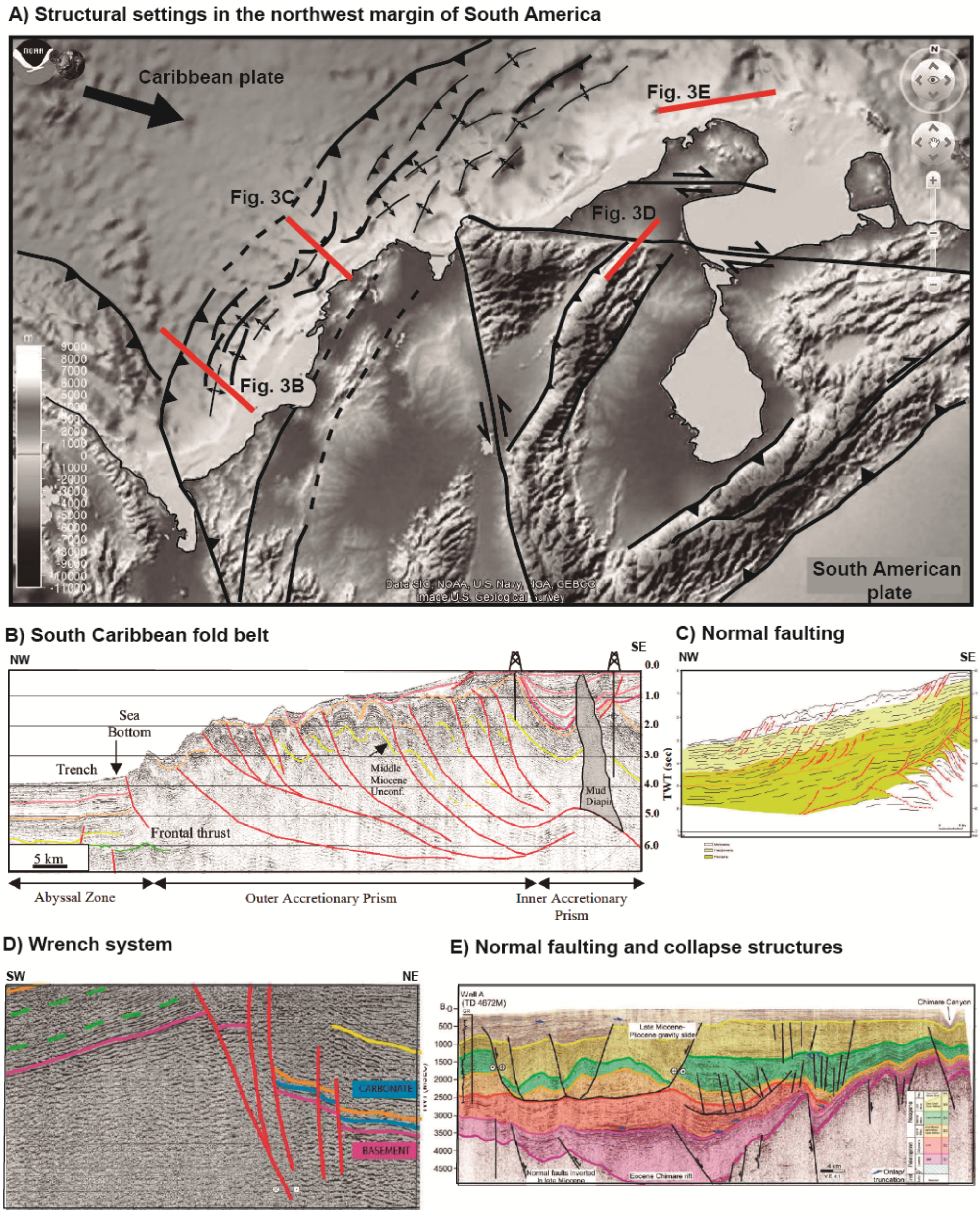

Fig.3. Diverse structural styles in the NW corner of South America which has been controlled by the oblique convergence between Caribbean and South American plates. A) Main structures in the NW corner of South America (combined bathymetry and topography from AMANTE and EAKINS, 2009). B) Reverse faulting, mud diapirism and contractional fault-related folds (image from MANTILLA-PIMIENTO et al., 2005). C) Normal faulting (image from FLINCH et al., 2003). D) Wrench system (image from FLINCH et al., 2003. E) Collapse structures (image from Agencia Nacional de Hidrocarburos, ANH, 2012).

Fig.3. Diferentes estilos estruturais na borda NW da América do Sul associados à convergência das placas Caribe e da América do Sul. A) Estruturas principais na borda NW da América do Sul (batimetria e topografia de AMANTE and EAKINS, 2009). B) Falhas reversas, diapirismo de folhelho e dobras associadas a falhas de contração (Fonte: MANTILLA-PIMIENTO et al., 2005). C) Falhamento normal (Fonte: FLINCH et al., 2003). D) Sistema de transcorrência (Fonte: FLINCH et al., 2003. E) Estruturas de colapso (Fonte: Agencia Nacional de Hidrocarburos, ANH, 2012).

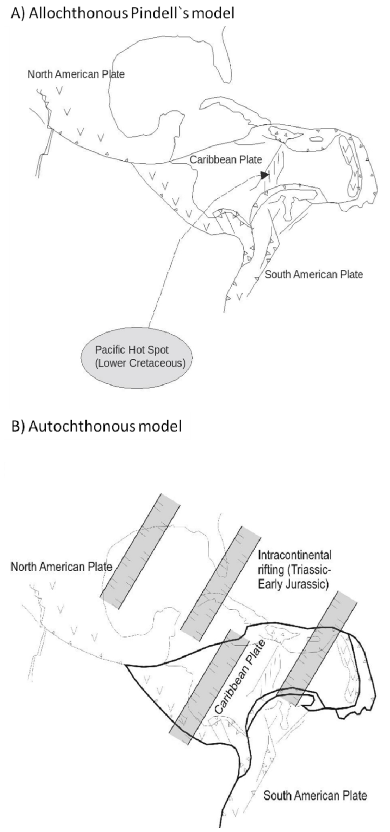

Fig.4. Two different models to explain the origin and evolution of the Caribbean plate. A) Allochthonous model of the origin and evolution of the Caribbean plate proposed for PINDELL & KENNAN, 2009. B) Autochthonous model of the origin and evolution of the Caribbean Plate proposed by STAINFORTH, 1969 and JAMES, 2009.

Fig.4. Dois modelos diferentes para explicar a origem e evolução da placa Caribe. A) Modelo alóctone da origem e evolução da placa Caribe segundo PINDELL & KENNAN, 2009. B) Modelo autóctone da origem e evolução da placa Caribe segundo STAINFORTH, 1969 e JAMES, 2009.

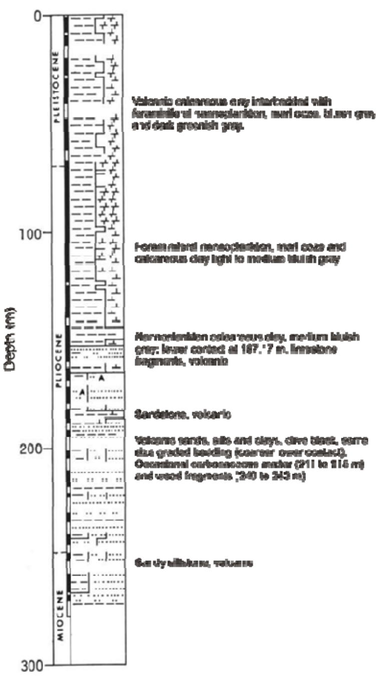

Fig.5. Stratigraphic column from well DSDP (Deep Sea Drilling Program) site 154. It is observed the predominance of volcanic and fine sediments of Miocene-Pleistocene. Note the well location in the figure 1.

Fig.5. Coluna estratigráfica a partir dos dados do poço DSDP (Deep Sea Drilling Program) site 154. É possível observar o predomínio de sedimentos finos e vulcânicos do Mioceno-Pleistoceno. Localização do poço na figura 1.

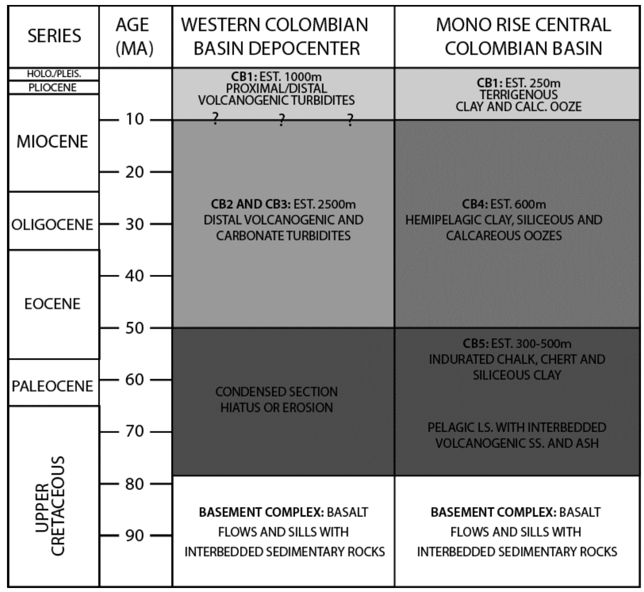

Fig.6. Chart chronostratigraphic of Colombian basin proposed by BOWLAND, 1993. Five seismic sequences (CB1, CB2, CB3, CB4 and CB5) and the acoustic basement were interpreted by Bowland, 1993 in the Colombian Caribbean.

Fig.6. Carta cronoestratigráfica da Bacia Colombiana segundo BOWLAND, 1993. Cinco sequências sismicas (CB1, CB2, CB3, CB4 e CB5) e o embasamento acústico foram interpretados por Bowland, 1993 no Caribe Colombiano.

4. Data and Methodology

In this study we used seismic, gravity and well data. We used a seismic line acquired in 1977 by the Geophysical Laboratory of the Marine Geoscience Institute at the University of Texas and extracted from the open source database of the Geophysics Jackson School of Geosciences of the University of Texas. The seismic data were obtained with a basic processing. It was applied a normal move-out correction with a constant velocity field, a band-pass filter (12 to 45Hz) and an automatic gain control with a window of 500ms. We interpret the seismic-stratigraphic features proposed in the seismic facies maps of the Eocene seismic sequence CB3 and the acoustic basement from BOWLAND, 1993. Well data from DSDP (Deep Sea Drilling Project Technical Reports site 154) site 154 was linked to the structural and stratigraphic seismic interpretation. In this form, we identified diverse diachronic and syndepositional structures in the west of the Colombian basin. From biostratigraphic and lithostratigraphic data we interpreted seismic units of Oligocene-Miocene and Pliocene-Pleistocene. We calibrated the seismic interpretation with gravity data from the *Instituto Tecnico Industriale – Liceo Scientifico Tecnologico E. Molinare*, 2010

4.1. Observations

We interpreted a NW-SE seismic line crossing the Hess Escarpment until the west zone of the Colombian basin (Figure 7). We identified four seismic horizons. The tops of the Late Pliocene and the Late Miocene were extracted from well DSDP site 154.The Late Miocene is clearly evident as a reflector of high amplitude and high continuity. In some areas this horizon is concordant but in others is defined by onlap terminations and erosive truncations toward the highest zones of the anticlines. The Eocene corresponds to a horizon of high amplitude and good continuity. This horizon is clearly defined by some erosional truncations toward the south of Hess Escarpment. The acoustic basement corresponds to a reflector of moderate amplitude and is marked by onlap terminations endings to the north of the basin. Because the well has not enough information; was performed a tie with maps of seismic facies of the Eocene and the acoustic basement made by BOWLAND in 1993 (Figure 8). Through the overlap of the seismic line of this study with the maps of BOWLAND, 1993, we completed the interpretation of the Eocene and acoustic basement along the seismic line.

We tie the seismic interpretation with gravity data (Figure 9) because the high grade of uncertainty in the position of the acoustic basement in the seismic line. It was noted that a gravity anomaly in the study area corresponds to an uplifted area related to a flower structure in the west of the Colombia basin, which is corresponds to an important basement-involved structure.

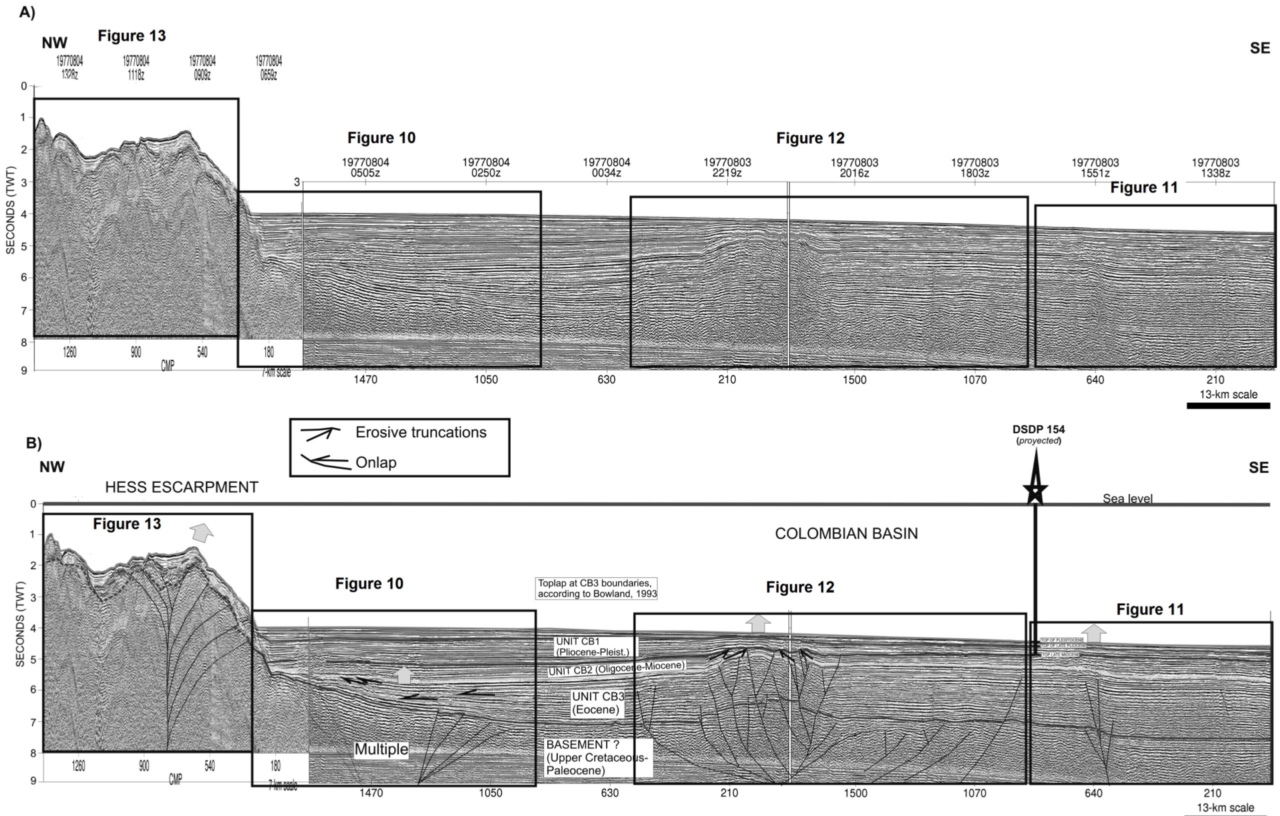

Fig.7. Seismic line used in the present study. A) Seismic line uninterpreted with areas of interest for this paper. B) Structural and stratigraphic interpretation. The location of this seismic line is shown in the figure 1.

Fig.7. Linha sísmica utilizada nesse estudo. A) Linha sísmica sem interpretação com as áreas de interesse para este artigo. B) Interpretação estrutural e estratigráfica. A localização dessa linha sismica é apresentada na figura 1.

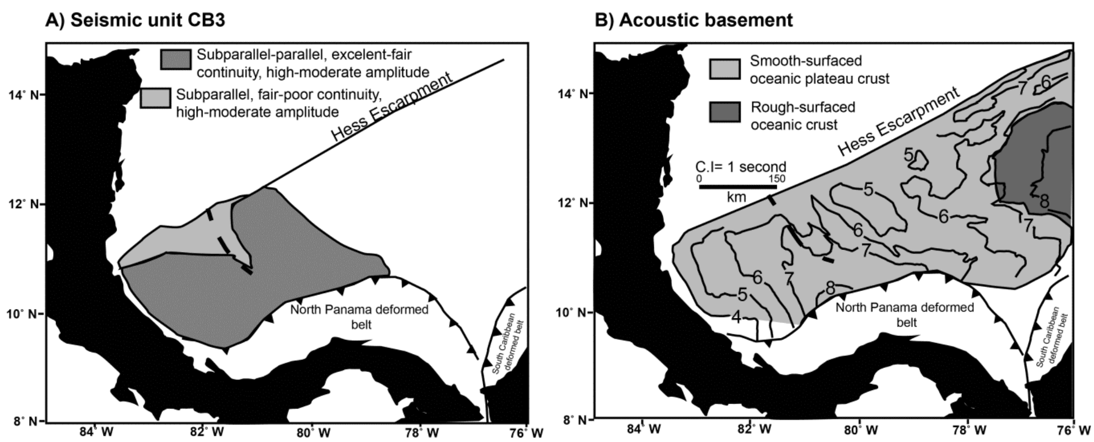

Fig.8. A) Map of seismic facies of the Eocene sequence in the Colombian basin from BOWLAND, 1993. B) Acoustic basement in the Colombian basin from BOWLAND, 1993. We can see in bold dashed black color the overlapping of seismic line used in this study.

Fig.8. A) Mapa de fácies sísmicas da sequência do Eoceno na Bacia Colombiana segundo BOWLAND, 1993. B) Embasamento acústico na Bacia Colombiana segundo BOWLAND, 1993. Pode-se observar a localização da linha sísmica desse estudo traçada em linhas tracejadas em preto.

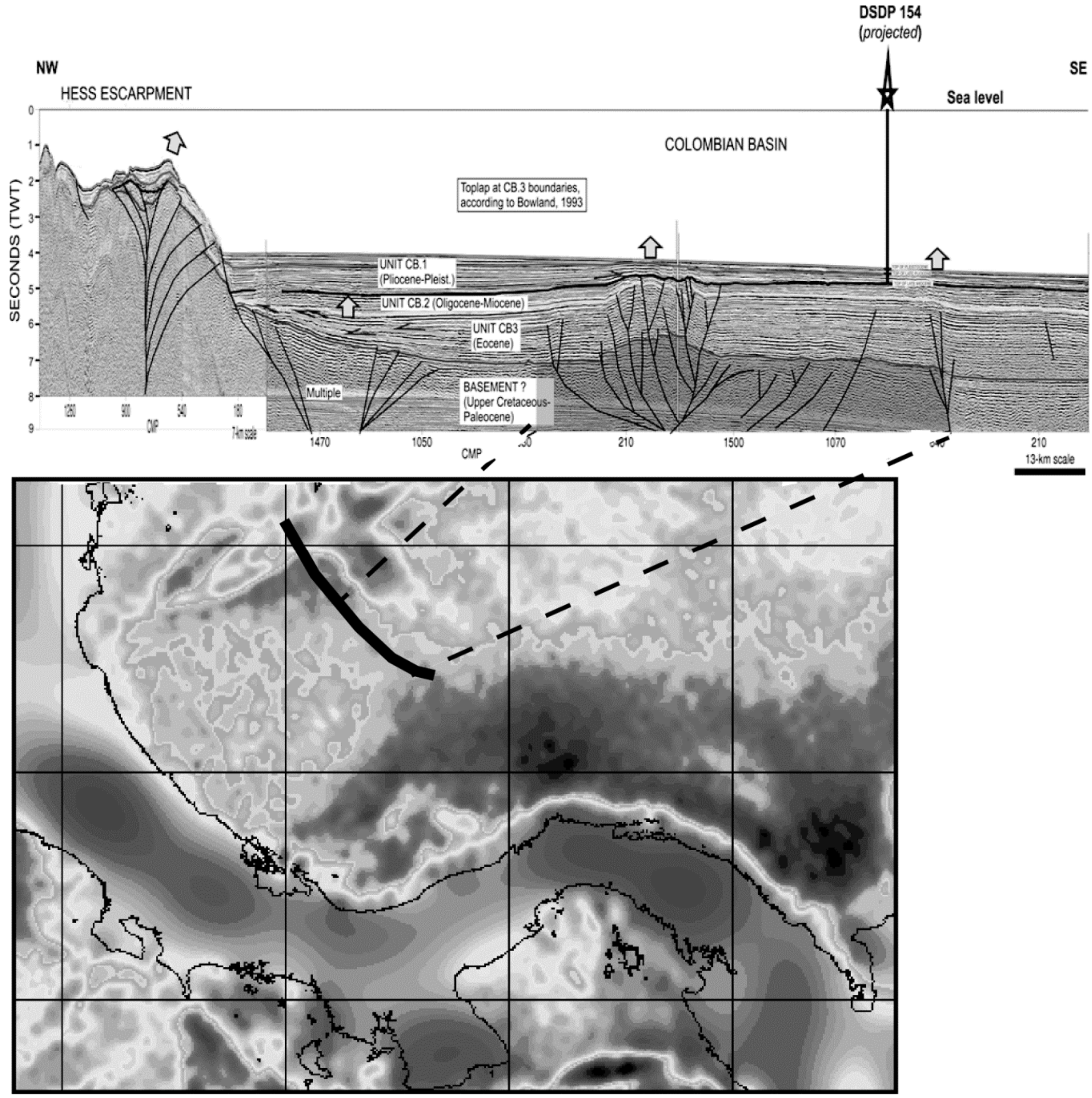

Fig.9. Gravimetric map of Caribbean region (modified from the Instituto Tecnico Industriale – Liceo Scientifico Tecnologico E. Molinare, 2010). We can see a gravity anomaly in the south of the Colombian basin which confirms the seismic interpretation of a basement high related to a flower structure.

Fig.9. Mapa gravimétrico da região Caribe (modificado do Instituto Tecnico Industriale – Liceo Scientifico Tecnologico E. Molinare, 2010). Pode-se observar uma anomalia de gravidade na zona sul da Bacia Colombiana reforçando a interpretação do alto do embasamento associado à estrutura em flor.

4.2. Interpretations

Through the detailed interpretation of the seismic line, tied to gravity and well data; we can identify the morphology, orientation, temporality and nature of the Cenozoic structures in the western of the Colombian basin. From these observations, we propose some hypothesis about the origin and tectonic styles that have prevailed in the Colombian basin. We interpret a contractional flower faulting with movement during Eocene (Figure 10). This is evident by the thinning of Eocene beds toward the anticlinal crests which correspond with growth strata. Therefore, this uplifting was caused by a contractional faulting simultaneously with deposition of unit CB3 during Eocene. According to this, the contractional structure has a vergence SE and NW. Erosive truncations in figure 10 confirm an Eocene uplifting which should be related to a tectonic inversion and closure of Colombian basin. This erosional unconformity becomes conformable toward the basin and should be an important regional correlative stratigraphic surface in order to realize any tectonic-stratigraphic modelling in Caribbean offshore. Also, it was identified a recent normal faulting at south of Hess Escarpment following a pre-existing plane fault.

We identified an extensional structure of high angle with vergence to northwest which was active between Eocene-Oligocene and was inverted since Oligocene to Pleistocene (Figure 11). The extensional component is evident in this type of structure because it tends to be vertical toward surface, taking a form of cactus. According to the degree of specularity, we can assume that the main structures are symmetrical. Growth strata of CB2 and CB1 units correspond with the main evidence of a tectonic inversion during the

Oligocene-Pleistocene along a contractional area (Figure 11). The compressive component is clearly interpreted for the development of anticlines with better growth towards the central-upper areas. Additionally is noted the deposition of growth strata in the CB2 unit with a progressive slight thinning to northwest, in the same direction of the compressive vergence (Figure 11). This evidence reveals that the development of the tectonic inversion was simultaneous with the deposition of the CB2 and CB1 units during the Oligocene-Pleistocene.

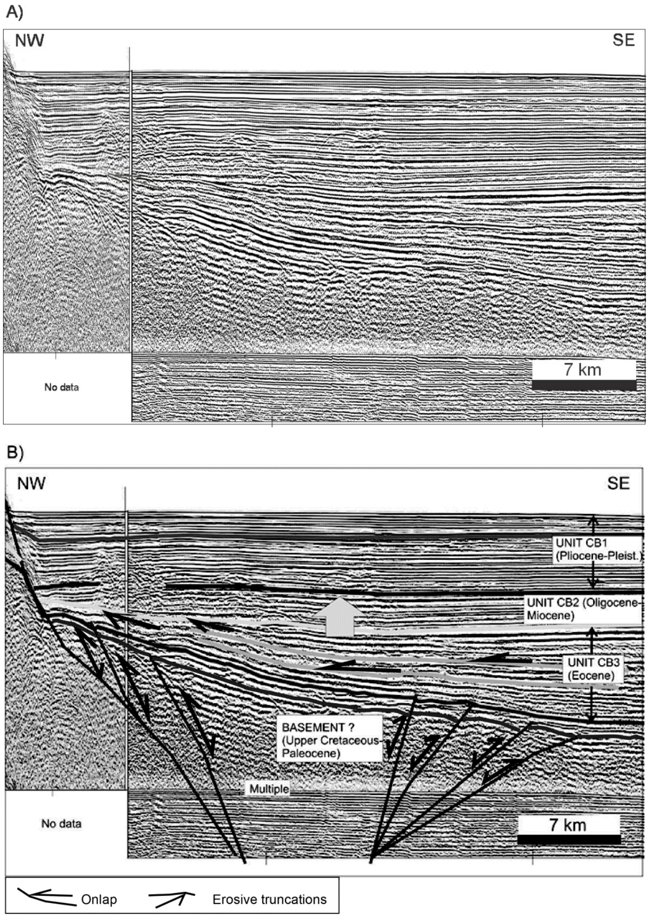

Fig.10. A) Portion of seismic line uninterpreted illustrated in the figure 7. B) Tectonic inversion along a contractional structure active during Eocene. This structure is related to a positive flower structure with an associated uplifting event evidenced by growth strata and erosive truncations.

Fig.10. A) Segmento da linha sísmica sem interpretação da figura 7. B) Inversão tectônica através de uma estrutura de contração ativa durante o Eoceno. Essa estrutura é associada à uma estrutura em flor positiva que gerou um evento de soerguimento. Esse evento é evidente pela presença de estratos de crescimento e truncamentos erosivos.

We identified another large negative flower structure that was active between Eocene-Oligocene and which was inverted during Oligocene-Pleistocene (Figure 12). The verticalization of faults toward surface, analogous to the shape of cactus or tulip; the occurrence of blocks with normal component and an apparently constant thickness of the CB3 unit, indicate that there was an important extensional faulting between Eocene-Oligocene. During Oligocene-Pleistocene occurs a tectonic inversion evidenced by some reverse faults and growth strata. These structures have a trend to flattening toward surface like a palm forming steep anticlines in southeast area. Additional evidence is the thinning of the CB2 and CB1 units toward the crest of the anticlines, which have been generated by the compressive component along of these syndepositional contractional structures. This inversion generated uplifting in the basement, which also is evident in the gravity anomaly in the figure 9.

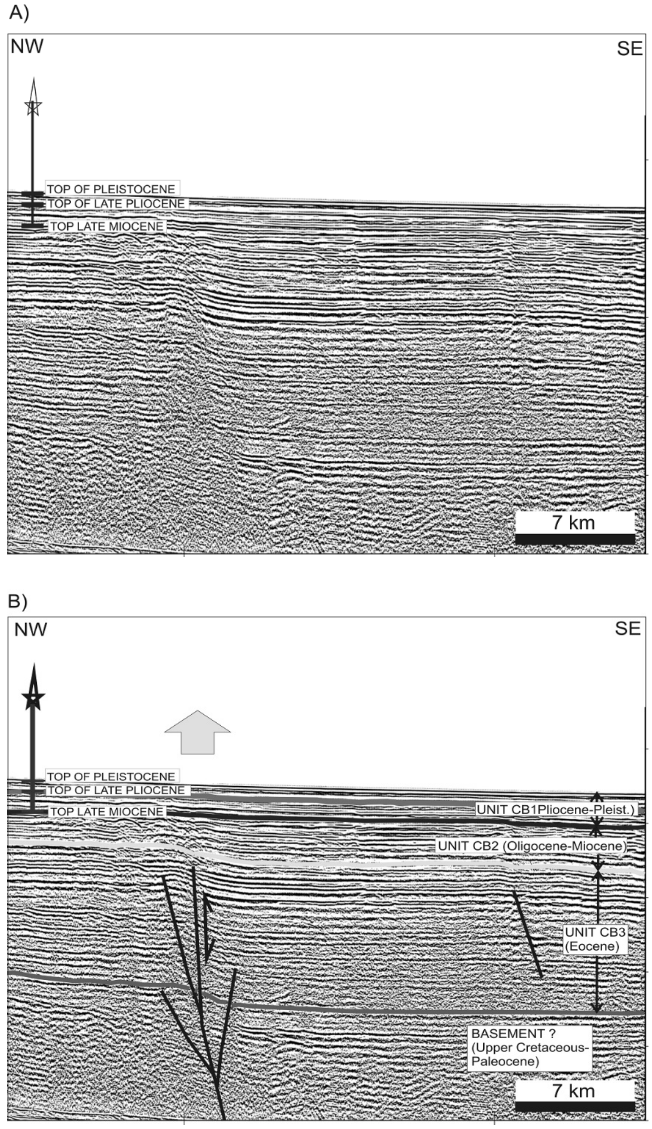

Fig.11. A) Portion of seismic line uninterpreted illustrated in the figure 7. B) Contractional faulting during Oligocene-Pleistocene is evident by growth strata in CB2 and CB1 units forming anticlines. It could be related to a tectonic inversion of older normal faults.

Fig.11. A) Segmento da linha sísmica sem interpretação da figura 7. B) Estratos de crescimento nos anticlinais das unidades CB2 e CB1 são evidências de um evento de falhamento de contração durante o Oligoceno-Pleistoceno. Esse evento é associado a uma inversão tectônica de antigas falhas normais.

An important structure has been active along of southwestern zone of the Nicaragua Rise evident like as a wide bathymetric regional lineament and as a positive flower structure in subsurface (Figure 13). According to its morphology, this structure is asymmetrical. We observed a high development of reverse faults with an evident horizontalization toward surface. This morphology could be related to the rheology of the rocks and/or the direction of stress (Figures 14 and 15).

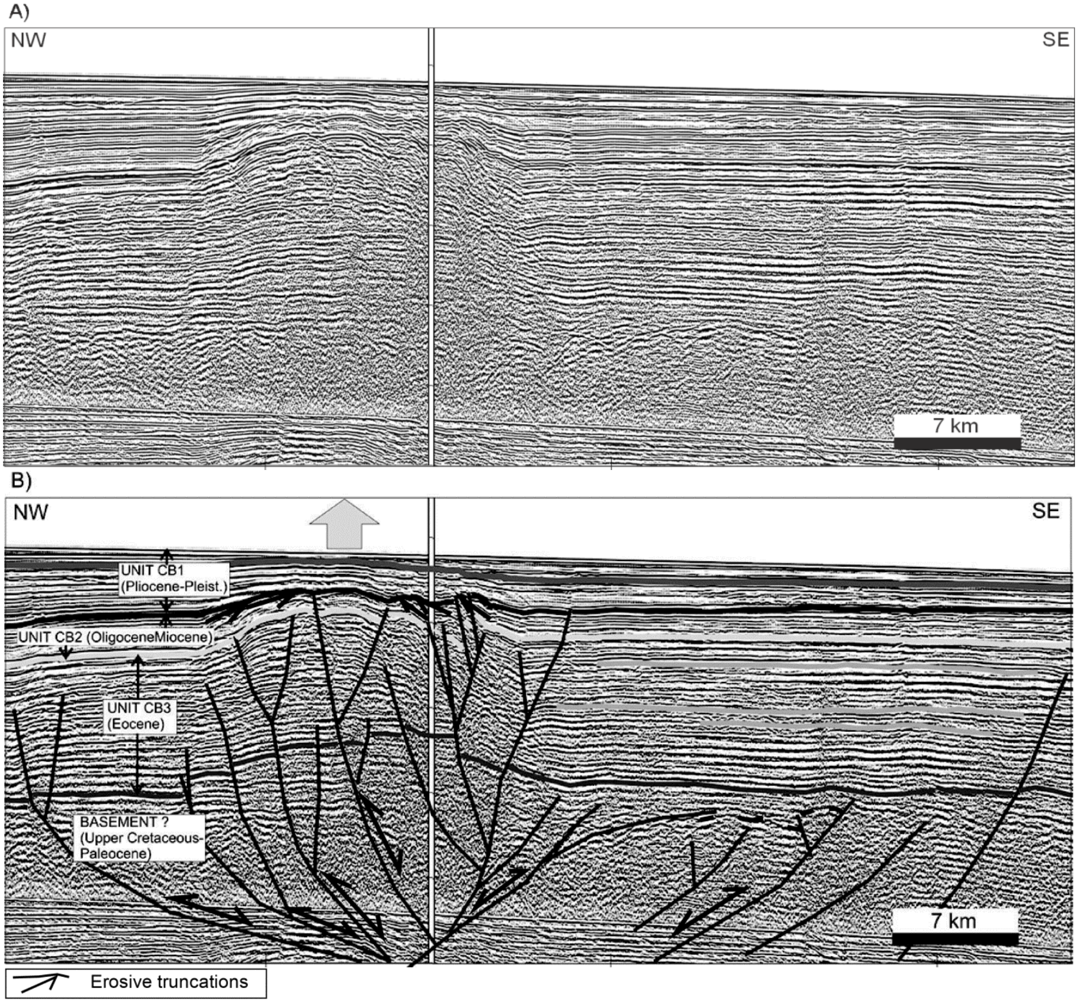

Fig.12. A) Portion of seismic line uninterpreted illustrated in the figure 7. B) Oligocene-Pleistocene contractional faulting forming anticlines because a possible inversion of older basement-involved normal faults. This is confirmed by gravimetric data (Figure 9).

Fig.12. A) Segmento da linha sísmica sem interpretação da figura 7. B) Anticlinais gerados pelo falhamento de contração do Oligoceno-Pleistoceno associado a uma inversão tectônica de antigas falhas normais que afetavam o embasamento. Essas estruturas são confirmadas por dados gravimétricos (Figura 9).

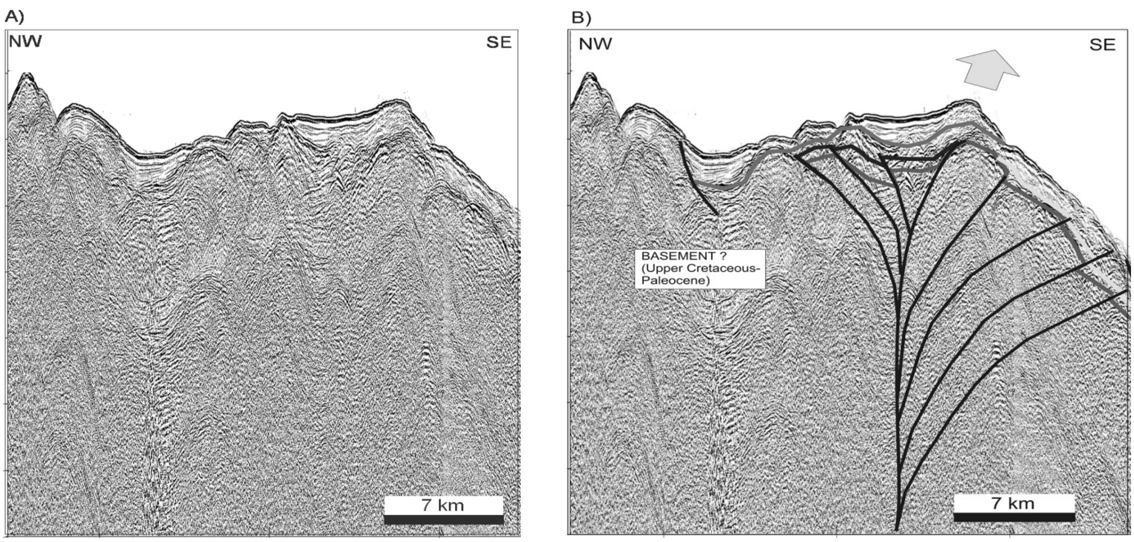

Fig.13. A) Portion of seismic line uninterpreted illustrated in the figure 7. B) Positive flower structure forming the Hess Escarpment.

Fig.13. A) Segmento da linha sísmica sem interpretação da figura 7. B) Estrutura em flor positiva formando a Escarpa de Hess.

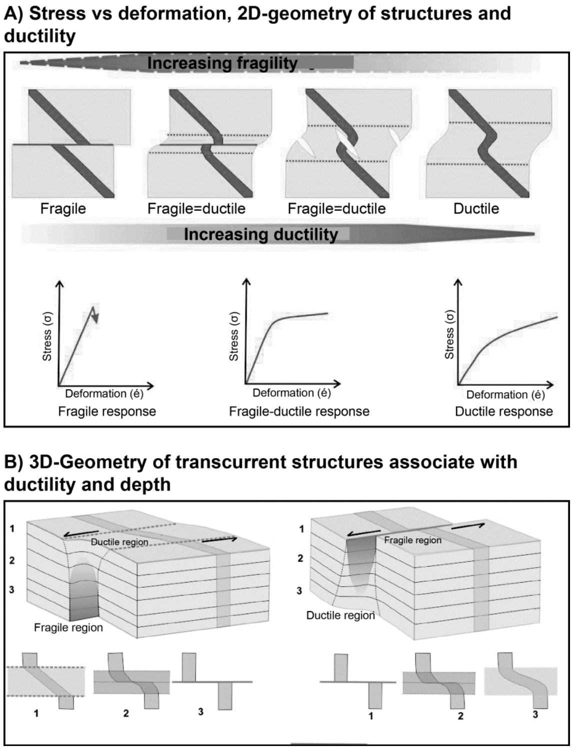

Fig.14. Structural morphology associate with rheology. A) Stress-deformation relation and 2D-geometry of transcurrent structures according to ductility. B) 3D-Geometry of transcurrent structures and associated ductility and depth.

Fig.14. Morfologia estrutural associada à reologia. A) Relação esforço-deformação e geometria 2D das estruturas transcorrentes segundo a ductibilidade. B) Associação entre a geometria 3D das estruturas transcorrentes, ductibilidade e profundidade.

5. Discussion

Due to submarine nature of Hess Escarpment, there is no direct evidence of cinematic data. However, the recognition of flower morphology associate with main structures in seismic data suggests a transcurrent origin for these structures. In agreement with this and according to the incidence angle of convergence between Cocos plate and Nicaragua Rise (Figure 16), we interpreted a sinistral component for this structure. Regarding the distribution and origin, this faulting has a clear bathymetric expression as a great structural lineament in northeast to southwest direction, related to a strike-slip fault system of a Riedel system. According to SILVER et al., 1998 in MESCHEDE and BARCKHAUSEN, 2000, during the Late Oligocene, the Farallon plate split into the Cocos and Nazca plates as a result of global rearrangement of plate boundaries. We interpret diverse diachronic structures related to the oblique convergence of the Cocos plate (with a motion rate of 9cm/year) with the Caribbean plate since approximately 23 Ma to present (Figure 16). The Eocene tectonic inversion should be related to an oblique convergence of Farallon and Caribbean plates.

5. Conclusions

We identified diverse tectono-stratigraphic events in the west zone of the Colombian basin occurred since Eocene to Pleistocene (Figure 17). Relations between syndepositional Riedel structures and subordinated structures demonstrate the occurrence of diachronic syndepositional Cenozoic wrenching in west area of offshore Caribbean Colombian basin. Wrench system correspond with diachronic extensional and contractional structures. A major tectonic inversion of Eocene and another of Oligocene to Pleistocene along of contractional structures were identified. Structures have been growing progressively from north to south and should be related to the interaction between the Farallon (after Cocos plate) and Caribbean plates. The tectonic inversions are clearly evident by growth strata, relations of strata, geometries of strata and erosional truncations. The Eocene unconformity has been well documented in the most of onshore sedimentary basins of Colombia and has been related to the uplift of mountains as part of Andean orogeny. In offshore Caribbean Colombian basin, Eocene inversion corresponds with closure of the basin and should be related to an oblique convergence of the Farallon and Caribbean plates. This erosional unconformity becomes conformable toward the basin and should be an important regional stratigraphic surface in order to realize a tectonic-stratigraphic modelling of Colombian Caribbean.

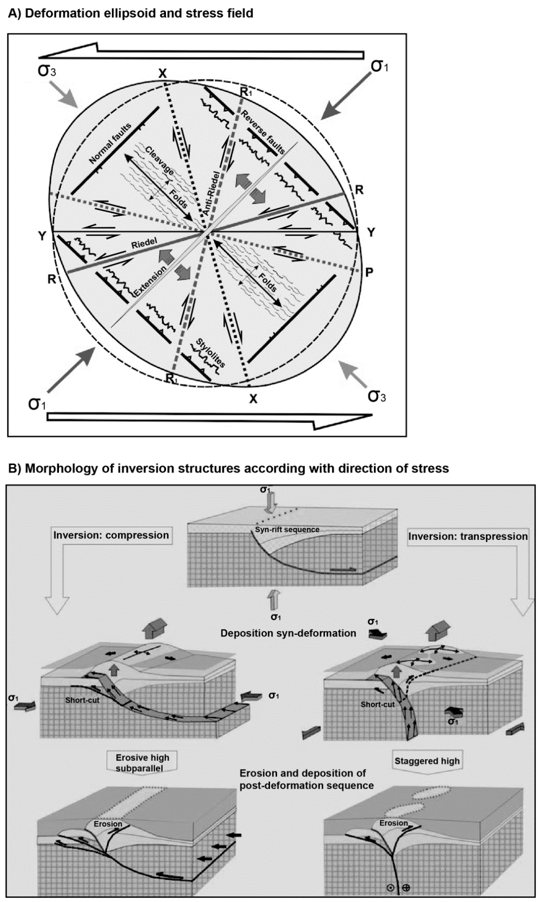

Fig.15. Structural morphology associate with direction of stress. A) Riedel system and subordinate structures associated with a stress field. B) 3-D Morphology of tectonic inversion associate with direction of stress.

Fig.15. Morfologia estrutural associada à direção dos esforços. A) Sistema de Riedel e estruturas subordinadas associadas com o campo de esforços. B) Morfologia 3D da estrutura de inversão tectônica associada à direção de esforço.

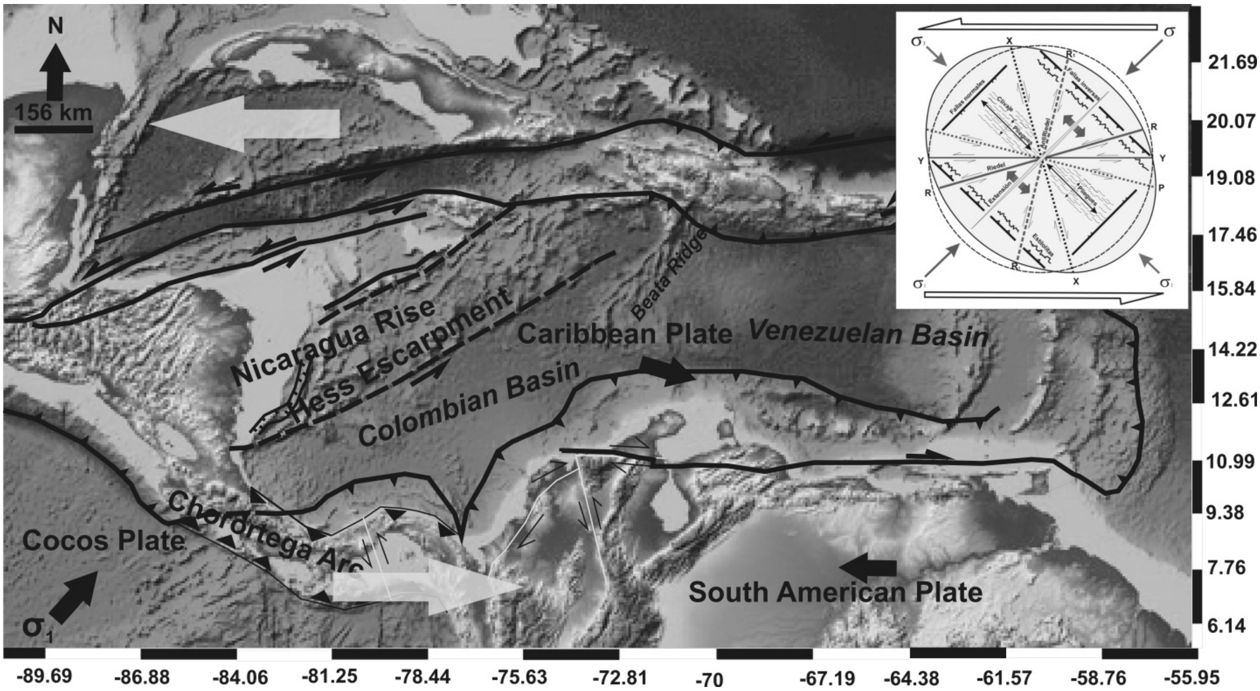

Fig.16. Interpretation of major structures in the Caribbean plate (Modified from General World Bathymetric Chart of the Oceans, 2004). The submarine nature of Hess Escarpment does not provide direct evidence to cinematic data. However, due to recognition of flower morphology of main structures in seismic data, it should be associated to a transcurrent tectonic. A sinistral component is interpreted, according to the incidence angle of convergence between Cocos plate and Nicaragua Rise.

Fig.16. Interpretação das estruturas principais da placa Caribe (Modificado do General World Bathymetric Chart of the Oceans, 2004). A natureza submarinha da Escarpa de Hess não permite uma evidência direta dos dados cinemáticos. Embora, esta estrutura pode ser associada a uma tectônica transcorrente devido ao reconhecimento das principais estruturas com uma morfologia em flor no dado sísmico. Segundo o ângulo de convergência entre a placa de Cocos e o Nicaragua Rise é possível interpretar uma componente sinistral para esta estrutura.

AGE	STRATIGRAPHY	TECTONIC EVENT
Pliocene/Pleistocene	NW **CB1 Sequence** SE Proximal/distal volcanogenic turbidites	Inversion
Oligocene/Miocene	**CB2 Sequence** Distal volcanogenic and carbonate turbidites	– Extension –
Eocene	Erosion **CB3 Sequence** Distal volcanogenic and carbonate turbidites	Inversion
pre- Eocene	Volcanic, basalts flows, and sills with interbedded sedimentary rocks	Extension

Fig.17. Generalized chart of stratigraphic and tectonic events in western of Colombian basin founded in the present study.

Fig.17. Quadro generalizado dos eventos estratigráficos e tectônicos na zona oeste da Bacia Colombiana encontrados nesse estudo.

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