Journal of South American Earth Sciences 56 (2014) 139–169

Contents lists available at ScienceDirect

Journal of South American Earth Sciences

journal homepage: www.elsevier.com/locate/jsames

Review of the chronostratigraphic charts in the Sinú-San Jacinto basin based on new seismic stratigraphic interpretations

Esteban Alfaro [a,*], Michael Holz [b]

[a] Instituto de Geociências, Programa de Pós-graduação em Geofísica, Universidade Federal da Bahia, Salvador, Bahia, Brazil
[b] Instituto de Geociências, GETA-UFBA/CPGG – Universidade Federal da Bahia, Salvador, Bahia, Brazil

A R T I C L E I N F O

Article history:
Received 20 March 2014
Accepted 2 September 2014
Available online 16 September 2014

Keywords:
Caribbean
Syn-rift sequence
Seismic stratigraphy
Sinú-San Jacinto
Chronostratigraphy
Passive margin

A B S T R A C T

Disperse and punctual studies; absence of integration of data ranging from local to regional focus; interpretations based only on lithostratigraphic features; and interpretation of data premised on an allochthonous origin of the Caribbean plate, are some of factors that increase the confusion and uncertainty in understanding the Sinú-San Jacinto Basin. The sedimentary record of Upper Cretaceous to Eocene has been traditionally interpreted as the record of deep-water settings. However, recently these sediments have been related to shallow marine and deltaic settings. Second problematic point is about the deposition environment of the Oligocene to Late Miocene succession. Some studies suggest canyons, turbidites and sediments deposited in deep-water settings. However, recent studies propose deltaic and shallow marine settings. The last stratigraphic problem is related to the controversial fluvial *vs.* shallow marine interpretations of the Pliocene sediments. Based upon seismic stratigraphic analysis in recent and reprocessed 2D seismic data, integrated with well data, we propose chronostratigraphic charts for the northern, central and southern zones of the Sinú-San Jacinto Basin. Twenty seismic facies based on amplitude, continuity, frequency and geometry of seismic reflectors and twelve seismic sequences were recognized. The seismic stratigraphic analysis in this study suggests that the sediments of Upper Cretaceous to Paleocene/Eocene were associated to continental to shallow marine settings. Lagoons, coastal plain and carbonate platform dominated during this period. The Oligocene to Middle Miocene record was characterized by deep-water deposition, whereas the Late Miocene to recent sedimentation was characterized by falling base level, characterized by deltaic and fluvial deposits. Five syn-rift sequences with wedge-shaped geometry were identified in this study. Three Triassic to Jurassic syn-rift sequences were characterized by seismic facies typical of fluvial to lacustrine and flood plain sedimentation. Two Cretaceous to Paleocene syn-rift sequences were characterized by seismic facies related to lagoons to coastal plain settings. Normal high-angle faults with a northeast-southwest direction related to rifting processes controlled the development of these sequences. The sheet-drape post-rift section was characterized by passive margin settings in the northern part of the Sinú-San Jacinto Basin and by diachronic tectonic inversion of older normal faults during Cenozoic, predominantly in the central and southern zones. The stratigraphic record related to the Mesozoic to Early Cenozoic rifting; the shallow marine sedimentation during Eocene and the tectono-stratigraphic continuity across the northern Colombia and northwestern Venezuela is coherent and well explained by the *in situ* origin of the Caribbean plate and is not explained by the "allochthonous" model.

1. Introduction

Diverse chronostratigraphic charts with mismatching interpretations have been proposed for the Sinú-San Jacinto Basin (e.g., Duque-Caro, 1990; Duque-Caro et al., 1996a, b; Guzmán, 2007; Bermúdez et al., 2009). Disperse studies in different geological localities; studies of punctual data (wells, outcrops); absence of integration of data ranging from local to regional focus; interpretations based only on lithostratigraphic features; and interpretation of data premised on the model of an "allochthonous" origin for the Caribbean plate, are some of factors that increase the confusion and uncertainty in interpretation and stratigraphic modelling of the Sinú-San Jacinto Basin.

The first stratigraphic problem in the Sinú-San Jacinto Basin is related to two contradictory interpretations about the depositional

* Corresponding author.
E-mail address: alfaro.ufba@yahoo.com.br (E. Alfaro).

http://dx.doi.org/10.1016/j.jsames.2014.09.004
0895-9811/

environment of the Upper Cretaceous-Eocene succession. Traditionally, the lithological record of Upper Cretaceous-Early Eocene has been associated to deep-water settings (Duque-Caro, 1969, 1990; Duque-Caro et al., 1996a, b; Flinch, 2003; Guzmán, 2007). On the other hand, some studies suggest shallow marine settings for this succession (Aleman, 1983; Bermúdez et al., 2009; García et al., 2009). Part of this succession has been characterized as hydrocarbon source in the Magdalena Valley (La Luna Formation) (e.g., Zumberge, 1984; Ramón and Dzou, 1999). The second contradictory interpretation is about the deposition environment of the Oligocene to Late Miocene succession. Duque-Caro (1990) and Duque-Caro et al. (1996a,b) suggest canyons, turbidites and sediments deposited in water depths of 1000–2000 m. However, recent studies such as Guzmán (2007) and Bermúdez et al. (2009), propose deltaic and shallow marine settings for those deposits. The last stratigraphic problem is related to the interpretation of the Pliocene sediments. Duque-Caro (1990), Duque-Caro et al. (1996a,b) and Bermúdez et al. (2009) have interpreted fluvial sediments during Pliocene, although, Guzmán (2007) suggests a littoral context, such as bars and tidal deposits, for these sediments. All these studies are characterized by the absence of data and methodologies that support the lateral continuity of the facies along the basin and the location and interpretation of depositional systems of the successions in a chronostratigraphic framework and in spite of being merely based on lithostratigraphy. This chronostratigraphic approach can be constrained from seismic data and seismic stratigraphic methodology. In the present study, the interpretation of the Upper Cretaceous-Eocene, Oligocene-Late Miocene and Pliocene successions are constrained from a seismic stratigraphic approach using a set of recent 2D seismic lines integrated with well data. This study provides a better understanding of the chronostratigraphic and tectono-stratigraphic frameworks of the Sinú-San Jacinto Basin. The scope of this paper is: (1) to define seismic sequences of Sinú-San Jacinto Basin; (2) to constrain the deposition environment related to the Mesozoic to recent sequences in the Sinú-San Jacinto Basin from seismic stratigraphic analysis correlated with well data and (3) to propose chronostratigraphic charts of this basin applying concepts of seismic stratigraphy.

2. Regional setting

The Sinú-San Jacinto Basin is located in northwestern Colombia in the Caribbean Colombian region (Fig. 1), where Neoproterozoic, Paleozoic, Mesozoic and Cenozoic rocks are deformed by predominantly strike-slip and compressive structures (Cediel et al., 2003; Flinch, 2003; Gómez et al., 2007) (Figs. 2 and 3). The structural framework of this area is characterized by normal faults, thrust faults and related folds with a regional northeast trend (Duque-Caro, 1979) (Fig. 3). The Sinú-San Jacinto Basin is bounded to the southeast by the Romeral Fault System, which has been traditionally interpreted as a paleo-suture that separates Paleozoic continental basement rocks to the east from Mesozoic oceanic basement rocks to the west. The Sinú Fault separates the older exposed San Jacinto Fold Belt to the east from the younger partially submerged Sinú Fold Belt to the west. The Romeral and Sinú structures have been interpreted as large-scale dextral strike-slip systems with compressive component (Cediel et al., 2003; Mantilla-Pimiento, 2007). This basin shows two depocenters in the northern and southern areas separated by a paleo-high structure revealed by gravimetric data (Fig. 4).

Diverse interpretations about the tectonic settings of the Caribbean Colombian region have been proposed. The Sinú-San Jacinto Fold-Belts have been interpreted as accretionary prisms characterized by Cenozoic low-angle thrust imbricates related to the subduction of the oceanic Caribbean plate under South America plate (Kellogg and Bonini, 1982; Toto and Kellogg, 1992; Van der

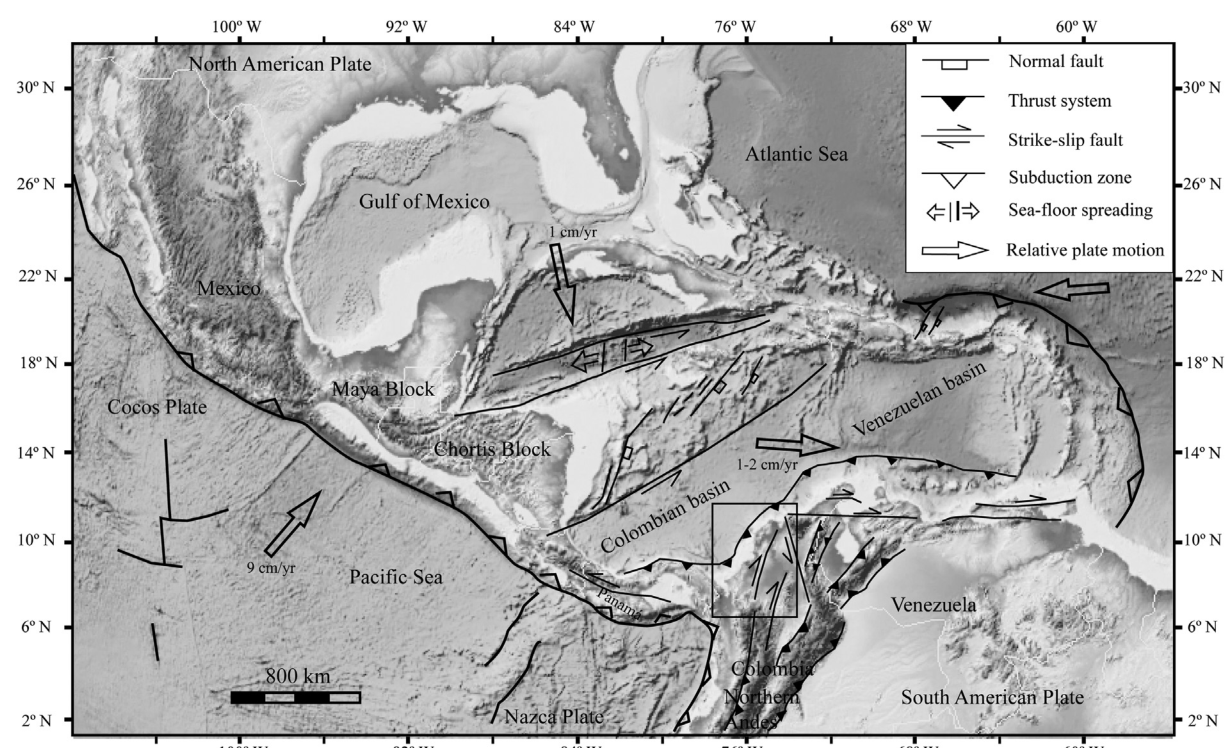


Fig. 1. Map of the Caribbean region showing the geodynamic features and the location of the study area (black square). Compiled from Pindell and Barrett (1990); Cediel et al. (2003); Piñero-Feliciangeli and Kendall (2008); Pindell and Kennan (2009); Taboada et al. (2000); Giunta et al. (2006); Mantilla-Pimiento (2007). Bathymetry and topography from Amante and Eakins (2009).

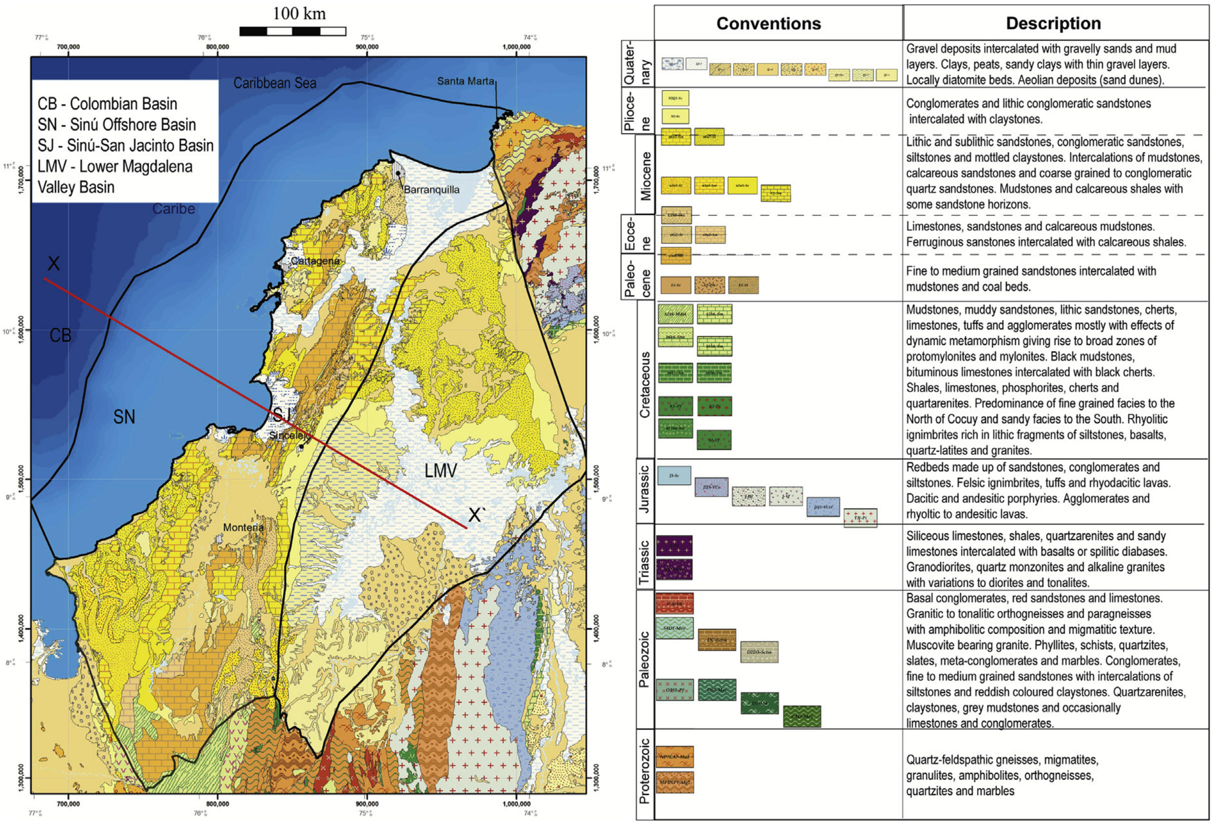


Fig. 2. Map of northern Colombia showing the lithologic units (surface geological data from Gómez et al., 2007). Neogene sedimentary rocks are predominantly outcropped along the Sinú-San Jacinto (SJ) and Lower Magdalena Valley (LMV) basins. These basins are bounded by Precambrian to Mesozoic igneous-metamorphic and volcano-sedimentary rocks. Location of cross section XX′ (red line) shown in Fig. 5. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Hilst and Mann, 1994; Taboada et al., 2000; Kellogg et al., 2005; Mantilla-Pimiento, 2007; Cardona et al., 2010) (Fig. 5). Some of these interpretations suggest that the crustal shortening in the Sinú-San Jacinto Fold Belts is the result of the convergence between the Caribbean plate and the northwest margin of South America (e.g., Toto and Kellogg, 1992). Other interpretations propose that these structures are related to the Andean Orogeny and the Panamá arc collision (e.g., Duque-Caro, 1978). Plate tectonic reconstructions suggest that the Caribbean-NW South America margin was transpressive during Paleocene to Late Eocene time and that as much as 1000 km of NW—SE convergence has occurred in the last 45 million years (Malfait and Dinkelman, 1972; Jordan, 1975; Pindell and Dewey, 1982). Upper Cretaceous obduction and Tertiary subduction of the Caribbean plate under northern South America have been also proposed (e.g., Flinch, 2003; Cardona et al., 2012). Some studies suggest the presence of a Mesozoic rift/passive margin and Cenozoic tectonic inversion in the northwestern South America (Walper, 1981; Audemard, 2002; Caro and Spratt, 2003; Rossello et al., 2004; Rossello, 2007). Diverse authors have studied the stratigraphic record of the Sinú-San Jacinto Basin. Two stratigraphic columns were compiled from diverse studies (Fig. 6), representing the stratigraphy for the Sinú and San Jacinto sub-basins.

2.1. Basement

The nature and age of the basement are controversial because conclusive data are lacking. According to field, well and gravimetric data, Mantilla-Pimiento (2007); Cerón et al. (2007) and Bermúdez et al. (2009); have suggested a pre-Upper Cretaceous igneous-metamorphic continental basement in the western area of the Romeral Fault System. However, some authors have also proposed an oceanic Upper Cretaceous basement (Duque-Caro, 1978; Ingeominas, 1997; Flinch, 2003; Guzmán, 2007). The Upper Cretaceous section consists of gabbro, basalt, and pillow lava, intruded by Paleocene monzo-diorite, monzonite, sienite and gabbro. This section is unconformably overlaid by the volcaniclastic facies of the Barroso Formation (Flinch, 2003). This formation consists of basalt and diabase interbedded with sandstone and conglomerate (Flinch, 2003).

2.2. Stratigraphy according to Duque-Caro (1978, 1979, 1980, 1984, 1990); Aleman (1983); Duque-Caro et al. (1996a,b) and Guzmán (2007)

2.2.1. Upper Cretaceous

In the San Jacinto sub-basin, the Upper Cretaceous succession is up to 2000 m thick, displaying chert, siltstone and interbedded basalt at the top. Some of this unit contents terrigenous elements such as mica and quartz and benthic foraminifera. In some places, Upper Cretaceous to Middle Eocene mafic, ultramafic and tonalitic rocks are affecting this unit. The cherts were formed during Coniacian to Campanian and are correlated to the seismic horizon B″ (Edgar et al., 1971). Basaltic breccia, tuffs and greywacke are identified at the base. Milonite, antigorite, lizardite, cristobalite and iron oxides are filling fractures. The Cansona Formation consists of grey siliceous mudstone with high content of chert, granitic conglomerates and sandstones. This formation can reach about 150 m of thickness in the San Jacinto area. The older part of this succession consists of basaltic flows, conglomerates and tuffs. Duque-Caro (1984) interpreted deep-water conditions during Upper

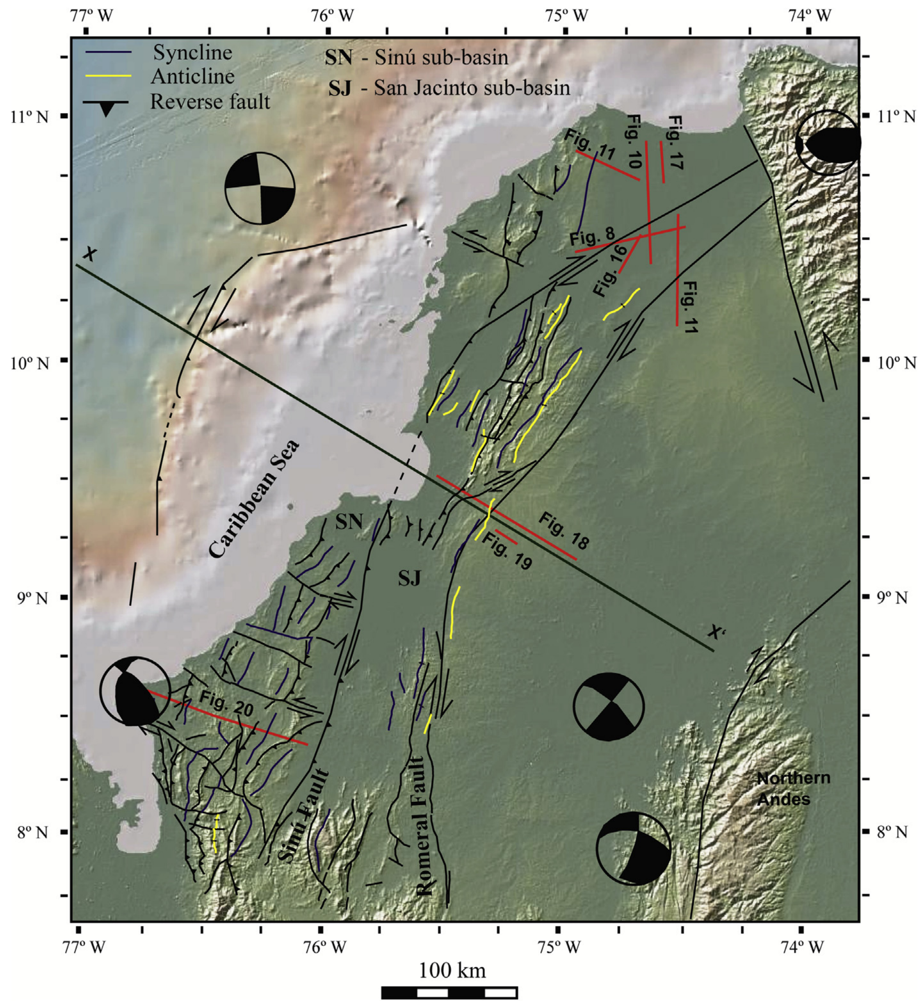


Fig. 3. Structural map of the Sinú-San Jacinto Basin and location of the figures in this study (red lines). Structures compiled from Gómez et al. (2007), Cediel et al. (2003), Mantilla-Pimiento (2007); topography/bathymetry from Ryan et al. (2009); centroid-moment-tensor solutions for earthquakes from Dziewonski et al. (1981); Egbue and Kellogg (2010); Ekström et al. (2012). Location of cross section XX' (green line) in Fig. 5. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Cretaceous. Environments related to bathyal slope have been proposed for the Cansona Formation (Guzmán, 2007). However, subaerial to subaqueous volcanic settings have been also interpreted (Aleman, 1983).

2.2.2. Paleocene – Early Miocene

The Upper Cretaceous succession is conformably overlying by Paleocene to Lower Eocene interbedded sandstones, silty sandstones, volcanic/metamorphic fragments, chert and detritic serpentinites, which were interpreted as deep-water (abyssal) deposits. Chert and pelagic mudstones are correlated with the seismic horizon A″ of the Colombian Basin (Edgar et al., 1971). The typical sedimentary structures of the sandstones and siltstones are parallel bedding and ripples. The Middle Eocene to Early Miocene succession consists of conglomerates, limestones, carbonate shale and deltaic sandstones. Chert was deposited in the Sinú sub-basin followed by deltaic sediments, siltstones and turbidites during Miocene.

2.2.3. Middle Miocene to recent

The Middle Miocene to recent succession consists of interbedded lithic sandstones with bivalves, volcanic fragments, thick mudstones, coastal siliciclastic facies, and siliciclastic sediments with high content of terrigenous sediment. These sediments are overlying by fluvial sandstones, conglomerates and lacustrine sediments. Mud diapirism has been active during this period in the Sinú sub-basin. The sedimentation during Pliocene in the Sinú sub-basin was related to transitional to shallow marine settings.

2.3. Stratigraphy according to Flinch (2003) and Bermúdez et al. (2009)

2.3.1. Cretaceous

The continental basement of the Sinú-San Jacinto Basin is overlying by thin strata of intercalated siliceous siltstone, grey limestone, organic-rich shale and chert (Cansona Formation) (Bermúdez et al., 2009). This sequence was related to shallow marine settings associated to an internal-middle platform and is time equivalent with and has similar facies as the La Luna Formation of Venezuela.

2.3.2. Paleocene – Middle Eocene

The Upper Cretaceous section constitutes a deepening upward section that is overlain by Paleocene-Middle Eocene hemipelagic shale with interbedded turbidites sandstones and conglomerates of the San Cayetano/Carreto formations. In the central zone near to

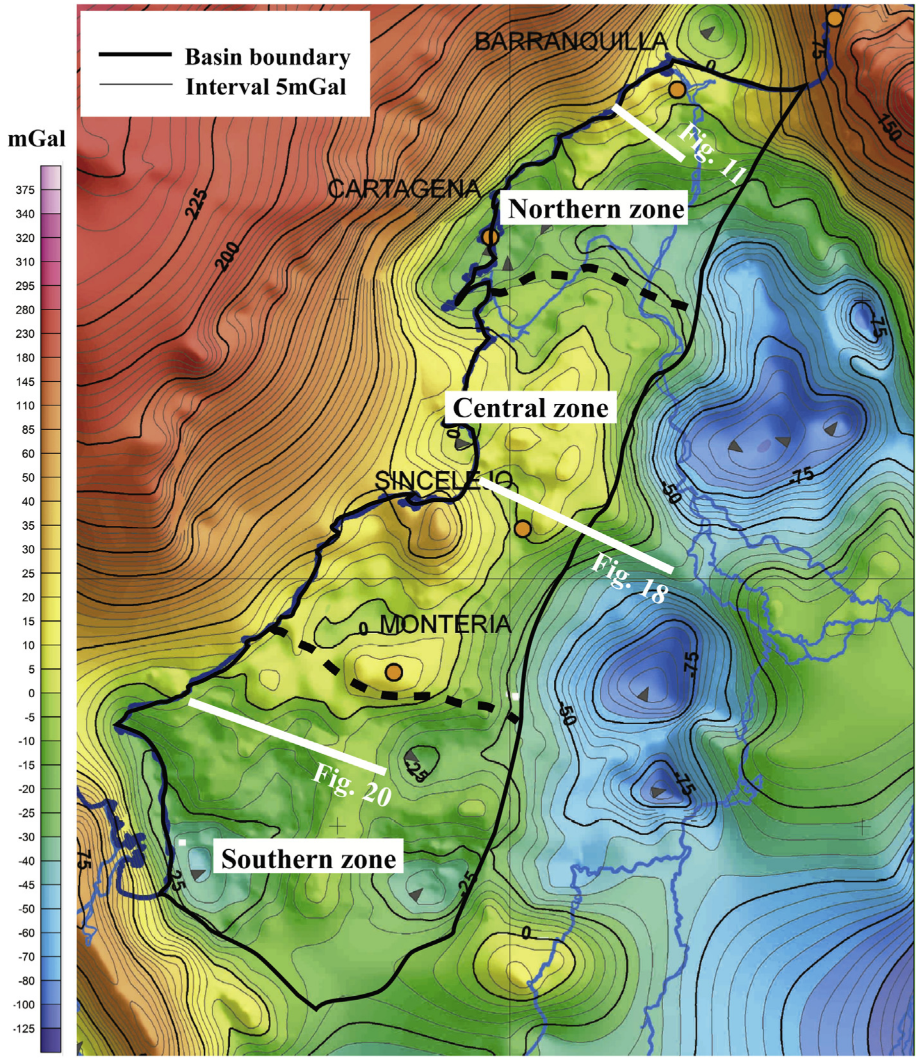


Fig. 4. Gravimetric map of northwestern margin of Colombia showing the northern, central and southern zones in the Sinú-San Jacinto Basin, which are delimited by a structural high based on Bouguer gravimetry data. Bouguer gravimetry data from Graterol and Vargas (2010).

the Morrosquillo Gulf, this section is dominated by sandy and silty facies of the Arroyo Seco Formation. The sandy section consists of lithic sandstones, massive limestones with some parallel, wavy, cross-bedding, hummocky, flaser and convolute structures. This section reveals the presence of *cruziana* ichnofacies, conglomerates with high content of muscovite, organic-rich sediments and coal. The fine-grained section consists of carbonate siltstones with bioturbation marks, parallel and flaser bedding, coal, chert, felsic and metamorphic fragments. The Arroyo Seco Formation was deposited in a deltaic system (deltaic plain, prodelta, delta front, deltaic slope) and platform. The Paleocene siliciclastic section is overlain by Eocene platform carbonates of the La Risa Formation consisting mostly of reefal limestones. The Lorica-1 well encountered 3000 m of Middle Eocene Chenge Formation, which consists of interbedded grey-to-brownish silty mudstone, marl, and fine-to-coarse-grained, subangular to sub rounded grey sandstone. Occasional fine-grained, quartz-rich sandstone intervals are common in the upper part of the section. Stratigraphic variations in the Eocene section between the Tolú and Lorica areas suggest strong facies changes in the Sinú area. In the Urabá region (southern zone), a thick volcaniclastic unit of probable Eocene age unconformably overlies the basement.

2.3.3. Upper Eocene – lower Oligocene

The Tolú Viejo/Chenge formations are composed mostly of bioclastic massive limestones (packstone and wackstone), locally sandy with bioclast of molluscs, echinoderms, macro-foraminifera and oncolites. The basal part of the Tolú Viejo Formation consists of massive carbonate siltstone with some flaser and wavy bedding and oncolites. This unit was deposited in terrigenous-carbonate shallow marine settings (Tolú Viejo Formation). The Chenge Formation has been related to braided deltaic settings.

2.3.4. Upper Oligocene – Middle Miocene

The Floresanto Formation consists of deep-water turbidites, limestones, sandy claystones, and pelagic shale with occasional thin-bedded conglomerates. In the Central zone, the El Floral/Ciénaga de Oro formations are composed of thick layers of massive carbonate siltstones with fossils, bioturbation marks, parallel bedding, fecal pellets and boudinage structures. The Ciénaga de Oro Formation is composed of lithic sandstone with parallel, wavy, flaser and lenticular bedding. Also, this formation consists of massive sandstone with high content of quartz, bioturbation marks, conglomerates and has been related to shallow marine, organic-rich and some continental affinity.

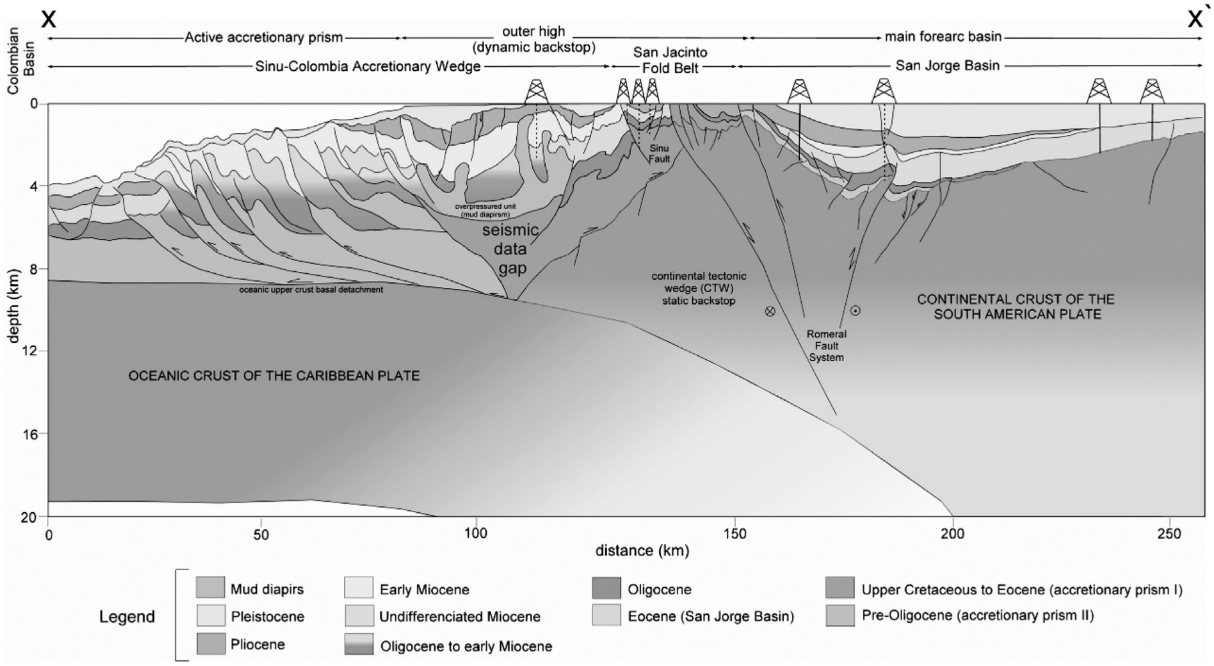


Fig. 5. Depth regional cross section from the offshore Caribbean to the Lower Magdalena Valley Basin showing the major tectonic features of the Colombian Caribbean margin (Morrosquillo area) (Cross section mainly based on geophysical data from Mantilla-Pimiento, 2007). Observe the predominance of thrusts and the dextral transpressive Romeral Fault System in the eastern boundary. For location see Fig. 3 and 4.

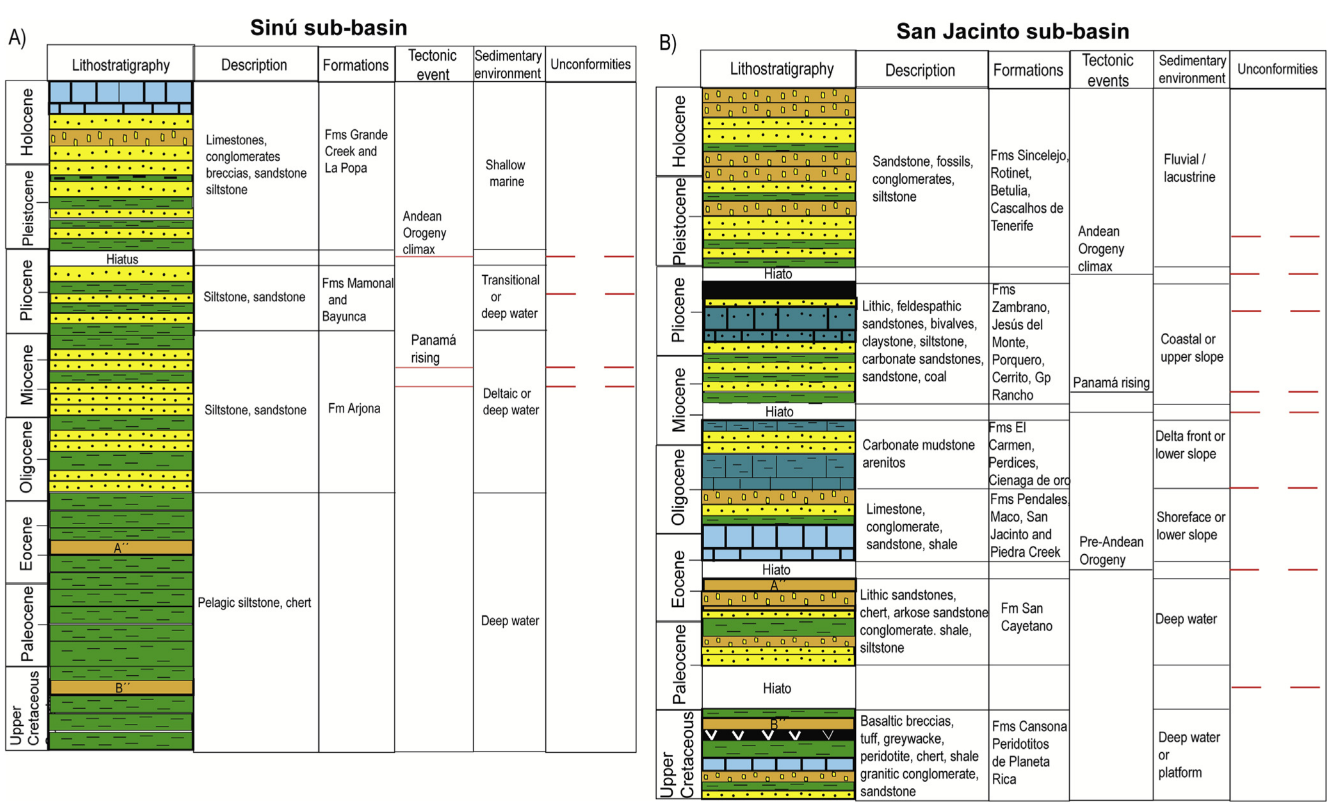


Fig. 6. Composite idealized stratigraphic columns of the Sinú and San Jacinto sub-basins compiled from Duque-Caro (1978, 1980, 1984, 1990); Duque-Caro et al. (1996a, b); Aleman (1983) and Guzmán (2007). A) Stratigraphic column of the Sinú sub-basin that illustrates the main Cenozoic deep-water to shallow marine sections that constitutes the Sinú belt. B) Stratigraphic column of the San Jacinto sub-basin showing the Upper Cretacous siliciclastic and volcano-sedimentary section and the Cenozoic deep-water to shallow marine and fluvial units.

2.3.5. Late Miocene

The Late Miocene Paujil Formation consists of sandstones and conglomerates interbedded with shale and occasional siltstones that represent shallow-water beach deposits. This formation is time equivalent to the El Cerrito Formation which is composed of sandstones with bivalves, benthic foraminifera, siderite, coal and intercalated shale. A relative sea-level falling has been interpreted during this period.

2.3.6. Pliocene – recent

During the Pliocene the Sincelejo/Corpa formations were deposited. The Sincelejo Formation is composed mostly of massive siltstones with bioturbation marks, high content of muscovite, coal, plants and root marks. Also, this unit consists of lithic sandstones with bioturbation marks and parallel, wavy and cut-and-fill bedding; conglomerates with volcanic/plutonic clasts, high content of quartz, siderite and chert. This succession has been related to fluvial environments with influence of channels, bars, flood plain and pedogenic processes. The time equivalent to this unit is the Corpa Formation, which is composed of grey shale and siltstones with occasional layers of sandstone and conglomerate. Fluvio-deltaic facies have been interpreted in the west and fluvial-alluvial facies in the east. The Pleistocene-recent succession is composed by predominantly terrigenous deposits.

3. Data and methodology

Seismic reflection and well data were provided by Ecopetrol and the Agencia Nacional de Hidrocarburos of Colombia. Seismic data consists of eight, high-quality (until 10.5 s), 2D seismic lines acquired at the Colombian onshore and processed from 1991 to 2008 by the Agencia Nacional de Hidrocarburos of Colombia. The seismic data was recorded at a 2 ms–4 ms sample interval. Depth conversion was made using interval velocities from sonic logs. Additional geological data was extracted from several well logs, core descriptions and biostratigraphic zones of some wells (Duque-Caro, 2001; Bermúdez et al., 2009) and from geological mapping (Gómez et al., 2007).

Pre-Cretaceous to present-time sequences were defined by regional unconformities, using standard seismic stratigraphic interpretation procedure (mapping of reflector terminations) and seismic facies analysis (Vail, 1975; Vail et al., 1977; Payton, 1977; Mitchum and Vail, 1977; Mitchum et al., 1977; Galloway, 2001; Posamentier and Kolla, 2003; Catuneanu, 2006; Catuneanu et al., 2009, 2010, 2011). Based on amplitude, continuity, frequency and external/internal geometry of seismic reflectors, a set of seismic facies units associated to each seismic sequence was mapped. Seismic interpretation was tied with surface and subsurface data. The timing of unconformities and the paleo-environmental interpretation of seismic facies were calibrated with the biostratigraphic zones of Duque-Caro (2001) based on benthic and planktonic fossils. Finally, three chronostratigraphic charts built from 2D seismic profiles located across northern, central and southern zones of the Sinú-San Jacinto Basin were constructed. The zones are delimited by the structural highs revealed by Bouguer gravimetry in the Sincelejo and Monteria region (Fig. 4). Each seismic reflector was interpreted and converted via flattening to a time–space diagram. Seismic facies was merged to this diagram in order to produce the final chronostratigraphic charts.

4. Results

Twelve seismic sequences and twenty seismic facies were recognized across the northern, central and southern zones of the Sinú-San Jacinto Basin. Each sequence is characterized by upper and lower terminations of reflectors and associations of specific seismic facies, which are compiled in Table 1. Geological interpretations were constrained from the integration of seismic facies with geological surface data (Fig. 2), focal mechanism solutions (Fig. 3), gravimetry (Fig. 4) and well data (Fig. 7). The benthic and planktonic zones *Ammonia Beccarii* (N22-MN23), *Uvigerina Subperegrina* (N17-N19), *Uvigerina Isidroensis* (N17-N18), Guttulina Caudriade (N9-N8), Uvigerina Mexicana (N5), Cibicidoides Perlucida (P21-P22), Bulimina Jacksonensis (P10, P12, P17, P18/P19), Rzehakina Epigona (Duque-Caro, 2001), were founded in the Pleistocene-recent, Pliocene, Late Miocene, Middle Miocene, Early Miocene, Oligocene, Eocene, Paleocene sequences.

4.1. Northern zone

The northern zone depicts the best evidence of the syn-rift and post-rift sequences. Several faulted and tilted blocks can be identified in this area (Figs. 8–10). Blocks are limited by large, normal, synthetic and planar normal faults. However, a few listric faults are also shown in the easternmost zone, with blocks distributed in a stepwise manner. Widths of blocks vary between 1 km and 10 km and the distribution of faults in seismic lines suggests a general northeast-southwest structural trend. The bulk of the syn-rift sequences is restricted to the deeper parts of the hanging walls, depicting locally wedge-shaped geometry, typical of syn-rift deposition (Figs. 8–11) Regionally the syn-rift sequences are thinning toward the eastern and western boundaries of the basin (Figs. 8 and 11). Seismic layers of these sequences are locally thickening toward the major normal faults, suggesting syn-rift deposition. The typical wedge-shaped geometry has been recognized in the Paleocene, Cretaceous and upper Jurassic sequences. The geometry of the middle Jurassic and Triassic sequences was interpreted strictly based on strata terminations and seismic facies analysis. On the other hand, sheet-drape geometries have been regionally recognized in the Eocene to recent sequences, suggesting post-rift deposition (Figs. 9 and 10). The maximum thickness of the syn-rift and post-rift successions are about 7.2 km (4.1 s) and 5.4 km (3.6 s), respectively, according to seismic velocities. Seismic data from the northwesternmost zone reveals the presence of a dramatic lateral changes in the thickness of the Paleocene syn-rift sequence at ramp anticlines and thicker packages of syn-rift strata lifted on the hanging wall of positively inverted faults (Fig. 11). Seismic facies analysis shows local environmental variations in the syn-rift depocenters (Figs. 12–14). Several depocenters reveal a lower part dominated by high-amplitude, chaotic and variable frequency reflections related to fluvial settings. Mudstones intercalated with coarse-grained sandstones and lithic conglomerates are related to these seismic facies according to well data. The upper part is related to variable amplitude and continuity and high frequency seismic facies related to lagoon settings embedded by extended low-amplitude, chaotic and variable frequency reflections associated to coastal plain environment (Fig. 12). Interbedded mudstone, sandstone and coal traces are related to these seismic facies according to well data.

Seismic facies of the Triassic to Jurassic successions are characterized by variable amplitude, intermediate to low continuity and high frequency seismic reflections and high amplitude, chaotic and variable frequency reflections (Figs. 12 and 14). The upper Jurassic sequence is seismically characterized by wedge-shaped geometry. Its lower boundary is defined by onlap terminations. The upper boundary of this sequence is characterized by erosive truncations and a change of seismic facies from high-amplitude to low-amplitude reflections. The middle Jurassic and Triassic sequences are difficult to observe because of the vertical seismic resolution. However, these sequences may be constraint from stratal

Table 1
Seismic facies proposed and used from seismic data in this study.

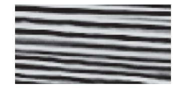
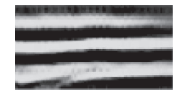
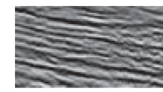
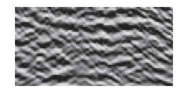
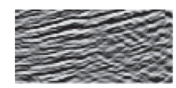
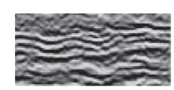
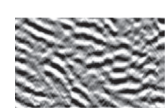
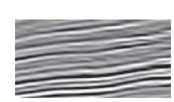
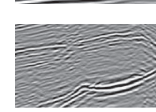
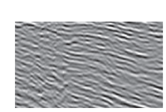
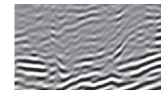
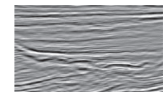
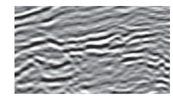
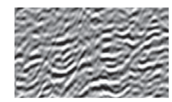
Seismic facies type	Amplitude	Continuity	Frequency	Geometry	Illustration
S1	High	High	High		
S2	High	High	Low		
S3	Intermediate/low	Intermediate/low	High		
S4	Intermediate/low	Intermediate/low	Low		
S5	Variable	Intermediate/low	High		
S6	High	Intermediate/low	Low		
S7	Low	High	Variable		
S8	Variable	Variable	Variable	Mounded	
S9	Variable	Variable	Variable	Wavy	
S10	Transparent				
S11	Low	Chaotic	Variable		
S12	High	Chaotic	Intermediate/high		
S13	High	Chaotic	Low		
S14	Intermediate	High	High		
S15	Transparent			Bank	
S16	Intermediate	Chaotic/low	High		

Table 1 (*continued*)

Seismic facies type	Amplitude	Continuity	Frequency	Geometry	Illustration
S17	Low	Chaotic	Low	Channel	
S18	Intermediate	Intermediate	Low	Channel	
S19	High	High	Low	Channel	
S20	High	Chaotic	High	Channel	

terminations and seismic facies changes (Figs. 8–10). The middle Jurassic sequence is characterized by erosional truncations at the top and onlap terminations at the base and by high-amplitude and high continuity reflections intercalated with low-amplitude and low-continuity seismic facies. Direct evidence for the age of these sequences is lacking, but Jurassic and Triassic ages are considered the most likely, considering the temporal and tectono-stratigraphic correlation with the nearest basins from Colombia and Venezuela (e.g., Edgar et al., 1971; Irving, 1975; Flinch, 2003; Summa et al., 2003; Sarmiento et al., 2006; James, 2009; Laya and Tucker, 2012; Cuadros et al., 2014).

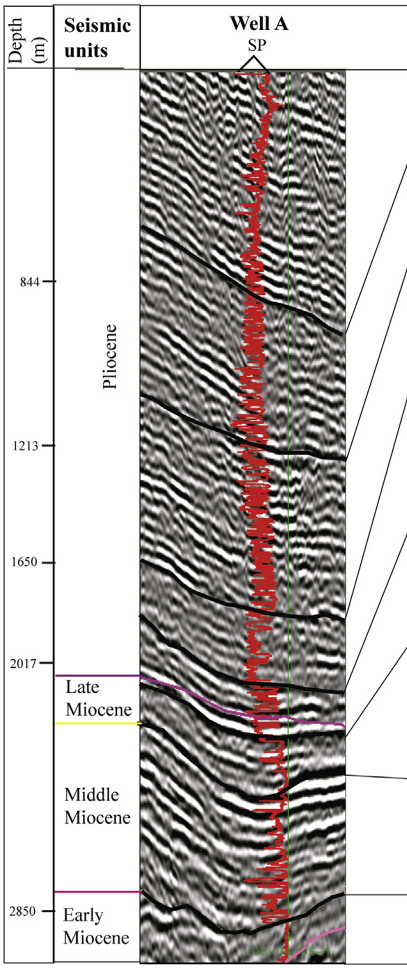
The Cretaceous sequence is seismically characterized by variable amplitude, intermediate to low continuity and high frequency pattern (Figs. 11 and 12). Seismic facies delimited by high amplitude reflectors are interpreted as carbonate banks (Fig. 13). This sequence also is characterized by wedge-shaped geometry and progressive thickening in the hanging walls. The top of this sequence corresponds to a seismic change from low-amplitude to transparent seismic facies at the upper part to high-amplitude and continuous reflections at the base of the Paleocene sequence.

The Paleocene sequence is the last syn-rift sequence and is characterized by a regional thinning towards east and local pinch-out caused by truncation at the top and onlap at the base (Figs. 8–10). The top of this sequence is the upper boundary of the syn-rift succession and the base of the post-rift section. The top of this syn-rift succession, also known as the break-up unconformity (BU), is characterized by an irregular, high-amplitude, erosional surface that reflects the structures and diverse lithologies of the faulted underlying strata. The BU also is recognized by a vertical seismic facies change from low-amplitude to transparent seismic facies in the syn-rift succession to a relatively uniform package of high-amplitude, high-continuity and low frequency reflections of the post-rift succession. The seismic facies of the Paleocene sequence is mainly characterized by low-amplitude to transparent, intermediate to low continuity and variable frequency reflections (Figs. 8–12). Limestones, marl with interbedded shale and some diorites are related to the uppermost part of the Paleocene sequence, according to well data.

Regionally, the Eocene sequence is predominantly a sheet-drape deposit overlying the Paleocene sequence or directly the Cretaceous sequence (Figs. 9 and 10). Locally, the Eocene sequence is onlapping tilted footwalls (Figs. 9 and 10). Downlap terminations have been also interpreted in this sequence, but might be related to onlap terminations that have been tilted due to post-depositional uplifting (Figs. 9 and 10). This sequence shows high amplitude, high continuity and low frequency reflections with bank and mounded geometries that lie directly on the rift footwalls (horst blocks) which have been interpreted as carbonate banks and mounds. Additionally, low amplitude, low continuity and high frequency reflections also have been recognized across the basin. Interbedded coarse-grained sandstones, conglomerate and micrite are correlated to these seismic facies according to well data.

The Oligocene sequence is characterized by onlap terminations onto the tilted blocks (Fig. 9). This sequence shows intermediate to low amplitude, low continuity and high frequency (Figs. 9–11). The Early Miocene sequence is an up to 1.5 km thick succession with sheet-drape geometry, seismically characterized by two interfingering seismic facies (Figs. 9 and 10). One seismic facies unit consist of highly deformed, tilted and high amplitude (some transparent) reflectors which have been associated to slumps (Fig. 9). Mudstone with glauconitic mica has been related to those deposits according to well data (Fig. 7). These deposits show the typical characteristics of depositional thrusting which indicates a south to north flow direction. Size of slumps varies from 3 km to 10 km width and 450 m (0.3 s) in thickness. The other seismic facies corresponds to high amplitude, high continuity, low frequency and sheet-drape reflections (seismic facies S2) which are downlapping onto the footwall rifted blocks.

The Middle Miocene sequence is characterized by mounds related to turbidites, depositional thrusts (slumps) and sheet-drape deposits (seismic facies S2) (Figs. 9 and 10). The size of slumps is similar to the Early Miocene sequence, whereas, width and thickness of mounds varies from 1 km to 12 km and 600 m (0.4 s), respectively. In the northwestern part, the Middle Miocene sequence is seismically characterized by high-amplitude and chaotic reflectors (Fig. 11). The Middle and Late Miocene-Recent sequences show the downward curvature (clinoforms), with undeformed aggradational/progradational pattern of the reflections which is typical of post-rift passive margins (Figs. 9, 11 and 15). The Miocene sequences also show large-scale, mounded turbidites deposits, submarine incised channels and canyons (Figs. 16 and 17). These sequences display an irregular erosive unconformity at the top (Fig. 10). This unconformity has been related to the top of the Pliocene sequence suggesting a regional uplifting in the basin. The Pliocene to Pleistocene sequences reveal a low-amplitude and chaotic seismic pattern (Fig. 11). In the northernmost part, the Pleistocene-recent sequence is onlapping onto the Miocene and Pliocene sequences and is seismically characterized by parallel, high amplitude, high continuity and low frequency reflections (Fig. 10).



Seismic facies	Lithology	Geological interpretation
S4: Intermediate/low amplitude, intermediate/low continuity, low frequency	Medium- to fine-grained, angular to subrounded sandstone intercalated with claystone. White, coarse- to medium-grained, poorly sorted sandstone.	Fluvial environment with predominance of sandstone possibly related to bars and channels.
S11: Low amplitude, variable continuity, low frequency	Medium- to fine-grained clayey sandstone. Chert granules	Coastal plain
S4: Intermediate/low amplitude, intermediate/low continuity, low frequency	Medium- to fine-grained, white sandstone.	Fluvial environment with predominance of sandstone possibly related to bars and channels.
S11: Low amplitude, variable continuity, low frequency	Coarse- to fine-grained, subangular sandstone intercalated with silty coal.	Coastal plain
S14: intermediate amplitude, high continuity, high frequency	Silty sandstone	Deltaic environment
S11: Low amplitude, variable continuity, low frequency		
S6: high amplitude, intermediate/low continuity, low frequency	Carbonate siltstone. Evaporitic sandstone grading upward to siltstone, coarse-grained sandstone and anhydrite. Some carbonate mudstone at the base.	Carbonate platform with high siliciclastic supply
S10: transparent pattern	Carbonate mudstone with glauconitic mica.	Gravity-driven deposits with high content of fine sediments

Fig. 7. Seismic-well section showing the correlation of the seismic facies interpretation with description of drill-cores in the basin and electric logs.

4.2. Central zone

The central zone depicts high-angle faults, local anticlines and an erosional unconformity (Paleocene Unconformity) related to compressive regime (Fig. 18). On the other hand, in the northern zone, this unconformity was related to the last stage of the rifting (break-up). Additionally, several tilted blocks limited by planar normal faults affecting the Triassic-Jurassic-Cretaceous sequences and the thickening of the Cretaceous sequence in the hanging walls related to these extensive faults have been observed (Fig. 18). These observations suggest a diachronic rifting, which ended in the Paleocene in the northernmost part but locally ended before Paleocene, probably during Cretaceous in the central zone. Furthermore, the coexistence of both normal and reverse throws along the same fault surface are suggesting that tectonic inversion processes have locally affected the syn-rift and post-rift sequences producing reversal faulting, uplift and partial extrusion of the basin fill (Fig. 18).

Large-scale steeply dipping and sub-vertical faults suggest the influence of positive flower structures which may be correlate with focal mechanism solutions suggesting that inversion occurred along large-scale, transpressive (dextral), northeast-southwest structures known as the Romeral Fault system (Fig. 3). The post-rift sequences in the central zone depict the following features with the respective interpretations: local erosional unconformities and depocenters related to uplifting during the Paleocene to Lower Miocene are suggesting initial uplift pulses (early uplift); a regional, angular (high-angle) and erosional unconformity related to the main uplift pulse during the Middle Miocene (climax uplift); and a large-scale compressive anticline associated to Late Miocene – Pliocene strata and a regional tilting of the Cenozoic sequences are suggesting a last uplifting event during the Late Miocene to recent (late uplift) (Fig. 18).

In the central zone, the Mesozoic syn-rift sequences are seismically characterized by discontinuous and low frequency reflectors (Fig. 18). The Paleocene, Eocene and Late Miocene sequences have high-amplitude, high continuity and low frequency seismic facies. Low-amplitude, high continuity and variable frequency reflections are typical in the Oligocene, Early Miocene and Middle Miocene sequences. Variable amplitude and discontinuous seismic facies are typical of the Pliocene to recent successions. Fluvial, coastal plain and lagoon facies were interpreted for the Mesozoic sequences; carbonate platform with reefs and carbonate banks during Paleocene and Eocene; deep-water deposition during Oligocene, Early Miocene and part of Middle Miocene and fluvial-deltaic systems during part of Middle Miocene to present (Fig. 19). Medium to fine-grained, angular to subangular sandstone with interbedded mudstone and poorly sorted sandstone are related to the seismic facies of the Pliocene sequences according to well data (Fig. 7).

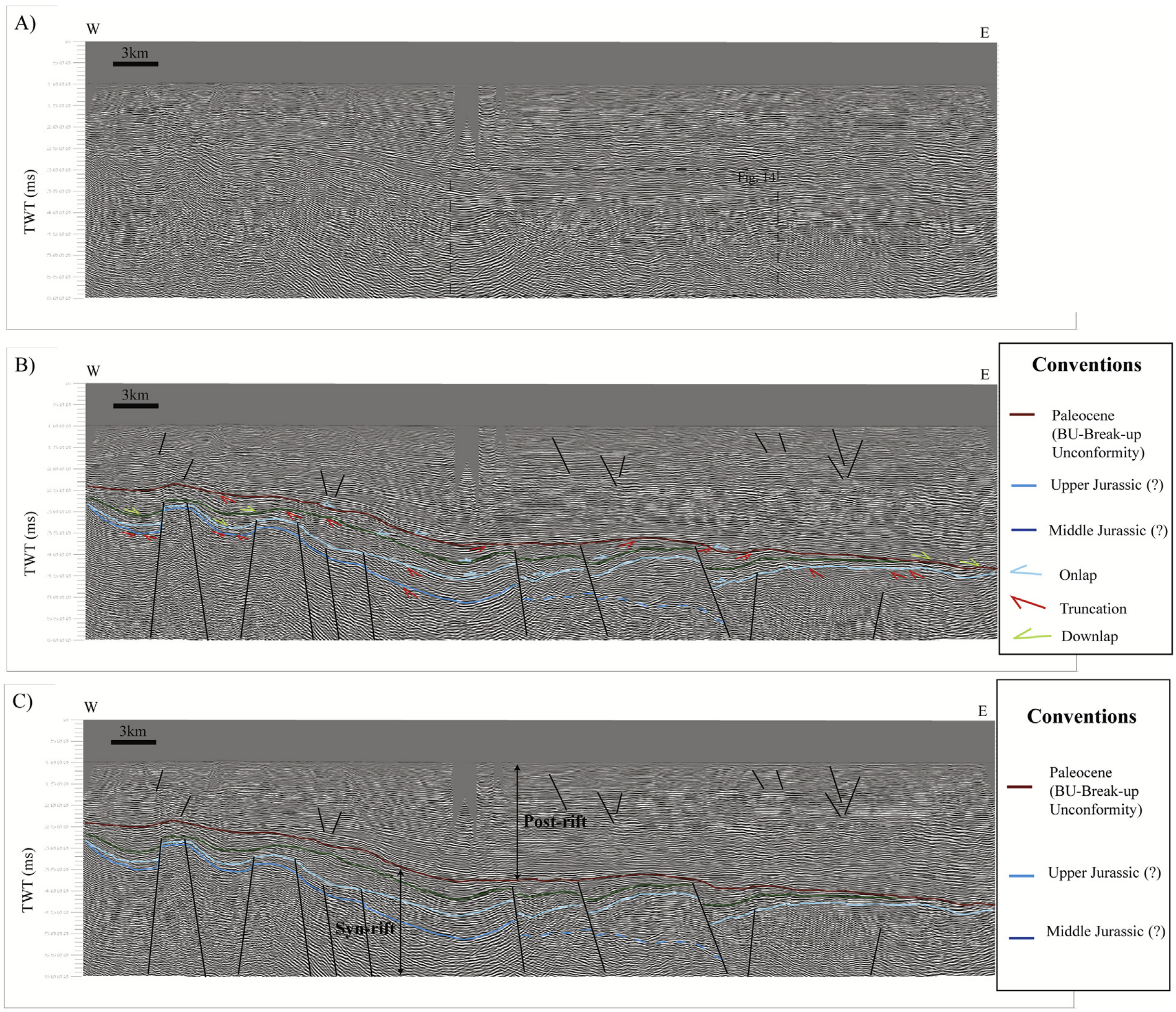


Fig. 8. Rift/passive margin system along the Sinú-San Jacinto Basin revealed by seismic reflection data. See location in Fig. 3. A) Uninterpreted seismic line (for location see Fig. 14, dashed square). B) Planar normal faults and wedge-shaped syn-rift Mesozoic sequences. Observe the thinning of the syn-rift sequences and the break-up unconformity (BU) at the top of the syn-rift section. C) Interpretation of the syn-rift (Middle Jurassic to Paleocene) and post-rift successions.

4.3. Southern zone

The sequences in the southern zone are highly deformed (Fig. 20), displaying sub-vertical, positive flower structures. Interpretation of sequence boundaries is very subjective and difficult, and the most reliable features are constrained from the analysis of seismic facies.

The Triassic and Jurassic sequences in the southern zone are characterized by high-amplitude, high continuity and low frequency seismic pattern (Fig. 20). Low-amplitude, discontinuous and high frequency seismic facies are typical of the Cretaceous and Paleocene sequences. Coarse-grained poorly sorted sandstone, coal and siltstone are related to these seismic facies according to well data. The Oligocene and Early Miocene sequences are characterized by high-amplitude, intermediate to low continuity and low frequency reflectors. Limestone, sandstone and siltstone with pyrite are related to these seismic facies according to well data. The Middle Miocene sequence reveals intermediate amplitude, high continuity and high frequency seismic facies. Intermediate to low continuity and low frequency seismic facies were identified in Late Miocene sequence. Predominantly coarse-grained sandstone and coal are related to these seismic facies, according to well data. In the southern zone, the Triassic and Jurassic sequences are related to lacustrine systems and flood plain deposits. The Cretaceous to Paleocene sequences are typical of coastal plain and lagoons. The Oligocene to Eocene sediments are linked to a carbonate platform with high content of siliciclastic and some turbidites. The Miocene to recent sediments are related to deltaic and fluvial systems.

4.4. Summary of the stratigraphic interpretation

Tectonics had an important control on the depositional systems of the Sinú-San Jacinto Basin. The seismic data calibrated with well and surface data reveal a consistent regional pattern of one polyphase rifting event and one post-rift phase. The post-rift phase is characterized by both a passive margin (northern area) and tectonic inversion (predominantly in the central and southern zones). The rifting and the tectonic inversion in general are diachronous from south to north. Local variations in seismic facies are affected by folds and faults. In the northern and central areas, the growth strata are evident during the Mesozoic to Paleocene rifting. Tectonic inversion is registered specially in Miocene growth strata. Three chronostratigraphic charts based on seismic sections as discussed

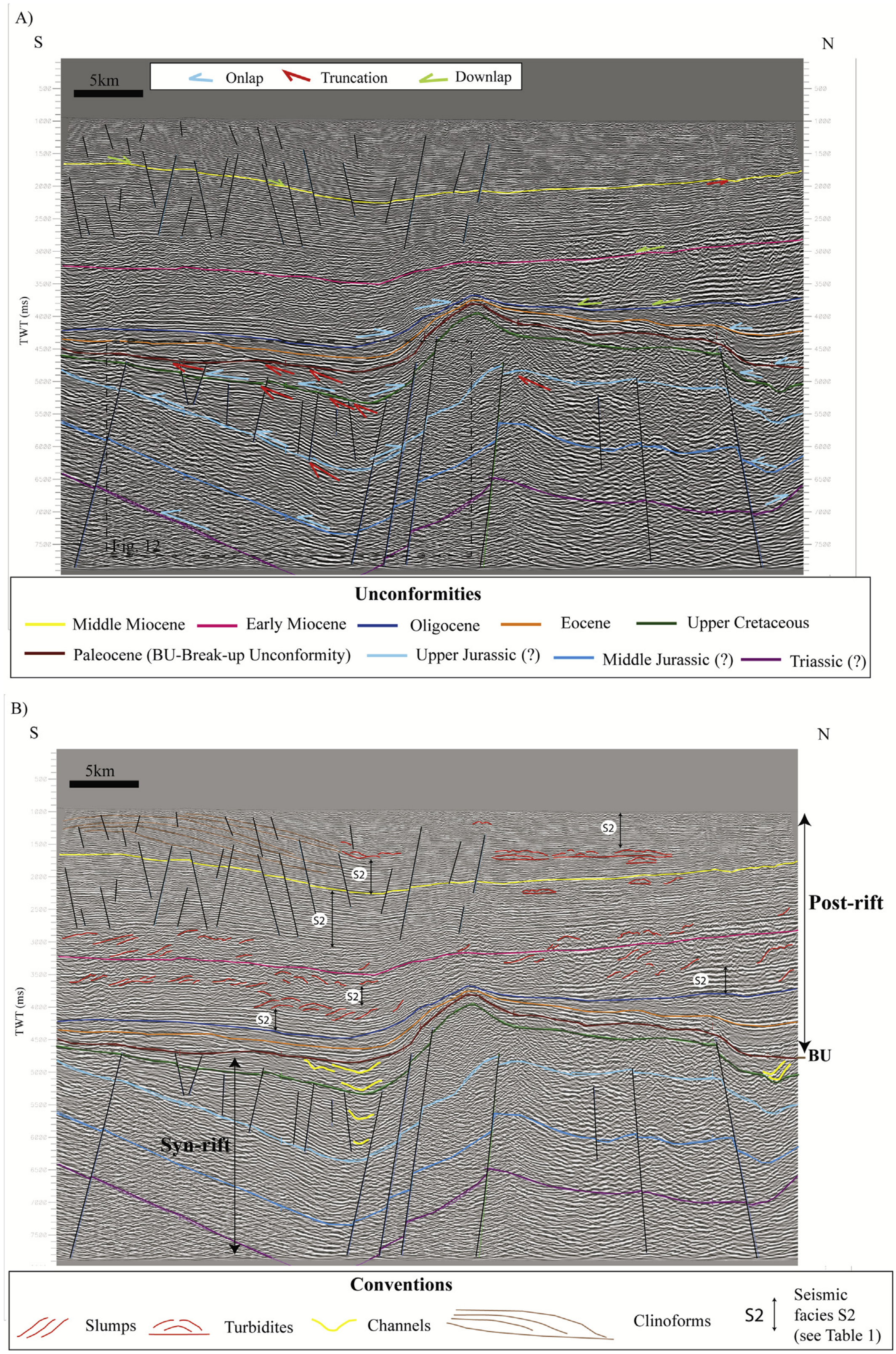


Fig. 9. System of horst and hemi-graben in the Sinú-San Jacinto Basin revealed by seismic reflection data. See location in Fig. 3. A) Termination of reflections in the boundaries of the sequences. Observe the erosive truncations at the top of the Paleocene sequences (break-up unconformity-BU). Location of the Fig. 12 in dashed square. B) The syn-rift sequences with the wedge-shaped geometry typical of rift processes. Note the sheet-drape geometry, clinoforms and gravity-driven deposits of the post-rift sequences.

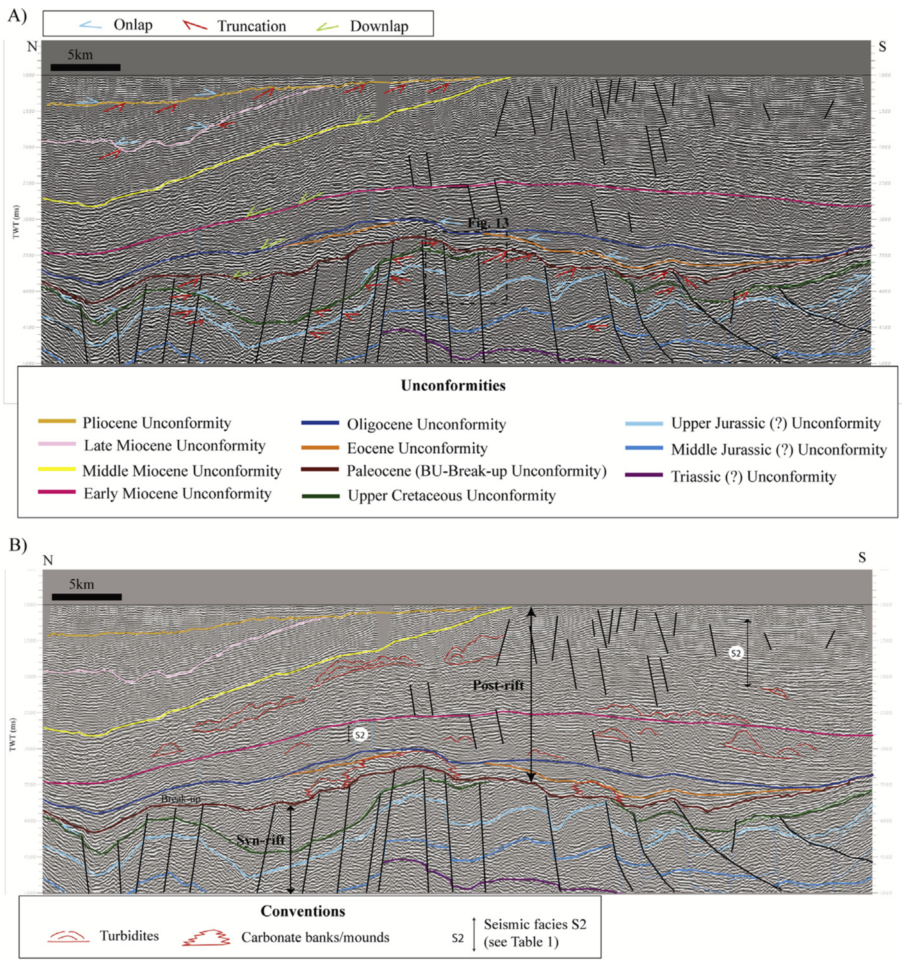


Fig. 10. Seismic line showing the tilted fault blocks, the basic tectonic element in the Mesozoic- Paleocene rift. See location in Fig. 3. A) Tilted blocks limited by normal faults and syn-rift wedge-shaped sequences in the hanging wall. Location of the Fig. 13 in dashed square. B) The syn-rift and post-rift successions in the northern zone of the Sinú-San Jacinto Basins.

in this study, summarize the stratigraphic configuration of the Sinú-San Jacinto Basin (Figs. 21–23).

4.4.1. Triassic

Deposition during Triassic was controlled by an extensional regime. Deposition of continental material occurred during early stages of grabens and hemigrabens. Fine sediments were deposited in the southeastern zone, whereas, coarse material was deposited in the northwestern area. Flood plain and lacustrine sediments related to the beginning of rifting were covering the southeastern zone (Fig. 24). Fluvial sediments with high content of coarse sandstone dominated the northernmost zone.

4.4.2. Jurassic

The Jurassic sequence is characterized by deposition of fine fluvial siliciclastic material in the northernmost zone (Fig. 25). In the southeastern zone, sedimentation was predominantly typical of lacustrine and flood plain settings. Sedimentation continues be controlled by the rifting.

4.4.3. Cretaceous

The Cretaceous sequence is characterized by a wide northeast-southwest oriented zone of lagoons and coastal plain sediments. Lagoons have an elongate and lobate morphology, shattered across a wide coastal plain along the entire basin. The northwestern region, however, is characterized by a mixed carbonate-siliciclastic platform, probably controlled by uplifting of horsts related to rifting.

4.4.4. Paleocene

The last rifting pulse occurred during the Paleocene in the northern zone. In the central zone, the rifting event ended before Paleocene. In this zone an initial phase of inversion during Paleocene has been recognized. This sequence is characterized by a carbonate platform and deposition of proximal deltas in the southern region. Coastal plain and lagoons were reduced. A northeast-southwest belt of shallow marine sediments is located in the basin, limited by lagoon sediments in the northern and southern zones.

4.4.5. Eocene

During the Eocene, the carbonate platform was expanded in the northern zone. Deltaic lobes and turbidites were deposited toward the northeastern region. The carbonate platform was characterized by high siliciclastic input, especially in the southern area. In the northwestern zone, large deposits related to lagoon and coastal plain were formed.

4.4.6. Oligocene

The Oligocene was characterized by rising of base level and deep-water deposition, resulting in large extensions of pelagic and

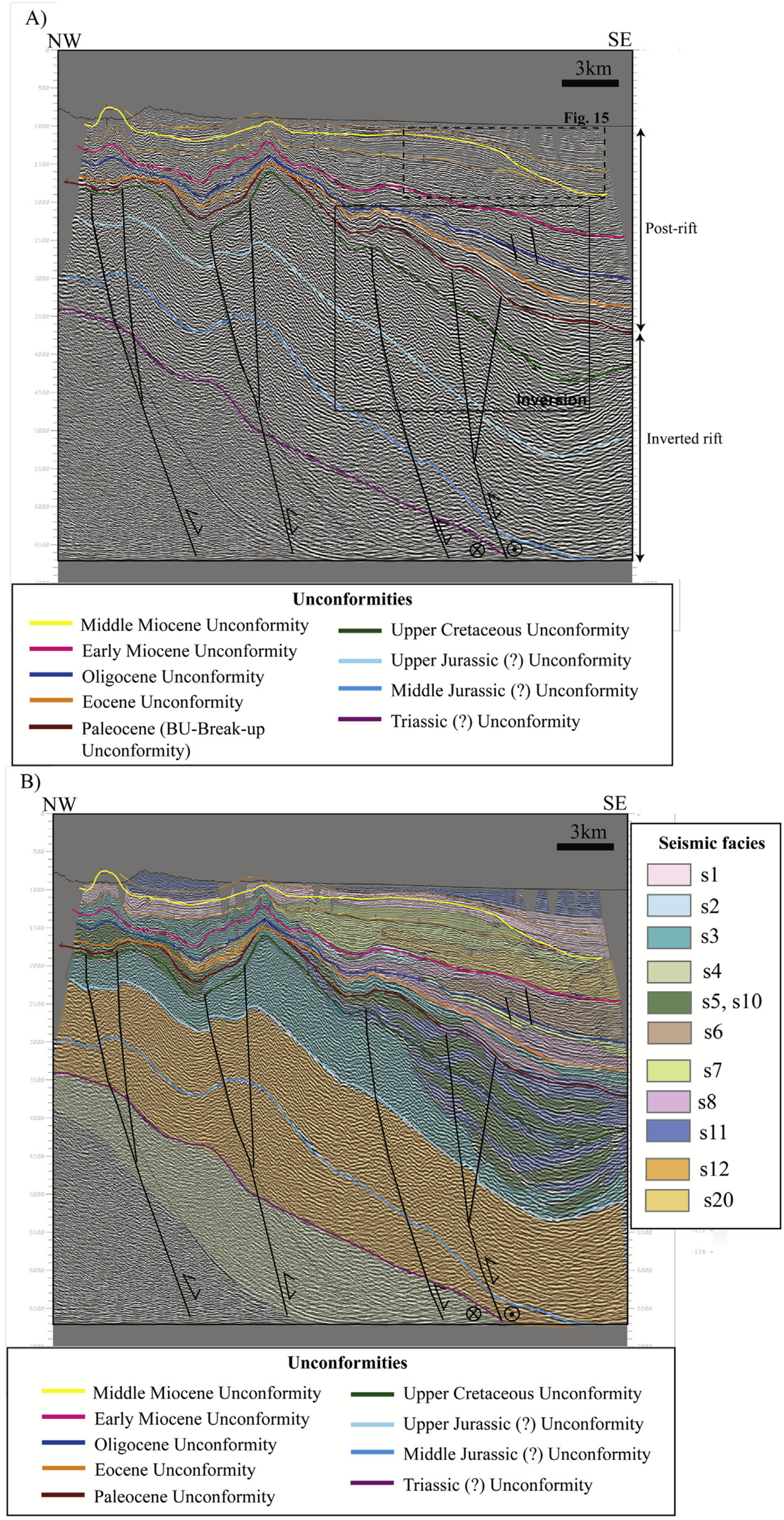


Fig. 11. Seismic line in the northern zone. See location in Fig. 3 and 4. A) Seismic line in the northern zone showing ten seismic sequences. Location of the Fig. 15 in dashed square B) Interpretation of seismic facies in this profile. Description of each seismic facies unit is shown in Table 1.

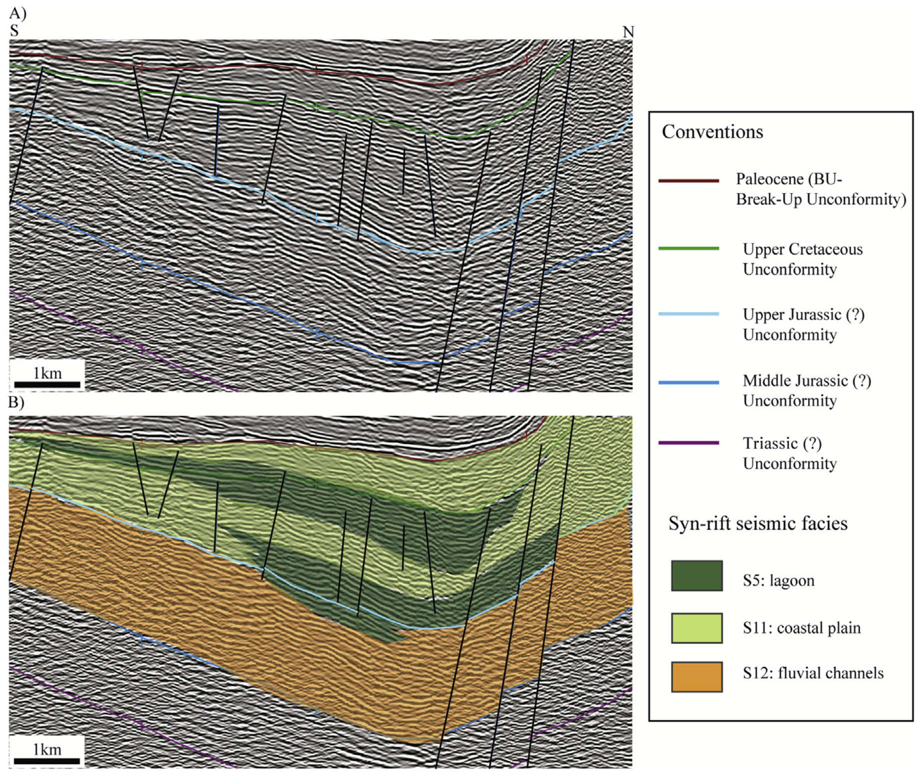


Fig. 12. Detailed seismic facies interpretation in the syn-rift succession in the Fig. 9. A) Uninterpreted Seismic line. B) Lagoon and coastal plain facies of syn-rift sequences during Cretaceous to Paleocene. Observe the fluvial facies related to Jurassic sequence.

hemipelagic sediments deposited in the central and northern region. North-directed deposition of turbidites occurred along the slope. Some carbonate banks and reefs developed in a shallow northeast-southwest-oriented deposition belt.

4.4.7. Early Miocene

During Early Miocene, falling of base level controlled erosion in the southern and central zone. Carbonate sedimentation was extended northwards, while some deltaic lobes were deposited in the southern zone.

4.4.8. Middle Miocene

Middle Miocene was characterized by deposition of fluvial to deltaic facies in the southern zone what is indicative of another event of falling base level. The main inversion pulse was recognized during the Middle Miocene in the central zone (climax uplift). Gravity-driven deposits with high content of fine sediments, controlled by a northeast-directed high-angle slope, were deposited in the northern zone. Over-bank sediments were deposited in the northwestern region of the basin.

4.4.9. Late Miocene

Coarse-grained fluvial sand bars, channels and wide coastal plains characterize the Late Miocene. Fluvial facies with high content of sandstones were deposited in the southern zone, whereas coastal plain deposits were formed in the northern zone. During this period, turbidite systems developed along a structural belt with a northeastern-southwestern direction. In the central zone, pelagic and hemipelagic material was deposited. The detected coastal plain facies in the north, suggests a transport direction toward that direction. According with this depositional direction, a shallowing trend toward north would be expected; however, the presence of turbidites and hemipelagic/pelagic facies in the central region are suggesting an important tectonic control. A late phase of the tectonic inversion during Late Miocene to recent has been recognized across the basin.

4.4.10. Pliocene

During Pliocene, fluvial sediments with high sandstones content related to fluvial channels and bars were deposited in the central and southern zones. In the central zone, proximal deltaic deposits are present. During that time, the northern zone was a region of non-deposition/erosion. Late inversion continues during Pliocene, predominantly in the northern area.

4.4.11. Pleistocene-recent

Pleistocene to recent sedimentation is characterized by continental facies. These facies correspond to coarse-grained sandstones associated to bars and fluvial channels. In the northwestern area, deposition of fine-grained sediments is related to coastal plain settings. The late tectonic inversion continues during Pleistocene to recent across the basin.

5. Discussion

The seismic data calibrated with well and surface data reveal a consistent and regional pattern of one poly-phase rifting event and one post-rift phase. The post-rift phase is characterized by both a passive margin (northern area) and tectonic inversion (predominantly in the central and south zones). The rifting and the tectonic inversion in general are diachronous from south to north. The rifting event can be subdivided in five pulses corresponding to the Triassic, middle Jurassic, upper Jurassic, Cretaceous and Paleocene sequences. The beginning of rifting remains unclear due to the poor seismic resolution, but the end was before or during the Upper Cretaceous in the southern zone; during Cretaceous in the Central

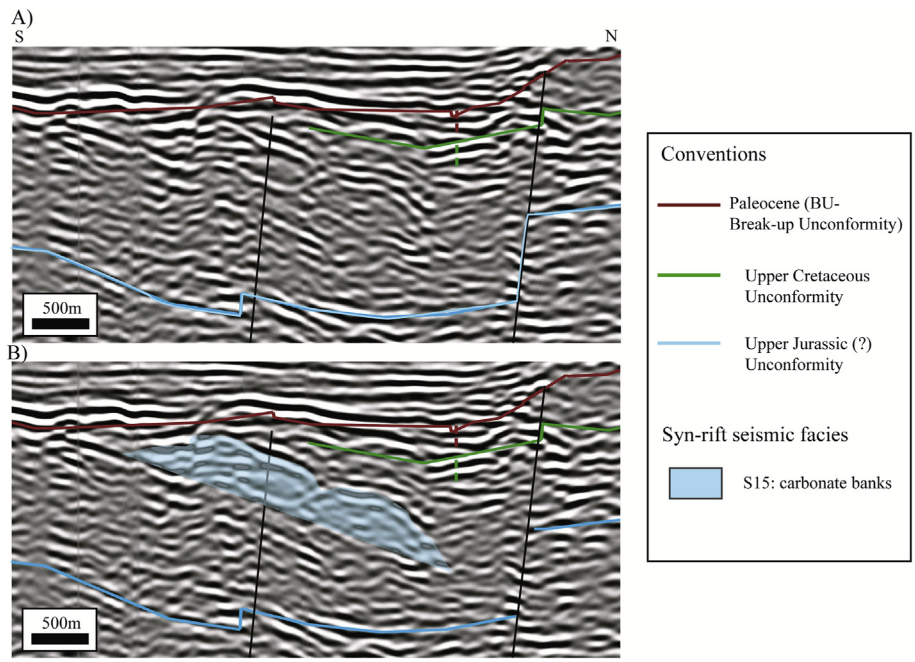


Fig. 13. Detailed seismic facies related to carbonate banks in the syn-rift sequences in the Fig. 10. A) Seismic line uninterpreted. B) Transparent seismic facies, delimited by high amplitude reflectors, are related to carbonate banks deposited during Cretaceous.

zone and during Paleocene in the northern zone. The tectonic inversion can be subdivided in three phases of deformation that in general are also diachronous from south (probably Upper Cretaceous to recent), central (from Paleocene to recent) to north (from Pliocene to recent, indeed there are some zones without evidence of inversion). The three phases of inversion are well preserved in the central zone and correspond to the early uplift phase during Paleocene to Early Miocene; the climax uplift phase during Middle Miocene and the late uplift phase during the Late Miocene to recent.

5.1. Pre-rift

In the absence of deep drilling, coherent seismic reflectors below the Triassic Unconformity are interpreted as pre-rift strata in the Sinú-San Jacinto Basin (Figs. 11 and 20). Arkosic sandstones, textural immature conglomerates, greywacke; and sandstones with high content of angular to subangular quartz have been identified in well data (used in this study) and have been identified in field data by Guzmán et al. (1998) and Gómez et al. (2007), which

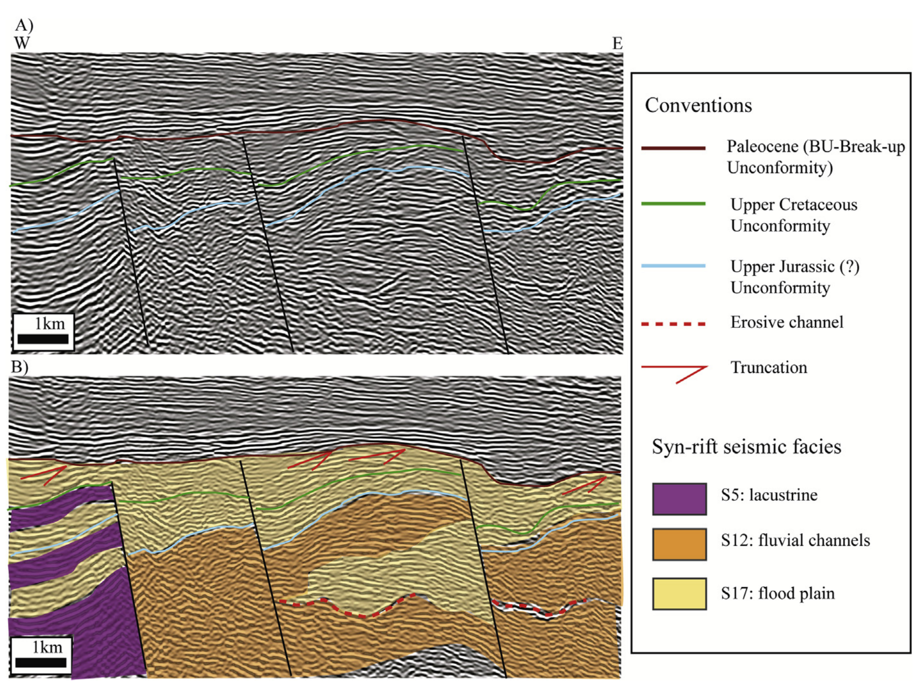


Fig. 14. Detailed seismic facies interpretation in the syn-rift succession in the Fig. 8. A) Uninterpreted Seismic line. B) High amplitude, chaotic and variable frequency seismic facies are related to fluvial channels of the Jurassic sequences.

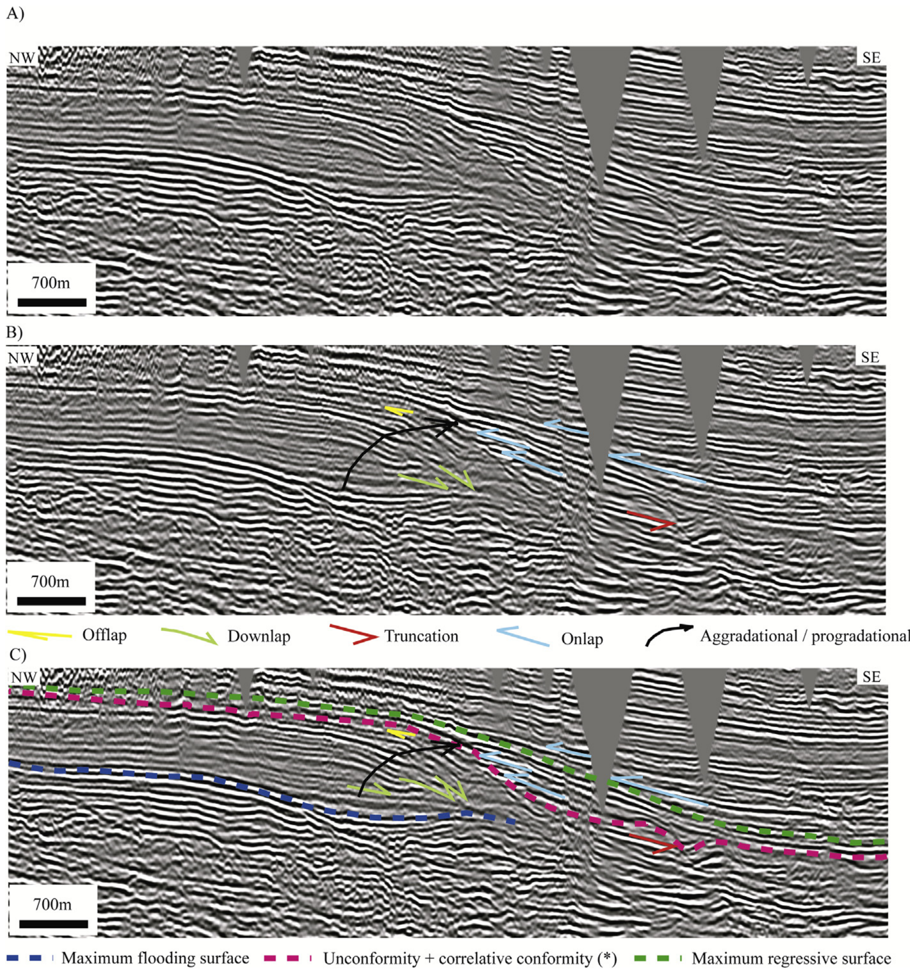


Fig. 15. Detailed stratigraphic seismic interpretation in the post-rift succession in the Fig. 11. A) Uninterpreted seismic line. B) Aggradational to progradational seismic pattern and termination of reflectors of a typical clinoform related to passive margin settings. C) Interpretation of stratigraphic surfaces. (*) – Correlative conformity (*sensu* Hunt and Tucker, 1992).

suggest a pre-Cretaceous continental crystalline protolith. Bermúdez et al. (2009) suggested that the composition of the sandstones of the Arroyo Seco Formation and the absence of a sedimentary barrier related to the Romeral Fault System in the eastern Sinú-San-Jacinto Basin during Upper Oligocene-Miocene are suggesting a continental igneous-metamorphic basement for the Sinú-San Jacinto Basin. A basement related to predominantly continental crust in the west side of the Romeral Fault System (includes the Sinú-San Jacinto Basin) has been suggested in gravimetric modelling by Mantilla-Pimiento (2007) and Cerón et al. (2007). Recently, geochemical studies by Cardona et al. (2012) have suggested the presence of sedimentary sources related to Late Cretaceous intra-oceanic, arc-related sources mixed with the Permo-Triassic continental basement of the northwestern South America. Furthermore, geological/geophysical evidence that has been presented in previous studies across the Caribbean region, allows to propose a pre-rift unit predominantly composed by Precambrian–Paleozoic, igneous-metamorphic continental rocks. Schuchert (1935); Dengo (1975) and James (2009) have documented continental Precambrian rocks outcrop in the Chortis Block (Central America). Amphibolite and granulite gneisses related to the Oaxaca Precambrian Complex outcrop in the southern Mexico (James, 2009). Migmatitic metagranite; granitic gneisses (granulite facies); porphyritic amphibolite with high content of garnet; charnocritic gneisses and anortositic metagabbros of the Meso-Neoproterozoic (Gneisse Novillo) outcrop in the Central Mexico (Trainor et al., 2011). Part of the basement of the Plato and San Jorge sub-basins (Lower Magdalena Valley Basin, Caribbean Colombia) consists of Paleozoic migmatite, granulite, amphibolite and biotitic gneisses (Flinch, 2003). Tschanz et al. (1969) and MacDonald and Hurley (1969) collected banded mafic paragneisses and granulitic quartz-feldespathic granulites in the Santa Marta Massif (Caribbean Colombia). Granites with 1250 Ma zircons in the Jojoncito area (Guajira Peninsula) have been documented by Irving (1975). Neoproterozoic hornblende gneiss with pegmatoid bands and Paleozoic granites and amphibolite outcrop in the west flank of the Santa Marta Massif (Gómez et al., 2007).

5.2. *Rift*

In this study, we propose an intracontinental Mesozoic to Paleocene rifting in the Sinú-San Jacinto Basin from the following observations: a) the presence of Jurassic, Cretaceous and Paleocene sequences with wedge-shaped geometry (thickening in the hanging wall of faulted blocks), typical of syn-rift deposition. b) The predominance of northeast-southwest trending and tilted blocks (half-graben and horst) limited by normal planar faults which is the basic tectonic element of the Mesozoic succession. c) The presence of rift-related faults resulting in graben and half-graben systems beneath the Paleocene break-up unconformity. d) The presence of

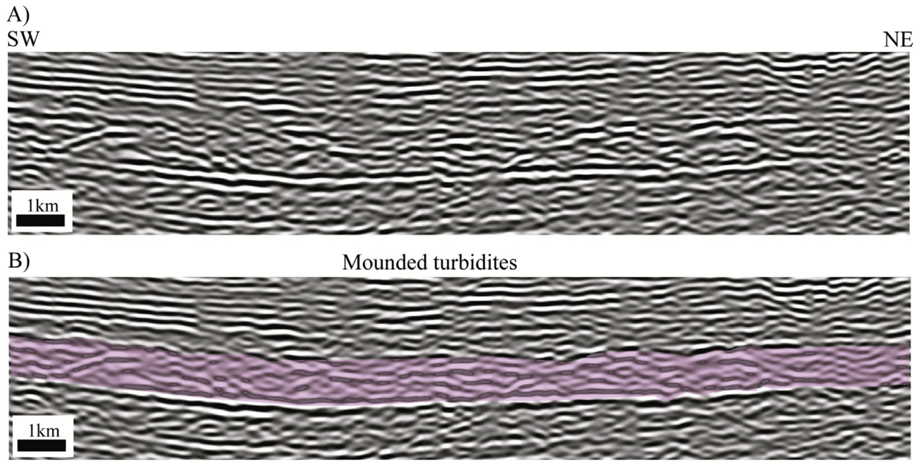


Fig. 16. Seismic line showing the gravity-driven deposits related to the post-rift section. See location in Fig. 3. A) Uninterpreted seismic line. B) Turbidite lobes deposited during Miocene characterized by mounded seismic facies.

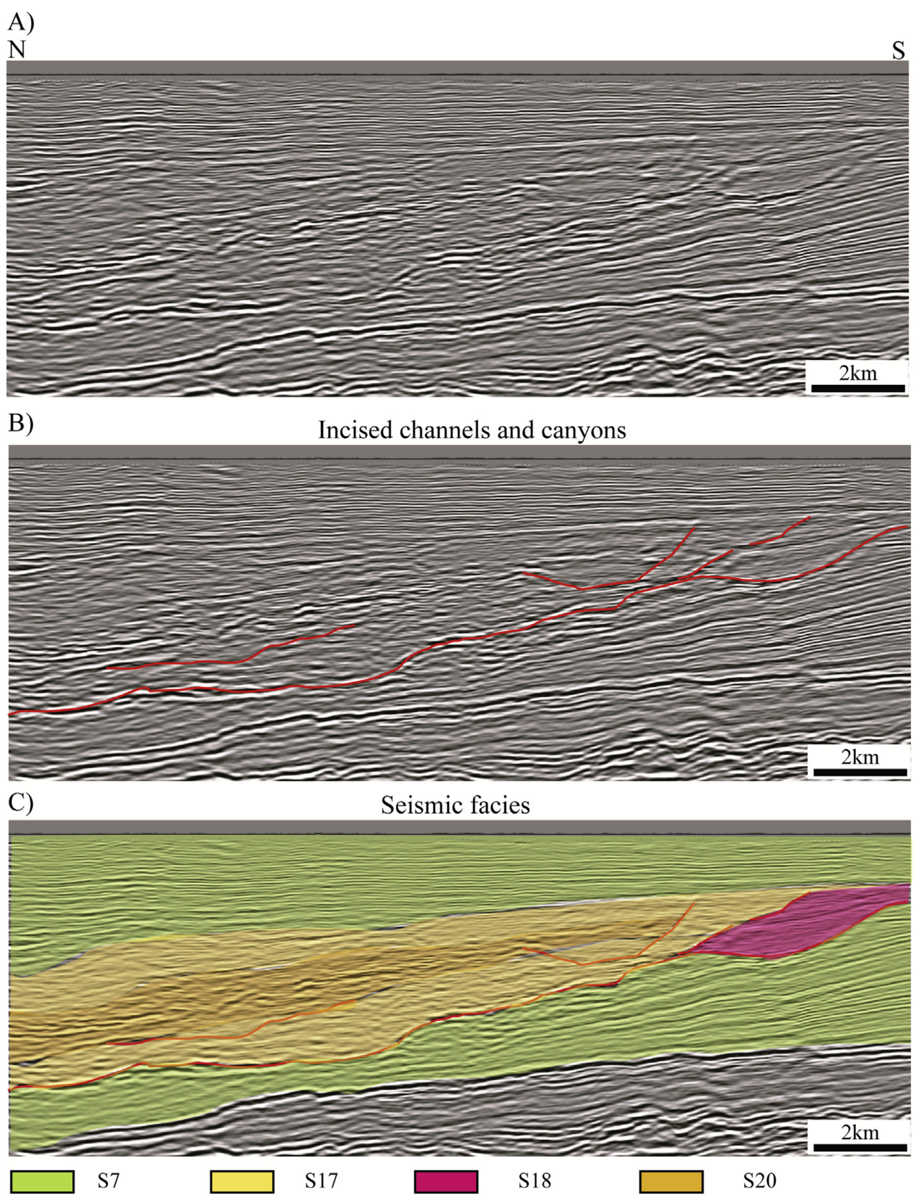


Fig. 17. Seismic line showing erosional surfaces related to channels and canyons in the post-rift section. See location in Fig. 3. A) Uninterpreted seismic line. B) Submarine Oligocene to Early Miocene channels and canyons. Observe seismic facies S7, which are related to pelagic to hemipelagic deep-water sediments.

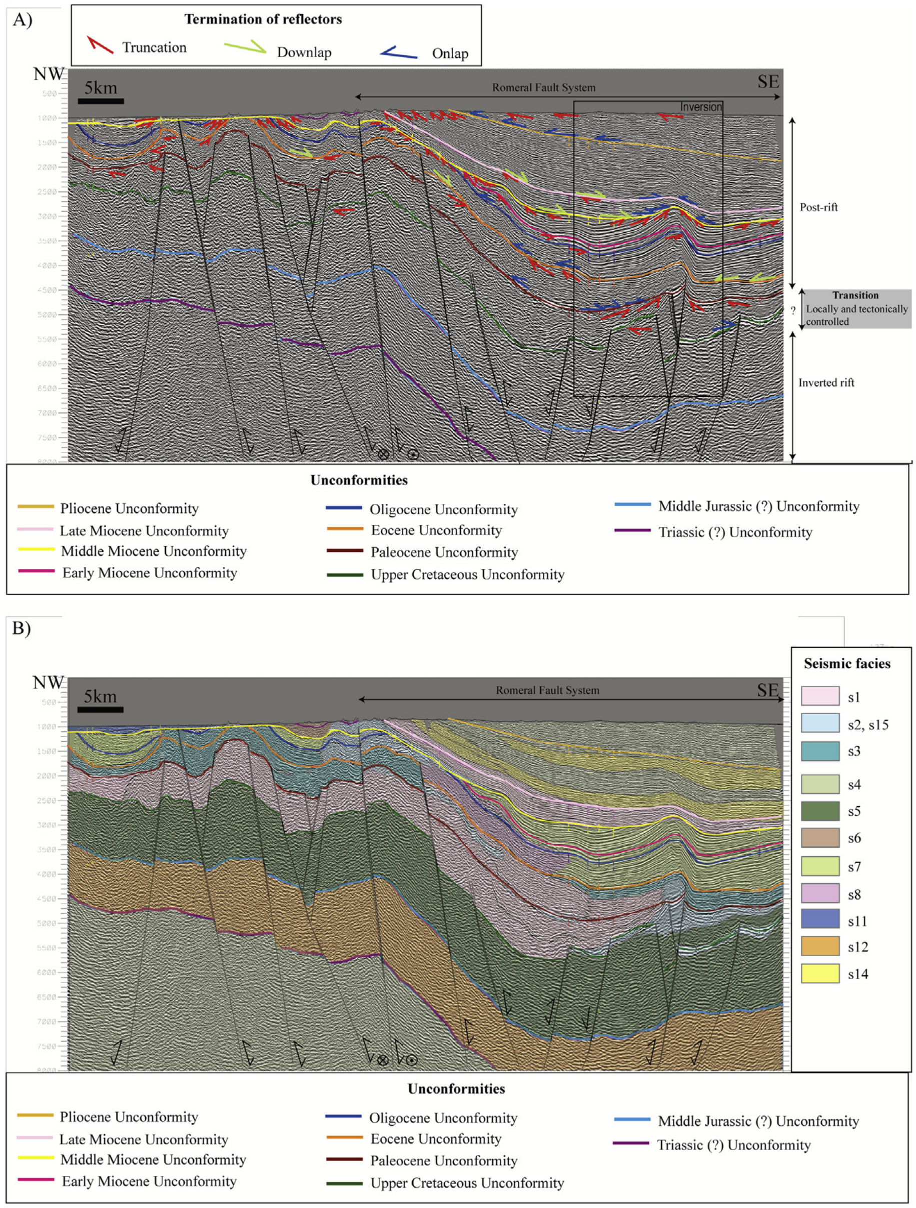


Fig. 18. Seismic line across the central zone. See location in Fig. 3 and 4. A) Seismic sequences delimited by terminations of reflectors (truncations, onlap and downlap). B) Seismic facies interpretation. Sequences of Jurassic to Paleocene are related to a rifting process. Description of seismic facies are shown in Table 1.

reflections with seismic facies (up to about 7 km thick) related to sediments deposited in fluvial, lacustrine and coastal plain settings during Triassic to Paleocene. e) The presence of extrusive Mesozoic-Paleocene subaerial mafic rocks, subaerial volcano-sediments and continental sediments (up to about 600 m thick), genetically associated to the normal faulting, observed in well and surface data and composed by interbedded angular/subangular conglomerates/sandstones, arkosic sandstones, greywacke, basalt flows, gabbro and tuffs.

We propose that this rift was in general diachronous from south to north based on the following observations: a) five rifting phases were identified in seismic data from the northern area. The rifting pulses were constrained from the Triassic, middle Jurassic, upper Jurassic, Cretaceous and Paleocene syn-rift sequences which display wedge-shaped geometry and progressively onlapping in the hanging walls, typical of syn-rifting processes. b) The presence of diachronic extensive faulting revealed by syn-tectonic sequences in the northern area. c) The presence of an irregular erosive Paleocene break-up unconformity (BU) at the top of the syn-rift succession in the northern zone. The post-rift sheet-drape sequences are onlapping onto the syn-rift successions. d) The Cretaceous sequence has a wedge-shaped geometry and onlap terminations at the base in the central zone. On the other hand, the Paleocene depicts erosive truncations and depocenters related to early uplifting pulses in this zone. This observation allows proposing that the rift ended during the Cretaceous in the central zone, before the finalization of rifting in the northern zone. e) The original structures related to the rifting are almost totally missed in the southern zone. Some normal faulting affecting Cretaceous strata could be related to the original rifting in this zone.

Studies of continental rifts worldwide suggests that “in the same way that tensile cracks in the side of a brick building generally follow the mortar between bricks, rifts initially follow the weakest pathways in the pre-rift materials” (Versfelt and Rosendahl, 1989).

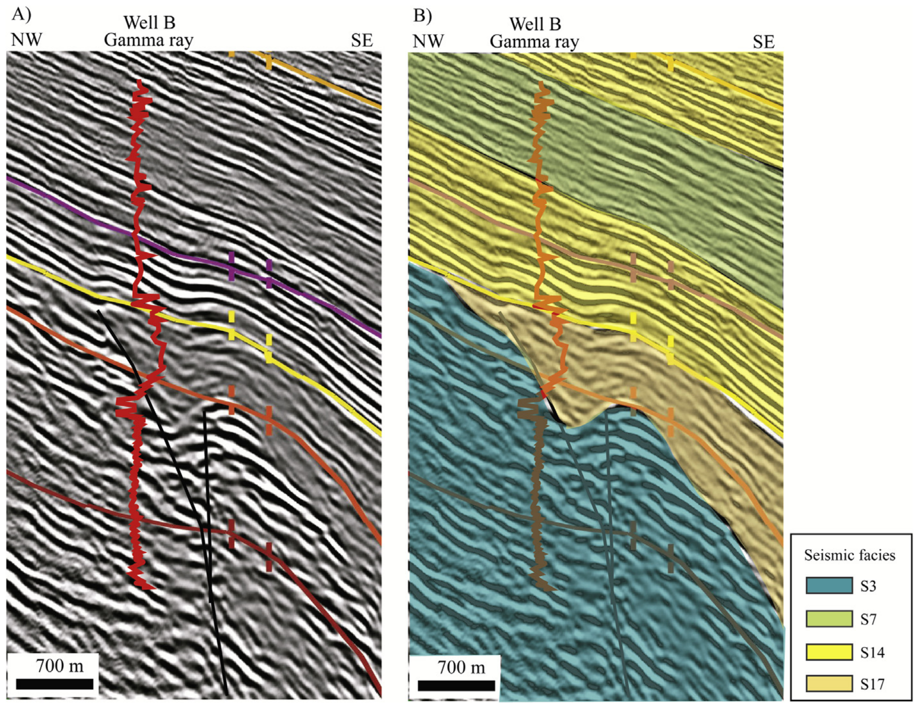


Fig. 19. Correlation between the seismic facies and the gamma ray response from well data. A) Uninterpreted seismic line. B) Repetitive successions of intermediate amplitude, high continuity and high frequency reflectors and low amplitude, high continuity and variable frequency seismic facies, related to fluvial-deltaic facies during Middle Miocene. Observe the correlation of these seismic facies with the gamma-ray response from well B.

Thus, since continental rifting results from the application of extensional stresses to a pre-deformed, anisotropic lithosphere, rift structures are not randomly distributed but tend to follow the trend of pre-existing weaknesses (such as ancient orogenic belts) avoiding stronger regions (such as craton; e.g., Dunbar and Sawyer, 1989; Versfelt and Rosendahl, 1989; Tommasi and Vauchez, 2001; Corti et al., 2003; Ziegler and Cloetingh, 2004) (Corti, 2009). Previous studies have suggested the same northeast-southwest structural/rifting trending, that has been observed in this study, along the Caribbean region, northern South America and southern North America (Trechmann, 1937; Contreras and Castillón, 1968; Bateson, 1972; Donnelly et al., 1973; Edgar et al., 1973; Case et al., 1980; Ghosh et al., 1984; Westercamp et al., 1985; Holcombe et al., 1990; Rosencrantz, 1990; Leroy et al., 1996; Bain and Hamilton, 1999; Diebold et al., 1999; Harry et al., 2003; Roberts et al., 2005; Sarmiento, 2001; Sarmiento et al., 2006; Andreani et al., 2008; James, 2009; Aristizábal et al., 2011). All these observations suggest that the rift location and initial evolution have been controlled by an NE–SW-trending lithospheric-scale pre-existing heterogeneity.

5.3. Post-rift

Post-rift succession depicts the typical features of passive margin settings predominantly in the northern zone. However, the central and southern zones show typical characteristics of tectonic inversion and a few passive margin features.

5.3.1. Passive margin

The northern zone (and partially the central and southern zones of the Sinú-San Jacinto Basin), depict the typical features related to passive margins between the Eocene to Miocene. These features are the following: a) the presence of Eocene to recent sheet-drape sequences onlapping faulted syn-rift sequences of continental origin. b) The presence of post-rift seaward-thickening (up to about 5 km thick) sediment clinoforms/prisms. c) The presence of post-rift sequences typically dominated by gravity-controlled deposition and deformation (slumps, turbidites, normal faulting). e) The change from continental syn-rift sediments to shallow marine and predominantly deep-water deposits in the post-rift succession.

Several analogous examples of intracontinental rift/passive margin basins can be founded around the world: the Red Sea Rifting (Augustin et al., 2014); the Colorado Basin, Argentina (Autin et al., 2013); the Artic margins (Buiter and Torsvik, 2014), the continental margin basins from Ireland to mid-Norway (Rockall, Faroe-Shetland and Vøring basins) (Ceramicola et al., 2005); the Main Ethiopian Rift (Corti, 2009); west Greenland (Buiter and Torsvik, 2014); the Wollaston Forland, East Greenland (Surlyk and Korstgård, 2013); the Namibian margin (Dauteuil et al., 2013) and the South Atlantic margins (Jackson et al., 2000; Karl et al., 2013).

5.3.2. Tectonic inversion

Observations from seismic data in the Sinú-San Jacinto Basin suggest a tectonic inversion predominantly in the central and southern zone from Paleocene to recent. Not all Mesozoic extensional faults were inverted (e.g. the northeastern zone). However, the northwesternmost part of the basin also depicts geological features related to tectonic inversion from Eocene to recent. These inversion features are: a) huge lateral changes in the thickness of stratigraphic units at ramp anticlines (due to earlier sedimentary wedges associated with normal faults that experienced reversal of fault movement producing uplift). b) The coexistence of both normal and reverse throws along the same fault surface. c) The presence of high-angle erosional unconformities. d) Deeper Cenozoic depocenters in the central zone that may be related to local flexural response of the lithosphere. e) The presence of sub-vertical positive flower structures.

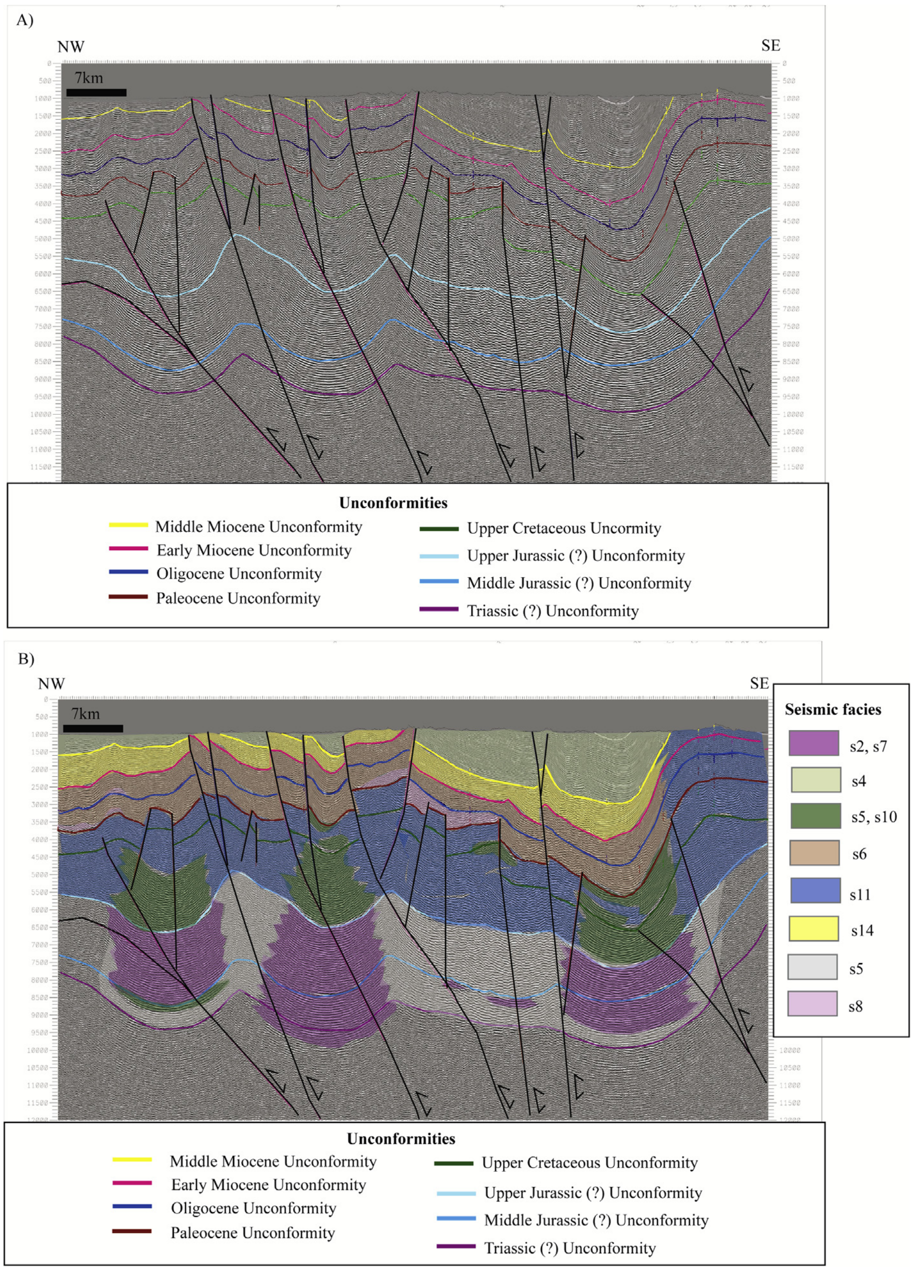


Fig. 20. Seismic line across the southern zone. See location in Fig. 3 and 4. A) Seismic line in the southern zone showing the seismic boundaries of each sequence. Several sequences have been controlled by flower structures. B) Interpretation of seismic facies in this profile. Description of each seismic facies unit is shown in Table 1.

We propose that the Mesozoic normal faults were inverted during Cenozoic, predominantly in the southern and central zones. This inversion was in general diachronous from south to north. We propose three phases of tectonic inversion: early uplift phase during Paleocene to Early Miocene; the climax uplift phase during Middle Miocene and the late uplift phase during the Late Miocene to recent. The following observations support the diachronic inversion event: a) the erosive Paleocene unconformity related to reverse sub-vertical faults in the central zone suggest the activity of the first pulse of inversion during Paleocene. This pulse was not generalized but locally occurred in the central zone. b) The presence of thick depocenters during Paleocene to Early Miocene and erosive unconformities suggesting that the early inversion continued to Early Miocene in the central zone. c) The presence of a high-angle erosive unconformity with a significant erosive hiatus (at least 10Ma) (Fig. 22) related to compressive regime during Middle Miocene. This event is interpreted as the climax of the uplifting phase. d) Growth strata onto the Middle Miocene sequence in the central zone are related to the late uplifting phase. e) The presence of the Pliocene high-angle erosive unconformity in the northern area is related to the late uplifting pulse. f) The Pliocene sequence is deformed and the Pleistocene to recent sequence is tilted due to the late phase of inversion in the central and southern zones.

5.4. Implications for the evolution models of the Caribbean plate and northern South America (Colombia and Venezuela)

There are two tectonic models to explain the origin of the Caribbean plate. The “allochthonous” model states that the

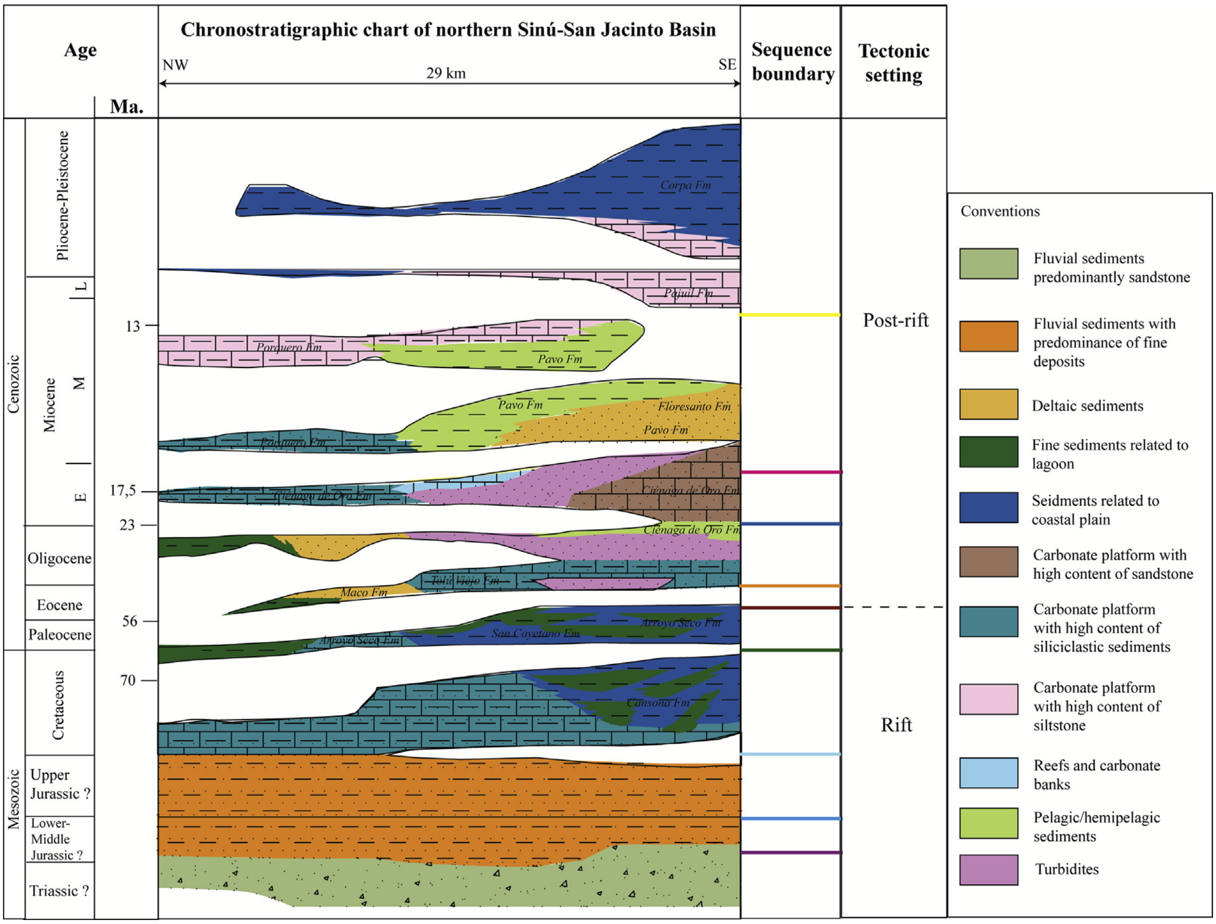


Fig. 21. Chronostratigraphic chart built from seismic profile in northern zone (Fig. 11), showing that carbonate platform changed to coastal plain facies during the finalization of the rifting event. Colours correspond to seismic facies as shown by Fig. 11. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Caribbean plate was formed during Upper Cretaceous in the vicinity of the present-day Galapagos hotspot in the Pacific Sea (Wilson, 1965; Malfait and Dinkelman, 1972; Burke et al., 1978, 1984; Pindell and Dewey, 1982; Duncan and Hargraves, 1984; Burke, 1988; Pindell et al., 1988; Ross and Scotese, 1988; Pindell and Barrett, 1990; Pindell, 1994; Kerr et al., 1996; Pindell et al., 1998; Kerr and Tarney, 2005; Pindell et al., 2005; Pindell and Kennan, 2009). The other model propose that the Caribbean plate was formed by the separation between North and South American plates during a Triassic to Jurassic intracontinental rifting (Ball et al., 1969; Stainforth, 1969; Skvor, 1969; Aubouin et al., 1982; Sykes et al., 1982; Klitgord and Shouten, 1986; Donnelly, 1989; Frisch et al., 1992; Meschede and Frisch, 1996; Giunta and Oliveri, 2009; James, 2005, 2006, 2009, 2012).

The depictured seismic facies of the Triassic and Jurassic sedimentary record are related to fluvial, lacustrine and flood plain settings in the Sinú-San Jacinto Basin, however, previous interpretations have studied just the Upper Cretaceous and Cenozoic record. These Triassic to Jurassic seismic facies are not adequately explained by the "allochthonous" origin of the Caribbean plate (Wilson, 1965; Malfait and Dinkelman, 1972; Burke et al., 1978, 1984; Duque-Caro, 1978; Kellogg and Bonini, 1982; Pindell and Dewey, 1982; Duncan and Hargraves, 1984; Burke, 1988; Pindell et al., 1988; Ross and Scotese, 1988; Pindell and Barrett, 1990; Pindell, 1994; Van der Hilst and Mann, 1994; Kerr et al., 1996; Pindell et al., 1998; Caro and Spratt, 2003; Flinch, 2003; Kerr and Tarney, 2005; Mantilla-Pimiento et al., 2005, 2009; Mantilla-Pimiento, 2007; Pindell et al., 2005; Pindell and Kennan, 2009; Cardona et al., 2010, 2012). According to the "allochthonous" model, the basement of the Sinú-San Jacinto Basin was formed during Upper Cretaceous, hence, should not have significant stratigraphic record older than Upper Cretaceous. However, in the present study we have observed the existence of a set of significant stratigraphic seismic facies older than Upper Cretaceous. These seismic facies are satisfactorily coherent with the *in situ* model, because, according to that model, the basement of the Caribbean plate was formed during Paleozoic/Precambrian and the Triassic/Jurassic sedimentary record was related to a rifting event (Ball et al., 1969; Stainforth, 1969; Skvor, 1969; Aubouin et al., 1982; Sykes et al., 1982; Klitgord and Shouten, 1986; Donnelly, 1989; Frisch et al., 1992; Meschede and Frisch, 1996; Giunta and Oliveri, 2009; James, 2005, 2006, 2009, 2012).

Three tectonic models have been proposed to explain the northern margin of South America, including the Sinú-San Jacinto Basin. The northern margin of the South American plate has been related to subduction processes of the Caribbean plate under South American plate during Cenozoic (Kellogg and Bonini, 1982; Van der Hilst and Mann, 1994; Taboada et al., 2000; Kellogg et al., 2005; Mantilla-Pimiento, 2007; Bayona et al., 2012). During the same time, the subduction of the Nazca plate under Caribbean and South American plates has been interpreted (Van der Hilst and Mann, 1994). Other models suggest that the obduction of the proto-

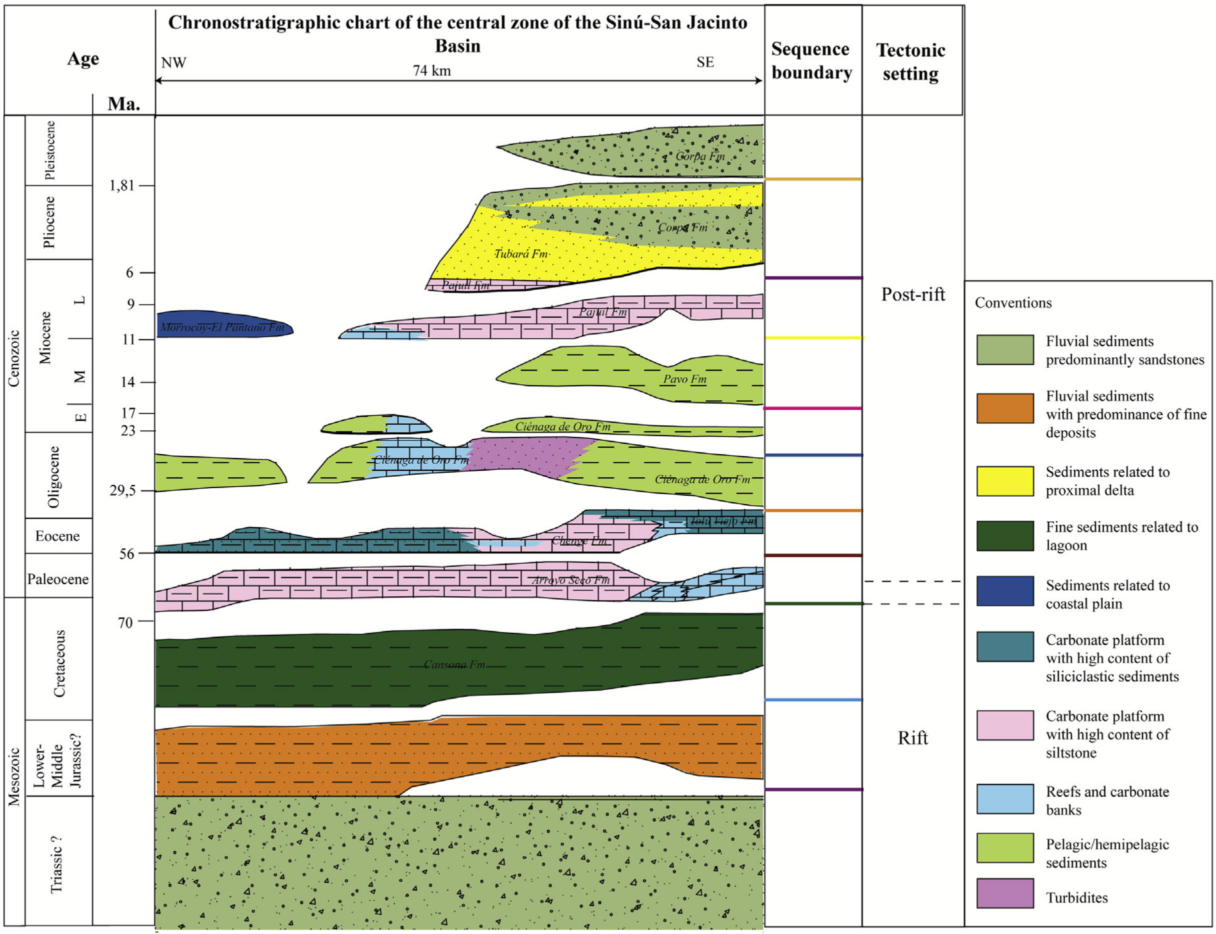


Fig. 22. Chronostratigraphic chart in the central zone built from seismic profile in Fig. 18. Colours correspond to seismic facies as shown by Fig. 18. Triassic (?) to Paleocene was characterized by deposition of continental to shallow marine facies. The Eocene facies consists in a wide carbonate platform. The Oligocene to Early Miocene correspond with deep-water facies related to rising of base level. During Middle Miocene to recent was deposited shallow marine to fluvial facies. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Caribbean oceanic crust over the South American plate during the Upper Cretaceous is followed by Neogene subduction and accretion, which is still active today (Flinch, 2003; Cardona et al., 2010, 2012). However, the Colombian Caribbean region (including the Sinú-San Jacinto Basin) doesn't show conclusive evidence of active magmatic arcs, significant seismic activity neither oceanic trench (Engdahl and Villasenor, 2002; Cortés and Angelier, 2005; Ekström et al., 2005) which are typical characteristics of subduction zones (Stern, 1998; Allen and Allen, 2005). On the other hand, we have observed the predominance of tectono-stratigraphic features typical of rift/passive margin settings and some inversion transpressive structures mainly during the Neogene, rather than the structures/stratigraphic signatures related to subduction processes. Our results are also consistent with the results of other studies (such as Walper, 1981; Audemard, 2002; Caro and Spratt, 2003; Rossello et al., 2004; Rossello, 2007).

5.4.1. Geologic continuity of the Sinú-San Jacinto basin and the northern South America (Colombia and Venezuela)

The major sequences identified in this study are equivalent to the sequences identified in the northern Colombia and Venezuela. Several authors have also recognized sequences related to Triassic to Cretaceous rifting in the Eastern Cordillera, Llanos and Magdalena Valley, northern Colombian Andes (Sarmiento et al., 2006). These sequences are typically continental to shallow marine deposits which are overlying Paleozoic rocks. Outcrops in the Upper Magdalena, Serranía de San Lucas and the western flank of the Eastern Cordillera suggest that continental deposits with redbeds and volcanic effusive and pyroclastic deposits are dominant in the Triassic to Jurassic successions (equivalent lithostratigraphic units: Motema, Palermo, Tiburon, La Quinta, Bocas, Giron, Jordan, La Rusia, Arcabuco, Luisa, Saldaña, Payande, El Sudan, Morrocoyal, La Mojana, Norean, Los Indios, Corual and Guatapuri) (Irving, 1975; Mojica et al., 1996; Sarmiento et al., 2006). Deposits related to continental, shallow marine and coastal plain settings have been identified along northeast-southwest grabens in the Middle Magdalena Valley and Eastern Cordillera basins (equivalent lithostratigraphic units: Rosablanca, Paja, Tibasosa, Las Juntas, Tablazo, Simití, Une, Chipaque, Labor, Dura, Gachetá, Guadalupe and Tierna) (Bürgl, 1967; Etayo-Serna and Laverde-Montaño, 1985; Fabre, 1985; Sarmiento, 1989; Villamil, 1993, 1994; Villamil and Arango, 1998; Sarmiento et al., 2006). A generalized Mesozoic rifting in the northern Venezuela (includes Maracaibo basin) and related-deposition of redbeds, lakes, volcanic and saline-lacustrine organic rich rocks have been also recognized by diverse authors (e. g., Summa et al., 2003; Bezada et al., 2008; Escalona and Mann, 2011). These observations are consistent with the Mesozoic syn-rift sequences recognized in this study.

General consensus indicates that during the Neogene, the Mesozoic extensional basin became inverted, deformed and

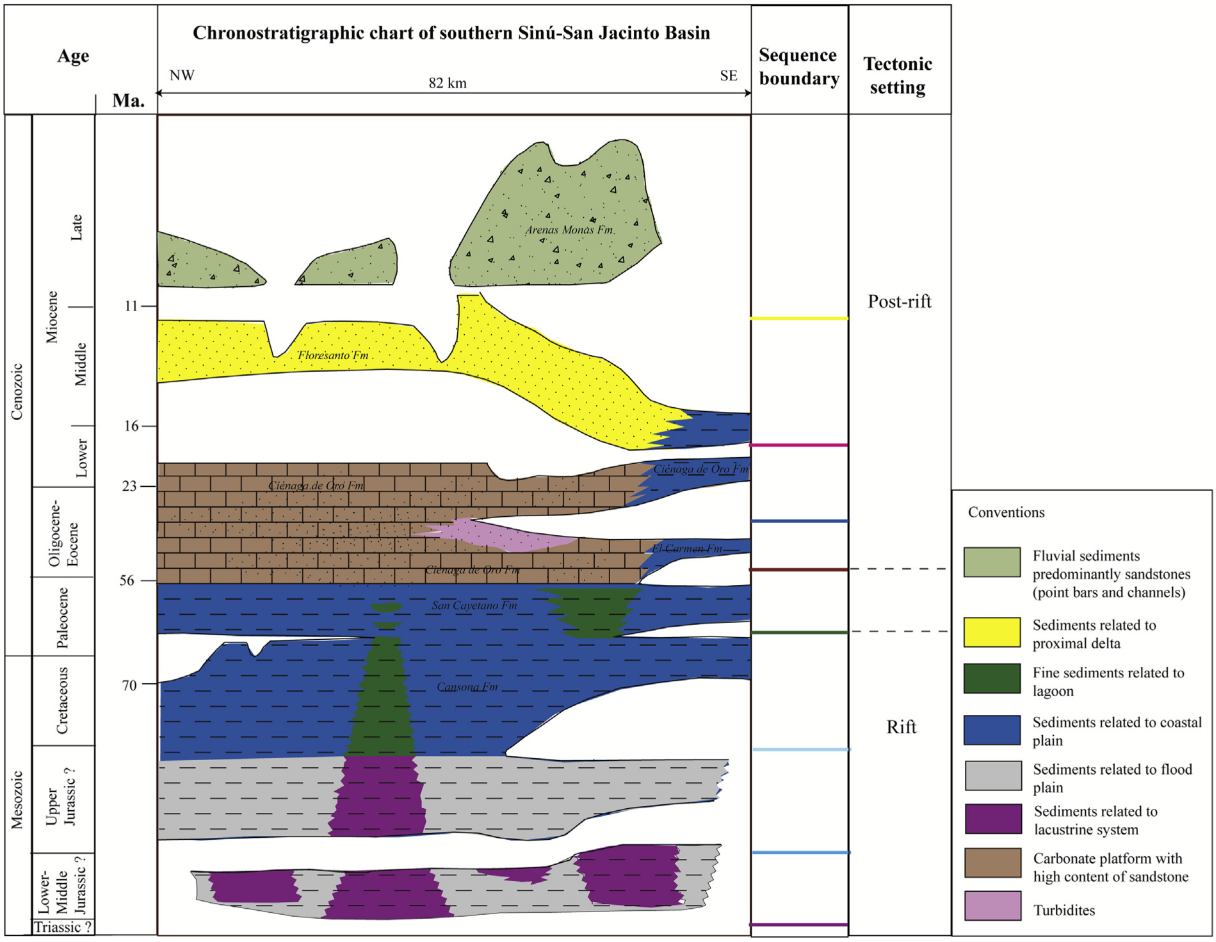


Fig. 23. Chronostratigraphic chart in the southern zone built from seismic profile in Fig. 20. Colours correspond to seismic facies as shown by Fig. 20. Observe the deposition of flood plain and lacustrine systems, which was related to early stages of rifting event. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

uplifted to form the Eastern Cordillera in Colombia (Cooper et al., 1995; Sarmiento, 2001; Sarmiento et al., 2006). In northern and northwestern Venezuela, (the Falcón, Bonaire, Blanquilla and Grenada basins) compressive structures, uplifting, mainly during Miocene, and recent strike-slip with compressive component during Recent have been also recognized (Audemard, 1995, 2009; Audemard et al., 1999; Audemard and Audemard, 2002; Summa et al., 2003; Jouanne et al., 2011). This generalized tectonic event in northern Colombia and Venezuela seems to correspond to the Cenozoic inversion event during the post-rift period that has been proposed in the present study.

The extraordinary correlation of the syn-rift and post-rift sequences in this study with the sequences in northern Colombia and Venezuela suggest a tectono-stratigraphic integrity of the Sinú-San Jacinto Basin with the northern South America, corroborating the *in situ* model for the origin of the Caribbean.

5.5. Trigger mechanisms, basin creation and subsidence

Intracontinental sags, rifts, failed rifts and passive continental margins fall within an evolutionary suite of basins unified by the process of lithospheric stretching (Allen and Allen, 2005). Passive margins represent special geodynamic features with two evolution stages: a first stage induced by the continental breakup associated with large tectonic and magmatic activities, and a second passive stage in response to the previous breakup dominated by thermal re-equilibrium and the large surface transfer of the material (Allen and Allen, 2005; Dauteuil et al., 2013). Thermal equilibrium generates subsidence of the thinned continental part and a small uplift of the non-stretched continent (Corcoran and Dore, 2005; Leroy et al., 2004).

5.5.1. Rifting mechanism

A considerable controversy exists about the role of the mantle during rifting, the subsequent formation of oceanic crust, and the precise nature of volcanism in the rifting process (Franke, 2013; Buiter and Torsvik, 2014). Meschede and Frisch (1998) proposed a model in which the Caribbean plate is an intra-American feature formed along the Caribbean spreading center as opposed to the model that considers the Caribbean plate as a far-travelled crustal segment that formed in the Pacific region. However, there is no evidence in the whole of Caribbean region, apart from the center of the Cayman Trough, of the presence of oceanic spreading anomalies and fractures (James, 2009). The Caribbean 'oceanic plateau' is thought by many to have been generated by a mantle plume (Kerr et al., 2009). However, since the Caribbean 'plateau' magmas formed at three different times and distant locations show similar petrological and chemical compositions, Révillon et al. (2000) questioned mantle plume genesis, noting instead that lithospheric thinning could produce the same melting conditions (James, 2009). Additionally, there is no indication anywhere in the Caribbean region of the radial strain expected over mantle plume

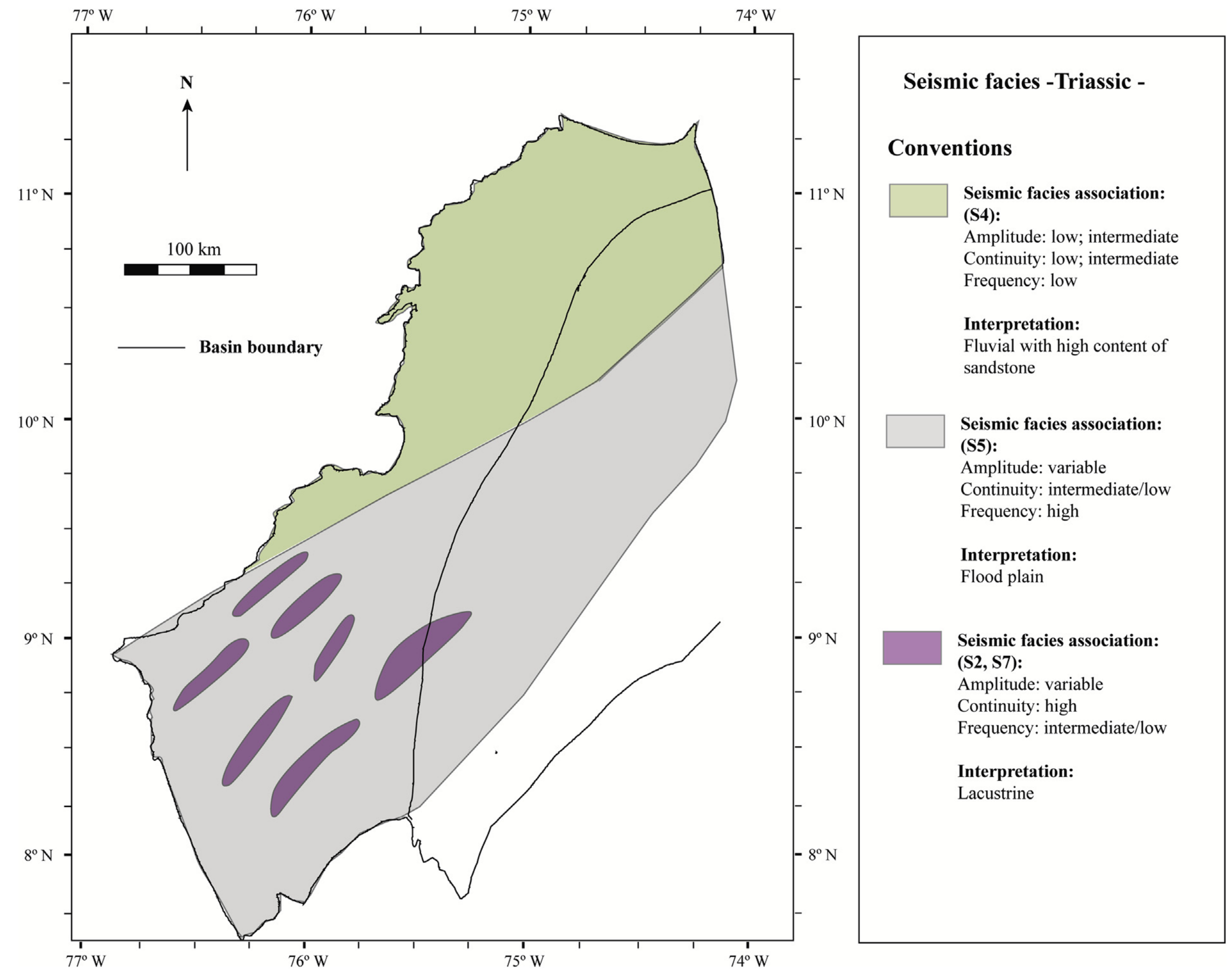


Fig. 24. Map of distribution of Triassic seismic facies. Note the predominance of continental facies. Initial rifting is characterized by lacustrine, flood plain and sandy fluvial facies during Early Mesozoic.

(Glen and Ponce, 2002). Instead, the whole of Middle America manifests NE structural grain that parallels Triassic – Jurassic rifts in neighbouring continental masses (James, 2009).

Traditionally active rifts are thought to evolve in response to thermal upwelling of the asthenosphere, whereas passive rifts develop in response to lithospheric extension driven by far-field stresses (Allen and Allen, 2005; Franke, 2013). Depending on the volumes of extension-related magmatism, two end-member passive margin types, either volcanic or magma-poor, are defined (Allen and Allen, 2005; Franke, 2013). Volcanic rifted margins evolve by extension accompanied by extensive extrusive magmatism over short time periods during breakup, manifested in reflection seismic data as seaward dipping reflectors. These margins are commonly related to mantle plumes (e.g., White and McKenzie, 1989). However, in the past years this has been questioned (Mutter et al., 1988; Anderson, 1988; Anderson, 1994; Keen and Boutiler, 1995; King and Anderson, 1998; Franke, 2013). Magma-poor rifted margins in contrast show wide domains of extended crust with wide-ranging extensional features as rotated faults blocks and detachment surfaces near the base of the continental crust, but limited magmatism that in addition seems to be systematically delayed to post-breakup (Franke, 2013).

Commonly, a breakup of the entire crust preceding breakup of the lithospheric mantle is a prerequisite for the exhumation of the mantle, one of the key findings at magma-poor margins, while at volcanic rifted margins the lithospheric mantle breaks before or at the same time with the crust to produce large volumes of syn-rift igneous rocks (Franke, 2013). However, nowadays these prerequisites are discussed. Recently, Buiter and Torsvik (2014) found that for the large igneous provinces, such as the North Atlantic margins (NAIP), Northwest Africa–Florida (CAMP), Arabia–Northeast Africa (Afar), and South Africa–East Antarctica (Karoo); the break-up occurs concurrent with emplacement of the associated large igneous province (LIPs). The same authors propose that in many of these margins, the rifting began before the main phase of volcanism. These authors indicate that rifting in these volcanic rifted margins was initiated by tectonic forces and that plume material ascended to the thinned rifted lithosphere to help trigger final continental break-up. Also, volcanic rifted margins (such as the Lavtep Sea, South China and South Atlantic margins) have been interpreted as response to lithospheric extension driven by far-field stresses. For these kind of margins, Franke (2013) reveals that a major controlling mode of deep, hot-spot related mantle processes on the rift evolution and rift-related magmatism cannot be observed. Instead, this author argues that passive margin evolution is controlled by several lithosphere-scale processes and parameters, including the mode of rift propagation and propagation barriers.

The accurate timing of the events when continental rifting initiated and ended, and when subsequent sea-floor spreading began is crucial to refine models of margin development (Franke, 2013). In this study, we propose that in the Sinú San Jacinto Basin

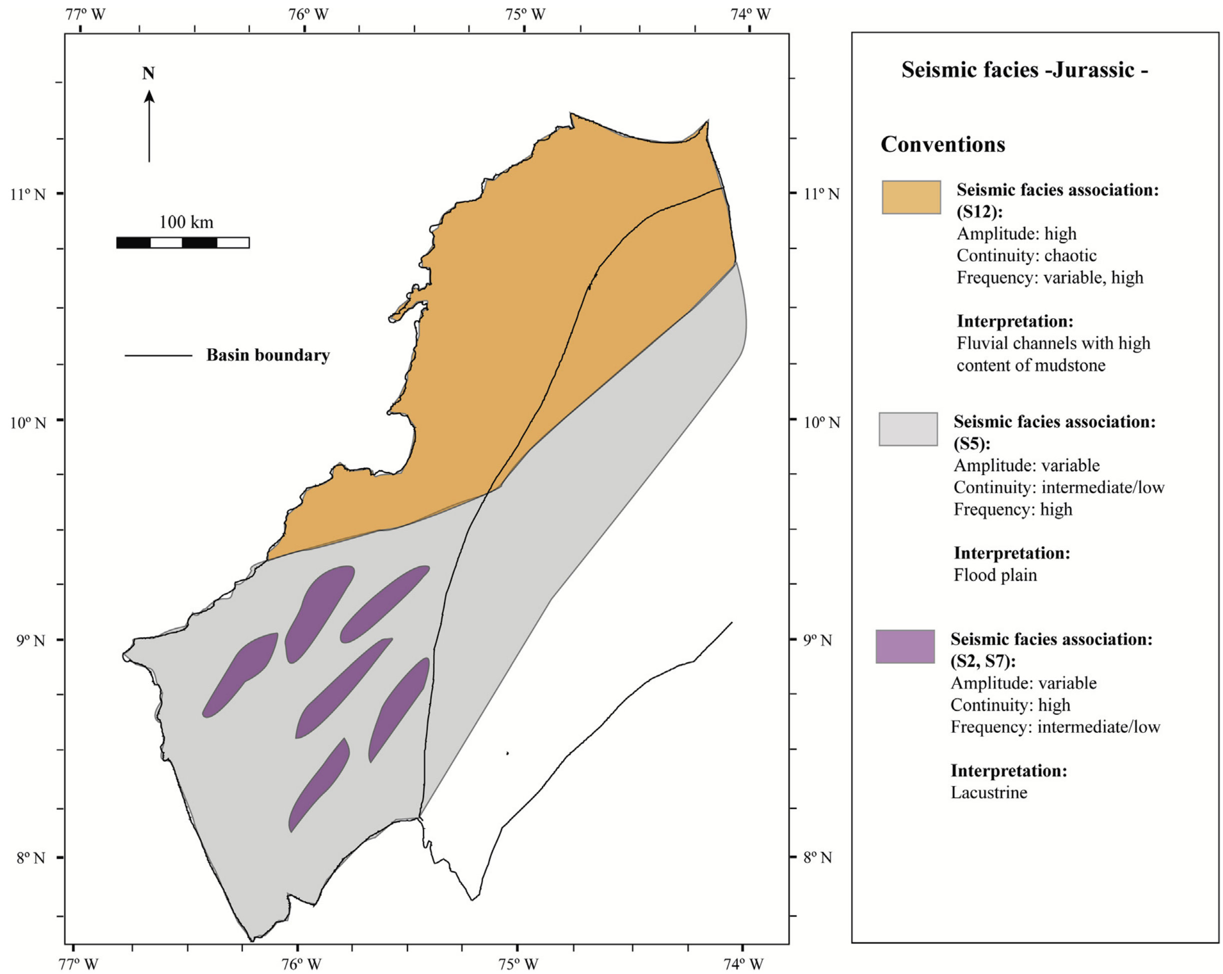


Fig. 25. Map of distribution of seismic facies of the Jurassic. Note the presence of muddy fluvial facies in the northern zone.

the rifting began before the main phase of volcanism from the following observation: the syn-rift sequences interpreted in the northern zone are suggesting that the rifting was active at least during upper Jurassic and continued during Cretaceous – Paleocene. On the other hand, the main phase of volcanism in the basin has been recognized since Upper Cretaceous (Gómez et al., 2007; Guzmán, 2007). Indeed, Révillon et al. (2000) have presented geochronological data from the Beata Ridge in the center of the Caribbean plateau that reveals a history of eruption extending over at least 30 Myr. Duque-Caro (1978, 1980, 1984, 1990); Duque-Caro et al. (1996a, b); Aleman (1983) and Guzmán (2007) have documented also mafic intrusions during Upper Cretaceous to Middle Eocene in the sedimentary successions of the San Jacinto sub-basin.

According to these observations it is proposed here that mode of rifting and the magnitude and timing of volcanism are controlled predominantly by relatively shallow processes (i.e. passive or plate driven) rather than by active, or plume-driven rifting. The absence of a mantle plume in the Caribbean has been also extensively discussed by James (2009), who states that this intracontinental northeast-southwest trending Mesozoic rifting was related to the separation (extreme extension) of the South American and North American plates during the Pangean break-up.

5.5.2. Mechanisms of tectonic inversion

Escalona and Mann (2011) proposed that the Late Jurassic-Early Cretaceous passive margin phase was interrupted by progressive west-to-east collision of the Caribbean arc with the passive margin in the Late Cretaceous in Colombia (Cooper et al., 1995); in the Late Paleocene–early Eocene in the Maracaibo basin region (Pindell and Barrett, 1990; Lugo and Mann, 1995; Mann et al., 2006; Escalona and Mann, 2006a,b); and during the Neogene in the area of eastern Venezuela and Trinidad (Erlich and Barrett, 1992; Babb and Mann, 1999; Di Croce et al., 1999; Pindell and Kennan, 2001). As a result of diachronous convergence between the South American and Caribbean plates, a more than 500-km-wide and 1500-km-long zone of transpressive and transtensional deformation and a series of sedimentary Cenozoic basins were formed along the margin (Pindell and Barrett, 1990; Lugo and Mann, 1995; Mann, 1999; Audemard and Serrano, 2001). In this study, we added that the Caribbean passive margin in Colombia was not interrupted by collisional events, but partially and locally affected by concurrent diachronic inversion pulses since Paleocene to recent.

Sinú-San Jacinto Basin depicts the classical characteristics of both Cenozoic tectonic inversion and passive margin settings. These two concurrent processes in the same basin are suggesting diverse and regionally/locally subsidence mechanisms (such as thermal subsidence and local tectonically induced subsidence). Indeed, Escalona and Mann (2011) have documented high rates of subsidence (more than expected by the sediment load) during Tertiary in the northeastern zone of South America. Summa et al. (2003) have been also recognized the generally post-rift eastward migration of broad depocenters across Venezuela that was supplemented by local, tectonically induced subsidence. Analogous processes are founded in the passive continental margin from

Ireland to mid-Norway (Ceramicola et al., 2005). Studies by Mutter (1984); Clift and Turner (1998); Nadin et al. (1997, 1999); Davis and Kusznir (2004); Ceramicola et al. (2005) suggest that the northwestern European margin has experienced large-scale departures from "normal" post-rift thermal subsidence which are invoking multiple rift episodes, subsidence of km-scale and/or other influences on subsidence such as post-rift uplift and permanent effects of the last episode of lithospheric extension and transient responses to its interaction with mantle.

The Sinú-San Jacinto Fold Belts and the regional unconformities in the Sinú-San Jacinto Basin have been related to the Andean Orogeny. Duque-Caro (1978) identified three tectonic events which controlled the evolution of this basin. According to this author, the pre-Andean Orogeny was characterized by uplift, folding and felsic plutonism and mafic volcanism during the Middle Eocene; the second event was characterized by diastrophism during Oligocene-Miocene and the third event correspond to uplift, folding, sedimentary volcanism and northeast normal and reverse faulting related to the main pulse of the Andean Orogeny during the Pliocene-Pleistocene. Duque-Caro (1990); Biju-Duval et al. (1982); Okaya and Ben-Avraham (1987); Mauffret and Leroy (1997); Jacques and Otto (2003); Benkovics et al. (2006); García-Senz and Pérez-Estaún (2008), also have recognized other regional unconformity related to the collision of the Panamá arc with the southwestern Caribbean along the Caribbean region during Middle Miocene. In this study we suggest that the Sinú-San Jacinto Fold Belts were related to diachronic tectonic inversion during the post-rift phase identified from seismic data. This inversion was controlled by the presence of pre-existing rheological heterogeneities such as normal syn-depositional faults and probably was related to pulses of the Andean Orogeny and the Panamá arc collision. We propose that the early, climax and late uplift phases may be correlated to the pre-Andean Orogeny and diastrophism; the Panamá arc collision; and the main pulse of Andean Orogeny, respectively and mentioned previously. Similar interpretations of the Sinú-San Jacinto Fold Belts have been provided by Caro and Spratt (2003).

Analogous models of evolution of passive margins and inverted rift with development of post-rift fold-belts/tectonic uplifting have been documented in the passive continental margin of Egypt (Korrat et al., 2005); southern Atlantic passive margin of Brazil (Karl et al., 2013); the passive margins bordering the Norwegian-Greenland (Lundin and Doré, 2002); the Zagros fold-and-thrust belt along the High Zagros Belt (Navabpour and Barrier, 2012); the North–Atlantic basins (such as Vøring, Møre, Northern North Sea, Faroe-Shetland, Rockall and Porcupine basins) (Praeg et al., 2005); the Saharan Atlas in Tunisia (Rigane and Gourmelen, 2011); the passive margin of northern South China Sea (Wu et al., 2014); the Chefchaouen area in Morocco (Vitale et al., in press); the western margin of South Africa (Viola et al., 2012); the Rhenohercynian fold-and-thrust belt in Belgium and Germany (Vanbrabant et al., 2002) and the Ligurian margin (Sage et al., 2011).

6. Conclusions

From this study we can conclude that:

1. Twelve seismic sequences were characterized, with fluvial, coastal plain and shallow to deep marine depositional systems related to diachronic rift and post-rift phases (passive margin and inversion) in the Sinú-San Jacinto Basin.
2. The sheet-drape post-rift section was characterized by passive margin settings in the northern part of the Sinú-San Jacinto Basin and diachronic tectonic inversion of older normal rift-related faults during Cenozoic predominantly in the central and southern zones
3. During Triassic to Jurassic rifting, seismic facies related to fluvial, lacustrine and flood plain settings were recognized. Sediments of Upper Cretaceous to Paleocene/Eocene were associated to continental to shallow marine settings. Lagoons, coastal plain and carbonate platform dominated during this period. The Oligocene to Middle Miocene record was characterized by deep-water deposition, whereas Late Miocene to recent was characterized by deltaic to fluvial deposition.
4. We propose three chronostratigraphic charts for the Triassic to recent strata from north to south of the Sinú-San Jacinto Basin, which represents typical deposition of rift and post-rift systems in the northern, central and southern zones in the Sinú-San Jacinto Basin, northwestern Colombia.
5. The stratigraphic record related to Mesozoic to Early Cenozoic rifting; the shallow marine sedimentation during Eocene and the tectono-stratigraphic continuity with the northern Colombia and northwestern Venezuela is coherent and well explained by the *in situ* origin of the Caribbean plate and is not explained by the "allochthonous" model.

Acknowledgements

The authors acknowledge the Agencia Nacional de Hidrocarburos of Colombia and Ecopetrol for supplying the seismic and well data which made the present study possible. Esteban Alfaro thanks Brazilian agency CAPES for Ph. D scholarship. Michael Holz acknowledges the Brazilian agency CNPq for personal research grant (PQ 303047/; 11-9).

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