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Chronology and geology of an Early Miocene mammalian assemblage in North of South America, from Cerro La Cruz (Castillo Formation), Lara state, Venezuela: implications in the 'changing course of Orinoco River' hypothesis

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ABSTRACT. In general the geology of paleontological sites in Venezuela is poorly known. With the purpose of improving this knowledge we describe the geology of the Castillo Formation (Late Oligocene to Early Miocene) at Cerro La Cruz locality, in Lara state, Venezuela, that contains several records of vertebrate and invertebrate fauna. Lithologically, the Cerro La Cruz sequence is composed by alternating packages of siliciclastic and carbonate sediments, with a predominance of mudstone. The paleoenvironment is inferred as a mainly near-shore marine complex that could be associated with regressive and transgressive phases. Nevertheless, into the middle part of the Cerro La Cruz outcrops two levels containing at least six mammalian remains were found, confirming the early continental mammal assemblage in Venezuela. The continental vertebrate assemblage includes Xenarthra, Notoungulata and Litopterna mammals, fresh water fishes, the turtle *Chelus*, wood and leaves, allows us to interpret the paleoenvironment of the continental episodes of this locality as a mosaic composed of an humid forest and lowland savanna. Four isotopic dates using Strontium ($^{87}Sr/^{86}Sr$), from the Cerro La Cruz locality were obtained, which bracket of the sediments to between 17.21 to 19.27 Ma, confirming an Early Miocene age for this locality. Biochronologically, the mammalian assemblage so far recovered does not permit to assign this fauna to any of the recognized South American Land Mammal Ages, however the isotopic ages suggest affinities with a Pansantacrucian mammalian sub-cycle. Our interpretation of the geology at Cerro La Cruz shows no evidence for the presence of a major river system crossing over that zone during the Early Miocene and does not support the hypothesis of the possible draining of a 'Proto-Orinoco' river into Maracaibo or Falcón basin during the Early Miocene.

Keywords: Early Miocene, Pansantacrucian, Castillo Formation, 'Proto-Orinoco' evolution, Venezuela.

RESUMEN. Cronología y geología de una asociación de mamíferos del Mioceno Temprano en el Norte de América del Sur, cerro La Cruz (Formación Castillo), estado Lara, Venezuela: implicaciones para las hipótesis del 'cambio del curso del río Orinoco'. En general los estudios geológicos detallados de las localidades paleontológicas de Venezuela son escasos. Con la finalidad de mejorar este conocimiento, se describe la geología de la Formación Castillo (Oligoceno Tardío a Mioceno Temprano) en afloramientos localizados en cerro La Cruz, estado Lara, Venezuela, la cual contiene reportes de una diversa fauna de vertebrados e invertebrados. Litológicamente la secuencia observada en cerro La Cruz está compuesta por una intercalación de paquetes siliciclásticos y carbonáticos, con predominio de lutita. El paleoambiente inferido para esta localidad es principalmente de un complejo marino-costero asociado a fases transgresivas y regresivas. Sin embargo, hacia la parte media de la sección del cerro La Cruz se reportan dos estratos portadores de al menos seis restos de mamíferos continentales, los cuales conforman la más diversa y antigua asociación faunística de Venezuela. Las asociaciones de vertebrados continentales que incluyen mamíferos de las familias Xenarthra, Notoungulata y Litopterna, peces de agua dulce, una tortuga del género *Chelus*, además de restos de madera y hojas, nos permiten interpretar la existencia de un mosaico de ambientes compuesto por bosques húmedos y sabanas bajas. También se presentan cuatro fechamientos isotópicos realizados sobre la base del método del Estroncio (^{87}Sr/^{86}Sr), en la localidad de cerro La Cruz, arrojando edades comprendidas entre 17,21 y 19,27 Ma, lo que confirma una edad Mioceno Temprano para esta localidad. Biocronológicamente la asociación de mamíferos no permite referirlo a ninguna Edad Mamífero de America del Sur, sin embargo, las edades isotópicas sugieren afinidad al subciclo mamaliano del Pansantacrucense. Nuestra interpretación de la geología de cerro La Cruz no muestra evidencias de la presencia de un gran río cruzando esta zona durante el Mioceno Temprano, y no es consecuente con la hipótesis del posible drenaje de un ancestro del río Orinoco hacia las cuencas sedimentarias de Maracaibo o Falcón durante el Mioceno Temprano.

Palabras clave: Mioceno temprano, Pansantacrucense, Formación Castillo, Evolución del 'Proto-Orinoco', Venezuela.

1. Introduction

The Early Miocene continental mammal fauna is poorly known in Venezuela, and has not been recorded from Colombia, Brazil, or Trinidad. The first record of a continental mammal from this age in Venezuela was *Xenstrapotherim christi* from the Chaguaramas Formation (Early Miocene *sensu* Wesselingh and Macsotay, 2006) (Stehlin, 1928). Later Collins (1934) reported *Pseudoprepotherium venezuelanum* from the Río Yuca Formation (Early Miocene *sensu* Macsotay *et al.*, 1995). The third terrestrial mammal, from the Quiamare Formation (Early to Late Miocene), *Boreostemma venezolensis* was reported by Simpson (1947). More recently (Sánchez-Villagra *et al.*, 2004; Weston *et al.,* 2004; O'Leary, 2004) reported another Early Miocene locality in the Castillo Formation with fossil mammals.

None of these localities has been dated using radiometric methods so their exact age is unclear. For example the age of the Río Yuca Formation has been determined based on palynological data (Macsotay *et al.*, 1995), and the proposed ages of the Chaguaramas (Fasola *et al.*, 1985), Quiamare and Castillo Formation (Wheeler, 1960, 1963; Lorente, 1987) are based on foraminifera and invertebrate data.

The first study of the faunal assemblage in the Castillo Formation was the molluscan fauna (Wheeler, 1960) from the Cerro Castillo locality. Additional studies by several authors (Sánchez-Villagra *et al.*, 2000; Dahdul, 2004; Aguilera and Rodríguez de Aguilera, 2004a y b; Sánchez-Villagra *et al.*, 2004; Brochu and Rincón, 2004; Weston *et al.*, 2004; O'Leary, 2004) have reported more or less thirty new faunal records for this formation, seven of which are mammals, but only two of these are terrestrial mammals. Most of these taxa are from a locality named Cerro La Cruz, Lara state. Previously at this locality Sánchez-Villagra *et al.* (2000, 2001) interpreted the depositional environment as near-shore to shallow marine for the base to 87 m of the exposed section.

Our research has documented 367 m of stratigraphic section that includes different sedimentary units from those previously reported. In this paper we describe these new sedimentary units of the Castillo Formation and present new strontium isotope (^{87}Sr/^{86}Sr) dates. In addition, we discuss the age and paleoenvironment of the exposures of the Castillo Formation at Cerro La Cruz and it implications in a South American context, specially taking into account the hypothesis of the 'changing of course of the Proto-Orinoco River' in northern of South America.

2. Reviews of paleontological, geological settings and age of Castillo Formation

The Castillo Formation was deposited in the Tertiary Falcón Basin, which extends into the states of Falcón and parts of Zulia, Lara and Yaracuy in northwestern Venezuela. Wheeler's (1960) original description of the Castillo Formation was based on outcrops at Cerro Castillo, located about 27 km to the southwest of Dabajuro, Buchivacoa Municipality, Falcón State.

The Falcón Basin is situated within the Caribbean-South American Plates boundary area. The framework of the basin is the result of the polyphase tectonics and is rather complex (Baquero *et al.*, 2009). It involves Late Cretaceous to Middle Eocene emplacement of the Lara Nappes followed by Late Eocene to Early Miocene tectonic collapse and graben formation, and by Middle Miocene inversion and out of sequence thrusting (Baquero *et al.*, 2009). The sedimentary record within the Falcón Basin has been almost continuous since Late Eocene time, except for three angular and/or erosional unconformities of some regional extent (Audemard, 1993, 2001). During the Oligocene and Miocene, the marine Falcón Basin was an elongate east-west trending depression bordered by topographic highs to the south, west and north, and formed the western end of the larger Bonaire Basin, at present the offshore portion of the Venezuelan Coast Range (Muessig, 1984; Audemard, 1993). Throughout the Middle-Late Miocene, NW-SE compression resulted in folding, tectonic inversion, and exposure of a nearly continuous record of sedimentation from the Eocene to the Pliocene (Audemard, 1993, 2001). The Castillo Formation during the Oligo-Miocene conforms to the northwest to southeast edge of the Falcón Basin, and its outcrops are found in a wide semicircular area that extends through the states of Falcón and Lara (Wheeler, 1960).

Wheeler (1960) suggested that the Formation was deposited in environments ranging from shallow water to brackish facies, with local continental facies. Based on the foraminifera and invertebrates, Wheeler (1960) estimated that the age of the Castillo Formation ranged from Late Oligocene in the north to Early Miocene in the south of the Falcón Basin. Lorente (1987) identified from drill hole TIG-141X (Castillo Formation North in Lara state, near type section) a sporomorph assemblage which was assigned to the *Magnastriatites-Cicatricosisporites dorogensis* zone (Late Oligocene) in the lower part of the formation, and the *Verrutricolporites* zone, which is indicative of an Early Miocene age in the upper part of the formation. Later, Sánchez-Villagra *et al.* (2000), based on the foraminifera assemblage, considered the entire Castillo Formation to be Early Miocene in age following the zonation of Cati *et al.* (1968). Johnson *et al.* (2009) studied the scleractinian reef coral assemblages from four different units in the northwestern portion of the Falcón Basin of Venezuela, including one from the Castillo Formation at Cerro Guariro (northern part of Formation) locality. The coral remains found in this assemblage included distinctive Oligocene genera such as *Antiguastrea* and *Diploastrea,* and suggest that at least at Cerro Guariro the Castillo Formation is Late Oligocene in age. López and Brineman (1943) proposed that the Castillo Formation in the south of Baragua Sierra is a typically sublittoral shallow water marine environment, with an Early Miocene age for this southern part of Castillo Formation.

From 87 m of clayey marls interbedded with numerous thin hardground units Sánchez-Villagra *et al.* (2000) reported the first vertebrate faunal assemblage from outcrops of the Castillo Formation at the Cerro La Cruz locality, in Lara State. These authors report a fauna composed of one turtle, one crocodile, two whales (Odontoceti), three sharks, along with a palm fruit, 20 molluscan species, and one crab. Subsequent studies carried out at the Cerro La Cruz locality (Sánchez-Villagra *et al.*, 2001; Dahdul, 2004; Aguilera and Rodríguez de Aguilera, 2004a and b; Sánchez-Villagra *et al.*, 2004; Weston *et al.*, 2004; O'Leary, 2004; Brochu and Rincón, 2004; Aguilera *et al.*, 2010; Aguilera and Lundberg, 2010; Sánchez-Villagra *et al.*, 2010; Rincón *et al.*, 2010a and b; Aguilera *et al.*, 2013) resulted in the recognition of a diverse vertebrate assemblage.

Additional records of vertebrate fauna from the Castillo Formation consist of a new genus and species of gharials, *Siquisiquesuchus venezuelensis*, which holotype was found in the vicinity of Siquisique Town, in the eastern of the Sierra de Baragua, Lara State (Brochu and Rincón, 2004), and fragmentary turtle and crocodile remains from the northwest of Bariro Town, northern part of the Castillo Formation, in Falcón State (Sánchez-Villagra *et al.*, 2010). The enigmatic Pyrotheria *Proticia venezuelensis*, was described by Patterson (1977) from the Trujillo Formation (Paleocene-Eocene). The Trujillo Formation represents a turbidite system, with a micromolluscs fauna that suggests a palaeobathymetry of 2-5 km, in a deep epicontinental slope environment (Mactosay *et al.*, 1989). Several authors (Sánchez-Villagra *et al.*, 2000, 2001, 2010; Bond and Gelfo, 2010) considered that the provence of *P. venezuelensis* should be put into a question, suggesting that this fossil was collected into Miocene rocks of the Castillo Formation instead in the Paleocene-Eocene rocks of the Trujillo Formation.

An updated vertebrate faunal list for the Cerro La Cruz locality is provided in Table 1, including the recent records of terrestrial mammals (Rincón *et al.*, 2010a and b).

3. The Geology of Cerro La Cruz

Cerro La Cruz is located around 78 km to the southeast of the type section of the Castillo Formation, close to La Mesa village, on the south flank of Sierra de la Baragua (10º22'05.16"N and 70º04'14.45"W), in the Pedro Leon Torres Municipality, Lara State, 20 km north of Carora town (Fig. 1). It has a well-exposed stratigraphic sequence of at least 367 m (Fig. 2) that was described here. The sequence consists predominately of mudstone, interbedded with limestone and sandstone, with local units of limonite and conglomerate. From the base to top the following units are recognized:

- **Unit A.** Total thickness is 96 m. It consists of alternating layers of mudstone, sandstone and conglomerate with the mudstone as the most abundant lithology (Fig. 3). They are bioturbated, motley grey with reddish and yellowish bands (jarosite). The individual strata thicknesses vary between 1-20 m. The sandstone presents light colors; with thicknesses varying between 30-200 cm. Mineralogically the sandstone is essentially composed of quartz, with a large grain size (0.8-0.1 mm), conglomeratic lenses, bad to moderately well-sorted to the base, and with fine grains, and well packed to the top. The thick sand layers were observed to be formed from moderately to well-rounded quartz fragments and metamorphic rocks, and at the base have local reworked oyster fragments. Ripple marks, low angle cross-bedded and parallel stratification are also observed in sandstone. The unit exhibits, in general, the presence of oxidation levels that increase towards the top of the strata. The bioturbation has a grade of intensity one (Droser and Bottjer, 1986) and two burrowed ichnofabrics are identified in this unit, *Thalassinoides* (Fig. 4a) and *Ophiomorpha*. The unit is poorly fossiliferous, but in the middle part contains some wood fragments and toward the top organic matter. Toward the base *Ostrea* remains are also present. The inferred depositional environment for this unit is near-shore marine with limited clastic terrigenous influx toward the top.
- **Unit B.** Total thickness 118 m. It consists of alternating mudstone, bioclastic limestone and sandstone (Fig. 3). The color of the mudstone ranges from light grey to lead-grey, is generally fossiliferous and bioturbated, with some iron oxide nodules toward the base. There is locally abundant organic matter. The thickness of the layers varies from 2.5-11 m. The limestone is bioclastic, consisting of fragments of invertebrates that are sometimes reworked, and ranges in color from orange to purple. There has been some compaction, the thicknesses ranges between 15-50 cm. Dunham (1962) classified them as: packstone, mudstone and wackstone with packstone predominant (with micritic matrix). Some limestone grades laterally into sandstone. The few sandstone present are restricted to the base of unit, have thick layers and large grains (0.8-0.1 mm), with decreasing size grain toward the top, with conglomerate levels, composed of quartz fragments and metamorphic rock remains toward the base. Bioturbation is conspicuous towards the top, and has a grade of intensity one to two (Droser and Bottjer, 1986), of the *Ophiomorpha* and *Thalassinoides* ichnofacies. Wave ripple marks are conspicuous toward the base (Figs. 4b and c).

  This unit is highly fossiliferous and preserves an abundance of invertebrate fossils including: *Anadara* sp., *Chionopsis tegulum, Clementia dariana dariana, Cyclinella cyclica, Liromissus quirosensis, Trachycardium* sp., *Glyptoactis quirosana, Ostrea* sp., *Pecten* sp., *Saccella gracillima, Architectonica nobilis, Cirsotrema* sp., *Conus* sp., *Melongena* cf. *M. venezuelana, Turritella larensis, Turritella venezuelana, Turritela* sp., *Dentalium bocasense,* abundant crab remains *Calappa larensis, Eriosalchila rathbunae, Palaeopinnixa perornata, Portunus* aff. *P. oblongus* and some Cnidaria indet. Toward the top many fish species (otolith based) are conspicuous along with shark and ray teeth. Toward the base indeterminate turtle remains and wood is present.

  Following the Standard Microfacies Model (SMF) of Wilson (1975) and Flügel (2004), the presence of bioclastic wackestone/packstone found in this unit (some of them composed of well-preserved skeletal shells and fragments) is interpreted as having been deposited in a shelf lagoon with

TABLE 1. UPDATED VERTEBRATE FAUNAL LIST AT CERRO LA CRUZ, CASTILLO FORMATION.

Class	Order	Family	Genera	Taxa
Chondrichthyes	Lamniformes	Otodontidae	*Megaselachus*	*M. megalodon*[1]
	Orectolobiformes	Ginglymostomatidae	*Nebrius*	*Nebrius delfortriei*[2]
	Carcharhiniformes	Hemigaleidae	*Hemipristis*	*Hemipristis serra*[1]
		Carcharhinidae	*Carcharhinus*	cf. *C. obscurus*[1]
				cf. *C. perezi*[1]
				C. falciformis[1]
				C. plumbeus[1]
		Myliobatidae	*Myliobatis*	*Myliobatis* sp.[1]
			Rhinoptera	*Rhinoptera* sp.[1]
Actinopterygii	Characiformes	Serrasalmidae	*Colossoma*	*C. macropomum*[1]
			Mylossoma	*Mylossoma* sp.[1]
	Siluriformes	Ariidae	*Bagre*	*B. protocaribeanus*[3]
			Cantarius	*C. nolfi*[3]
	Perciformes	Sciaenidae	*Ctenosciaena*	aff. C. *gracilicirrhus*[1]
			Equetus	*Equetus davidandrewi*[1]
			Paralonchurus	*P. schwarzhansi*[1]
				P. trinidadensis[1]
			Plagioscion	*Plagioscion marinus*[1]
			Protosciaena	*Protosciaena neritica*[1]
			Larimus	*Larimus henrici*[1]
		Sphyraenidae	*Sphyraena*	*Sphyraena* sp.[1]
		Scombridae	*Achanthocybium*	*Achanthocybium* sp.[1]
Sauropsida	Crocodilia	Gavialidae	*Siquisiquesuchus*	*S. venezuelensis.*[4]
				Tomistominae indet.[5]
		Alligatoriidae		Alligatoriidae, indet.[2]
	Testudines	Trionychidae		Trionychidae, indet.[6]
		Podocnemidae	*Bairdemys*	*Bairdemys* sp.[8]
		Chelidae	*Chelus*	*Chelus* sp.[2]
Mammalia	Cetartiodactyla	Squalodontidae	*Prosqualodon*	aff. *P.australis*[7]
		Squalodelphinidae	*Notocetus*	aff. *N. vanbenedini*[9]
		Iniidae		Iniidae, indet.[6]
		Platanistidae		Platanistoidea, indet.[6]
	Sirenia			Sirenia, indet.[6]
	Xenarthra	Orophodontidae		Orophodontidae, Indet.[10]
		Pampatheriidae	*Scirrotherium*	*Scirrotherium* sp.[10]
				Phyllophaga indet.[6]
	Notoungulata	Astrapotheriidae		Astrapotheriinae, IndetA[6]
				Astrapotheriinae, IndetB[6]
	Litopterna			Litopterna, indet.[10]

[1] Aguilera and Lundberg, 2010; [2] Rincón *et al*., 2010b; [3] Aguilera *et al*., 2013; [4] Brochu and Rincón, 2004; [5] Sánchez-Villagra *et al*., 2001; [6] Sánchez-Villagra *et al*., 2010; [7] Sánchez-Villagra *et al*., 2000; [8] Sánchez-Villagra *et al*., 2004; [9] O'Leary, 2004; [10] Rincón *et al*., 2010a.

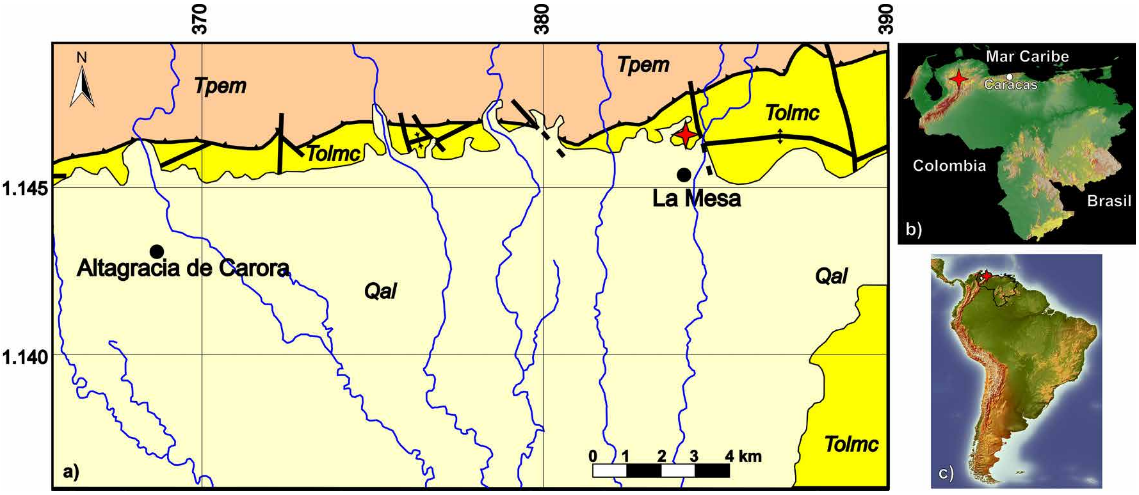

FIG. 1. Location and geological setting of Cerro La Cruz, Castillo Formation, Lara state, Venezuela. Red star shows the location of the analyzed section. **a.** Geological map of Cerro La Cruz Locality, modified from Martínez and Valletta (2008); **b.** Regional; **c.** Continental map of the location of the described section. Abbreviations: **Tpem**= Matatere Formation (Eocene), **Tolmc**= Castillo Formation (Early Miocene), **Qal**= Alluvial (Quaternary).

FIG. 2. Cerro La Cruz landscape with the outcrops of Castillo Formation.

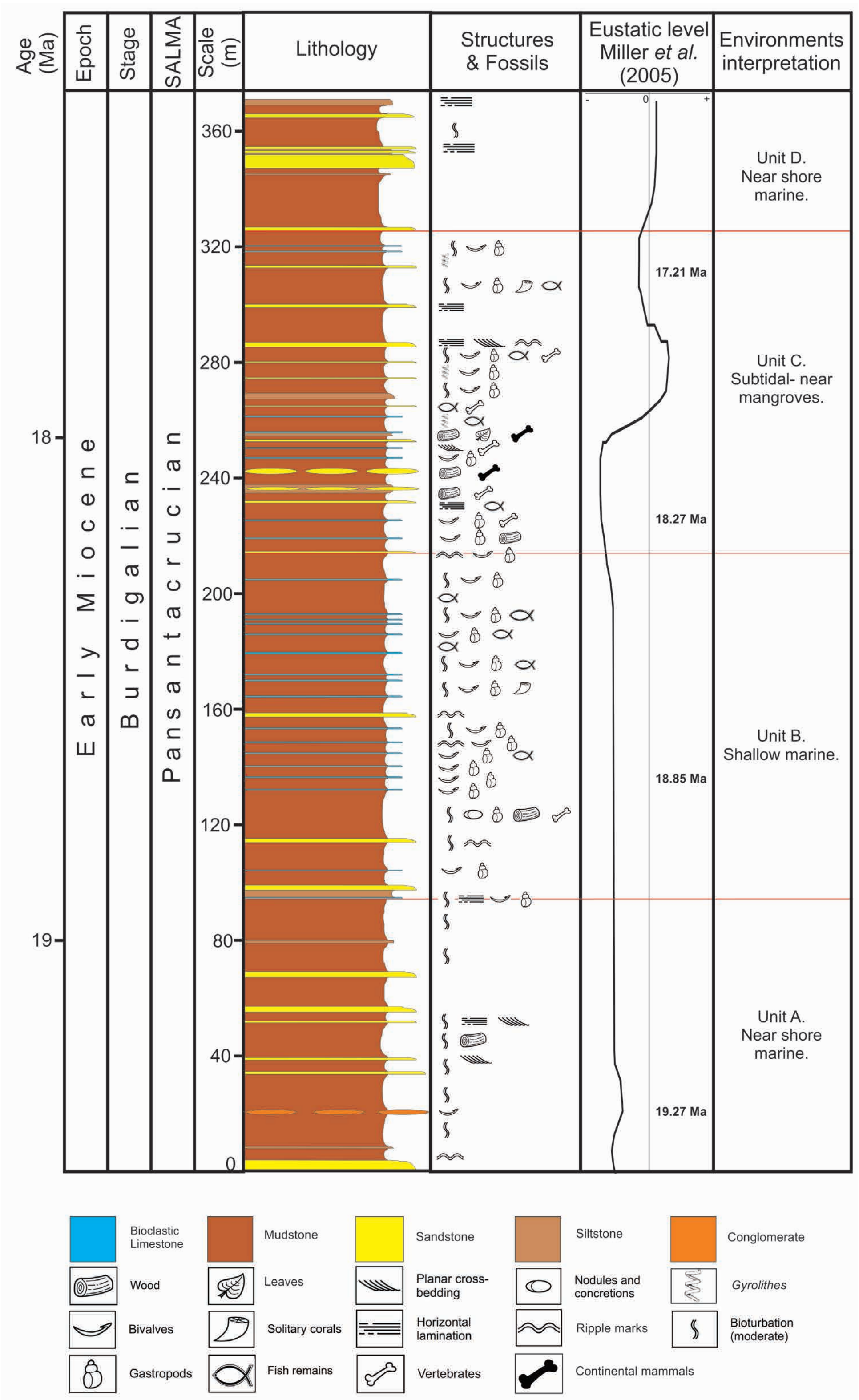

FIG. 3. Stratigraphic column of Cerro La Cruz, Castillo Formation, Lara State.

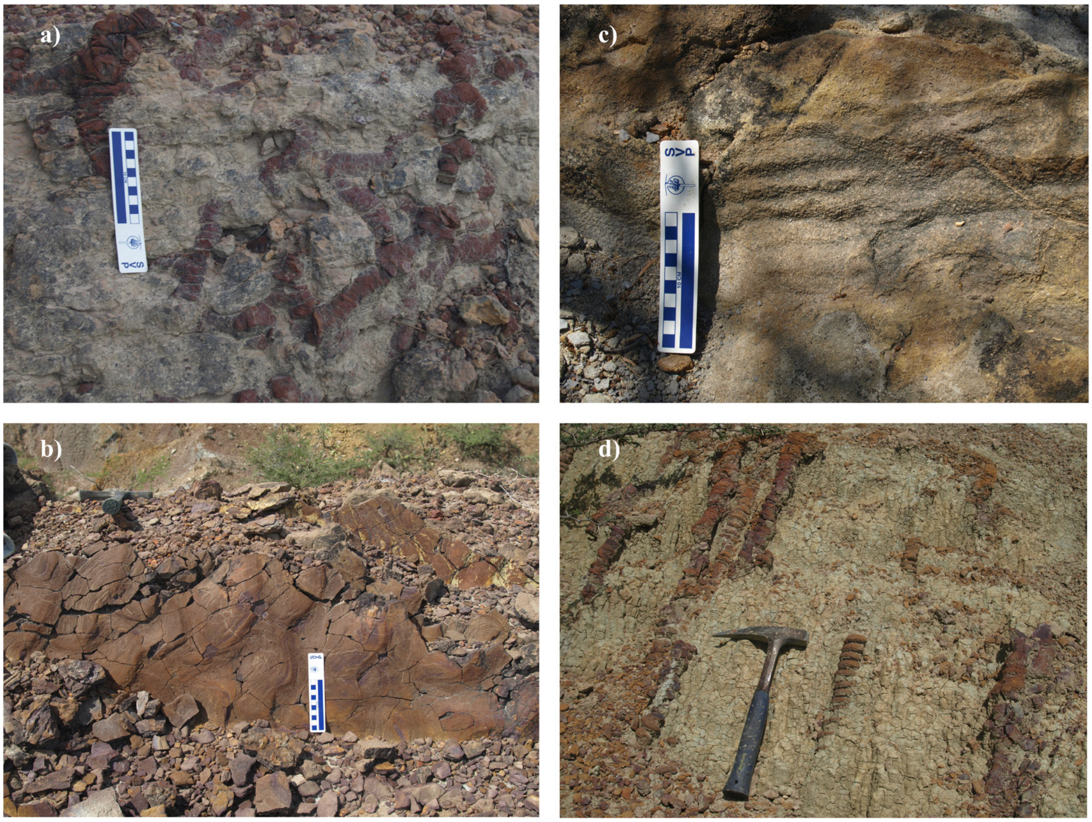

FIG. 4. Sedimentary structures in Cerro La Cruz, Castillo Formation, Lara State. **a.** Thalassinoides; **b.** Oblique view of wave ripple marks; **c.** Lateral view of wave ripples marks; **d.** *Gyrolithes*.

low energy water circulation (SMF No. 8). The bioclastic mudstone is interpreted as deposited in shallow water with open circulation close to wave base? (SMF No. 9).

The high diversity of invertebrate remains is conspicuous in this unit. They are better preserved in the mudstone layers whereas in bioclastical limestone they are sometimes reworked. In mudstone the low degree of disarticulation of the bivalves and gastropods, also suggests a low energy conditions, with a short high energy interlude during which the fauna was smothered and buried by sediments, with minimal post-mortem disturbance. Moreover the *Thalassinoides*-*Ophiomorpha* ichnofacies assemblage could be interpreted as having developed on subtidal substrates under well aerated agitated shallow waters (Verde, 2002), which is consistent with the presence of wave ripple marks (Figs. 4b and c). The presence of many oxidation levels is interpreted as caused by short periods of subaerial exposure. The poor sandstone development indicates a limited contribution of continental clastic sediments. In general this configuration is consistent with shallow water, with well aerated agitated waters, that is probably slightly deeper towards the top, limiting the development of ripple marks and clastic input, and encouraging the presence of fishes.

- **Unit C.** Total thickness is 110 m. It consists of alternating mudstone, sandstone and bioclastic limestone, with mudstone being most conspicuous (Fig. 3). This unit includes the top of Cerro La Cruz hill. The mudstone ranges between light grey, lead grey and dark gray, is generally fossiliferous, mostly toward the base, and is bioturbated mostly toward the top. Thin iron oxidation levels (hematite and goethite) are common and interbedded between mudstone layers. Subarkose sandstone is the second predominant lithology (Dott, 1964) and is composed of medium to fine grains (0.6-0.1 mm) with muscovite, altered plagioclase, and quartz. The grains are finer toward the top, generally with subrounded and moderately well-sorted grains. They are moderately to well packed, and range from 30-200 cm in thickness. The contact between grains is punctual and always surrounded by the matrix. Cement is present and in part composed of iron oxide (limonite). Toward the base the sandstone can have lenticular bedding, but in general the strata are tubular. Ripple marks, parallel lamination and stratification, and planar cross-bedding are common. The limestone is bioclastic, consisting of many fragments of invertebrates sometimes reworked specially toward the base, which range in color from orange to purple, being more abundant toward the base. There has been some compaction, the thicknesses range between 20-35 cm. Dunham (1962) classified them as: grainstone (with spar cement), packstone, and wackstone, with packstone being predominant (with micritic matrix). This unit presents a highly lateral variation, in some cases the bioclastic limestone will laterally transition into sandstone and vice versa.

In general, most of the published fauna from Cerro La Cruz (Sánchez-Villagra *et al.*, 2004; Aguilera *et al.*, 2010; Sánchez-Villagra *et al.*, 2010) comes from this unit. The unit preserves an abundance of marine invertebrate fossils including: *Anadara mirandana, Anadara* cf. *A. inutilis, Chionopsis tegulum, Clementia dariana dariana, Trachycardium* sp.*, Glyptoactis quirosana, Ostrea* sp.*, Pecten* sp.*, Saccella gracillima, Architectonica nobilis, Conus* sp.*, Melongena* cf. *M. venezuelana, Turritella larensis, Turritella venezuelana, Turritella montanitensis, Turritela* sp.*, Dentalium bocasense,* and abundant indeterminate crab remains, mostly present in the bioclastic limestone and mudstone. Are also present are many marine fish species (mostly based on otoliths), ray and shark teeth, while toward the top of the unit in the sandstone bed Cetartiodactyla remains, Squalodontidae, aff. *Prosqualodon australis* (Sánchez-Villagra *et al.*, 2000), and Squalodelphinidae aff. *Notocetus vanbenedini* (O'Leary, 2004) have been reported. In addition to the marine fauna found in this unit, in two level located toward the base of this unit Rincón *et al.* (2010a y b) reported a varied 'continental or fresh water' fauna (housed at the paleontological collection in the Instituto Venezolano de Investigaciones Científicas (IVIC), Caracas, Venezuela) represented by an astragalus (IVIC-P-1829) with the typical spool-like astragalar body characteristic of a Litoptern (Fig. 5a); a mandible (IVIC-P-1830) with the external sulcus on m1 lacking, but present in m2, characteristic of members of the Astrapotheriinae (Fig. 5b); a partial imbricating osteoderm (IVIC-P-1827) that is relatively thin with a small number of well-spaced follicular pits connected by a distinct channel, typical of the pampathere, *Scirrotherium* (Fig. 5c); and a partial mandible (IVIC-P-1828) with the alveolus of the first molariform, and the second to fourth molariforms, composed of a very thin outer layer of cement (0.5 mm), a thicker internal layer of osteodentine (6.3 mm) and a core of vasodentine (1.3 mm), diagnostic of the sloth family Orophodontidae *sensu* Hoffstetter, 1969 (Fig. 5d). Additional 'continental or fresh water' fauna mentioned by Rincón *et al.* (2010a and b) consist of Alligatoriidae indet., turtle remains of *Chelus* sp. (IVIC-P-2136), and some Testudine indet. In the lenticular sandstone and sandy siltstone associated with continental vertebrate fauna several teeth of fresh water Serrasalminae (*Colossoma* sp. and *Mylossoma* sp.), previously reported from this locality by Dahdul (2004) were recovered along with common plant leaves that were found in association with the continental mammal remains.

Some levels are bioturbated, especially toward the middle and top, and have a grade of intensity one to two (Droser and Bottjer, 1986). *Ophiomorpha, Thalassinoides* and *Gyrolithes* ichnofacies are recognized, with the last two being conspicuous. The *Gyrolithes* ichnofacies is restricted to a middle upper part of the unit, (Fig. 4d) and is commonly reported from brackish-water mudstone, siltstone and sandstone, in marginal-marine settings, and are also associated to intertidal zones, near mangrove areas (mud flats and channels, Netto *et al.*, 2007). The presence of *Gyrolithes* combined with abundant wood remains (some associated with oysters in living position) were observed in the middle and upper part of the unit and reflects episodes of brackish-water probably near mangrove areas or estuarine enviroments. The near-shore marine complex environments are dominant in this unit, but the mammal assemblage is found only in two levels from the middle part of this unit indicating the presence of this continental environment only for a short duration.

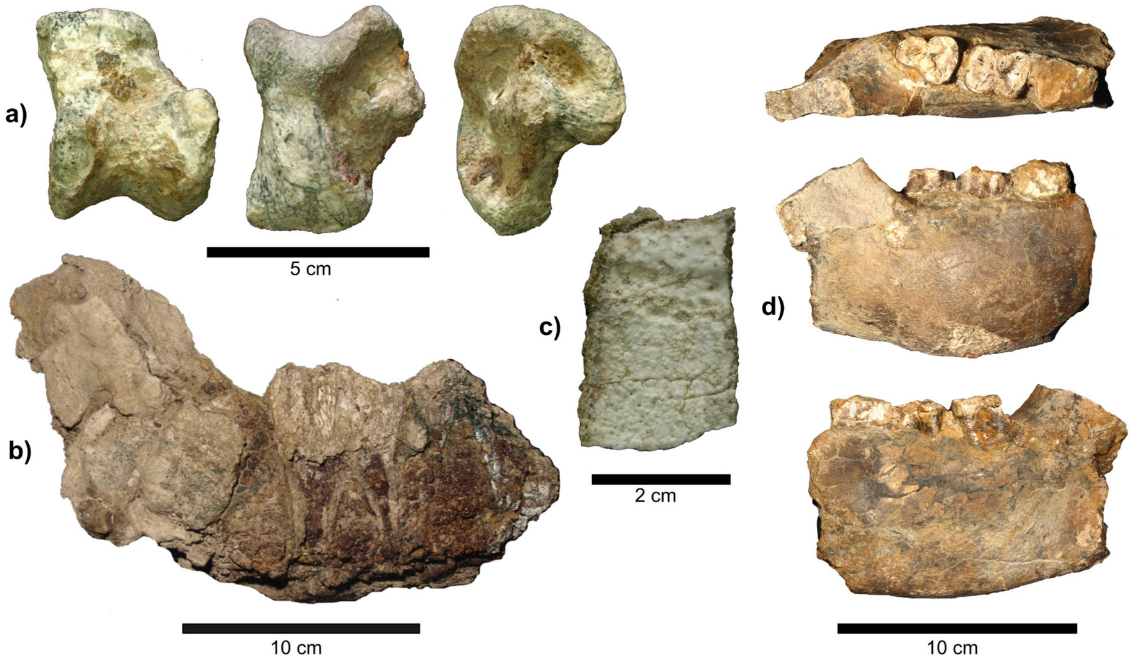

FIG. 5. Mammal fossils from Cerro La Cruz, Castillo Formation. **a.** Astragalus of Litoptern (IVIC-P-1829); **b.** Mandible of Astrapotheriinae (IVIC-P-1830); **c.** Partial imbricating osteoderm of *Scirrotherium* (IVIC-P-1827); **d.** Partial mandible of Orophodontidae (IVIC-P-1828).

- **Unit D.** Total thickness is 43 m. It mainly consists of alternating mudstone and sandstone (Fig. 3). The color of the mudstone ranges from light grey to mottled-grey, and is not fossiliferous, generally it contains organic matter, and some iron oxide nodules are present toward the base. The thickness of the layers varies from 0.5-18 m. The sandstone presents light colors to mottled; with thicknesses varying between 1-2 m. Mineralogically it is essentially composed of quartz, with scarce muscovite, thin grain size (0.25-0.125 mm), that are moderately to well sorted, rounded, and subspherical. In the sandstone are conspicuous floating rounded pebbles (up to 4 cm), consisting of quartz and metamorphic rock fragments reflecting rapid changes in energy level. In general the sandstones present parallel lamination. The inferred deposition environment for this unit is near-shore marine.

3.1. General settings

Gypsum is abundant in most of the sequence, but this cannot be considered as evidence for an evaporitic environment because its location is restricted to oblique and vertical joints and fractures and is typical of secondary mineralization.

Towards the top of the section, the strata analyzed were in tectonic and in discordant contact with the underlying rocks of the Matatere Formation (not Misoa Formation *sensu* Sánchez-Villagra *et al.*, 2000; Fig. 1a) of Eocene age, that consist of a type flysch sequence, a monotonous alternation of sandstone and shale with conglomeratic levels and blocks (olistolit and olistostrome) of different lithologies embedded in the sequence. The contact between Matatere and Castillo Formations in the vicinity of Cerro La Cruz is a thrust fault, caused by compressive stress associated with tectonic inversion of the Falcón Basin which started in the Middle Miocene (Baquero *et al.*, 2009; Urbani and Mendi, 2011). This thrust fault relationship documents changes in subsidence and uplift during the evolution of the Falcón Basin (Baquero *et al.*, 2009). Lower contacts are not observed in the outcrops. The section at Cerro La Cruz is located on the northeast flank of an elongated dome on a hinge line oriented N65E. In general, the strata analyzed presents an orientation of N65E with a dip slope varying between 20º and 40ºN. In general, outcrops of the Castillo Formation in Baragua Sierra, are highly deformed, with folding axes subparallel to the thrust front.

3.2. ^{87}Sr/^{86}Sr Dating

Precise and detailed data on the variability of strontium isotopes with time in the world's oceans is known for a significant part of Phanerozoic time (Howarth and McArthur, 1997), and local curves for specific stratigraphic sections are being increasingly used to infer absolute ages (Graham *et al.*, 2000). For the middle Cenozoic in particular, the strontium isotope sea-water curve changes rapidly with time, and so is particularly suitable for geochronology (Graham *et al.*, 2000). In this time interval, resolution of stage boundaries is better than 0.5 my (Oslick *et al.*, 1994; Howarth and McArthur, 1997), making the method a powerful tool for improving correlation between biostratigraphic and chronostratigraphic timescales (Graham *et al.*, 2000).

We analyzed the remains of four invertebrates from Cerro La Cruz beds on the South flank of the Sierra de la Baragua, Lara State. We used a Mass Spectrometry Finnigan MAT-262 to determinate the isotopic relationship of the Strontium (^{87}Sr/^{86}Sr), with a Standard laboratory value NBS987=0.710240±28, n=422. This analysis was made by the Laboratorio Universitario de Geoquímica Isotópica (LUGIS) at the Universidad Nacional Autónoma de México, México. Results are shown in the Table 2, and provide an age range between 17.21 and 19.27 Ma.

4. Discussion

4.1. Age

The isotopic age obtaining by the Strontium (^{87}Sr/^{86}Sr) relationship shows that sediments at the Cerro La Cruz locality were deposited between 17.21 (+0.41/-0.49) to 19.27 (+0.64/-0.53) Ma, and allows to us to infer that the sediments in the stratigraphic section at the Cerro La Cruz to be Early Late Miocene in age (Burdigalian age), including the Magnetic Chrons C5Cr, C5Dn, C5Cn, C5Dr and C5En (Cande and Kent, 1995). This age corroborates the previously estimated age proposed by several authors based on foraminifera and invertebrates (López and Brineman, 1943; Wheeler, 1960; Sánchez-Villagra *et al.*, 2000). In addition, it allows a refinement the age of the vertebrate fauna found in this locality, confirming that the Cerro La Cruz Fauna represents the oldest mammal assemblage of Venezuela, as proposed by several authors (Sánchez-Villagra *et al.*, 2000, 2010; Bond and Gelfo, 2010), and hence the enigmatic *Proticia venezuelensis* would be highly probably from Castillo Formation at Quebrada AguaViva, located about 5 km northwest of Cerro La Cruz.

Within the context of the South American Land Mammal Ages (SALMA), the isotopic values obtained in the stratigraphic section of Cerro La Cruz allows to us to assign a post-Colhuehuapian SALMA (~20 Ma *sensu* Ré *et al.*, 2010), and pre-Santacrucian SALMA (17.8 to ~16.0 Ma *sensu* Marshall *et al.*, 1986) age to the fauna. Nonetheless the Cerro La Cruz locality is chronologically closer in time to the Santacrucian and 'Pinturan' SALMA. The type area for the 'Pinturan' SALMA is the northeast of Santa Cruz Province, Argentina and has been dated to be between 16.5 and 17.5 Ma (Kramarz *et al.*, 2010). However, Dunn *et al.* (2012) based on the section at the Gran Barranca, Central Patagonia, Argentina, proposed that the 'Pinturan' SALMA is bracketed between 19.04 and 18.62 Ma, so the maximum duration for the 'Pinturan' is between 19.04-16.5 Ma (Dunn *et al.*, 2012). Otherwise the Santacrucian SALMA age is usually considered to be between 16.3-17.5 Ma (Flynn and Swisher, 1995) or 16-17.8 Ma (Marshall *et al.*, 1986).

TABLE 2. RELATIONSHIP OF THE STRONTIUM ISOTOPES (^{87}Sr/^{86}Sr) IN THE CERRO LA CRUZ SAMPLES.

Sample	^{87}Sr/^{86}Sr	1 sd*	2 SE(M)	n	Type	Ma	Ma (+/–)	Depth (m)
Cast-58	0.708667	30	4	57	*Turritela* sp.	17.21	0.41/0.49	305
Cast-38	0.709	25	7	54	Shell	18.27	0.42/0.37	230
Cast-6	0.70853	38	5	58	*Ostrea* sp.	18.85	0.70/0.61	138
Cast-B25	0.708502	28	4	58	*Ostrea* sp.	19.27	0.64/0.53	20

n= Value of relationship made by series; **1 sd**=1 Standard deviation, **2 SE(M)** = 2sd/root n.

In contrast Croft *et al.* (2004, 2007) reported an age estimate of 17.0-19 Ma for the Santacrucian SALMA based on a locality from northern Chile. If we accept the proposal of Croft *et al*. (2004, 2007) this would extend the Santacrucian SALMA to be between 16-19 Ma. The latter indicates that the 'Pinturan' and Santacrucian SALMA at least partially overlap. The recognition of a 'Pinturan' SALMA as a distinct biochronologic unit is still controversial (Kramarz *et al.*, 2010), and for that reason at this time we do not yet consider the 'Pinturan' SALMA to be a distinct and recognizable SALMA unit, and probably represents only a local fauna within the Santacrucian.

None of the terrestrial mammalian fauna from Cerro La Cruz recovered so far allows us to assign the fauna unequivocally to either the 'Pinturan' or Santacrucian SALMA as defined by Marshall *et al.* (1983). Neither the litoptern nor astrapothere specimens recovered so far can be identified to genus, let alone species, so they cannot be used to refine our understanding of where the fauna fits biostratigraphically. The known records of orophodonts are from the Deseadan SALMA of Argentina, while the pampathere *Scirrotherium* is known from Laventan SALMA, Colombia, the Late Miocene of Costa Rica (Laurito and Valerio, 2013), and the Huayquerian SALMA (Late Miocene ~9.0-6.8 Ma) of Argentina and Brazil (Dozo *et al.*, 2008; Góis *et al*., 2013). So either the biostratigraphic range of the orophodonts is younger than previously known, and the stratigraphic range of *Scirrotherium* extends farther back in time. Neither pampatheres nor orophodonts are currently known from the classic Santacrucian or 'Pinturan' faunas.

So far the oldest known record of the fresh water turtle *Chelus* comes from the lower Miocene of Barzalosa Formation (Cundinamarca Department, Colombia), based on the xiphiplastron and costals referred to *Chelus colombiana* (Cadena *et al.*, 2008). Thus, the records of *Chelus* sp. from the Early Miocene of Cerro La Cruz, Castillo Formation confirms its early appearance in the fossil record of the north of South America (during the Early Miocene), and also represent the oldest record of this genus in Venezuela. The presence of the Serrasalmidae, *Colossoma* and *Mylossoma* during the Early Miocene of Cerro La Cruz represent one of the oldest records of these genera in the Neogene of South America (Lundberg *et al.*, 2010).

The levels from which the Cerro La Cruz mammals were recovered could be correlated with the C5Dr Magnetic Chron (Cande and Kent, 1995), which has an estimated age of 18 Ma (Burdigalian). Ortiz-Jaureguizar (1986) observed a direct link between the Colhuehuapian (early Burdigalian, ~20 Ma), and Santacrucian (late Burdigalian, ~17-16 Ma) SALMAs and grouped them into a single major evolutionary unit, called the Pansantacrucian faunal sub-cycle. This idea has been used by Bostelmann *et al.* (2013), for a succession of marine and continental strata from outcrops in southern Chile, with a rich assemblage of terrestrial vertebrate fossils, that are also biostratigraphically equivalent to a post-Colhuehuapian, pre-Santacrucian time interval, suggesting an age range of 19 to 17.8 Ma (Bostelmann *et al.*, 2013), a situation similar to that of our current understanding of the biochronology at Cerro La Cruz based on the Strontium based ages presented her which places it between 17.21 (+0.41/-0.49) to 19.27 (+0.64/-0.53). At this time the finest time resolution possible for the locality is to consider this mammal assemblage as part of the Pansantacrucian mammalian subcycle.

Another localitiy in Venezuela that probably could be associated with Pansantacrucian mammalian sub-cycle includes the Quebrada Honda site from the Early Miocene of Chaguaramas Formation, eastern Venezuela, with a little known fauna composed by *Xenastrapotherium christi* (Stehlin, 1928), *Podocnemis geologorum* (Simpson, 1943), and indeterminate crocodilian remains (Stehlin, 1928; Wesselingh and Macsotay, 2006; Sánchez-Villagra *et al*., 2010). In addition, the true age of the other two 'Early Miocene' Venezuelan localities that contain *Pseudoprepotherium venezuelanum* and *Boreostemma venezolensis* from Río Yuca and Quiamare Formation respectively remains unclear.

4.2. Paleoenvironments

In general, the Castillo Formation has been interpreted to have been deposited as an extensive coastal and marginal marine complex that includes a diverse range of paleoenvironments; terrestrial, fluvial, tidal, and brackish to open marine subtidal (Wheeler, 1960, 1963; Sánchez-Villagra *et al.*, 2000; Johnson *et al.*, 2009). However, the Cerro La Cruz sequence presents a wide variety of lithologies that have both lateral and vertical geometries that are consistent with Wheeler's (1960) ideas, and reflect gradual changes in sedimentary environments being the result of eustatic changes.

The Cerro La Cruz sequence was deposited in the form of alternating packages of siliciclastic and carbonate sediments (Fig. 3). Its lower part is predominantly composed of siliciclastic sediments (mainly unfossiliferous mudstone along with a few interbeds of sandstones and conglomerate). Overlying, the sequence becomes predominately carbonate sediments represented by highly fossiliferous (mostly composed of marine invertebrates and fish otoliths), limestone strata (wackestone and packstone) with interbeddedby shale beds, and some sandstone, the mudstones (sometimes unfossiliferous and sometimes containing skeletal grains). This is followed by a siliciclastic-carbonate sequence predominantly represented by mudstones (sometimes fossiliferous) and sandstone interbedded with fossiliferous limestone beds (wackestone grainstone and packstone), with two levels containing 'continental or fresh water' vertebrate remains, leaves, and wood. The upper package is again primarily siliciclastic sediments, which is predominantly a shale sequence with intercalated beds of sandstone.

Bioturbation is common in the Cerro La Cruz section. Three main ichnofabrics are recognizing: *Gyrolithes*, *Ophiomorpha* and *Thalassinoides*, with *Thalassinoides* being conspicuous, and *Gyrolithes* more locally distributed. The paleoenvironmental distribution of *Thalassinoides* is quite varied, ranging from tidal flats, and both shoreline settings, to outer shelf facies, and even deep sea fan deposits (Ekdale *et al.*, 1984; Myrow, 1995). *Ophiomorpha* are common in, but is by no means confined to or mainly indicative of beaches and near-shore sublittoral sands, as it also can occur in shoals, tidal flats, tidal stream point bars, and lagoon, bay, sound, and estuary floors, wherever the salinity and current energy are moderately high and the substrate consists mainly of sand (Frey *et al.*, 1978). The *Thalassinoides*-*Ophiomorpha* ichofacies assemblage could be interpreted as having developed on subtidal substrates with well aerated agitated shallow water which are dominant in the most of the Cerro La Cruz section (Verde, 2002).

The *Gyrolithes* ichnofacies represents deep dwelling burrowers that are common in marginal-marine settings and its vertical helical morphology represents a specialized burrowing architecture that permits its makers to seek refuge from extreme salinity fluctuations in brackish-water environments (Beynon and Pemberton, 1992; Buatois *et al.*, 2005; Netto *et al.*, 2007). The modern laomediid shrimp *Axianassa australis* sometimes produces spirals identical to *Gyrolithes* (Dworschak and Rodríguez, 1997; Felder, 2001), and five of the six known extant species of *Axianassa* inhabit intertidal zones, near mangrove areas (mud flats and channels) and only one species lives in deep-marine settings (Dworschak and Rodríguez, 1997; Netto, 2007). Toward the middle of the section analyzed, the presence of *Gyrolithes* combined with abundant wood remains (some associated with oysters in living positions) that we have observed in the middle and upper part of the unit reflects episodes of brackish-water probably lagoons near mangrove areas.

Transitions from siliciclastic to carbonate sedimentation such as that observed at Cerro La Cruz usually occurs mainly in near-coastal and inner shelf environments, and the changes from carbonate to non-carbonate deposition and vice versa are the result of variations in the supply of terrigenous clastic material and is determined by several factors like climatic, tectonic, or eustatic changes (Nichols, 2009).

The climate during the Late Oligocene to Early Miocene was a period characterized by relative higher global warmth possibly with higher atmospheric carbon dioxide (CO_2) levels (Pagani *et al.*, 1999; Paul *et al.*, 2000). Wright and Miller (1992) have identified twelve significant $\delta^{18}O$ increases in Oligocene and Early late Miocene benthic foraminiferal records (classified as Oi and Mi zones) that have been interpreted by several authors (Wright and Miller, 1992; Paul *et al.*, 2000; Zachos *et al.*, 2001) as indicative of the presence of large, transient Antarctic glaciations. The first and most prominent of these oxygen isotope excursions in the Miocene, Mi-1, occurred near the Oligocene/Miocene (O/M) boundary (Paul *et al.*, 2000). Based on benthic foraminifera oxygen isotope records Wright and Miller (1992) also recognized that the maximum δ^{18} values were associated with these increases at the base of two zones: Mi-1a and Mi-1b. More recently, Billups *et al.* (2002) dated the events Mi-1a at 21.69 Ma and Mi-1b at 18.0 Ma. Therefore the event Mi1b could be recorded in Cerro La Cruz sequence specifically in Facies C, and it is possible that the Mi-1b may be correlated with the presence of the continental and fresh water faunas present in the sequence.

The major part of the rocks of Falcón Basin was deposited during an extensional tectonic regimen dominated by tectonic collapse and graben formation, which was almost continuous since Late Eocene until Early Miocene. This extensional tectonic regimen was more pronounced during Late Eocene-Oligocene due to low-angle subduction in north of the region, between the current Caribbean Plate to the north and the Bonaire Block to the south (Baquero *et al.*, 2009). The Cerro La Cruz sequence represents sedimentation of the south part of Falcón Basin deposited during the last episodes of the extensional tectonic regimen, with constant decline until the convergence of the Caribbean Plate from the north and the consequent tectonic inversion during the Middle Miocene, justifying the continuous decrease in sedimentation rate observed in the Unit B and Unit C compared with Unit A (Table 2, Fig. 3).

The Cerro La Cruz sequence includes a time period of at least 2 My. During this interval, according to several authors (Haq *et al.*, 1987; Miller *et al.*, 1998; Kominz *et al.*, 1998; Miller *et al.*, 2005; Browning *et al.*, 2008; Kominz *et al.*, 2008), the sea level started to regress between ~19-18 Ma, follow by a transgression starting about ~18 until ~17 Ma. This sequence could be correlated with the dynamics of the change in the facies present at Cerro La Cruz. Facies A and B represent the regressive phase (probably with some oscillations, Fig. 3), and facies C a trangressive phase followed by a later regression with eustatic variations. Most of the Cerro La Cruz faunas would be associated with the start of the transgression around 18 Ma ago, and to the Mi-1b event of Antarctic glaciations.

Generally the near-shore marine environments (subtidal shallow marine, lagoon, intertidal zone near mangroves) are dominant in the Cerro La Cruz sequence, but the mammal assemblage from the two levels from the middle part of the section indicate the presence of continental environments, although for a short duration. Ecologically, the Orophodontidae, Astrapotheriinae and Litopterna represent forest taxa, while members of the Pampatheriidae are considered grassland inhabitants. Other taxa with fresh water affinities present at Cerro La Cruz are the Characiform (Serraselmidae) fish *Colossomma* and *Mylossoma* with multicuspid molariform teeth, which facilitate crushing fruits and hard-coated seeds (Correa *et al.*, 2007). According to Dahdul (2004) *Colossoma macropomum* is present in Cerro La Cruz fauna. This is an extant species that does occur in muddy- or black-water rivers but is limited to clear-water, shield-draining rivers in their lower reaches, often below large waterfalls or cataracts (Araújo-Lima and Goulding, 1997). Both *Colossoma* and *Mylossoma* have a diet based on vegetable material like fruits and hard-coated seeds, which it takes from the water surface of rivers, under the forest cover (Useche *et al.*, 1993). The extant species of the turtle *Chelus fimbriata* is a highly aquatic, lowland tropical species, found equally in rivers in both forested areas and savannah habitats in low tropical regions of Venezuela (Pritchard, 2008). Living species of *Colossomma*, *Mylossoma* and the turtle *Chelus* could be found in modern Orinoco and Amazon Basin.

The presence of fresh water and continental faunal assemblage suggests a predominance of forest with probably some savanna areas, and some rivers in the Cerro La Cruz, which agree with Strömberg *et al.* (2013), who using a high-resolution record of plant silica (phytoliths) from Patagonia described a dominance of forest areas (at least 70%) with minor open-habitat grasses (about 5 to 30%) in South America during the Early Miocene.

4.3. Implications of the 'Orinoco River shifting' hypothesis

The dynamic geologic history of South America should thus be very relevant for understanding the origins of the present diversity in the Amazonia (Hoorn *et al.*, 2010). During the Cenozoic an ancient river-dominated landscape usually called the 'Proto-Orinoco' or 'Proto-Amazon' was present in the northern of South America, collecting most of the Colombian, Ecuadorian and Peruvian Amazon tributaries and flowing mostly towards the Caribbean Sea (Rod, 1981; Hoorn *et al.*, 1995; Díaz de Gamero, 1996; Lundberg *et al.*, 1998; Hooghiemstra *et al.*, 2006; Wesselingh and Salo, 2006; Hoorn and Wesselingh, 2010; Shephard *et al.*, 2010; Hoorn *et al.*, 2010; Mora *et al.*, 2010; Aguilera *et al.*, 2013). Based on the fluvial and deltaic sediments of Paleocene age of the Orocue Group and the Marcelina Formation, the Eocene sediments of the Mirador Formation from the Venezuelan Llanos Basin, and the vast deltaic sedimentation of the Misoa and Carbonera Formations (Eocene) in the Maracaibo Basin, the existence of a large river system flowing in a general south-north direction during Paleocene to

Eocene in the Maracaibo Basin is accepted (Kasper and Larue, 1986; Díaz de Gamero, 1996).

Later, during Oligocene or Miocene times the course of this major river system changed to a clockwise direction until the present day position (Rod, 1981; Díaz de Gamero, 1996). Commonly, this change has been attributed to the Andean uplift (Hoorn *et al.*, 1995; Díaz de Gamero, 1996; Hoorn *et al.*, 2010), or driven by mantle convection (Shephard *et al.*, 2010). But the timing of this change is still unclear.

Different hypothesis exist regarding the evolution of the north of the 'Proto-Orinoco' River during Oligocene/Miocene to its present-day position (Guzmán and Fisher, 2006). The first hypothesis considered that until the Early Miocene, most of the area of the contemporary western Amazon drained northward to a delta located in the area of the modern Maracaibo Basin (Hoorn *et al.*, 1995; Lundberg, 1998; Toro and Steel, 2002; Albert *et al.*, 2006). However, the initial uplift and exhumation of the Colombian Eastern Cordillera during Oligocene and the paleogeographic reconstructions based on structural, stratigraphic, and sedimentological data from Maracaibo Basin and other Venezuela and Colombia basins shows no evidence for deposition of thick and extensive deltaic sedimentary deposits that would be expected with the outflow of a major river system similar to modern Orinoco or Amazon rivers (Villamil, 1999; Parra *et al.*, 2005; Guzmán and Fisher, 2006). The recent Orinoco basin drains 75% of Venezuelan territory and most of the eastern lowlands of Colombia, covering an approximate area of 1×10^6 km^2 (Meade, 1994; Méndez, 2005). With approximately 30.000 km^2 the Orinoco delta is one of the largest deltas in America (Méndez, 2005). The recent Orinoco River ranks third in the world in terms of water discharge and about tenth in sediment discharge, with an average of suspended-sediment load of about 150×10^6 tons (Meade, 1994). These ideas discard a paleo-Maracaibo outlet for most of the majors rivers flowing north during the Early Miocene (Johnson *et al.*, 2009; Mora *et al.*, 2010).

A second hypothesis proposed that during the Oligocene-Miocene boundary the major river system ('Proto-Orinoco') drained into the Falcón Basin northwestern of Venezuela (Rod, 1981; Díaz de Gamero, 1996; Aguilera *et al.*, 2013). It is due to some geological evidence from the Falcón Basin, besides the biogeographical relationships of the rich fresh-water vertebrate fossil fauna found in the northwestern Falcón (Socorro, Urumaco, Codore and Tío Gregorio Formations) to the recent Orinoco River system (Díaz de Gamero, 1996). Among others, Díaz de Gamero (1996) proposed that the clastics sediments present in the Castillo Formation, western margin of Falcón Basin, probably represent the fluvio-deltaics facies of the 'Proto-Orinoco' River. Nonetheless, Díaz de Gamero (1996) notes that the Castillo Formation was poorly studied, and this author, following Wheeler (1960) reported the presence of coal seams, and interpreted the formation as fluvial deltaic and coastal marine. But Wheeler (1960, 1963) described only the continental to brackish shales (along the basin edge) that contain a few thin coal seams, and in more than 360 m of stratigraphic section at Cerro La Cruz outcrops we did not observe any coals seam level. Furthermore, based in the presence of the Serrasalmidae fishes *Colossoma* and *Mylossoma* found in Cerro La Cruz, Dahdul (2004), Aguilera and Rodríguez de Aguilera (2004a), and Sánchez-Villagra *et al*. (2004) suggest that records of 'Proto-Orinoco' shift is contained in the Miocene sections of Cerro La Cruz, Castillo Formation. Also Aguilera *et al.* (2013) proposed the presence of a major river system in the western margin of the Falcón Basin during the earliest Miocene, with clear faunal affinities to the Amazon and Orinoco, probably referring to the Cerro La Cruz fauna.

In contrast with the last two hypotheses, the geological settings and the paleontological affinities of the vertebrate fauna so far recovered from Cerro La Cruz (Castillo Formation, Early Miocene, Falcón Basin) do not provide any conclusive proxy to indicate the presence of a major river system that could be interpreted as the 'Proto-Orinoco'. Nevertheless, the occurrence of some freshwater taxa such as *Colossoma, Mylossoma*, and *Chelus* from Cerro La Cruz suggests the presence of local fluvial environments associated to these fresh water faunas, and the fauna so far recovered from Cerro La Cruz shows Orinoco-Amazon affinities. This is based on the presence of extant species of *Colossoma, Mylossoma*, and *Chelus* in the recent Orinoco Basin, although some of these genera can be found in other hydrographic basins such as Maracaibo Basin, where *Mylossoma acanthogaster*, and *Chelus fimbriata* have been found.

Thus we consider unlikely a direct connection between the Cerro La Cruz sections with a major river system during the Early Miocene. The inferred direction of the flow of this local fluvial environment (river) was to the north. The limited clastic terrigenous influx and the immature sandstone observed in the analyzed section suggest this fluvial environment probably had a low water volume and a short path. We consider more probable that Cerro La Cruz was part of the same hydrographic basin that gave rise to the modern Orinoco River before Miocene, but being isolated at least since the Early Miocene.

Observations from Cerro La Cruz support a third hypothesis, which indicated that the drainage axis of the major river system ('Proto-Orinoco' River) had been diverted to the northeast since the Late Oligocene (Villamil, 1999). Furthermore, Guzman and Fisher (2006) propose that the Maracaibo Basin has been isolated from extrabasinal drainage systems since the Late Oligocene, and sediments derived from the surrounding highlands were either deposited in the basin or delivered into the neighboring Falcón Basin through a narrow marine passage. So the Oligocene-Miocene intrabasinal drainage systems in the Maracaibo and Falcón Basins support that the course of the 'Proto-Orinoco' River must have been permanently shifted away from the Maracaibo Basin since the Oligocene or earlier. This third hypothesis was also supported by the presence of the bivalve *Pachydon hettneri* in the Chaguaramas Formation (Late Oligocene/Early Miocene, with outcrops in Guárico State, Eastern of Venezuela), Perú and Colombia, implying that during the Burdigalian-Langhian a lowland aquatic biogeographic connection existed between the Amazon region and Venezuela through the East Andean foreland basins (Wesselingh and Macsotay, 2006). In addition, the sandstones and gravels of the Chaguaramas Formation contain a heavy mineral suite characteristic of the Colombian Central Cordillera, and the clay mineralogy of the silt component of this formation indicates both a Colombian Central Cordilleran and a Venezuelan coastal range origin (Vivas and Macsotay, 1995; Wesselingh and Macsotay, 2006). Consequently, the sedimentological and paleontological records suggest that the Chaguaramas Formation could be considered as relict of 'Proto-Orinoco' delta (Vivas and Macsotay, 1995; Pindell *et al*., 1998; Wesselingh and Macsotay, 2006), discarding the possible draining of a major river system ('Proto-Orinoco') to the Maracaibo or Falcón Basin during the Early Miocene.

5. Conclusions

The recorded fauna of Cerro La Cruz includes 40 taxa: nine Chondrichthyes, 13 Actinopterygii, four Testudines, four Cetartiodactyla, three Crocodilia, one Sirenia, three Xenarthra, two Notoungulata and one Litoptern. The last six confirm the presence of the earliest and most diverse terrestrial mammal assemblage in Venezuela. The geologic analysis of the sediments present at Cerro La Cruz allows us to interpret the upper part of the Castillo Formation, with outcrops in the southwestern Sierra de la Baragua, Lara state, as a mainly near-shore marine complex with local brackish-water probably lagoon near mangrove areas, subtidal shallow marine environments, shelf lagoon with low energy water circulation, and shallow water with open circulation close to wave base, associated to regressive and trangressive phases probably due to Antarctic glaciations, during Early Miocene ($^{87}Sr/^{86}Sr$ ages between 17.21-19.27 Ma). Nevertheless, at least two different continental episodes, that contains an Early Miocene mammalian assemblage were found. The number of terrestrial mammalian taxa discovered to date, does not permit assignment to a specific SALMA, although does fit within the earlier part of the broader defined Pansantacrucian mammalian sub-cycle. The continental vertebrate assemblage is interpreted as indicative of an ecosystem consisting of a mosaic that includes dominant tropical humid forest and some lowland savanna.

Our interpretation of the geology at Cerro La Cruz shows no conclusive evidence for the presence of a big river crossing over that zone during the Early Miocene, and does not support the hypothesis of the possible draining of a 'Proto-Orinoco' river into Maracaibo or Falcón Basin during Early Miocene. The recorded vertebrate fauna indicate some similarities with other northern South America fossil localities with Orinoco-Amazon affinities, the Middle-Late Miocene fauna of La Venta (Colombia) and Urumaco (Venezuela), nevertheless futures analyses will be needed corroborate this hypothesis.

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