



ELSEVIER

Journal of South American Earth Sciences 17 (2004) 39–48

Journal of
**South American
Earth Sciences**

www.elsevier.com/locate/jsames

Revision of the Upper Cretaceous rudists from northwestern Peru

Jean Philip^{a,*}, Etienne Jaillard^b

^aCentre de Sédimentologie-Paléontologie, Université de Provence, 3 Place Victor Hugo, Marseille Cedex 313331, France

^bIRD-LGCA, Maison des Géosciences, BP 53, 38 041 Grenoble cedex 09, France

Abstract

Revision of the Upper Cretaceous rudists of northwestern Peru has led to new discoveries and enabled the specification of their taxonomy and stratigraphic locations. Different species have been identified: *Biradiolites* cf. *jamaicensis* Trechmann 1924, *Radiolites* cf. *macroplicatus* Whitfield 1897, *Praebarrettia sparcilirata* (Whitfield, 1897) of Late Campanian age, and *Macgillavryia nicholasi* (Whitfield, 1897) of Middle-Late Maastrichtian age. During the Campanian and Maastrichtian, rudists of Peru show paleobiogeographic affinities with those of the Mexican and Caribbean domains. A paleogeographic route for rudist migrations may have existed at that time along the Caribbean arc and the Curaçao-Ecuador coastline.

© 2004 Published by Elsevier Ltd.

Keywords: Paleobiogeography; Peru; Rudists; Upper Cretaceous

1. Introduction

Although, the earliest mention of rudists in South America was by d'Orbigny (1842), the first descriptions of Upper Cretaceous rudists in Peru were provided by Gerth (1928) and Olsson (1934, 1944). A recent stratigraphic revision of the Upper Cretaceous of northwestern Peru and southwest Ecuador (Jaillard et al., 1998, 2004) has resulted in the discovery of well-preserved rudists and their stratigraphic context. We present a revision of the Upper Cretaceous rudists from northwestern Peru to examine their paleobiogeographic relationships with both the Caribbean and Central America provinces during Campanian and Maastrichtian times.

2. Geological setting

In northwestern Peru (Fig. 1), outcrops of Campanian and Maastrichtian sediments occur in elongated SSW–NNE-trending forearc basins, located south of the Amotape-Tahuin Paleozoic basement and west of the mid-Cretaceous Celica-Lancones basin. Rudist-bearing beds are well exposed in the La Tortuga section, which crops out south

of the town of Paita, and the Monte Grande area, located east of Talara (Fig. 1).

In Paita, following Olsson (1944), Fischer (1956), and Alemán (1999), Jaillard et al. (1998, 2004), Taipe et al. (2000) subdivide the Campanian-Maastrichtian interval into three formations, from base to top: La Mesa, La Tortuga, and Cenizo. Their respective ages have been established on the basis of ammonite and inoceramid records (Jaillard et al., 2004). Rudists occur in the middle and upper members of the La Mesa Formation, in the middle unit of the La Tortuga Formation, and in the upper part of the Cenizo Formation.

3. Stratigraphy

3.1. La Mesa Formation

In La Mesa (Fig. 2), located west of Cerro La Mesa, the La Mesa Formation unconformably rests on the Paleozoic basement. The lower member is made up of transgressive facies bearing rounded bioclasts and oyster debris, followed by an alternation of shales and sandstones that correspond to an open shelf environment.

The middle member is dominated by carbonate and represents the upper part of a transgressive–regressive sequence. It is formed by shelf limestones rich in rudists (Radiolitids), corals, and gastropods (*Actaeonella*). Rudist-rich floatstones and rudstones are well represented in the upper part. In these facies, rudists are generally crushed,

* Corresponding author.

E-mail addresses: jphilip@univ-mrs.fr (J. Philip), etienne.jaillard@ujf-grenoble.fr (E. Jaillard).

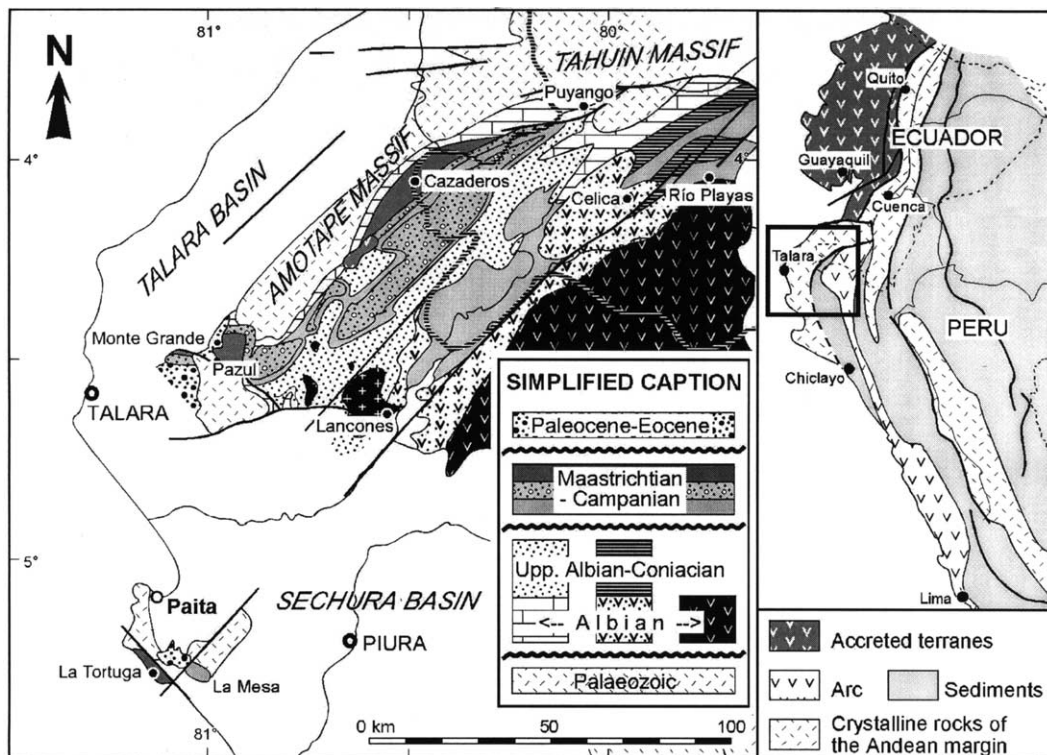


Fig. 1. Location of the studied sections and the main localities cited in the text.

though we identified numerous fragments of conical depressed right valves, bearing subpolygonal and reticulate cell structures, and bifurcated vessels on the commissural surface, possibly attributed to the genus *Macgillavryia*. Gerth (1928) cites *Praebarrettia peruviana* from this middle member, though we did not find it.

The upper member is represented by an alternation of shales and sandstones bearing numerous inoceramids and rudists, associated with ammonites, corals, bivalves, and echinoids. We determine from this member the following samples: *Praebarrettia sparcilirata* (Whitfield), *Radiolites* cf. *macroplacatus* Whitfield, and *Biradiolites* cf. *jamaicensis* Trechmann. Ammonites and inoceramids (Fig. 2) suggest an Upper Campanian age for the upper member.

3.2. La Tortuga Formation

In the La Tortuga section (Fig. 3) along the shore (La Tortuga, Cenizo, and Perico beaches), rudists occur in the middle unit of the La Tortuga Formation (Tortuga beds of Olsson, 1944) and the upper part of the Cenizo Formation (Radiolites sandstones of Olsson, 1944). The lower and upper parts of the 3500 m thick La Tortuga Formation are dominated by coarse-grained alluvial fan breccias, intercalated with fan delta breccias and shoreface sandstones. The lower breccia evolves toward a transgressive–regressive cycle, whose maximum flooding is represented by the shaled marine middle unit (Tortuga beds). The latter contains ammonites (*Sphenodiscus* sp.), bivalves,

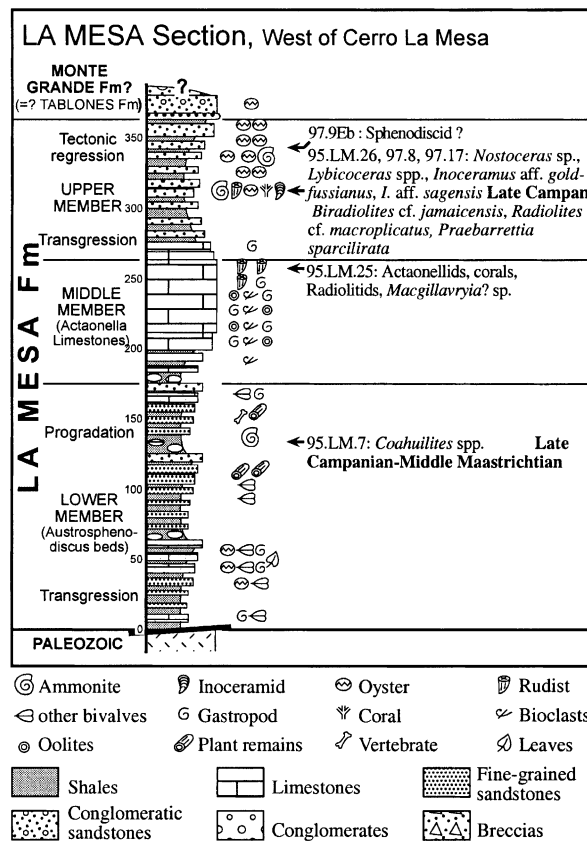


Fig. 2. Section of the La Mesa Formation (west of Cerro la Mesa, Paita area) and location of rudists. Ammonites and inoceramids from Jaillard et al. (2004) and Bengtson (pers. comm.).

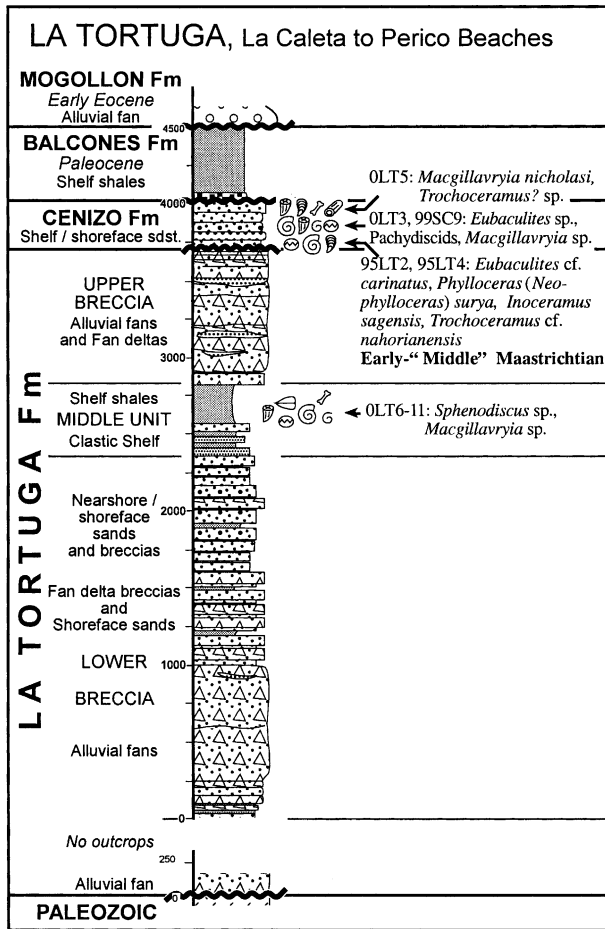


Fig. 3. Section of the La Tortuga Formation (beaches southwest of La Tortuga, Paita area) and location of rudists. Ammonites and inoceramids from Jaillard et al. (2004) and Bengtson (pers. comm.).

and the rudist *Macgillavryia*. This middle unit should be ascribed to the Lower Maastrichtian.

3.3. Cenizo Formation

The Cenizo Formation is formed by a 300 m thick, clastic-dominated succession (Fig. 4) that unconformably overlies the alluvial breccias of the upper member of the La Tortuga Formation. The first sequence is represented by the transgressive ‘Baculites sandstones’, which grade upward into black sandstones and breccias of a fan delta environment and represent the regressive part of the sequence.

A new transgression is marked by ammonite-bearing dark sandstones, which locally rest on the Paleozoic basement and grade upward into finer-grained, yellow sandstones of the shallow shelf to nearshore environment (Radiolites sandstones of Olsson, 1944). The Radiolites sandstones, more than 100 m thick, are truncated by a major erosive angular unconformity, which encompasses the Maastrichtian/Paleocene boundary.

Rudists are associated with inoceramids and marine reptiles and overlie ammonite-bearing beds (Fig. 4), which suggest the lower-middle Maastrichtian (Taipe et al., 2000).

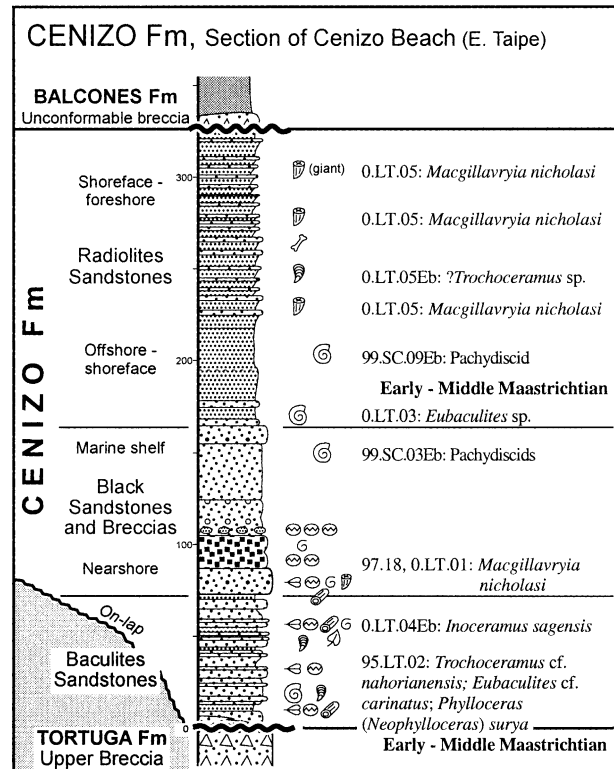


Fig. 4. Section of the Cenizo Formation (beaches west of La Tortuga, Paita area) and location of rudists. Ammonites and inoceramids from Jaillard et al. (2004) and Bengtson (pers. comm.).

Rudists are mainly represented by specimens of *Macgillavryia nicholasi* (Whitfield). Giant specimens of this species occur at the top, just beneath the disconformable Paleocene Balcones Formation.

4. Systematic paleontology

The described specimens are housed in the Centre de Sédimentologie Paléontologie, Université de Provence, Marseille.

4.1. Family Radiolitidae d'Orbigny 1847

Subfamily Biradiolitinae Douvillé 1902

Genus *Macgillavryia* Rojas, Itturalde-Vinent and Skelton 1995

Type species *Radiolites (Lapeirousia) nicholasi* Whitfield 1897

M. nicholasi (Whitfield 1897) (Pl. 1, 2)

1897 *Radiolites (Lapeirousia) nicholasi* Whitfield, pp. 186–188, Pl. VI–IX.

1934 *Sphaerulites (Lapeirousia) cf. nicholasi* (Whitfield), Olsson, pp. 49–50; Pl. 1, 8; Figs. 2 and 4.

1944 *Sauvagesia peruviana*, Olsson pp. 206–208; Pl. 8, Figs. 1–5.

1971 *Durania nicholasi* (Whitfield), Chubb, pp. 199–201, Pl. 43–46, Figs. 1, 2 and 6.

1971 *Durania nicholasi* (Whitfield), Alencaster, p. 48, Pl. 10, Figs. 3 and 4.

1995 *Macgillavryia nicholasi* (Whitfield), Rojas, Itturalde-Vinent, and Skelton, pp. 285–288, Pl. 3, Figs. 1–3.

4.1.1. Material

Six entire or fragmented right valves (O.LT.5a–d; O.LT.1; 97.18).

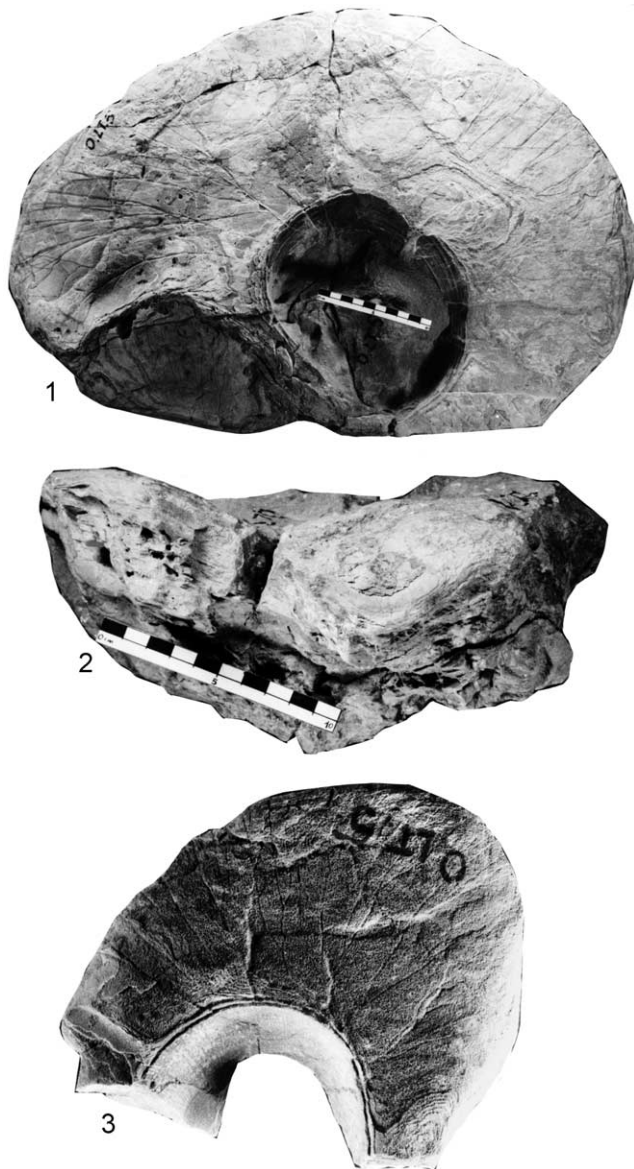


Plate 1. Playa Cenizo section. (1) View of the commissural surface of the attached valve of *Macgillavryia nicholasi*. The diameter of the valve is 60 cm. Note the bifurcated vessels that ornament the commissural area. The scale bar is 10 cm long. Specimen O.LT.5a, upper part of the Cenizo Formation. (2) View of the ventral side of specimen O.LT.1 from the middle part of the Cenizo Formation. (3) Close-up of the commissural surface of the attached valve of specimen O.LT.5c showing the bifurcated vessels, $\times 0.75$, upper part of the Cenizo Formation.

4.1.2. Description

Right (attached) valve of large size, depressed conical. Individuals commonly have a diameter of 20–30 cm, up to 60 cm for specimens from the top of the Cenizo Formation (Plate 1). Funnel plates are thin, largely expanded all around the shell. Cellular network with fine reticulate cells (0.3–0.5 mm), sometimes subpolygonal or amoeboid. Commissural area large, bearing bifurcated or polyfurcated radial vessels. Radial bands rarely well preserved, corresponding to slight undulations of the outer layer in adult stages of the shell. However, one specimen (O.LT.5b) shows a depressed smooth subrectangular furrow that may represent the ventralward (Vb) band. Interband convex, well pronounced. Body cavity conical, extending to the base of the shell. No ligamental ridge. Right valve sometimes encrusted by epibiontic (calcareous Annelids?) organisms (Plate 2, Fig. 3).

Despite the absence of a free valve and preservation of the cardinal apparatus, specimens from Peru fit well with descriptions of *M. nicholasi* from Jamaica (Chubb, 1971) and Cuba (Philip, 1999).

4.1.3. Occurrence

In Paita, *M. nicholasi* has been collected in the middle unit of the La Tortuga Formation, where it is represented by coarse fragments of right valves. Well-preserved specimens come from the Radiolites sandstones. According to Olsson (1934), *M. nicholasi* should be present in the Early Maastrichtian Monte Grande Formation of the Lancones basin.

The species is known to accompany both the Campanian *Barrettia gigas-multilirata* and the Maastrichtian *Titanosarcolithes giganteus* faunas in the Caribbean province (Philip, 1999) and Mexico (Alencaster, 1971).

4.2. Genus *Biradiolites* d'Orbigny 1850

Type species *Biradiolites canaliculatus* d'Orbigny 1850
Biradiolites cf. *jamaicensis* Trechmann 1924 (Plate 3, Figs. 3 and 4)

1924 *Biradiolites jamaicensis* Trechmann, p. 404, Pl. 24, Figs. 5, 5a, 6, 6a, 7.

1971 *Biradiolites jamaicensis* Chubb, pp. 186–187, Pl. 35, Figs. 8–12.

4.2.1. Material

One individual (LM.26).

4.2.2. Description

Right valve elongated, of relatively small size (length, 6 cm; diameter, 2.5 cm). Outer surface of the shell smooth, bearing nine sharply angular costae separated by angular furrows. Siphonal bands smooth, separated by a broad costa with a narrow groove down its middle.

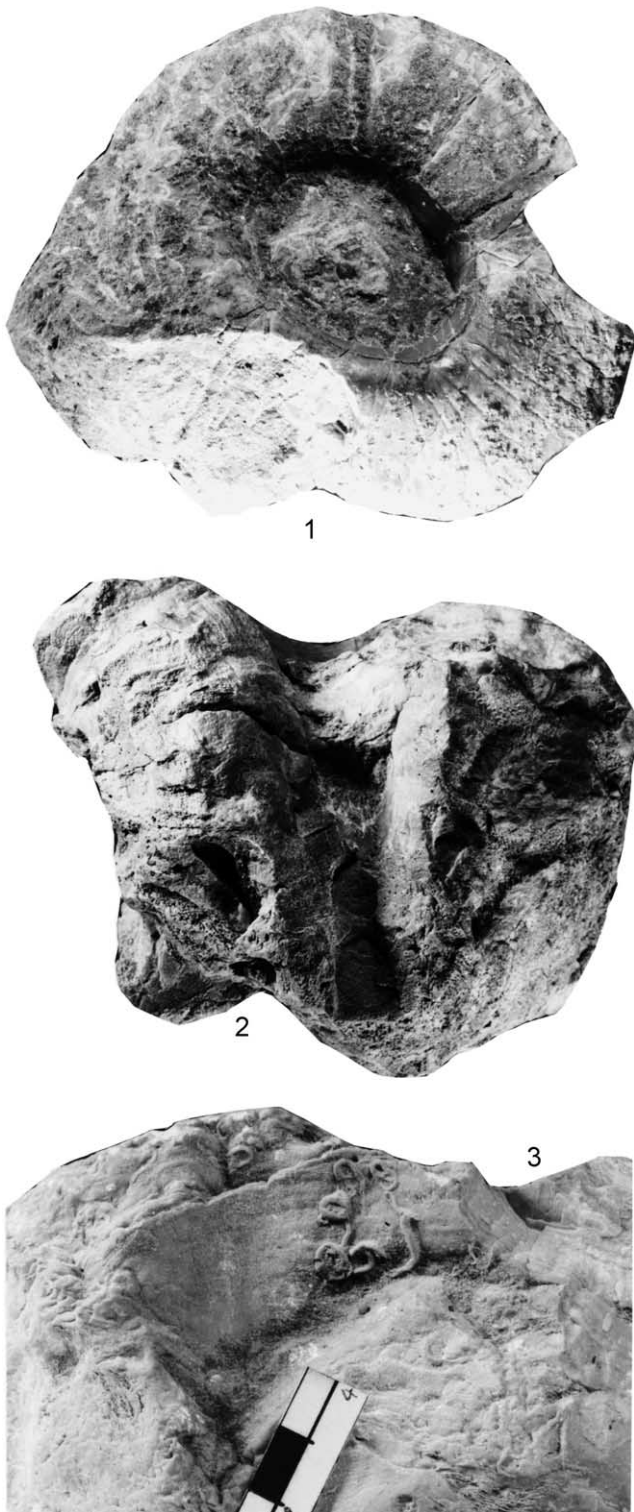


Plate 2. (1) View of the commissural surface of the attached valve of *Macgillavryia nicholasi* from the lower part of the Radiolites sandstones. Specimen 97.18, $\times 0.47$, Las Playas La Caleta Perico section. (2) Ventral view of the attached valve of specimen 0.LT.5b of *M. nicholasi* showing the depressed smooth subrectangular furrow corresponding to the ventralward band, $\times 1$, upper part of the Cenizo Formation, Playa Cenizo section. (3) Close-up of encruster organisms (Serpulidae?) on the ventral part of *M. nicholasi*. Specimen 0.LT.1, $\times 1$, middle part of the Cenizo Formation, Playa Cenizo section.

4.2.3. Occurrence

In the Paita area, the specimen comes from the upper member of the La Mesa Formation. The species is cited from the *Titanosarcolites* limestone of Jamaica, which has been ascribed to the Maastrichtian (Chubb, 1971) or the Upper Maastrichtian (Steuber et al., 2002). It has also been found in the Maastrichtian of Guatemala, the upper part of the Ixcoy Formation (Scott, 1995), and the El Ceibo section (Fourcade et al., 1997).

4.3. Subfamily Radiolitinae

Genus *Radiolites* Lamarck 1801

Type species *Ostracites angeiodes* (Picot de Lapeirouse) 1781

Radiolites cf. *macroplicatus* Whitfield 1897 (Plate 3; Figs. 5 and 6)

1897 *Radiolites macroplicatus* Whitfield, p. 190, Pl. 12–14, Figs. 1, 2 and 8.

1971 *Sauvagesia macroplicata* (Whitfield), Chubb, p. 196, Pl. 41, Figs. 1–4.

1971 *Sauvagesia macroplicata* (Whitfield), Alencaster, p. 52, Pl. 21, Figs. 1 and 2.

1992 *Radiolites macroplicatus* Whitfield, Alencaster and Pons, pp. 327–329; Pl. 1, Figs. 1 and 2.

4.3.1. Material

Eleven weathered fragments of right valves (LM.26a–k).

4.3.2. Description

Right valve elongate conical. The diameter can reach 10 cm. Commissural surface presenting plications characteristic of the species. Outer surface ornamented by coarse longitudinal costae corresponding to downfolds of the funnel plates separated by wide angular furrows corresponding to upfolds of the funnel plates. Cells polygonal to subpolygonal are 0.50–1 mm in diameter. Siphonal bands and ligamental ridge not preserved in our specimens. In radial section, funnel plates appear to form an angle of approximately 50° with the longitudinal axis of the right valve.

4.3.3. Occurrence

In the study area, *R. cf. macroplicatus* has been found in the upper member of the La Mesa Formation. It is reported in the literature as a rare species in the *Titanosarcolites* limestone from Jamaica, ascribed to the Maastrichtian (Chubb, 1971) and recently to the Upper Maastrichtian (Steuber et al., 2002); however, it locally occurs in rock-forming abundance (S.F. Mitchell, pers. comm.). It has also been cited in the Maastrichtian of Chiapas (Alencaster, 1971; Alencaster and Pons, 1992) and the Maastrichtian of the El Ceibo section in Guatemala (Fourcade et al., 1997).

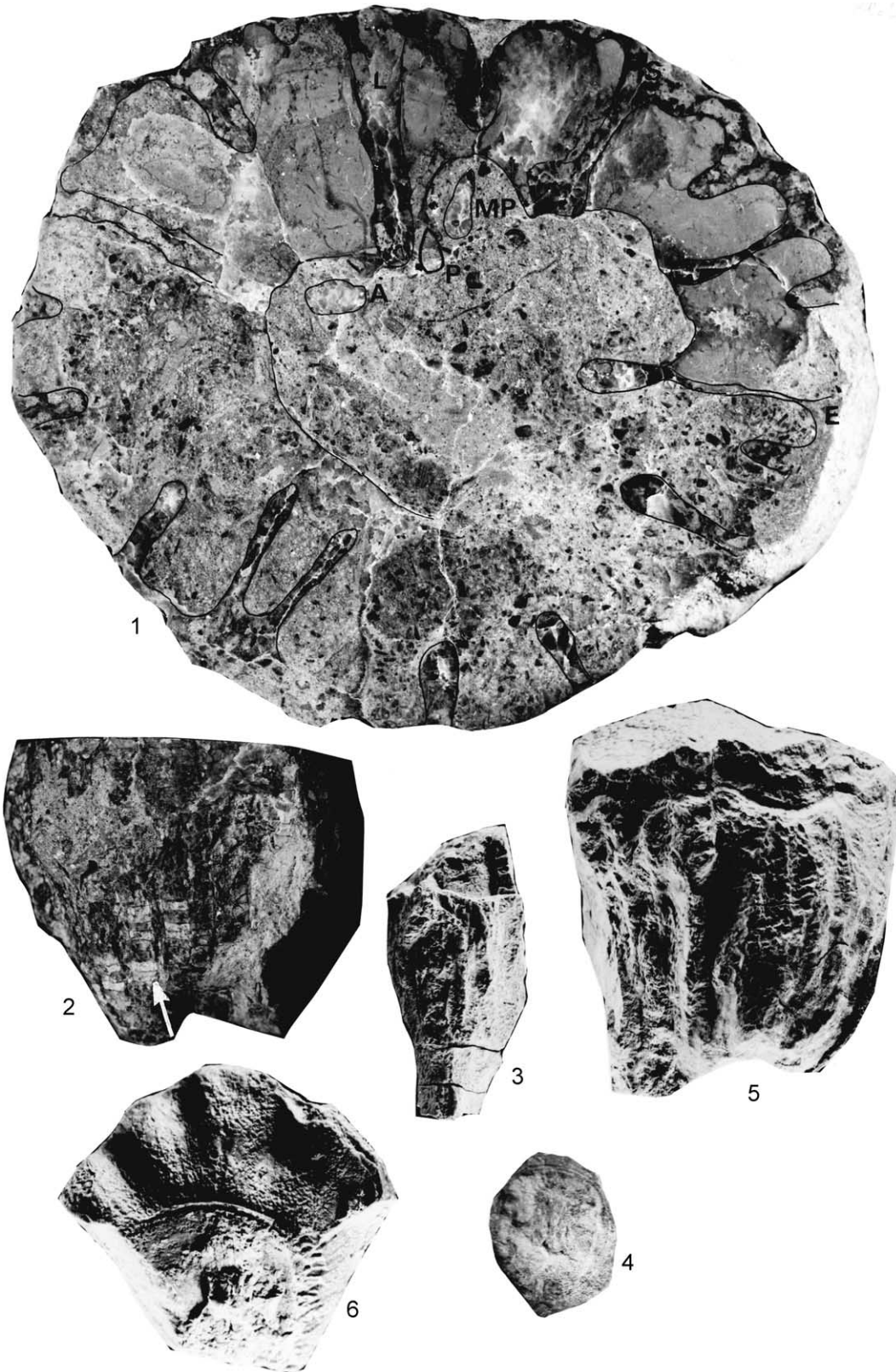


Plate 3. (1) Transversal section of the lower valve of *Praebarretia sparcilirata*. Specimen 97.8A, $\times 3.07$, upper member of La Mesa Formation, La Mesa section. L = ligamental ridge; S, E = pillars; MP = Posterior myophore; P = posterior tooth; and A = anterior tooth (nomenclature after Dommelen, 1971). (2) Lateral view of the lower valve of the same specimen showing the tabulae (white arrow), $\times 1$. (3) *Biradiolites* cf. *jamaicensis* (LM.26), $\times 1$, upper member of La Mesa Formation, La Mesa section. (4) Same specimen, transversal section, $\times 2.3$. (5) *Radiolites* cf. *macroplicatus*. Lower valve shows the coarse longitudinal costae. Specimen LM.26a, $\times 1$, upper member of La Mesa Formation, La Mesa section. (6) *Radiolites* cf. *macroplicatus*. Commissural surface shows the plications of the commissural surface, characteristic of the species. Specimen LM.26b, $\times 1$, upper member of La Mesa Formation, La Mesa section.

4.4. Family Hippuritidae Gray 1848

Genus *Praebarrettia* Trechmann 1924

Type species *Barrettia sparcilirata* Whitfield 1897

P. sparcilirata (Whitfield, 1897) (Plate 3, Figs. 1 and 2)

1897 *Barrettia sparcilirata* Whitfield, pp. 245–246, Pl. 36–37.

1928 *Pironaea peruviana* Gerth, pp. 235–237, Figs. 2–3.

1933 *Praebarrettia porosa* Palmer, p. 99, Pl. 6, Figs. 3–6.

1971 *Praebarrettia sparcilirata* (Whitfield) Chubb, pp. 215–216, Pl. 57, 58, Figs. 1 and 2.

1971 *Praebarrettia sparcilirata* (Whitfield), Van Dommelen, pp. 69–75; Pl. III, IV, Figs. 12 and 13 (1–10), 20, 22.

1971 *Praebarrettia sparcilirata* (Whitfield), Alencaster, p. 70, Pl. 14, 15, Figs. 1–6.

4.4.1. Material

Four specimens (97.8 a–d).

4.4.2. Description

Keys of determination and morphological nomenclature from Dommelen (1971). Right valves of moderate dimensions; diameter 50–60 mm. Ligamental ridge (L) thick and elongated with slight constrictions and a rounded tip. Pillar S pediculated, tip (knoll) rounded and thickened. Pillar E with thin pediculate stem and suboval tip. Angle LvE = 107°. $r/U = 1/3.5$. Myophore (MP) parallel to the axis of L and projecting on it. Posterior tooth (P) suboval, near the tip of the ligamental ridge. Anterior tooth (A) perpendicular to the axis of L. Angle A – P – MP = 140° (dentition type B). Rays alternate irregularly: triangular (type 1a and b) and elongated no more than one constriction (type 1c); absence of beads. Number of rays: 19–20. Presence of well-developed tabulae (Plate 3, Fig. 2) with interradiol extensions forming quadrangular cells between the rays. Mean space between tabulae: 2 mm as shown by *P. sparcilirata, porosa*-type (Dommelen, 1971).

A weathered left (free valve) preserved only in one specimen (97.8 a); height about 12 mm; apex central. Typical radial canals covered with a thin, more or less continuous reticulate layer of small pores (0.3–0.5 mm.). Transverse furrows described by Dommelen (1971) were not observed in our specimens. Peruvian specimens differ from *P. corrali* (Palmer) by the type of dentition and rays and the space between the tabulae.

4.4.3. Occurrence

In the Paita area, the species was collected in the upper member of La Mesa Formation. It is known from the Maastrichtian of the Caribbean area: Jamaica (Chubb, 1971; Dommelen, 1971), Cuba (Palmer, 1933; Philip, 1999), and Mexico (Alencaster, 1971).

Unfortunately, the Monte Grande Formation (Upper Campanian-lowermost Maastrichtian?) had not been investigated in the Lancones basin, from which Olsson (1934) described a multiple-fold hippuritid that he named *Orbignya pacifica*. The arrangement of rays of this form, figured by Olsson (1934, pl. 8, Figs. 1 and 2) suggests attribution to the genus *Praebarrettia*, close to the species *P. corrali* Palmer.

5. Discussion

As generally demonstrated (e.g. Philip, 1998), rudists are excellent biostratigraphic markers of upper Cretaceous stages and substages. Recent work has refined the biostratigraphy of rudists through calibrations of ammonites, planktonic foraminifera, or strontium isotopic stratigraphy (Steuber et al., 2002). In northwestern Peru, biostratigraphic data drawn from rudists can be compared with those provided by ammonites.

Three distinct rudist assemblages can be distinguished (Fig. 5). The first, and oldest, corresponds to the middle member (*Actaeonella* limestone) of the La Mesa Formation ascribed to the Middle Campanian (Taipe et al., 2000; Jaillard et al., 2004). Rudists are very abundant, but unfortunately poorly preserved due to high energy conditions that prevailed during their deposition. The existence of the genus *Macgillavryia* in this unit may be interpreted as a first appearance of the genus in the American domain, though it is younger than the appearance of the genus in the Arabian domain, where *Macgillavryia* is reported from

This work		
Balcones		Paleocene
Cenozoic	Radiolites Sst.	3rd rudist assemblage
	Dark breccia	
	Baculites Sst.	
La Tortuga	Up. Breccia	Early Maastrichtian?
	Mid. Unit	
	Low. Breccia	
La Mesa	Up. Conglomerate	2nd rudist assemblage
	Up. Member	
	Mid. Member	1st rudist assemblage
	Low. Member	
		Middle to Late Campanian
Paleozoic		

Fig. 5. Proposed rudist assemblages and age assignments.

the Lower Campanian Samhan Formation (Philip, 1999, 2003).

The second assemblage is better characterized. It is related to the upper member of La Mesa Formation dated by Late Campanian ammonites (Taibe et al., 2000; Bengtson, pers. comm.). It is formed by a relatively more diversified association, including *P. sparcilirata*, *B. cf. jamaicensis*, and *R. cf. macroplicatus*. In the Caribbean domain, the distribution of these species suggests a Maastrichtian age instead of a Late Campanian one. In Jamaica, *P. sparcilirata* occurs near the top of the *Titanosarcollites* series in the Logie Green area (S.F. Mitchell, pers. comm.), recently dated as Upper Maastrichtian (Steuber et al., 2002). The relatively small size of the *P. sparcilirata* specimens in northwestern Peru may be due to inamical paleoecologic conditions, but it also may be a chronospecies of smaller size, ancestor of the Upper Maastrichtian, larger *P. sparcilirata* of the Caribbean.

The third assemblage fits with the Radiolites sandstones, which constitute the upper part of the Cenizo Formation and contain only one species, *M. nicholasi*. The age of this Formation is well constrained at its base by ammonites (i.e. *Eubaculites*), which indicate lower-middle Maastrichtian (Taibe et al., 2000). However, the question of the age of the overlying Radiolites sandstones remains. In Jamaica, *M. nicholasi* occurs up to the *Titanosarcollites* limestone, which has been ascribed to the latest Maastrichtian (66–65 Ma) by the strontium isotope ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) method (Steuber et al., 2002). Therefore, the Radiolites sandstones may be attributed to the Upper Maastrichtian, and the giant forms of *Macgillavryia* at the top of the Formation could represent the youngest rudists in the American province, roughly coeval

with those of the *Titanosarcollites* limestone in the Caribbean.

6. Paleobiogeography

Comparing the rudist diversity of the Caribbean/American areas as a whole (Fig. 6), it appears that the diversity of Peru and Ecuador is very low, with only four genera, none of them endemic. The impoverishment of rudist fauna, compared with Cuba, Puerto Rico, Jamaica, or Mexico, could be due to unfavorable environmental and/or climatic conditions in Peru and Ecuador or possibly an incomplete sampling.

A reconstruction of the Campanian-Maastrichtian paleogeographic framework of South America and the Caribbean (Fig. 7) shows that the most diversified rudist-rich areas, encompassing Mexico, Jamaica, Cuba, and Puerto Rico, are located at $\sim 20^\circ$ north latitude in relatively large shelves with moderate clastic inputs, whereas the rudist areas of Ecuador and northern Peru are located at the equator and experienced important clastic inputs from the South American margin and possibly relative sea water heating. These adverse paleoenvironmental conditions may explain the low diversity of rudists observed in northwestern Peru. From a paleobiogeographic point of view, rudist settlement in Peru and Ecuador is probably linked to Campanian and Maastrichtian marine transgressions that dispersed rudist larvae in a large area including Central America, the Caribbean, Peru, and Ecuador.

Three possible routes for interprovincial exchanges can be proposed: (1) along the Costa Rica-Panama arc, though little data document this assumption; (2) through the oceanic

	Peru-Ecuador This work	Curaçao-Bonaire Steuber 2002	Puerto Rico (Steuber 2002) Cuba Rojas et al. 1995	Jamaica Chubb 1971	Guatemala Steuber 2002	Mexico Steuber 2002
GENERA	<i>Macgillavryia</i> <i>Biradiolites</i>	<i>Durania</i>	<i>Macgillavryia</i> <i>Biradiolites</i> <i>Bournonia</i> <i>Durania</i> <i>Thyrastylon</i> <i>Chiapasella</i> <i>Radiolites</i> <i>Sauvagesia</i> <i>Tampsia</i> <i>Distefanella</i>	<i>Macgillavryia</i> <i>Biradiolites</i> <i>Bournonia</i> <i>Durania</i> <i>Thyrastylon</i> <i>Chiapasella</i> <i>Radiolites</i> <i>Sauvagesia</i> <i>Distefanella</i> <i>Praeradiolites</i> <i>Agriopleura</i>	<i>Biradiolites</i> <i>Bournonia</i> <i>Thyrastylon</i> <i>Radiolites</i> <i>Praeradiolites</i>	<i>Macgillavryia</i> <i>Biradiolites</i> <i>Bournonia</i> <i>Durania</i> <i>Thyrastylon</i> <i>Chiapasella</i> <i>Radiolites</i> <i>Sauvagesia</i> <i>Tampsia</i>
Campanian-Maastrichtian interval	<i>Praebarretia</i>	<i>Praebarretia</i> <i>Hippurites</i>	<i>Praebarretia</i> <i>Barretia</i> <i>Vaccinites</i> <i>Parastroma</i> <i>Torreites</i>	<i>Praebarretia</i> <i>Barretia</i> <i>Vaccinites</i> <i>Hippurites</i> <i>Parastroma</i> <i>Torreites?</i>	<i>Barretia</i>	<i>Praebarretia</i> <i>Barretia</i> <i>Vaccinites</i> <i>Hippurites</i>
Other families			<i>Titanosarcollites</i> <i>Antillocaprina</i> <i>Plagioptychus</i> <i>Mitrociprina</i>	<i>Titanosarcollites</i> <i>Antillocaprina</i> <i>Plagioptychus</i> <i>Mitrociprina</i> <i>Monopleura*</i> <i>Gyropleura*</i> <i>Antillosarcollites</i>		<i>Titanosarcollites</i> <i>Antillocaprina</i> <i>Plagioptychus</i> <i>Corallochama</i>
* Endemic genus						
Number of genera	4	3	19	24	6	17
Number of species	4	3	42	59	7	36

Fig. 6. Comparison of rudist genera diversity between the Peru–Ecuador and other regions of the Caribbean and Central and North America (Steuber, 2002).

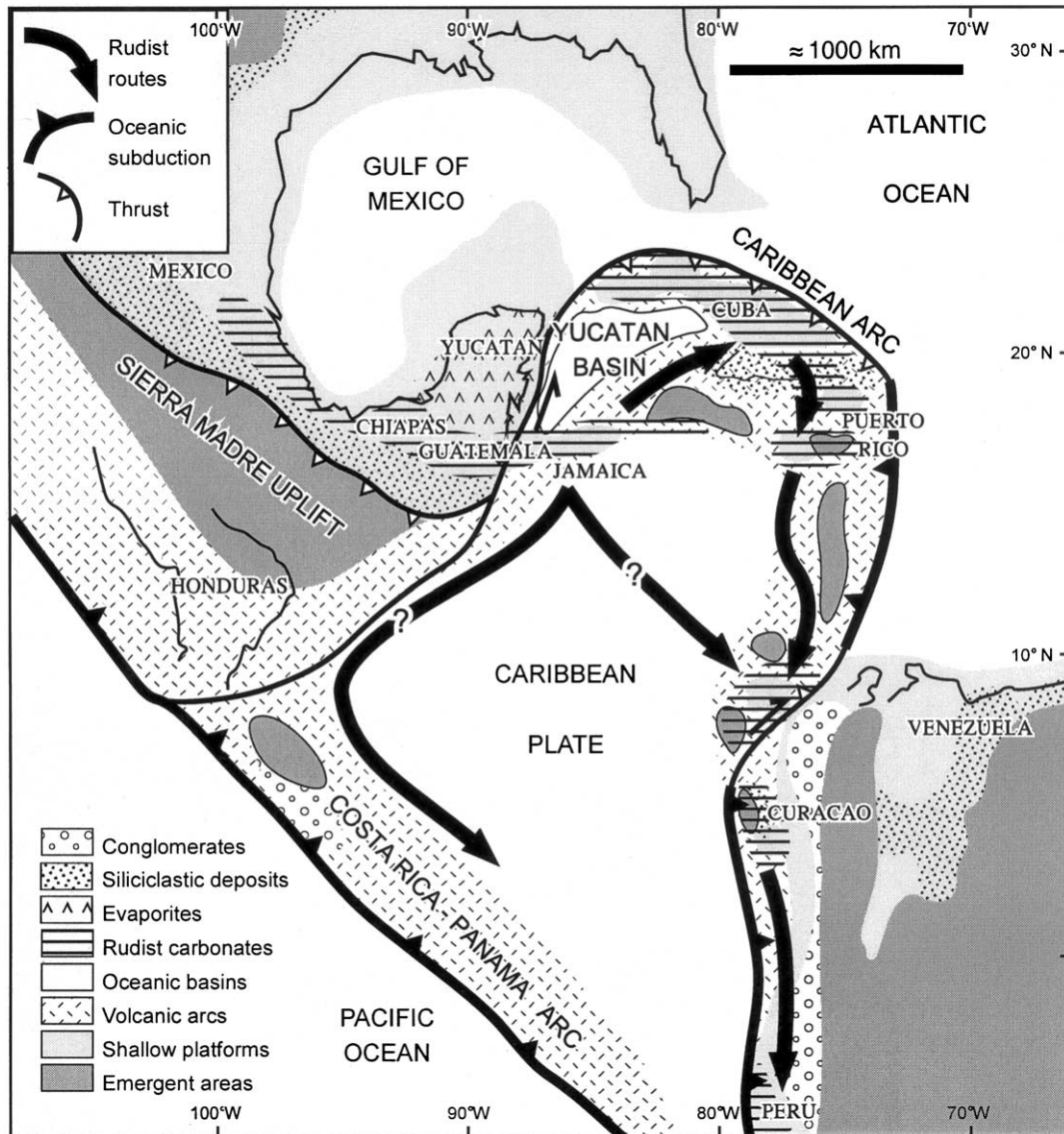


Fig. 7. Paleobiogeographic reconstruction of the northwestern South America, Mexico, and Caribbean areas during Campanian-Maastrichtian times showing possible migration routes for rudists (paleogeodynamic map modified after Stéphan et al., 1990, Pl. 8).

space corresponding to the Caribbean plate, approximately 800 km across. This possibility depends on the existence of north–south oceanic surface currents in this area, which have not yet been documented; or (3) along the Caribbean arc, then along the Curaçao–Ecuador coastline. This route is supported by paleobiogeographic stepping stones established on volcanic highs (i.e. Puerto Rico), where rudist larvae were able to attach and thrive. These paleobiogeographic staging posts may link the high-diversity rudist areas of North America and the Caribbean to Peru and Ecuador.

The direction of migration cannot be accurately determined due to poor knowledge about the oceanic surface circulation in this area. However, southward migrations can be inferred from the highly diversified rudist areas to marginal, poorly diversified areas (i.e. Ecuador and northwestern Peru).

The genus *Macgillavryia* has also been recently described (Philip, 1999, 2003) from the Campanian of Oman. Hence, the northwest Peruvian area appears to be a new stepping stone for the trans-Pacific migration of the genus *Macgillavryia* between the Caribbean and Oman.

7. Conclusions

In northwestern Peru, rudists are present in the La Mesa, La Tortuga, and Cenizo Formations of Middle-Upper Campanian, Lower Maastrichtian, and probably Upper Maastrichtian age, respectively. Three rudist assemblages, characterized by a low diversity that probably is related to adverse paleoenvironmental/climatic conditions, have been identified.

The Peruvian rudist fauna shows paleobiogeographic affinities with the North American (Mexico) and Caribbean areas. Rudist settlement in northwestern Peru was favored by Campanian and Maastrichtian marine transgressions, which broadly dispersed rudist larvae and connected rudist carbonate platforms and submerged paleohighs (volcanic islands), where rudists became established. A paleobiogeographic route for rudist migrations probably existed along the Caribbean arc and the Curaçao-Ecuador coastline.

New investigations may provide a better understanding of the paleobiogeographic role played by northwestern Peru and Ecuador with respect to the migration of ubiquitous rudists (e.g. *Torreites*, *Macgillavryia*) through the Pacific and Indian Oceans and between the Arabian and American domains during Santonian, Campanian, and Maastrichtian times.

Acknowledgements

We thank Gloria Alencaster and Simon F. Mitchell for their constructive comments and improvement of the English text. Photographs of rudists are by J.J. Roccabianca and Axel Arnoux.

References

- Alemán, A., 1999. Late Cretaceous forearc extension in northwestern Peru: geodynamic implications, Fourth International Symposium on Andean Geodynamics-ISAG, Göttingen, IRD Publications.
- Alencaster, G., 1971. Rudistas del Cretácico superior de Chiapas. *Paleontologia Mexicana* 34(I), 91.
- Alencaster, G., Pons, J.M., 1992. New observations on the upper Cretaceous rudists of Chiapas: comparison between American and European faunas and taxonomic implications. *Geologica Romana* 28, 327–339.
- Chubb, L.J., 1971. Rudists of Jamaica. *Palaeontographica Americana* VII(45), 159–257.
- Dommelen, H.v., 1971. Ontogenetic, phylogenetic and taxonomic studies of the American species of *Pseudovaccinites* and of *Torreites* and the multiple-fold *Hippuritids*, University of Amsterdam, 125pp.
- d'Orbigny, A., 1842. Voyage dans l'Amérique méridionale. *Paléontologie* 4, 1–188.
- Fischer, A.G., 1956. Cretaceous of northwest Peru. International Petroleum Co. Ltd, unpublished Geological Report. WP-13, 72pp.
- Fourcade, E., Alonzo, M., Barrillas, M., Bellier, J.-P., Bonneau, M., Cosillo, A., Cros, P., Debrabant, P., Gardin, S., Masure, E., Philip, J., Renard, M., Rocchia, R., Romero, J., 1997. La limite Crétacé-Tertiaire dans le sud ouest du Peten (Guatemala). *Comptes Rendus de l'Académie des Sciences Paris* 325(1), 57–64.
- Gerth, H., 1928. Neue faunen der Oberen Kreide mit Hippuriten aus Nord Peru. *Leidsche Geologische Mededeelingen*, Deel, 2, Afl. 4, 231–241.
- Jaillard, E., Laubacher, G., Bengtson, P., Dhondt, A., Philip, J., Bulot, L.G., Robert, E., 1998. Revisión estratigráfica del Cretáceo superior del noroeste peruano y suroeste ecuatoriano. Datos preliminares, consecuencias tectónicas. *Boletín de la Sociedad Geológica del Perú* 88, 101–115.
- Jaillard, E., Bengtson, P., Dhondt, A., 2004. Late Cretaceous marine transgressions in Ecuador and northern Peru: a refined stratigraphic framework. *Journal of South American Earth Sciences* same 494, this issue.
- Olsson, A.A., 1934. Contributions to the paleontology of northern Peru: The Cretaceous of the Amotape region. *Bulletin of American Paleontology* 20(69), 1–104.
- Olsson, A.A., 1944. Contributions to the paleontology of northern Peru. Part VII: The Cretaceous of the Paita region. *Bulletin of American Paleontology* 28(III), 163–305.
- Palmer, R.H., 1933. Nuevos rudistas de Cuba. *Revista de Agricultura, Comercio y trabajo* 14(15/16), 95–125.
- Philip, J., 1998. Biostratigraphie et paléobiogéographie des rudistes: évolution des concepts et progrès récents. *Bulletin de la Société Géologique de France* 169, 689–708.
- Philip, J., 1999. Description of well-preserved specimens of *Macgillavryia*, Rojas, Itturalde-Vinent and Skelton, from the early Campanian of Filim (Eastern Oman): Systematics and palaeobiogeographic implications. Fifth International Congress on Rudists. *Erlanger Geol. Abh. Sonderband*, 3(53), Erlangen.
- Philip, J., 2003. Paleocological and paleobiogeographical significance of the rudist *Macgillavryia chubbii* sp. n. in the Campanian of Oman. *GeoArabia* 8(1), 129–146.
- Scott, R.W., 1995. Cretaceous rudists of Guatemala. *Revista Mexicana de Ciencias Geológicas* 12(2), 294–306.
- Stéphan, J.F., Mercier de Lépinay, B., Calais, E., Tardy, M., Beck, C., Carfantan, J.-Ch., Olivet, J.-L., Vila, J.-M., Bouysse, Ph., Mauffret, A., Bourgois, J., Théry, J.-M., Tourmon, J., Blanchet, R., Dercourt, J., 1990. Palaeogeodynamic maps of the Caribbean: 14 steps from Lias to Present. *Bulletin de la Société Géologique de France* (8), 915–919.
- Steuber, T., 2002. A palaeontological database of Rudist Bivalves (Mollusca, Hippuritoidea, Gray, 1848). <http://www.ruhr-uni-bochum.de/sediment/rudinet/intro.htm>.
- Steuber, T., Mitchell, S.F., Buhl, D., Gunter, D., Kasper, H.U., 2002. Catastrophic extinction of Caribbean rudist bivalves at the Cretaceous-Tertiary boundary. *Geology* 30, 999–1002.
- Taipe, E., Jaillard, E., Jacay, J., Pachas, R., Quintana, J., 2000. Ciclos de transgresión marina en la Fm La Tortuga de la serie del Cretáceo superior de Paita (5°20'S). X Congreso Peruano Geología. Soc. Geol. Perú, Publ. Espec., Lima 2, 54.

Corrigendum

Corrigendum to “Revision of the Upper Cretaceous Rudists from
Northwestern Peru” [South American Earth Science 17 (2004) 39–48]

Jean Philip^{a,*}, Etienne Jaillard^b

^aCentre de Sédimentologie-Paléontologie, Université de Provence, 3 Place Victor Hugo Marseille Cedex 313331, France

^bIRD-LGCA, Maison des Géosciences, BP 53, 38 041 Grenoble Cedex 09, France

The author regrets that during the publication of this paper several errors occurred. These errors have now been corrected and the updated sections are reproduced below.

Section 4.1.2 Para 1

However, one specimen (O.LT.5b, pl.2, fig 2) shows a depressed smooth subrectangular furrow that may represent the ventralward (vb) band.

Section 4.1.2 Para 2

Despite the absence of a free valve and preservation of the cardinal apparatus, specimens from Peru fit well with descriptions of *M. nicholasi* from Jamaica (Chubb, 1971) and Cuba (Rojas et al., 1995)

Section 4.1.3 Para 2

The species is known to accompany both the Campanian *Barrettia gigas-multilirata* and the Maastrichtian *Tiano-sarcolithes giganteus* faunas in the Caribbean province (Rojas et al., 1995) and Mexico (Alencaster, 1971)

Section 4.4.3 Para 1

It is known from the Maastrichtian of the Caribbean area: Jamaica (Chubb, 1971; Dommelen, 1971) and Cuba (Palmer, 1933; Rojas et al., 1995)

The following references were missing from the original publication:

References

- Rojas, R., Itturalde-Vinent, M., Skelton, P.W., 1995. Stratigraphy, composition and age of Cuban rudist-bearing deposits. *Revista Mexicanas de Ciencias Geológicas* 12 (2), 272–291.
- Trechmann, C.T., 1924. The Cretaceous limestones of Jamaica and their Mollusca. *Geological Magazine* 61 (9), 385–410.
- Whitfield, R.P. 1897a. Descriptions of species of Rudistae from the Cretaceous rocks of Jamaica, West Indies, collected and presented by Mr. F. C. Nicholas. *Bulletin of American Museum of Natural History* 9, 185–196.
- Whitfield, R.P., 1897b. Observations on the genus *Barrettia* Woodward, with descriptions of two new species. *Bulletin of American Museum of Natural History* 9, 233–246.

DOI of original article: 10.1016/j.jsames.2004.05.008

* Corresponding author.

E-mail addresses: jphilip@up.univ-mrs.fr (J. Philip), etienne.jaillard@ujf-grenoble.fr (E. Jaillard).