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ARTICLE

Stratigraphic relationships between the Colombian, Sinú Offshore and Sinú-San Jacinto basins based on seismic stratigraphy

Relações estratigráficas entre as bacias Colômbia, Sinú Offshore e Sinú-San Jacinto baseadas em estratigrafia sísmica

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ABSTRACT: There are diverse controversial and contradictory models about the geological history of the Caribbean region. Some issues such as the origin of the Caribbean plate, the nature of basement of the Caribbean basins and the regional tectonics, have been in discussion during decades. There are disperse and punctual studies across the Caribbean. Application of seismic stratigraphy in regional seismic lines across the Colombian, Sinú Offshore and Sinú-San Jacinto basins suggests a stratigraphic continuity between these regions. A chronostratigraphic chart of the Colombian and Sinú Offshore basins based on stratal terminations and seismic facies was proposed. Seven stratigraphic stages were identified in the Colombian, Sinú Offshore and Sinú-San Jacinto basins, which, also, have been recognized across the Caribbean region. First stratigraphic stage was characterized by continental to restricted marine deposition during a Triassic/Jurassic rifting. Second, third and fourth stages correspond with deposition of a wide carbonate platform in the Cretaceous, sandy carbonate platform during the Paleocene and carbonate and coarse-grained fluvial sedimentation during the Eocene, respectively. Another stage was characterized by rising of base level and deep-water deposition (turbidites and pelagic/hemipelagic sediments) during the Oligocene. The Early to Middle Miocene was characterized by shallow marine to fluvial sedimentation during falling base level, which was controlled by episodic events of tectonic inversion. During the Late Miocene to recent, the sedimentation consisted of terrigenous coarse-grained deposits. Stratigraphic relationships between these zones, suggest a shared geological history between the Caribbean and northern South America. The geologic continuity founded in this study is easily explained by the model of an *in situ* origin for the Caribbean plate.

KEYWORDS: Caribbean; rifting; sequence; seismic stratigraphy.

RESUMO: *Existem diferentes modelos controversiais e contraditorios sobre a história geológica da região do Caribe. A origem da placa Caribe, a natureza do embasamento das bacias do Caribe e o contexto tectônico regional tem sido discutido durante décadas. Existem alguns estudos dispersos e pontuais na região do Caribe. A estratigrafia sísmica aplicada em linhas sísmicas regionais nas bacias Colômbia, Sinú Offshore e Sinú-San Jacinto sugere uma continuidade estratigráfica entre essas bacias. Neste estudo foi proposto uma carta cronoestratigráfica das bacias Colômbia e Sinú Offshore baseada em terminacões estratais e fácies sísmicas. Sete etapas estratigráficas foram identificadas nas bacias Colômbia, Sinú Offshore e Sinú-San Jacinto. Essas etapas também foram reconhecidas na região do Caribe. A primeira etapa estratigráfica foi caracterizada por deposição continental para marinho restrito durante um evento de rifting no Triássico/Jurássico. As segunda, terceira e quarta etapas foram caracterizadas pela deposição de extensas plataformas de carbonatos durante o Cretáceo, deposição de uma plataforma carbonática arenosa no Paleoceno e sedimentação carbonática e fluvial de grão grosso durante o Eoceno, respectivamente. Uma outra etapa foi caracterizada pelo aumento do nível de base e deposição marinha profunda (turbiditos e sedimentos pelágicos/hemipelágicos) durante o Oligoceno. O Mioceno Inferior e Médio foi caracterizado pela sedimentação marinha rasa para fluvial durante uma caída do nível de base controlada por eventos episódicos de inversão tectônica. Durante o Mioceno Superior até o presente a sedimentação foi principalmente terrígena de grão grosso. As relações estratigráficas entre as bacias Colômbia, Sinú Offshore e Sinú-San Jacinto sugerem uma história geológica comum entre o Caribe e o norte de América do Sul. A continuidade geológica proposta neste estudo é facilmente explicada pelo modelo in situ da origem da placa Caribe.*

PALAVRAS-CHAVE: *Caribe; rifte; sequência; estratigrafia sísmica.*

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INTRODUCTION

Intensive exploratory activities of resources have improved the understanding of continental basins in local scale in North and South America. However, there are diverse and disperse studies along the Caribbean region. The studied area consists of the Sinú-San Jacinto, Sinú Offshore and Colombian basins in the northwestern region of the Colombian Caribbean (Fig. 1). About the Colombian, Sinú Offshore and Sinú-San Jacinto basins there are some studies, such as, Duque-Caro (1990); Duque-Caro *et al.* (1996); Bowland (1993); Guzmán (2007); Bermudez *et al.* (2009) and Porras and Ortiz (2009), which reflect on the absence of geologic integration, with local to regional focus. These studies, also reflect interpretations based only on lithostratigraphic features; and interpretation of data premised on the model of an allochthonous origin for the Caribbean plate.

There are not studies about the relationship between stratigraphic record of the Sinú-San Jacinto, Sinú Offshore and Colombian basins, neither about the relationship of those records with the geology along the Caribbean region. According with the hypotheses of the model of an *in-situ* origin for the Caribbean plate, the Caribbean region shows a shared tectono-stratigraphic history from south of North America to north of South America (Klitgord & Shouten 1986; Donnelly 1989; Frisch *et al.* 1992; Meschede & Frisch 1996; Giunta & Oliveri 2009; James 2005, 2006, 2009, 2012).

The scope of this paper is: (1) to facilitate the correlation between the stratigraphic sequences of the northwestern zone of Colombia and the Caribbean region; (2) to demonstrate the stratigraphic continuity between the Colombian, Sinú Offshore and Sinú-San Jacinto basins; and (3) to propose a chronostratigraphic chart of the Colombian and Sinú Offshore basins using seismic stratigraphy procedure.

DATA AND METHODOLOGY

Seismic and well data were provided by the Ecopetrol and by the Agencia Nacional de Hidrocarburos of Colombia. Geological and age data were extracted from several well logs descriptions and biostratigraphic zones of some wells (Duque-Caro 2001) and from geological mapping (Gómez *et al.* 2007).

The seismic and well data were tied using a synthetic seismogram (Fig. 2). This seismogram was constrained from sonic log and checkshot data. The seismic sequences were defined by regional unconformities, using standard seismic interpretation procedure (mapping of stratal terminations) and seismic facies associations. Based on amplitude, continuity, frequency and geometry of seismic reflectors, a set of seismic facies units was mapped.

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.

The paleoenvironmental interpretations from seismic facies were correlated with these biozones and descriptions of drill-cores (Fig. 3). The typical deep-water and carbonate seismic facies found in this study have been detailed in several previous seismic facies models (*e.g.* Sangree & Widmier 1977; Galloway 2001; Posamentier & Kolla 2003; Posamentier & Walker 2006; Weimer & Slatt 2007).

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. We compiled and reviewed several published studies along the Caribbean region to produce a chronostratigraphic chart which summarizes the stratigraphic record and sequences of the Caribbean region.

RESULTS

Nine seismic sequences from the Jurassic period to the present were recognized in the Sinú Offshore basin. Twelve seismic sequences from the Triassic period to the present were recognized in the Sinú-San Jacinto basin.

Each sequence was characterized by upper and lower terminations of reflectors and seismic facies associations. A total of twenty seismic facies were recognized in this study (Tab. 1). Stratigraphic surfaces and seismic facies were correlated with several calibration wells; they provided lithological and sedimentological data (Fig. 3).

Triassic and Jurassic

Sinú-San Jacinto basin

The northern Sinú-San Jacinto basin is the best example of a Mesozoic rifting. Regionally the syn-rift sequences are thinning toward the eastern and western boundaries of the basin (Fig. 4). Seismic reflectors of these sequences are divergent toward the major normal faults, suggesting syn-rift deposition (Figs. 4 to 6).

The typical wedge-shaped geometry has been recognized in the Paleocene, Cretaceous and upper Jurassic sequences. High-amplitude, chaotic and low frequency reflectors are

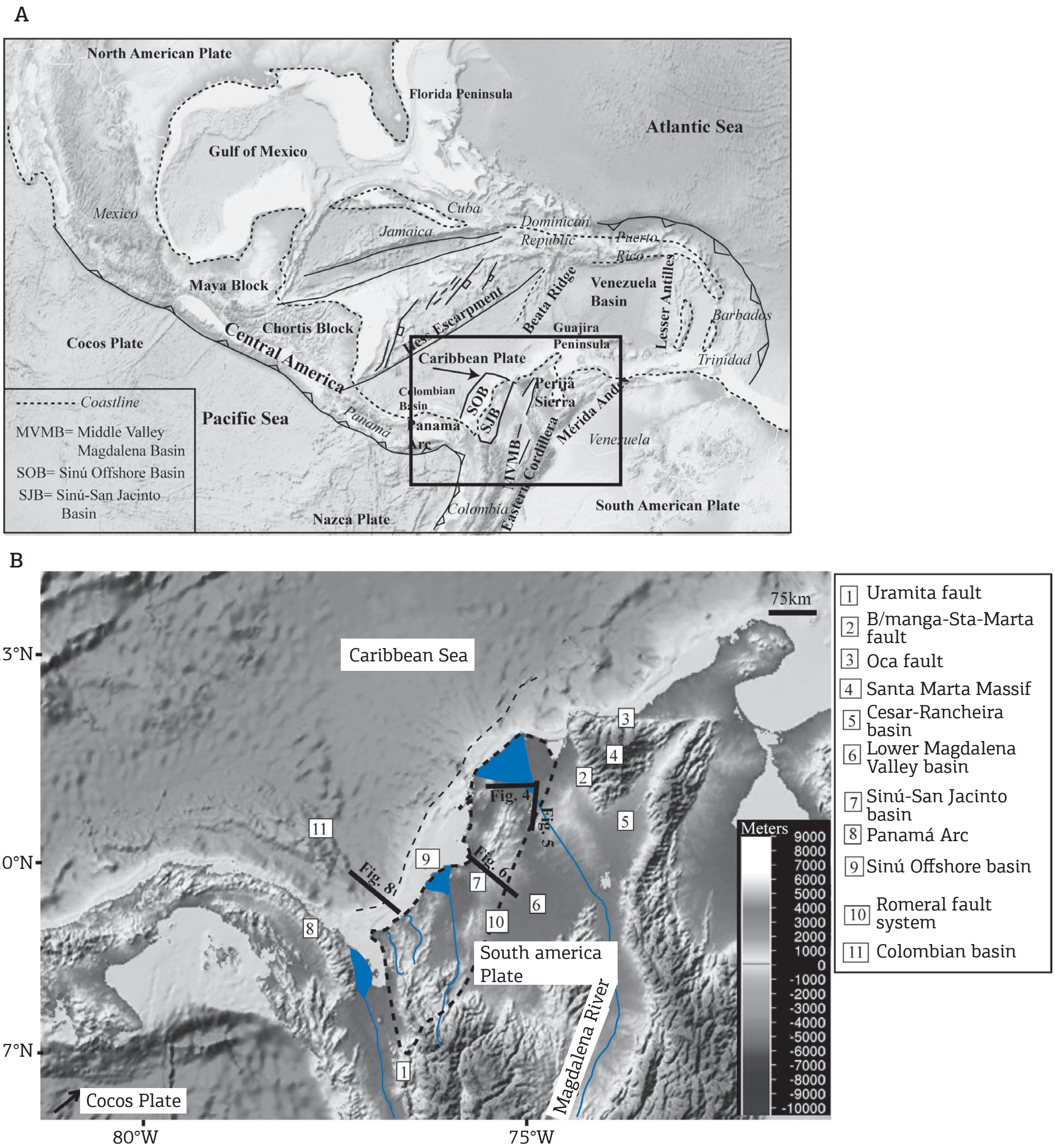
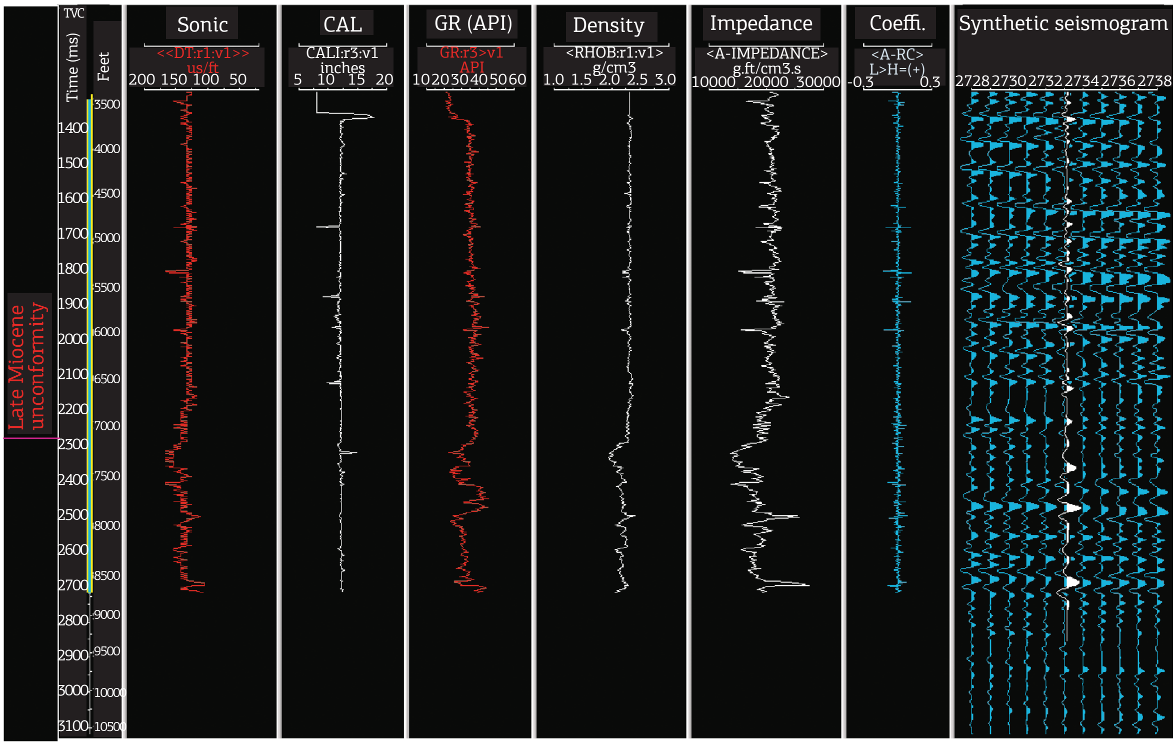


Figure 1. (A) The Caribbean region and the sedimentary basins of the northwestern area of Colombia. Black arrow indicates the relative motion of Caribbean plate respect to the South America plate (according to Egbue & Kellogg 2010). Note the oblique convergence between these plates. Rectangle in bold line shows location of figure in (B). (B) Location map of seismic lines (bold black lines). Structures compiled from Gómez *et al.* (2007) and 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).

typical of the Jurassic sequence in the Sinú-San Jacinto basin (Fig. 6).

In the southern and central zone, seismic facies show wide areas of variable amplitude, intermediate to low continuity and high frequency reflectors. Reduced areas of variable amplitude, high continuity and intermediate to low frequency reflectors are dispersed. Interpretation of seismic facies suggests fine-grained sediment of wide areas of flood plain systems with influence of lobate lacustrine areas shattered across flood plains (Figs. 6 and 7). Syn-depositional normal faults continue controlling sedimentation.



The synthetic seismogram was generated from checkshot data and a sonic log. CAL: caliper; GR: gamma ray; RC: reflection coefficient.

Figure 2. Well-seismic tie using a synthetic seismogram in the Sinú Offshore basin.

The Triassic record of the Sinú-San Jacinto basin is characterized by intermediate amplitude, low frequency and intermediate continuity reflectors, which are affected by syn-depositional high angle normal faults (Figs. 4 to 6). These seismic facies suggests the presence of continental sedimentation associated to grabens and hemigrabens during early stages of a rifting event. Coarse-grained fluvial sediments, fine-grained sediments related to flood plain and lacustrine systems are associated to this event (Figs. 6 and 7).

Sinú Offshore and Colombian basins

The Sinú Offshore basin was dominated by shallow marine sedimentation during the Lower Jurassic. Carbonate and fine-grained coastal plain sediments are typical in the Sinú Offshore area. Carbonate banks and reefs are characterized by high amplitude, high continuity and low frequency seismic facies (Fig. 8).

Sediments of coastal plain show low amplitude, chaotic pattern and variable frequency reflectors. The Colombian basin was filled by fluvial sediments during the Middle Jurassic. These sediments show intermediate to low amplitude, intermediate to low continuity and low frequency seismic facies. Deposition of coastal plain and fluvial sediments is recorded as growth strata related to high-angle normal faulting during a rifting event (Figs. 8 and 9).

Cretaceous

Sinú-San Jacinto basin

The Cretaceous sequence is characterized by variable amplitudes, intermediate to low continuity and high frequency seismic facies, which are shattered across wide areas of intermediate to low amplitude, low to chaotic and high frequency reflectors. Elongate and lobate lagoons placed across a wide coastal plain were deposited during that period.

Sinú Offshore and Colombian basins

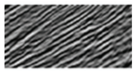
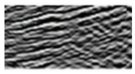
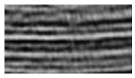
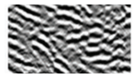
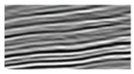
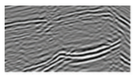
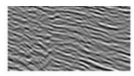
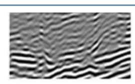
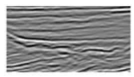
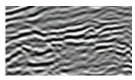
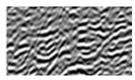
In the Sinú Offshore and Colombian basins, sedimentation was characterized by high amplitude, intermediate to low continuity and low frequency seismic facies related to a sandy carbonate platform with some carbonate banks and reefs.

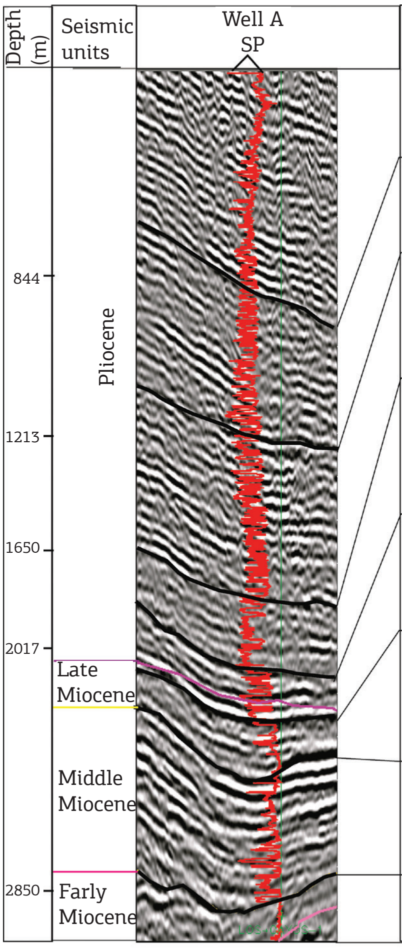
Paleocene

Sinú-San Jacinto basin

The Paleocene record is characterized by high amplitude, high continuity and high frequency seismic facies. Some zones show high amplitude, high continuity and low

Table 1. Seismic facies used in this study (Alfaro & Holz 2014).

Seismic facies type	Amplitude	Continuity	Frequency	Geometry	Ilustration
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			
S12	High	Chaotic	Intermediate/high		
S13	High	Chaotic	Low		
S14	Intermediate	High	High		
S15	Transparent			Blank	
S16	Intermediate	Chaotic/Low	High		
S17	Low	Chaotic	Low	Channel	
S18	Intermediate	Intermediate	Low	Channel	
S19	High	High	Low	Channel	
S20	High	Chaotic	High	Channel	



Seismic facies	Lithology	Geological interpretation
S4: Intermediate/low amplitude, intermediate/ low continuity, low frequency	Medium- to fine-graned, angular to subrounded sandstone intercaled with claystone. White, coarse - to medium- -grained, poorly sorted sandstone.	Fluvial enviroment with predominance of sandstone possibility 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, interediate/ low continuity, low frequency	Medium- to fine-grained, with sandstone.	Fluvial environment with predominance of sandstone possibility 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: Intemediate amplitude, high continuity, high frequency	Silty sandstone	Deltaic environment
S11: Low amplitude, variable continuity, low frequency		
S6: High amplitude, intermidiate/low continuity, low frequency	Carbonate siltstone. Evaporitic sandstone granding 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 galuconitic mica.	Gravity-driven deposits with high content of fine sediments

Figure 3. Seismic-well tie showing the correlation of the seismic facies and the description of drill-cores in the central Sinú-San Jacinto basin and electric logs (Alfaro & Holz 2014).

frequency reflectors. Interpretation of seismic facies indicates the development of a large-scale silty carbonate platform formed in the Sinú-San Jacinto basin.

Sinú Offshore and Colombian basins

In the offshore basins, seismic facies are characterized by low amplitude, high continuity and variable frequency reflectors. In the northernmost zone, reflectors have high amplitude, intermediate to low continuity and low frequency. Also, restricted zones with high amplitude, high continuity and low frequency seismic facies do occur.

During Paleocene, the Sinú Offshore and Colombian basins were controlled by deep-water sedimentation with some carbonate influence. Several carbonate banks and reefs were formed in the footwall of rift structures. Deep-water settings in these basins were related to late stages of a rifting event. During this period the sedimentation was contemporaneous with activity of normal faults.

Eocene

Sinú-San Jacinto basin

The Eocene sequence represents a wide carbonate platform. Three seismic facies related to carbonate settings were interpreted. Wide areas with high amplitude, high continuity and high frequency reflectors correspond with a silty carbonate platform. In the eastern and western zones, sedimentation was characterized by a carbonate platform with high siliciclastic input. Some seismic facies with high amplitude, high continuity and low frequency and zones with transparent seismic facies delimited by high amplitude reflectors suggest influence of carbonate banks and reefs.

Oligocene

Sinú-San Jacinto basin

The Oligocene was characterized by rising base level. Sedimentation was dominated by deep-water settings. Seismic

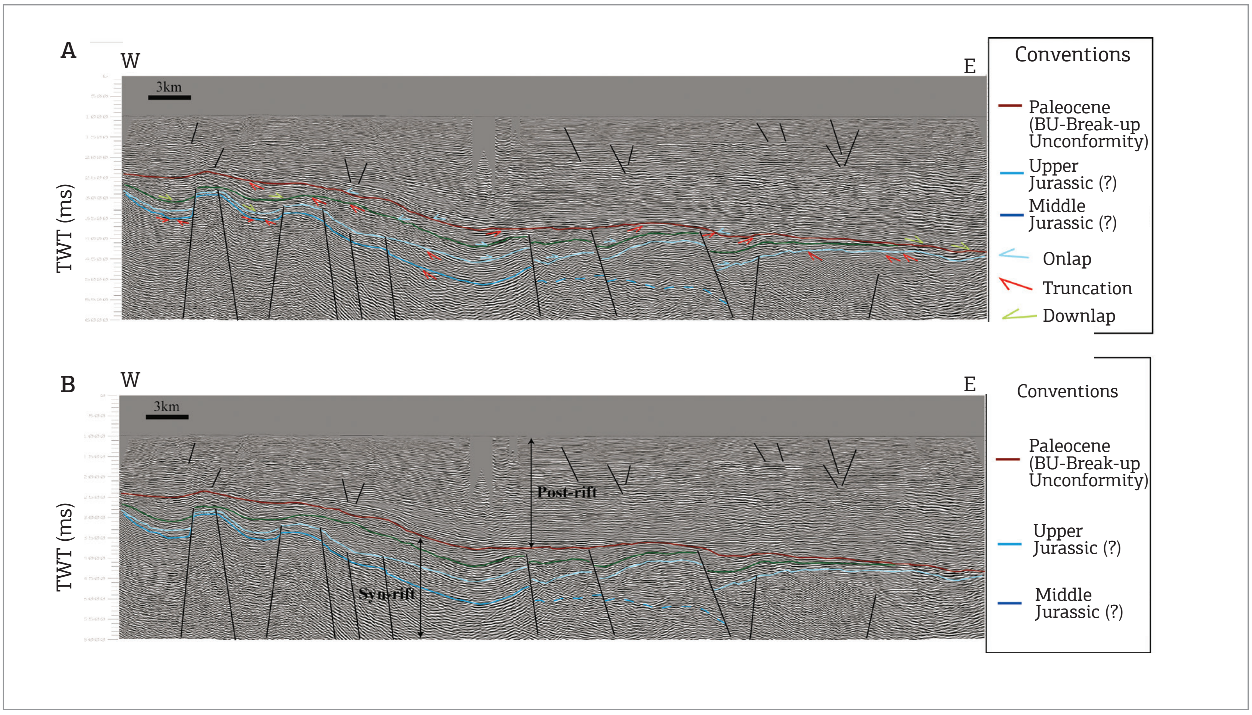


Figure 4. Rift/passive margin system in the northern Sinú-San Jacinto basin (Alfaro & Holz 2014). See location in Fig. 1. (A) Planar normal faults, wedge-shaped syn-rift Mesozoic sequences and divergent reflectors related to rifting processes. The final rifting is suggested by the break-up unconformity – BU. (B) Interpretation of the syn-rift (Middle Jurassic to Paleocene) and post-rift successions. Seismic line in time (ms).

facies consists of low amplitude, high continuity and variable frequency reflectors. Oligocene also was characterized by deposition of lobate turbidites, which show mounded seismic facies. The influence of carbonate banks also is evident in the Oligocene record.

Sinú Offshore and Colombian basins

The Sinú Offshore and Colombian basins were characterized by sedimentation on a slope system. Gravity-driven debris flow deposits were controlled by high angle slope and recorded seismic facies characterized by transparent to chaotic reflectors. Lateral changes of this seismic facies show hemipelagic to pelagic sedimentation toward the southern zone.

Miocene

Sinú-San Jacinto basin

Stratigraphic record of the Early Miocene in the Sinú-San Jacinto basin is poor. Seismic facies are characterized by low amplitude, high continuity and variable frequency reflectors. The Middle Miocene sequence was characterized by deep-water deposition. Seismic facies correspond to low amplitude, high continuity and variable frequency reflectors. Erosional truncations and growth strata, suggest a structural reactivation.

Older normal faults were inverted since Eocene and especially during Middle Miocene. Seismic facies of the Late Miocene sequence are characterized by high amplitude, high continuity and high frequency. Also, low amplitude, chaotic and variable frequency reflectors were identified in the western zone. This sequence is related with a silty carbonate platform and coastal plain settings in the western zone.

Sinú Offshore and Colombian basins

Seismic facies of the Early Miocene are characterized by low amplitude, high continuity and variable frequency reflectors. In the northernmost zone, seismic facies with wavy geometry were mapped. These seismic facies show lateral changes to high amplitude, high continuity and high frequency reflectors toward the southern zone, suggesting a south to north variation of depositional settings.

Facies are changing from mixed carbonate/siliciclastic platform in the south to deep-water settings characterized by slumps deposits in the northern area. These slumps are characterized by inclined reflectors related to depositional thrusting (Fig. 10).

The Sinú Offshore and Colombian basins show lateral changes similarly to Early Miocene ones. Mixed carbonate/siliciclastic seismic facies are located in the southernmost area. Increase in deposition of marine deposits related to

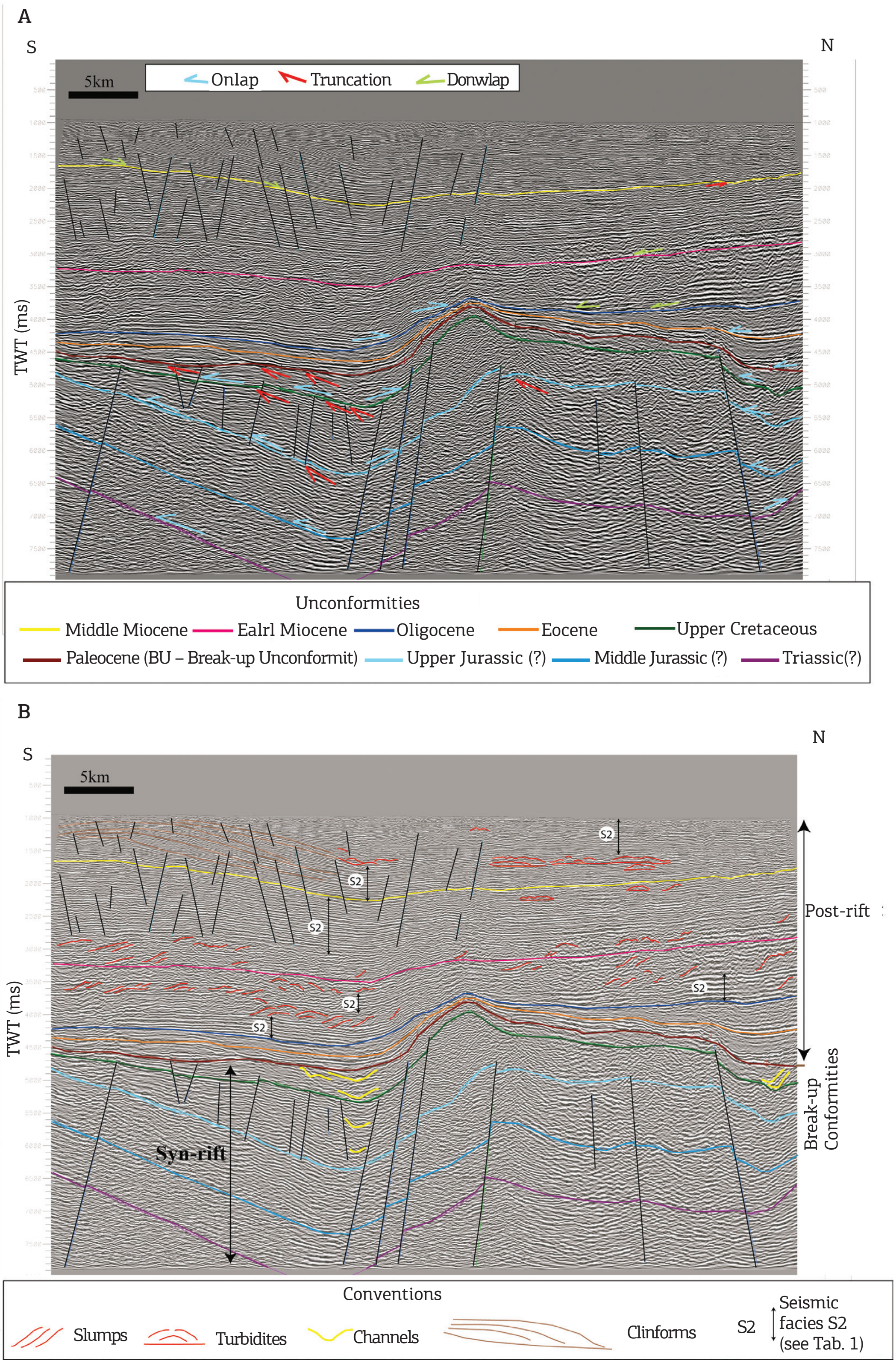


Figure 5. System of horst and hemi-graben in the northern Sinú-San Jacinto basin (Alfaro & Holz 2014). See location in Fig. 1. (A) Termination of reflections in the boundaries of the sequences. Observe the erosive truncations at the top of the Paleocene sequences (break-up unconformity – BU). (B) The syn-rift sequences with the wedge-shaped geometry and divergent reflectors typical of rift processes. Seismic line in time (ms).

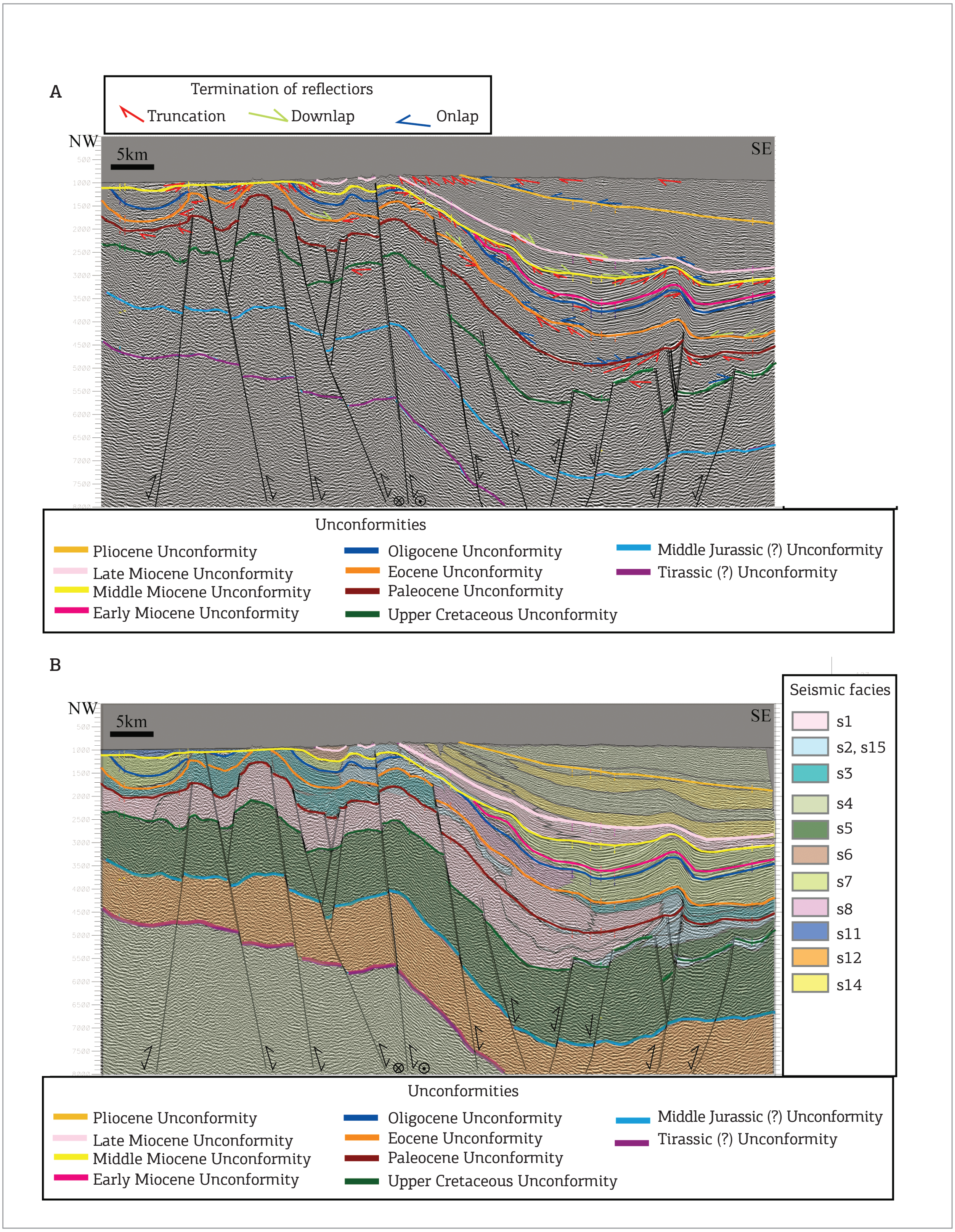


Figure 6. Seismic line in time (ms) in the central Sinú-San Jacinto basin (Alfaro & Holz 2014). (A) Interpretation of seismic sequences delimited by termination of reflectors in the central Sinú-San Jacinto basin. Note that these sequences are affected by a flower structure. Note the solution of focal mechanism in Fig. 1 suggests the dextral sense of strike-slip structure in this seismic line. (B) Interpretation of seismic facies. Description of each seismic facies unit is shown in Tab. 1. See location in Fig. 1.

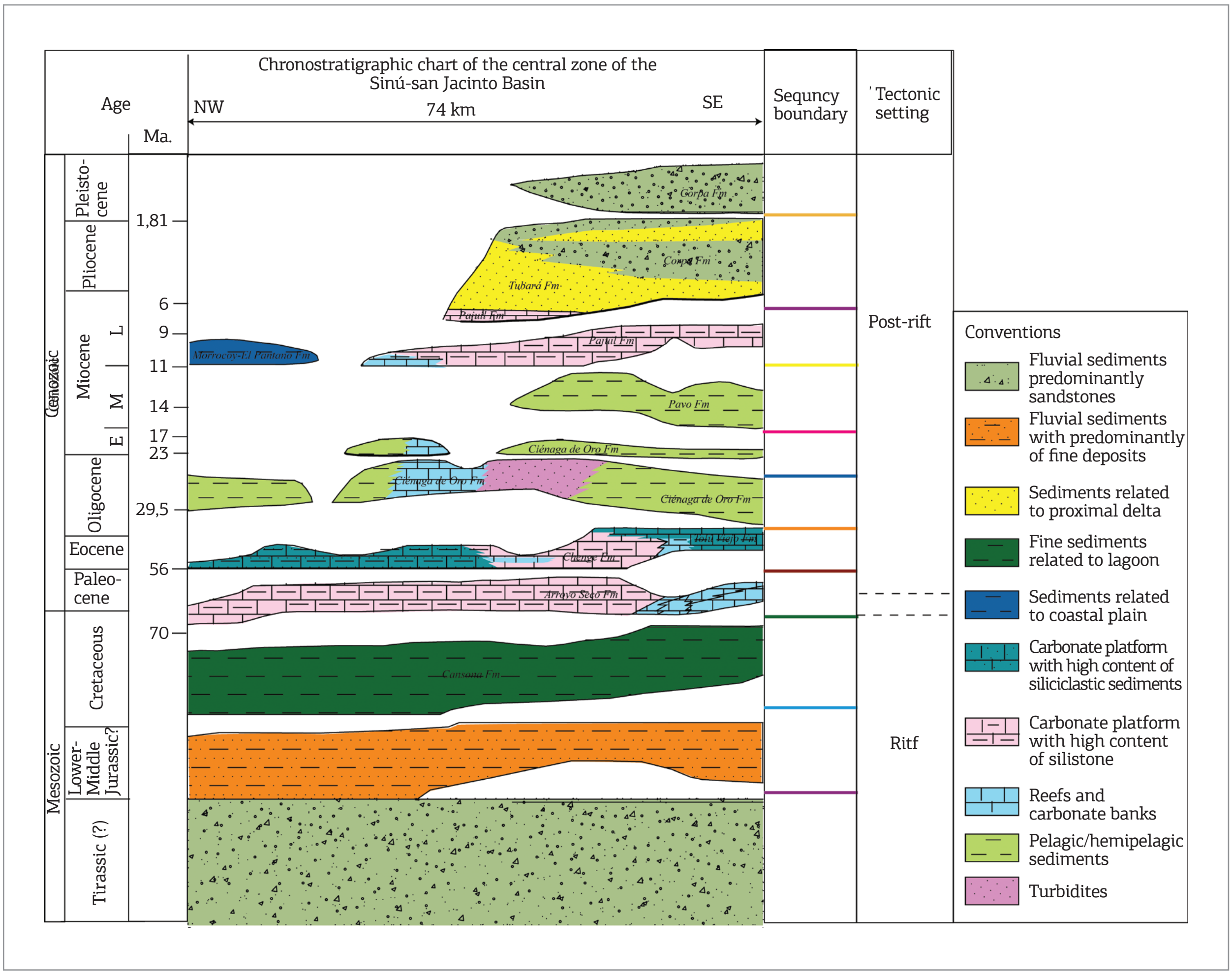


Figure 7. Chronostratigraphic chart built from seismic line in previous figure (Alfaro & Holz 2014). Note that the rifting event was characterized by continental to shallow marine sedimentation.

waves, debrites, submarine leveed channels and turbidites occurred in the Colombian basin (Fig. 11).

The Late Miocene sequence is seismically characterized by low amplitude, high continuity and variable frequency in the Sinú Offshore basin. In the Colombian basin, a sequence characterized by intermediate to low amplitude, intermediate to low continuity and high frequency reflectors was deposited. This basin also shows some zones of transparent seismic facies. During Late Miocene, the southern Sinú Offshore was dominated by a coastal plain, which was affected by a syn-depositional flower structure (Fig. 8).

Our proposal is that the oblique convergence between the Caribbean and South American plates (Fig. 1) suggests a transpressive regime, which has been controlled the falling base level and consequently the generation of incised channels in the Sinú Offshore basin (Fig. 12). The Colombian basin was affected by deposition on a mixed carbonate/siliciclastic platform with influence of some gravity-driven deposits controlled by a high angle slope.

Pliocene and Pleistocene-recent

Sinú-San Jacinto basin

The Pliocene sequence in the Sinú-San Jacinto basin is characterized by intermediate amplitude, high continuity and high frequency reflectors. Also, this sequence shows intermediate to low interbedded amplitude, intermediate amplitude and low frequency reflectors. This seismic signature indicates that the Sinú-San Jacinto area was dominated by highly siliciclastic sedimentation.

Deposition on a proximal deltaic setting was affected by episodic deposition of coarse-grained fluvial sediments. The Pleistocene to present is characterized by intermediate to low amplitude, intermediate to low continuity and low frequency seismic facies. This basin was dominated by fluvial sedimentation during Pleistocene to present.

Sinú Offshore and Colombian basins

The Pliocene sequence in the Sinú Offshore basin is characterized by variable amplitude, intermediate to low

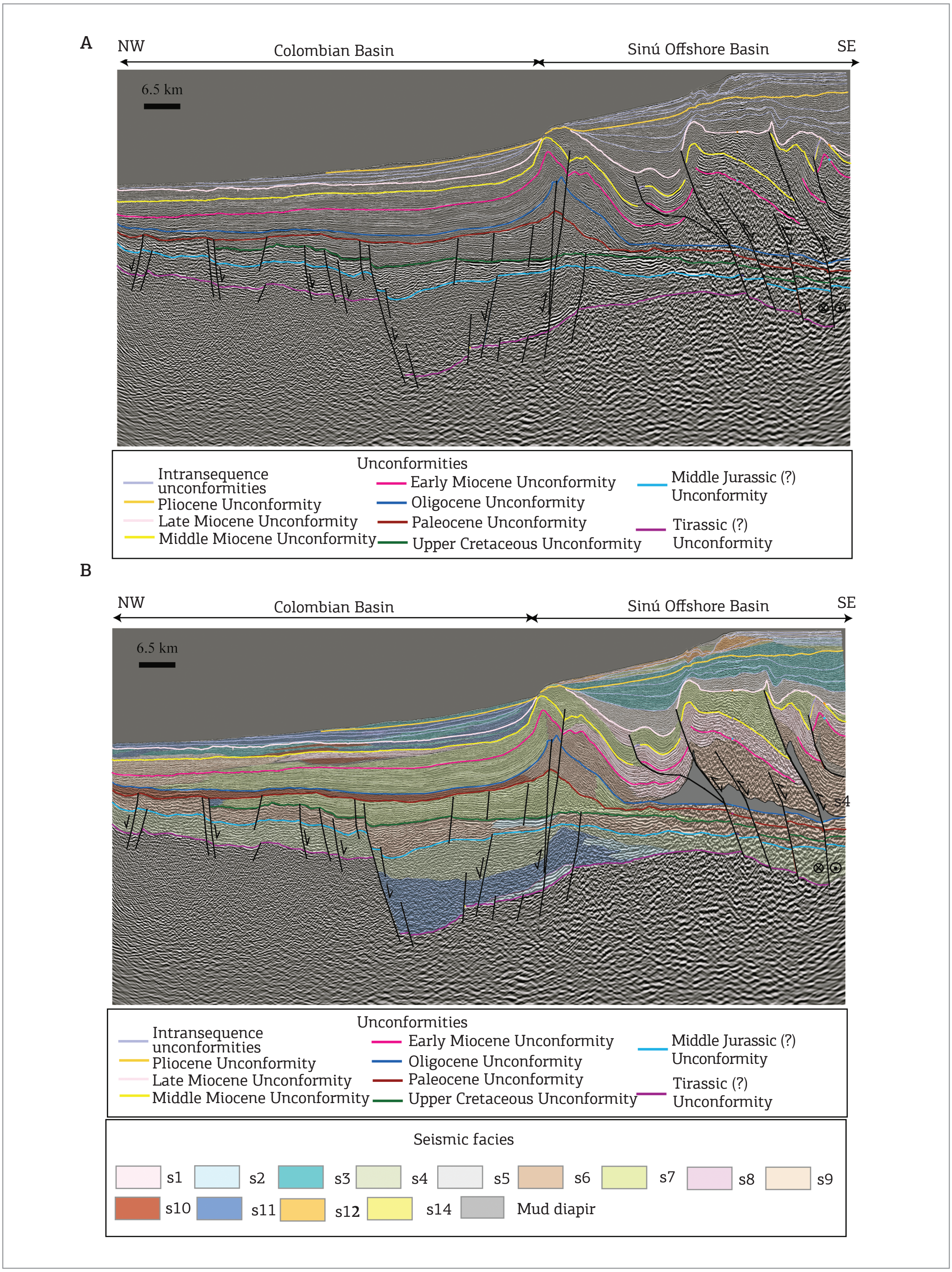


Figure 8. (A) Interpretation of nine seismic sequences in a seismic line across the Sinú Offshore and Colombian basins in the offshore Colombian Caribbean. Seismic line in time (ms). Note that the high-angle normal faults and flower structures observed in the onshore zone are also recognized in the offshore area. Observe that the solution of focal mechanism in Fig. 1 suggests the dextral sense of strike-slip structure in this seismic line. (B) Interpretation of seismic facies in the Sinú Offshore and Colombian basins in the offshore Colombian Caribbean. Description of each seismic facies unit is shown in Tab. 1. See location in Fig. 1.

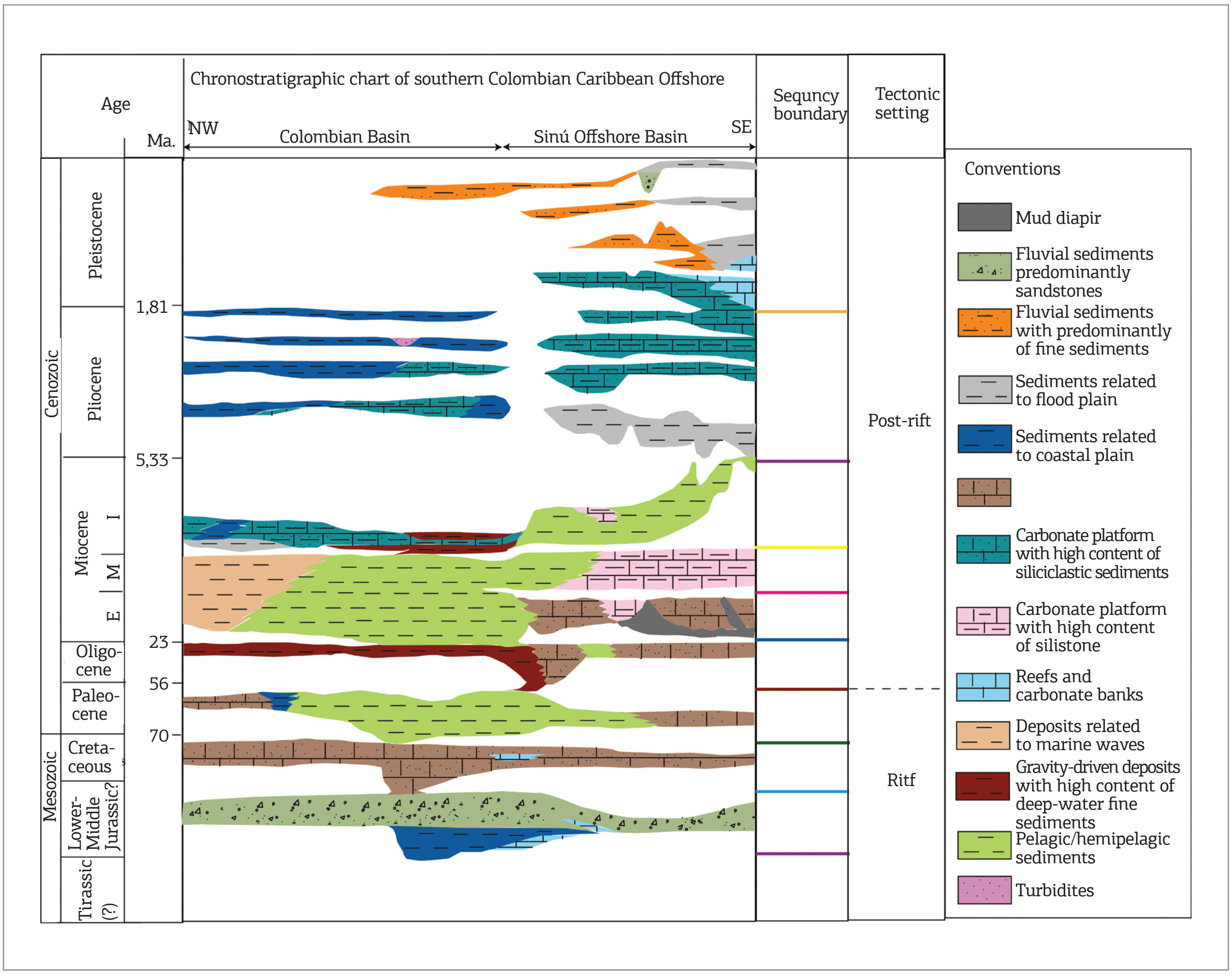


Figure 9. Chronostratigraphic chart across the Sinú Offshore and Colombian basins built from seismic line in previous figure. Observe that the rifting event was characterized by continental to shallow marine sedimentation. The Oligocene to Early Miocene was dominated by deep-water deposition during rising of base level, whereas, the Middle Miocene to recent was characterized by shallow marine to fluvial depositions.

continuity and high frequency seismic facies. This basin was dominated by mixed carbonate/siliciclastic sedimentation. Carbonate banks and reefs, also, were deposited in this basin. During Lower Pliocene, fine-grained sediments related to flood plain were deposited.

In the Colombian basin, the Pliocene sequence shows low amplitude, chaotic and variable frequency seismic facies. Reduced areas are characterized by variable amplitude, intermediate to low continuity and high frequency seismic facies. This suggests that sedimentation on a coastal plain with little influence of a mixed carbonate/siliciclastic platform dominated the Colombian basin during Pliocene.

The Sinú Offshore basin is characterized by high amplitude, chaotic and variable to intermediate to high seismic facies. Also, this basin show intermediate to low amplitude, intermediate to low continuity and low frequency reflectors. The Sinú Offshore basin was dominated by fine-grained fluvial channels and flood plain sedimentation during Pleistocene; however, there is influence of canyons related to high-angle slope during late stages of Pleistocene to the present. The Pleistocene to recent in the Colombian basin is characterized by high amplitude, chaotic and intermediate to high seismic facies. This basin was mostly characterized by development of fluvial channels.

DISCUSSION

Seismic interpretation in this study suggests that sedimentation was controlled by a diachronic rifting event in the Sinú-San Jacinto, Sinú Offshore and Colombian basins during the Triassic to Paleocene. This event correlates with the Mesozoic rifting previously documented across the Caribbean region. It also has been characterized

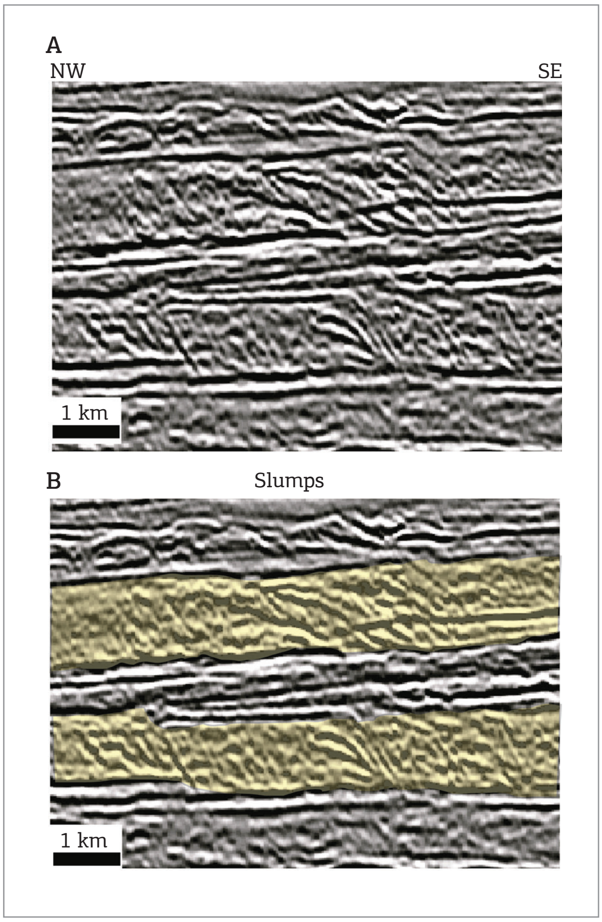


Figure 10. (A) Seismic line uninterpreted in the Colombian Basin. (B) Slumps deposits deposited during Early Miocene, across a high angle slope in the Colombian basin. Observe the depositional thrusts, which are suggesting a flow direction toward northwestern.

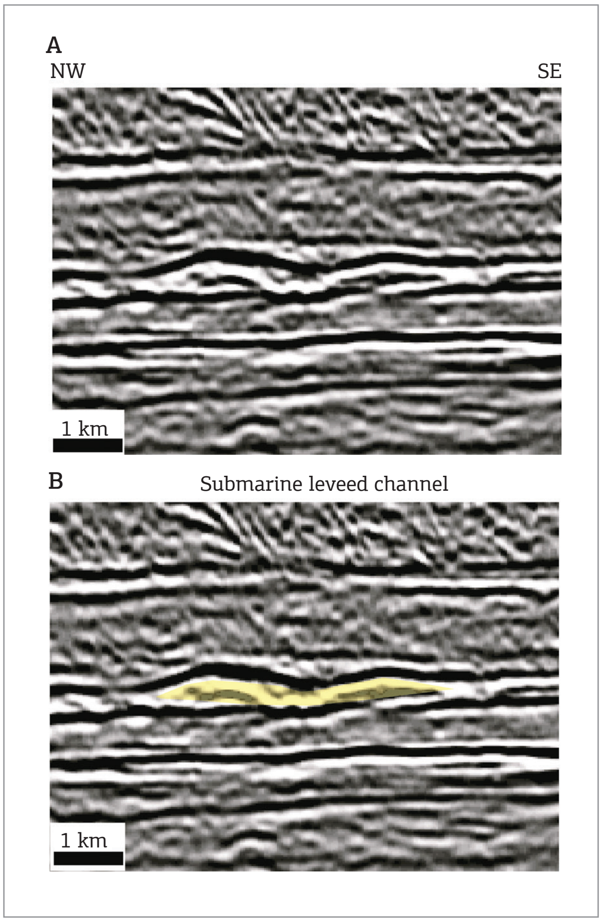


Figure 11. (A) Seismic line uninterpreted in the Colombian basin. (B) Submarine leveed channels deposited during Middle Miocene in the Colombian basin. Seismic line in time (ms).

by the formation of red beds and evaporites in the Gulf of Mexico; volcanism in Cuba; red beds, carbonates, volcanic sills and flows in the Guajira Peninsula and Mérida Andes; volcanic and red tuffs in the Santa Marta Massif; thick sequences of marine sediments in North Range of Trinidad; sediments of neritic settings in the western area of Cuba; thick successions of dolomite in north of Cuba; red beds in the Perijá Sierra and Eastern Cordillera in northern Colombia and Venezuela; thick red beds with a northeast direction in the Maya and Chortis blocks in Central America and grabens and horst with a northeastern direction (MacDonald 1964; Lockwood 1965, 1971; Rollins 1965; Álvarez 1968; Stainforth 1969; Bellizia 1972; Kugler 1972; Irving 1975; Pardo 1975; Walper 1981; Feo-Codecido *et al.* 1984; Maze 1984; Crawford *et al.* 1985; González & Lander 1990; McCollough & Carver 1992; James 2009) (location in Fig. 1).

A wide carbonate platform was deposited during Eocene in the Sinú-San Jacinto basin (Alfaro & Holz 2014). This depositional event is equivalent to sedimentation of chert interbedded with chalk and carbonate in the Beata Ridge and the Venezuela basin in the Caribbean offshore (James 2009) (location in Fig. 1). This chert event has been also documented in the Florida Peninsula; Lesser Antilles and has been related to the seismic horizon A´´ in the Caribbean offshore (Mattson *et al.* 1972; Edgar *et al.* 1973; Schlager *et al.* 1984; Roberts *et al.* 2005).

The Sinú Offshore and Colombian basins in this study, meanwhile, doesn't show evidence of Eocene record, which suggest a major erosive or non deposition event in these basins. This event is also suggested by low-sorting and thick flysch deposits in the Caribbean (Stainforth 1969; James 1997, 2005, 2006).

Flysch sediments and an erosive hiatus is documented in the Central America in the Rivas, Las Palmas and Brito formations; between the Maya and Chortis blocks; in the Guaniguanico Cordillera in Cuba; in the Richmond Formation in Jamaica; in the German Formation in

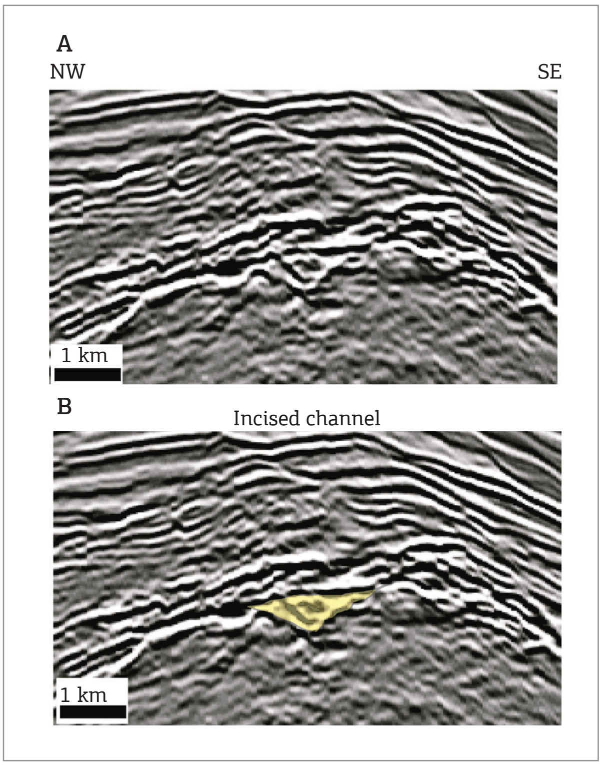


Figure 12. (A) Seismic line uninterpreted in the Sinú Offshore basin. (B) Incised channels seismically characterized by high amplitude, discontinuous reflectors and "V" geometry. Seismic line in time (ms).

Puerto Rico; in the Point-a-Pierre, Chaudiere and Lizard Spring Formations in Trinidad; in the Rincón Formation in Venezuela offshore; in the Scotland Group in Barbados; in the boundary of the Hess Escarpment and the Colombian Basin; in the Ocozocuautla Formation in southeastern Mexico; in the Parras and Chicontepec basins in northeastern Mexico, in the Veracruz Basin in eastern Mexico and in the Middle Valley of Magdalena Basin in Colombia (Dengo 1968; Mattson *et al.* 1972; Mossman & Viniegra 1976; Tardy *et al.* 1994; Mora *et al.* 1996; James 2009; Alfaro *et al.* 2013) (Fig. 1).

According to this study, lateral and vertical changes of seismic facies in the Sinú-San Jacinto, Sinú Offshore and Colombian basins, suggest a major falling base level event, during which shallow marine sediments shifted to continental sedimentation in the Miocene to recent. This event was characterized by a major pulse in the Middle Miocene, which, is recorded seismically in this study, as a regional erosive unconformity. This unconformity has been also recognized in Panamá, Dominican Republic and interior of the Caribbean plate (Biju-Duval *et al.* 1982; Okaya & Ben-Avraham 1987; Duque-Caro 1990; Mauffret & Leroy 1997; Jacques & Otto 2003; García-Senz & Pérez-Estaun 2008). This erosive event has been associated to the collision of the Panama Arc with southwestern Caribbean during Middle Miocene (James 2009; Duque-Caro 1990) (Fig. 1).

In the Interior Sierra in eastern Venezuela, occurred an important structural event during Middle Miocene. Erosive truncations of Miocene were observed in the southern boundary of Hess Escarpment (Alfaro *et al.* 2013).

According to the observations in this study, the Sinú-San Jacinto, Sinú Offshore and Colombian basins in northwest Colombia, show a shared geologic history. The seismic sequences of Triassic to recent in the Sinú-San Jacinto correlate with the sequences that have been interpreted in this study, in the Sinú Offshore and Colombian basins. These basins suggest events of shallow marine to continental sedimentation during a Mesozoic rifting.

The sequences deposited in the Oligocene and Early Miocene were characterized by deep-water sedimentation during an event of rising base level. The sequences of Middle Miocene to recent suggest major events of falling base level, which were characterized by shallow marine to continental settings. These observations suggest a stratigraphic and tectonic continuity between the Colombian, Sinú Offshore and Sinú San Jacinto basins.

Compilation from previous studies shows that the same sequences and events also can be traced along the Caribbean region (Fig. 13). Therefore, we suggest that the geologic features (tectonic and stratigraphic) founded in these basins have continuity along the Caribbean region. In fact, these observations are not adequately explained by the allochthonous origin of the Caribbean plate, due to the fact that the allochthonous model implies significant differences in the geological history of the Caribbean region, northern South America and southern North America.

According to the allochthonous model, the Caribbean plate was formed during Upper Cretaceous near to the present-day, in the Galapagos hotspot in the Pacific Sea (Burke 1988; Pindell *et al.* 1988; Kerr & Tarney 2005; Pindell & Kennan 2009). On the other hand, the geologic continuity observed in this study, is easily explained by the model of an *in-situ* origin for the Caribbean plate, which proposes a conservation of stratigraphic trends along the Caribbean region, northern South America and southern North America. According with *in-situ* model, 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 & Shouten 1986; Donnelly 1989; Frisch *et al.* 1992; Meschede & Frisch 1996; Giunta & Oliveri 2009; James 2005, 2006, 2009, 2012).

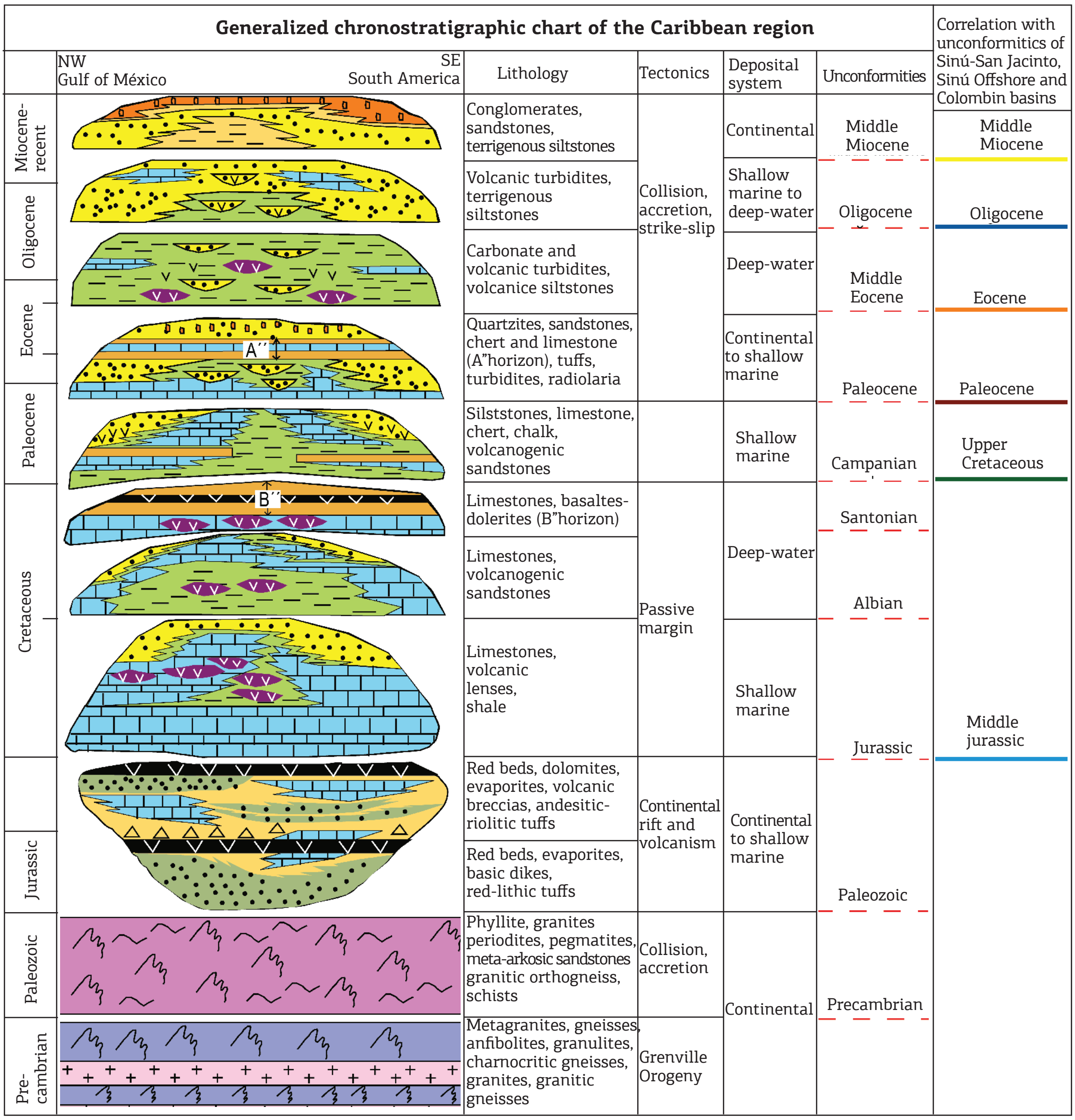


Figure 13. Generalized cronostratigraphic chart along the Caribbean region, from southern North America to northern South America and its correlation with sequences identified in the Sinú-San Jacinto, Sinú Offshore and Colombian basins. Observe a shared geologic history with the stratigraphic evolution of the Sinú-San Jacinto, Sinú Offshore and Colombian basins summarized in Figs. 7 and 9. Generalized cronostratigraphic chart proposed in this study along the Caribbean region, from southern North America to northern South America with information compiled from MacDonald (1964); Rollins (1965); Lockwood (1965, 1971); Álvarez (1968); Forero (1967); Burgl (1967); Radelli (1967); Dengo (1968, 1975, 1985); MacDonald and Hurley (1969); Skvor (1969); Stainforth (1969); Tschanz *et al.* (1969); Edgar *et al.* (1971); Hall *et al.* (1972); Kugler (1972); Mattson *et al.* (1972); Meyerhoff and Meyerhoff (1972); Wehrmann (1972); Kauffman (1973); Saunders *et al.* (1973); Bowin (1975); Irving (1975); Ludwing *et al.* (1975); Pardo (1975); Horne *et al.* (1976); Mossman and Viniegra (1976); Ortega-Gutiérrez (1978); Dickey (1980); Barker and McFarlane (1980); Rémane (1980); Abouin *et al.* (1982); Biju-Duval *et al.* (1982); Walper (1981); Bouysse (1984); Feo-Codecido *et al.* (1984); Mattson (1984); Maze (1984); Schlager *et al.* (1984); Crawford *et al.* (1985); Pereira (1985); Wadge and MacDonald (1985); Bourgois *et al.* (1987); Okaya and Ben-Avraham (1987); Sharp and Snoke (1988); Donnelly (1989); Frost and Snoke (1989); González and Lander (1990); Holcombe *et al.* (1990); McCollough and Carver (1992); Restrepo-Pace (1992); Bowland (1993); Tardy *et al.* (1994); Driscoll *et al.* (1995); James (1997, 2005, 2006); Mauffret and Leroy (1997); Muñoz *et al.* (1997); Ysaccis (1997); Lewis (2002); Jacques and Otto (2003); Wright (2004); Roberts *et al.* (2005); Nance *et al.* (2006); Rogers and Mann (2007); García-Senz and Pérez-Estaun (2008); Cooney and Lorente (2009) and Trainor *et al.* (2011). Seven stratigraphic stages were identified in the Colombian, Sinú Offshore and Sinú-San Jacinto basins, which, also exist along the Caribbean region.

CONCLUSIONS

According with this study, we can conclude that:

1. Seven stratigraphic stages were identified in the Colombian, Sinú Offshore and Sinú-San Jacinto basins, which, also can be traced across the Caribbean region. This fact suggests a tectonic and stratigraphic continuity between these zones.
2. First stratigraphic stage was characterized by continental to restricted marine deposition during a Triassic/Jurassic rifting. Second, third and fourth stages correspond with deposition of a wide carbonate platform in the Cretaceous, sandy carbonate platform during the Paleocene and carbonate and coarse-grained fluvial sedimentation during the Eocene, respectively. Another stage was characterized by rising of base level and deep-water deposition during the Oligocene. The Early to Middle Miocene was characterized by shallow marine to fluvial sedimentation during falling base level, which was controlled by episodic events of tectonic inversion. During the Late Miocene to recent, the sedimentation consisted of terrigenous coarse-grained deposits.
3. This geologic continuity is easily explained by the model of an *in situ* origin for the Caribbean plate.

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