

Paleoenvironmental inferences based on benthic foraminifera from the Uitpa Formation (Guajira, Colombia)

Sofía Barragán Montilla and Carlos Alberto Sánchez Quiñónez

Departamento de Geociencias, Universidad Nacional de Colombia, Sede Bogotá

email: sbarraganm@unal.edu.co; casanchezq@unal.edu.co

ABSTRACT: The Uitpa Formation is a lithostratigraphic unit that crops out in the Guajira peninsula, northeastern Colombia in the Cocinas Basin. This formation consists mainly of marly and argillaceous mudstones of gray to light brown color, intercalated with sandstone and calcarenite beds. The lower contact with de Siamana Formation is unconformable, and at the top the contact with the Jimol Formation is conformable at Uitpa. These units contain an abundant and diverse fauna of planktic and benthic foraminifera that has not been studied in detail yet. In this research, two outcrop sections from the upper Guajira containing the Uitpa Formation were analyzed: the Pisülü hill and Jososuwou creek sections. Planktic foraminifera were extracted and taxonomically classified, allowing to assign an age of Chattian (Late Oligocene) (planktic foraminifera biozones O6 – O7). This investigation presents for the first time in Colombia a paleoenvironmental reconstruction integrating various methodologies using quantitative and qualitative analyses in benthic foraminifera. From these analyses an outer neritic to upper bathyal paleodepth was inferred, with environments characterized by high organic matter inputs in eutrophic conditions for both sections. Oxygenation levels were higher in the Pisülü hill section, represented by high diversity heterogeneous assemblages, while for the Jososuwou creek section oxygenation was very low producing stressed environments and low diversity homogeneous assemblages.

Keywords: Chattian, Colombia, benthic foraminifera, paleoenvironmental interpretation, planktic foraminifera, Uitpa Formation.

INTRODUCTION

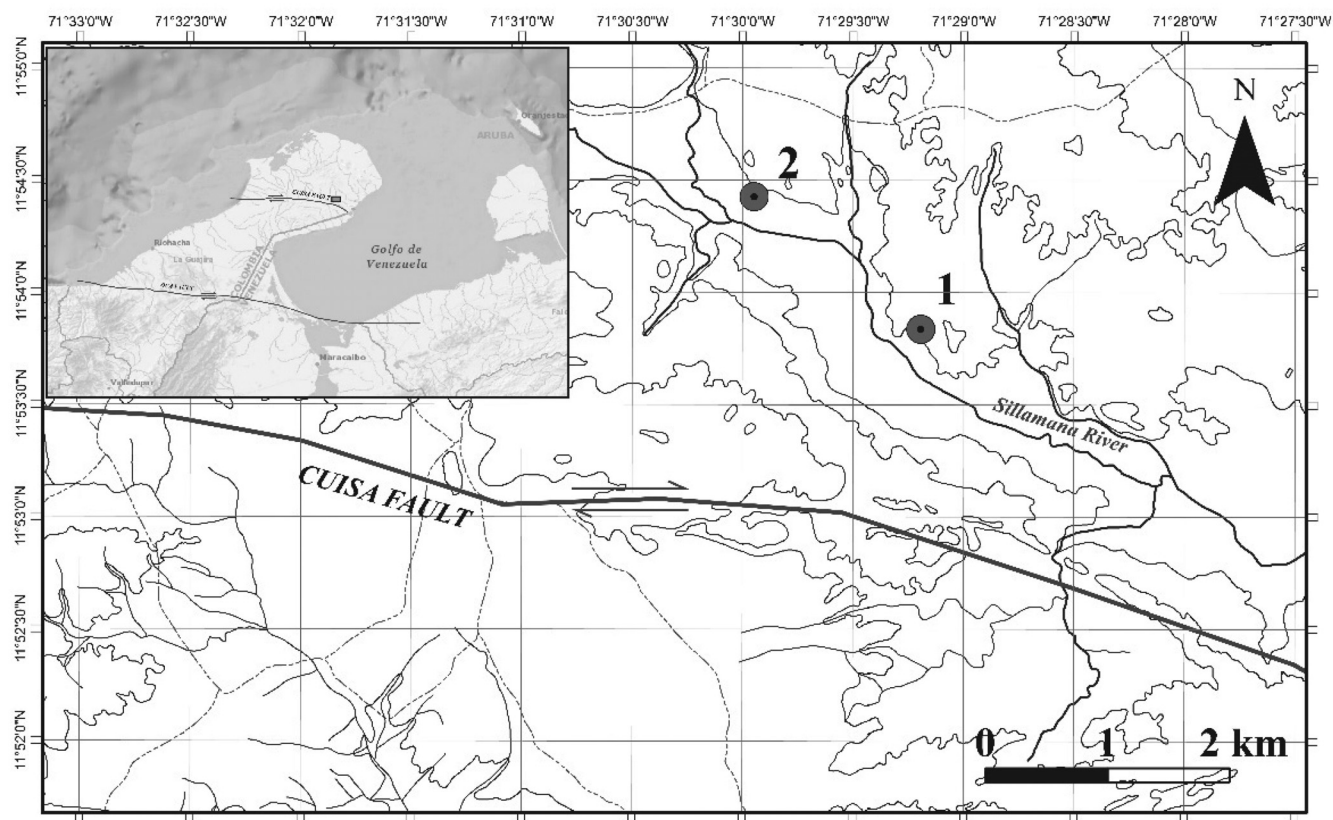
The study of distribution, abundance and diversity of extant benthic foraminifera species has aided in the improvement of the interpretation of past paleoenvironmental conditions, given that the knowledge of the environmental settings in which certain species live today, provides us with information that can be applied to the fossil record containing such species (Murray 2006).

Benthic foraminifera can be used to determine the environmental conditions of marine settings such as paleobathymetry, sea-level variations, water salinity, temperature, oxygenation, trophic levels and other chemical features of the environment at the moment of deposition (Haq and Boersma 1978; Wynn 2014; Murray 2006). The construction of paleoenvironmental models from benthic foraminifera analysis is based on the quantitative and qualitative analyses of relative abundances of these microorganisms, carried out with the help of a large taxonomic database. Jorissen et al. (1995) proposed the TROX model, that makes it possible to infer trophic levels from bottom-waters based on the proportions of infaunal-epifaunal morphogroups. Although the concept of eco-marker species has not been well studied yet, some studies have suggested that the presence of certain species of benthic foraminifera can be used to infer specific environments (Widmark and Speijer 1997). An example of this is *Epistominella exigua*, a deep-water benthic foraminifera that in high abundances indicates the presence of high fresh organic matter deposition (Murray 2006). Quantitative and qualitative analyses were used by Murray (1991) to describe benthic foraminifera associations occurring in certain present marine settings, characterizing marginal marine, platform and bathyal

faunas. The database resulting from this study and further summarized by Murray (2006) is as today the most widely accepted and used in paleoenvironmental studies.

The Uitpa Formation groups mudstones and fine to medium-grained sandstones with a high gypsum content. It also includes some intercalations of sandstones and calcareous siltstones at the base and top of this unit (Zapata 2010; Numpaque and Corredor 2008). Rollins (1965) identified an unconformity with the underlying Siamana Formation, seen at the borders of the Cocinas basin where an angular unconformity is observed, while at the center of the basin on the Uitpa area the contact is conformable. The upper contact with the overlying Jimol Formation is conformable (Rollins 1965; Zapata 2010). Zapata (2010) also observed in this unit the scarce presence of sedimentary structures (only plane-parallel and wavy laminations).

The abundant fossil fauna found in the Uitpa Formation allowed several investigators to propose a marine origin to this unit (Becker and Dusenbury 1958; Renz 1960; Rollins 1965; Moreno et al. 2015; Hendy et al. 2015). More specifically the high planktic and benthic foraminifera diversity and abundance has made possible a detailed biostratigraphy and paleoenvironmental interpretation for this unit, providing important data for the understanding of the geological evolution of the Guajira Peninsula (Northeastern Colombia) during the Paleogene–Neogene transition. The introduction in the last decades of new information, methods and proxies to paleoenvironmental studies, has made it necessary to reevaluate de benthic foraminifera fauna of this unit to establish a more complete and up to date paleoenvironmental model.



TEXT-FIGURE 1

Location of the studied sections in the upper Guajira area. 1. Pisülü Hill Section; 2. Jososuwou Creek Section.

The aim of this investigation is to extract, taxonomically classify and analyze the planktic and benthic foraminiferal faunas of the Uitpa Formation in the upper Guajira area, to propose a paleoenvironmental interpretation made through an integrated methodology of benthic foraminifera qualitative and quantitative studies. At the same time, it is proposed an age no younger than Chattian (late Oligocene) based on planktic foraminifera. This study, makes valuable contributions to the knowledge of the foraminiferal fauna of the Colombian Caribbean and their importance in paleoenvironmental studies. It also contributes to the understanding of the geological evolution of the Guajira peninsula at the end of the Paleogene.

PREVIOUS BIOSTRATIGRAPHIC AND GEOLOGICAL STUDIES IN THE AREA

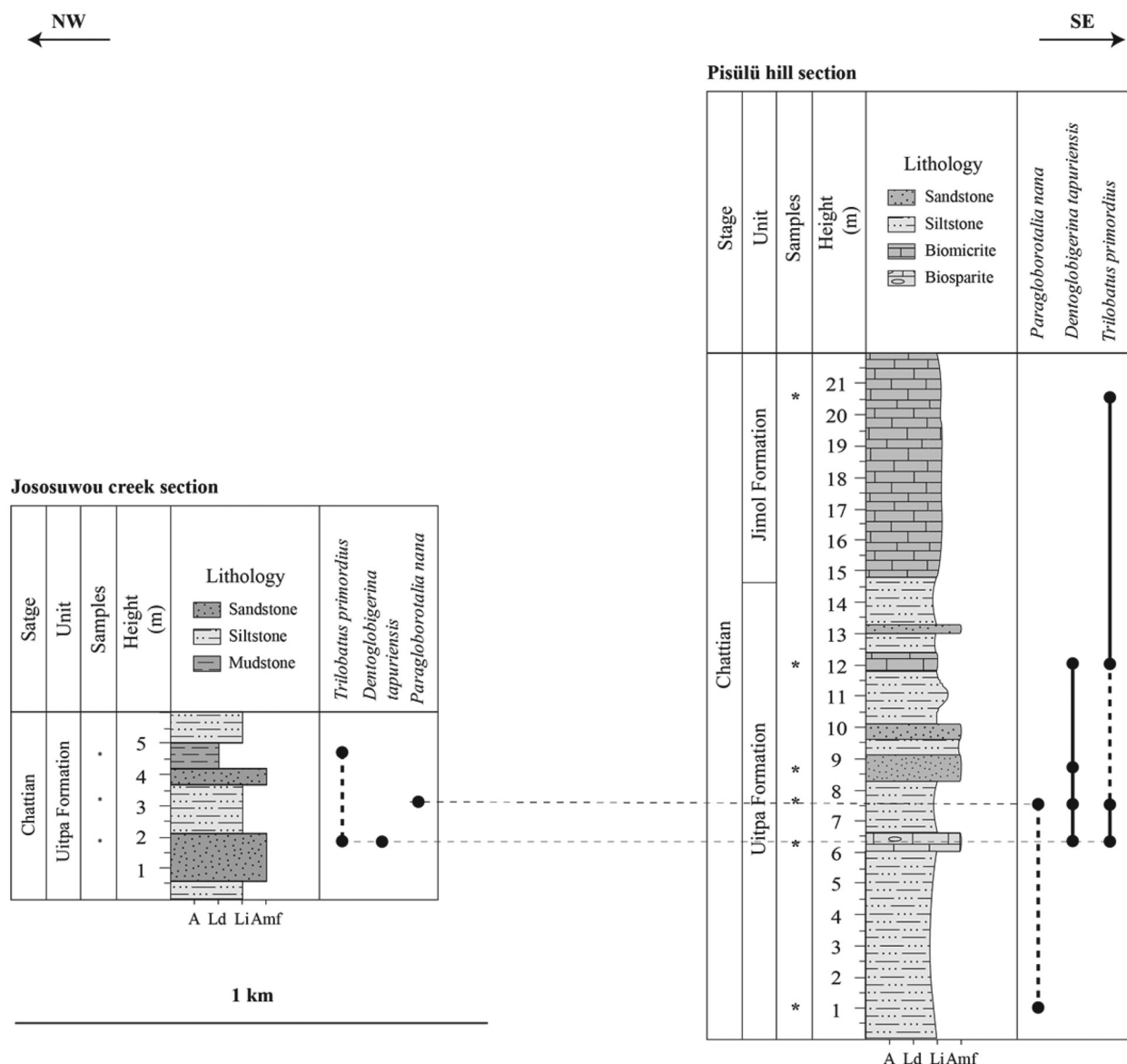
Rollins (1965) recognized for the first time in the upper Guajira the planktic foraminifera biozones *Catapsydrax dissimilis* (Bolli, Loeblich and Tappan), *Catapsydrax stainforthi* (Cushman and Bermúdez) and *Globorotalia kugleri* (Bolli), also identified by Duque (1973; 1975). Such biozones assigned an Aquitanian age (early Miocene) to the Uitpa Formation (Rollins 1965).

Becker and Dusenbury (1958) analyzed the high foraminifera content in random samples from the Uitpa Formation adding 7 new species to 137 previously described in the area of Uitpa and Sillamana. This fauna allowed them to infer that the Uitpa

Formation was deposited in open sea conditions and contains the maximum flooding surface of the late Oligocene – early Miocene in the Guajira peninsula. According to these authors, 50% of the taxa belong to the families Lagenidae and Buliminidae, which indicates a paleodepth between 183–550 m and water temperatures of 12–20 °C. From the identified fauna, some taxa restricted to the Aquitanian age was found and the presence of *Heterosteginoides ecuadorensis* supports an Early Miocene age for the Uitpa Formation.

Zapata (2010), based on a detailed study of an early Miocene sequence, suggested that the predominant siltstones and mudstones from the Uitpa Formation, were deposited in an outer shelf open sea environment, with transgressive facies at the base of the unit. For this author, the middle part of the Uitpa Formation shows a stability of the basin, and a rapid regressive event deposited the shallower sediments from the Jimol Formation.

The age of the Uitpa Formation has been interpreted based on the abundant foraminiferal fauna: Aquitanian after Becker and Dusenbury (1958); upper-middle Oligocene because of the occurrence of *Miogypsina* according to Renz (1960); and Rollins (1965) assigned an Oligocene – early Miocene age based on the presence of planktic foraminifera biozones *Globorotalia* (*Turborotalia*) *kugleri*, *Catapsydrax dissimilis* and *Catapsydrax stainforthi*. The ages proposed by Rollins (1965) are the most widely accepted.



TEXT-FIGURE 2
Correlation of the Pisulü hill and Jososuwou creek sections of this study.

On more recent studies, the early Miocene age for the Uitpa Formation has been confirmed by paleoenvironmental, biostratigraphic, and strontium isotopes studies made in fossil mollusks and marine sediments from the Siamana and Jimol formations (Moreno et al. 2015; Hendy et al. 2015).

LOCATION AND GEOLOGICAL SETTING

The studied area is located on the Guajira peninsula northeastern Colombia, immediately north of the Cuisa Fault (text-fig. 1). Two sections 1.5 km apart, north of the Sillamana river were used in this study: the Pisulü hill Section at the east (1), and the Jososuwou creek Section (2) at the west.

The Uitpa Formation crops out in the central and north part of the Guajira Peninsula and contains the maximum flooding

event of the Cenozoic in the Cocinas basin (Renz 1960; Rollins 1965). The unit is better exposed near the indigenous settlements of Uitpa and Sillamana (Becker and Dusenbury 1958) and was formally defined by Renz (1960) as the group of gray mudstones with some calcareous sandstone levels, deposited in marine settings.

In the upper Guajira area two sections were studied. The Pisulü hill section contains from base to top 14.6 m of gray siltstones interbedded with some biosparites, siltstones and very fine-grained sandstones from the Uitpa Formation, and 7.4 m of biomicrites of the Jimol Formation at the top. The Jososuwou creek section consists of 6 m of intercalated gray siltstones, mudstones and very fine-grained sandstones from the middle part of the Uitpa Formation (text-fig. 2). Correlation was pro-

TABLE 1
Numbers of benthic and Planktic foraminifera species identified in each sample.

Section	Sample	Planktic foraminifera		Benthic Foraminifera			
		Number of specimens	Number of species	Coarse fraction specimens	Fine fraction specimens	Total	Number of species
Pisülü Hill Section	CN-6IID-006	298	9	308	254	562	36
	CN-6IID-005	291	6	300	250	550	22
	CN-6IID-004	296	6	140	250	390	24
	CN-6IID-003	286	9	305	251	556	25
	CN-6IID-002	304	10	193	250	443	20
	CN-6IID-001	201	8	106	252	358	35
Jososuwou Creek Section	CN-6IID-036	277	7	6	318	324	7
	CN-6IID-035	307	6	24	300	324	11
	CN-6IID-034	292	7	20	300	320	15

posed based on the presence of planktic foraminifera biostratigraphic markers *Dentoglobigerina tapuriensis* (Blow and Banner 1962), *Trilobatus primordius* (Blow and Banner 1962) and *Paragloborotalia nana* (Bolli 1957).

MATERIALS AND METHODS

For this research eight samples were analyzed. Six samples from the Pisülü hill Section (five from the Uitpa Formation and one from the base of the Jimol Formation, the contact between these units is conformable and three from the Jososuwou creek Section belonging to the Uitpa Formation. The field work was carried out by Numpaque and Corredor (2008).

Approximately 300 planktic foraminifera and 300 benthic foraminifera were collected and analyzed for each sample (Table 1), collected from a fine fraction (63–125 µm) and a coarse fraction (>125 µm). The specimens were placed in micropaleontological slides that remain in the micropaleontological collection of the Geosciences Department of the National University of Colombia (Bogota) along with an identification manual for academic purposes.

The benthic foraminifera were separated from their morphological features and were taxonomically classified in most cases to a specific level. The genus classifications were made after Loeblich and Tappan (1987), while species were identified based on references such as Renz (1948), Bermúdez (1949), Bolli et al. (1994) and Becker and Dusenbury (1958). For planktic foraminifera identifications the references mostly used were Bolli (1985), Kennett and Srinivasan (1983), and the on-line database mikrotax.org.

Age determinations were made with the actualized biozonation of Banner and Blow (1965), calibrated with the International Chronostratigraphic Chart version 2020/01 (Cohen et al., 2020). The chronostratigraphic ranges of each species were consulted on mikrotax.org and in the Atlas of Oligocene Planktic Foraminifera (Wade et al. 2018).

SEM images from the planktic and benthic foraminifera collected were taken in the Scanning Electron Microscopy Laboratory of the National University of Colombia in Bogota.

Methodology for Paleoenvironmental

The paleoenvironmental inferences were made based on benthic foraminifera quantitative and qualitative analyses, carried on through the integration of several methodologies proposed by several authors (van Morkhoven et al. 1986; Jorissen et al. 1995; Murray 1991, 2006; van der Zwaan et al. 1999). In general, seven parameters were used for the interpretation: variation of diversity indexes, morphogroup distributions, shell type proportions, relative abundances of stress taxa, P/B ratio, upper depth limits of some species, and finally determination of representative faunal assemblages identified by multivariate analysis.

The paleoenvironmental interpretation starts with the analysis of diversity variations measured in changes of indexes such as Fisher diversity and Shannon's heterogeneity $H(s)$ to test the environmental stability of a studied section (Jones 2014; Murray 2006). Also, part of the paleoenvironment determinations were made following the conceptual model established by Murray (1991, 2006), in which Fisher indexes with values under 5 are mainly related to marginal marine environments and values over 5 correspond to shelf and slope settings. Furthermore, Shannon indexes between 0 and 2 indicate marginal marine environments, values from 2 to 4 shelf and slope settings, and abyssal plain environments are represented by values around 3.

During this investigation, it was considered convenient to interpretation to propose some descriptive terms to refer to diversity and heterogeneity. For Fisher α values under 5 diversity is considered low (if it is close to 0 very low), from 5 to 10 moderate, from 10 to 15 moderate to high, from 15 to 20 high, and for values over 20 diversity is very high. Regarding the Shannon heterogeneity index, we considered an assemblage homogeneous if the index is less than 2 (very homogeneous close to 1), moderately heterogeneous from 2 to 3, and highly heterogeneous from 3 to 4. This terminology is introduced in the aim to improve the descriptive part of the paleoenvironmental interpretation.

Morphogroups distributions of infaunal and epifaunal species, were used to determine the trophic conditions applying the TROX model proposed by Jorissen et al. (1995). This model describes the distribution of benthic foraminifera microhabitats in relation to the trophic and oxygenation levels of bottom waters. In this sense, the depth of a microhabitat is defined by the critic

TABLE 2

Bathymetric distributions of some benthic foraminifera species of the Uitpa Formation extracted from van Morkhoven et al. (1986), Holbourn et al. (2013) and Boersma (1984).

Species	Known bathymetry	Upper Depth Limit (van Morkhoven et al. 1986)
<i>Anomalina mantaensis</i>	Upper – middle Bathyal (van Morkhoven et al. 1986)	
<i>Globobulimina pacifica</i>	Middle neritic – Upper bathyal (Holbourn et al. 2013)	
<i>Rectuvigerina multicostata</i>	Bathyal (Holbourn et al. 2013; van Morkhoven et al. 1986)	
<i>Transversigerina transversa</i>	Upper bathyal (Holbourn et al. 2013; van Morkhoven et al. 1986)	
<i>Bulimina striata</i>	Upper – middle bathyal (Holbourn et al. 2013; van Morkhoven et al. 1986)	
<i>Uvigerina isidroensis</i>	Outer shelf (Boersma 1984)	
<i>Melonis pompiloides</i>		Upper bathyal
<i>Globocassidulina subglobosa</i>		Upper bathyal

level of available food in oligotrophic environments and by the critical oxygenation level in eutrophic settings.

In oligotrophic conditions, the determining factor for the presence of infaunal species is the trophic level. The nutrients that can be metabolized are consumed at the surface of the sediment, and the underlying layers will only have small amounts of organic matter available restricting the occurrence of infaunal species. In mesotrophic environments (with a moderate organic matter input) the organic matter is not restricted only to sediment surface but is also partially transported to deeper sediment layers by bioturbation, providing nutrients for both epifaunal and infaunal communities. In eutrophic settings with high organic matter input, oxygenation of bottom waters becomes the critical parameter determining the penetration depth of foraminifera in the sediment. Degradation of organic matter in these settings consumes more oxygen than it is produced, leading to an excess of organic matter and shallowing of redox levels resulting in a high concentration of infaunal benthic foraminifera at the interface sediment-water (Jorissen et al. 1995).

Another parameter used in this study is the proportion of test types (calcareous, porcelaneous, and agglutinated). The predominance of any of these test types can be used to determine salinity and other parameters of the environment. Murray (1991) associated an abundance of more than 20% of porcelaneous foraminifera to normal saline marine settings or hypersaline lagoons, while values of less than 20% are related to shelf or slope settings. The predominance of calcareous forms indicates normal marine environments of salinities of ≥ 35 ppm. Other variations of test types percentages can indicate more specific environments like lagoons or turbiditic deposits (represented by a high abundance of certain agglutinated foraminifera species).

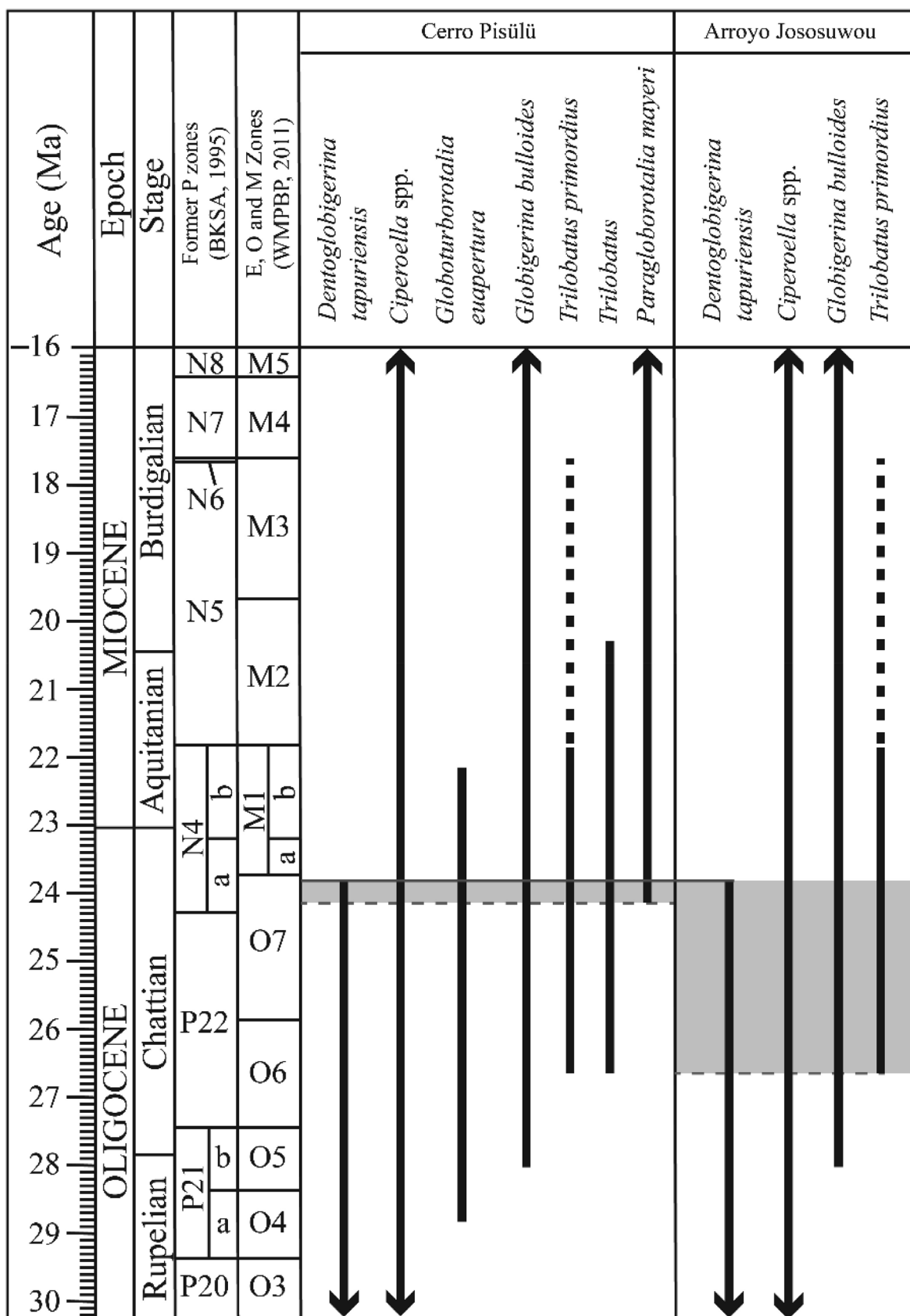
The relative abundances of buliminids and other stress taxa can be used to estimate the relative oxygenation levels of bottom waters. A high percentage of such taxa portrays stressful envi-

ronmental conditions related to low oxygenation of the environment (<1 ml/L of oxygen). High productivity associations include these genera and are related to high organic matter influxes produced mainly by primary productivity. These fluxes can also be associated with upwelling, hydrographic fronts, or fluvial discharges in marine settings. High productivity associations include the genera *Bulimina*, *Bolivina*, *Cassidulina*, *Chilostomella* (e.g., *C. oolina*), *Globobulimina*, *Fursenkoina*, *Uvigerina* and *Melonis* (e.g., *M. affinis*) (Jorissen et al. 2007; Sen Gupta 2003; Murray 1991, 2006; Southward 2003; van Hinsbergen et al. 2005).

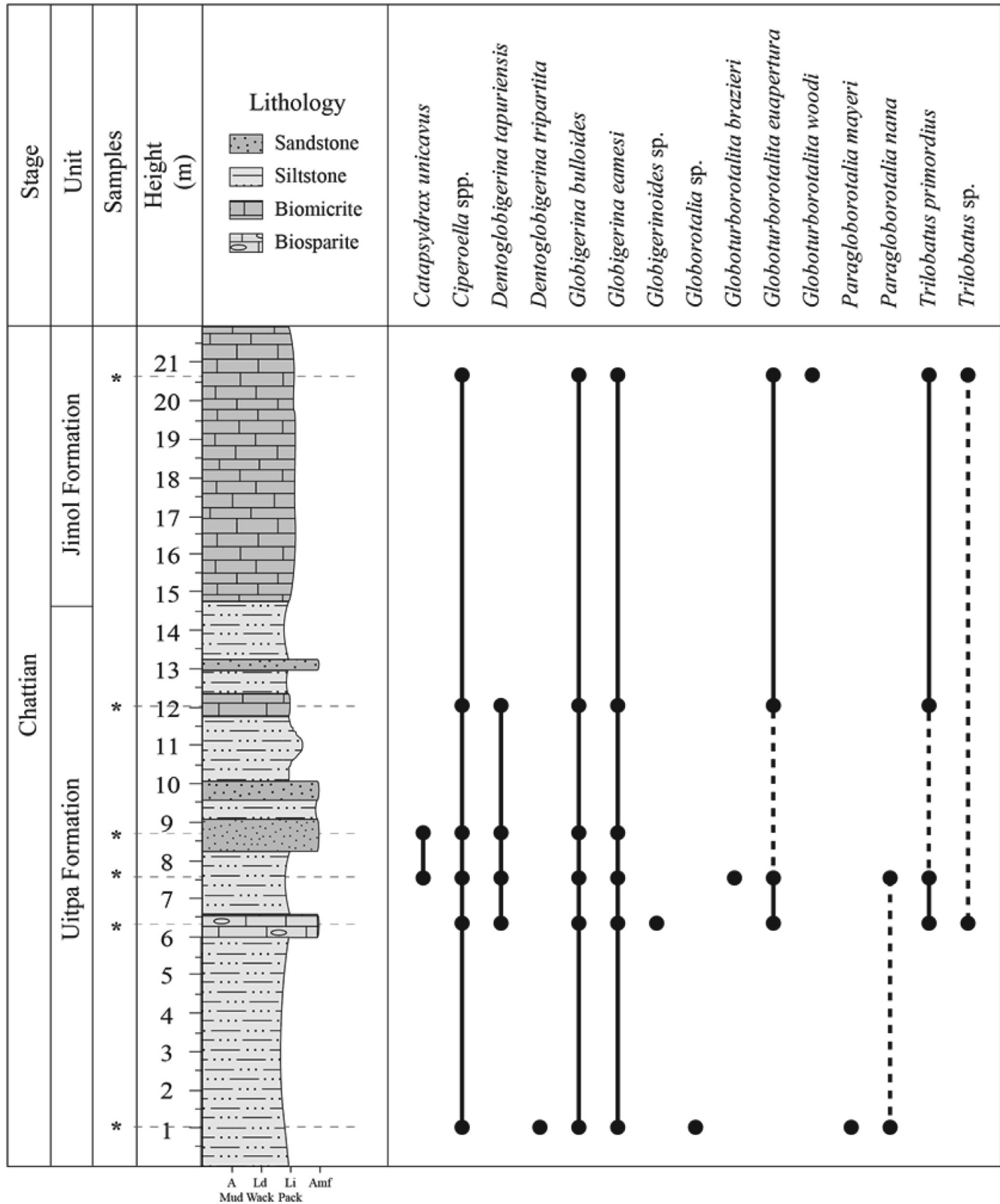
The percentage of stress taxa can also be used to estimate paleobathymetries from the application of the planktic – benthic ratio (P/B). As pointed out by van der Zwan et al. (1990) and van Hinsbergen et al. (2005), shelf and slope environments with high proportions of stress species can affect paleodepth inferences made using the P/B ratio, because the high abundance of stress taxa responds not only to paleodepth variations, but also to changes in paleoenvironmental conditions. For this reason, when using the P/B ratio to calculate and observe paleodepth variations in deep water environments with stress conditions, the contribution of high productivity assemblages should be eliminated to avoid misinterpretations.

For this research, the paleobathymetric determinations were made using the upper depth limits proposed by van Morkhoven et al. (1986) and the paleobathymetric zones established by the same author and also used by Murray (1991, 2006). The upper depth limits concept is widely accepted by the micropaleontological community (Alegret 2003) and defines that a species does not occur above its upper depth limit. For these determinations, known paleobathymetric limits of some species (Table 2) were also integrated into the interpretation (Holbourn et al. 2013; Murray 1991, 2006; van Morkhoven et al. 1986).

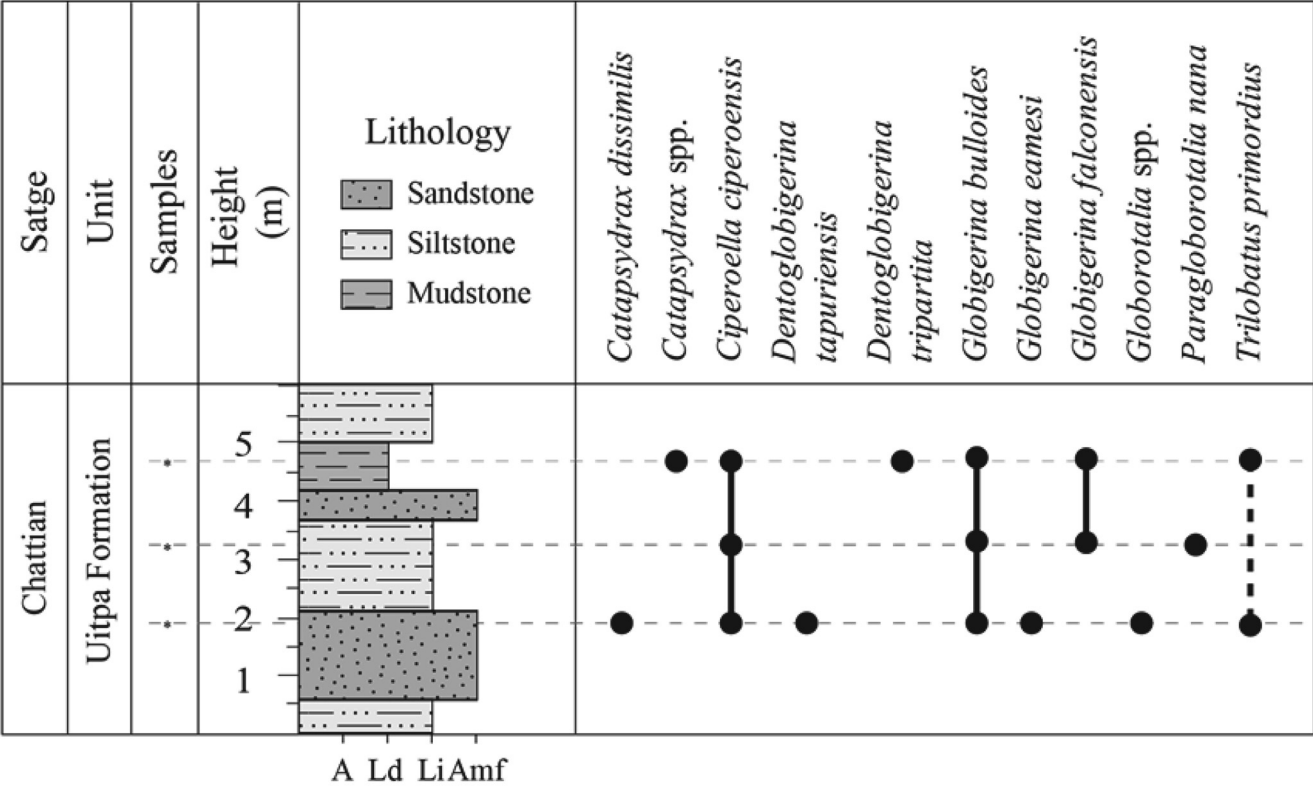
Known specific environmental features of the most abundant benthic foraminifera species in this study were used to corroborate



TEXT-FIGURE 3
Ages of planktic foraminifera biostratigraphical markers identified in the Uitpa Formation after the scheme from Wade et al. (2018).



TEXT-FIGURE 4
Planktic foraminifera distribution in the Pisulü Hill Section.



TEXT-FIGURE 5
Planktic foraminifera distribution in the Jososuwou Creek Section.

rate the presented interpretation. Such features were taken from van Morkhoven et al. (1986), Bolli et al. (1994), Holbourn et al. (2013), Murray (1991, 2006), and others.

With the aim of properly reporting the paleoenvironmental conditions interpreted for the Uitpa Formation of the Upper Guajira, multivariant analysis was carried out. These analyses were made with the relative abundance values of the benthic foraminifera species identified in each sample, and facilitated the identification of the existent faunal assemblages and the paleoenvironmental conditions they represent.

RESULTS AND DISCUSSION

Planktic foraminifera

The planktic foraminiferal faunas were taxonomically identified using the references mentioned above. From the collected fauna, 14 species were recognized belonging to the genera *Catapsydrax*, *Ciproella*, *Dentoglobigerina*, *Globigerina*, *Globigerinoides*, *Globorotalia*, *Paragloborotalia* and *Trilobatus* (Plate 1).

Globigerina bulloides d'Orbigny 1826 and *Ciproella* spp. are the most abundant species in both sections, and their average relative abundance is 64.3% and 17.2% respectively. In the Pisülü hill section *Trilobatus primordius* (Blow and Banner 1962) (13.2 %) and *Globigerina eamesi* Blow 1959 (5.9%) are abundant.

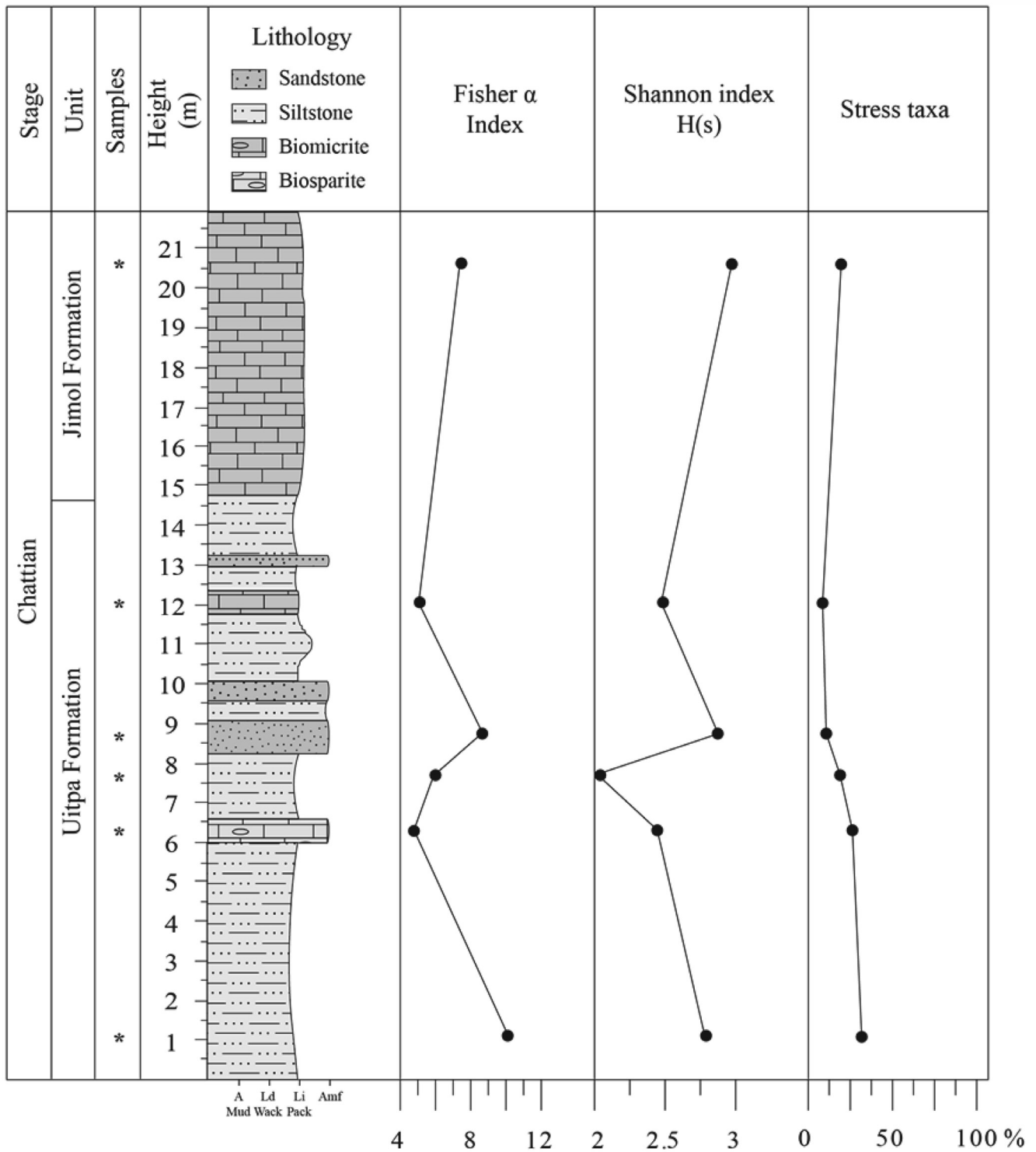
The predominance of *G. bulloides* and the occurrence of *Globorotalia* sp., *Paragloborotalia mayeri* (Cushman and Ellis 1939), and *Trilobatus* sp. indicate an age not older than Chattian (late Oligocene), and *Ciproella ciperoensis* (Bolli 1954), *Dentoglobigerina tapuriensis*, (Blow and Banner 1962) and *Globorotalia euapertura* (Jenkins 1960) indicate an age not younger than Aquitanian on the early Miocene (text-fig. 3).

For the Pisülü hill section (text-fig. 4), the biostratigraphic markers are *Paragloborotalia mayeri* found in the sample CN-6IID-001 and *Dentoglobigerina tapuriensis* present in samples CN-6IID-002 to CN-6IID-005. Based on the distribution of these species, the age of the studied interval is Chattian (late Oligocene), contained specifically in the top of biozone O7 (N4a following the former P zonation) (text-fig. 3).

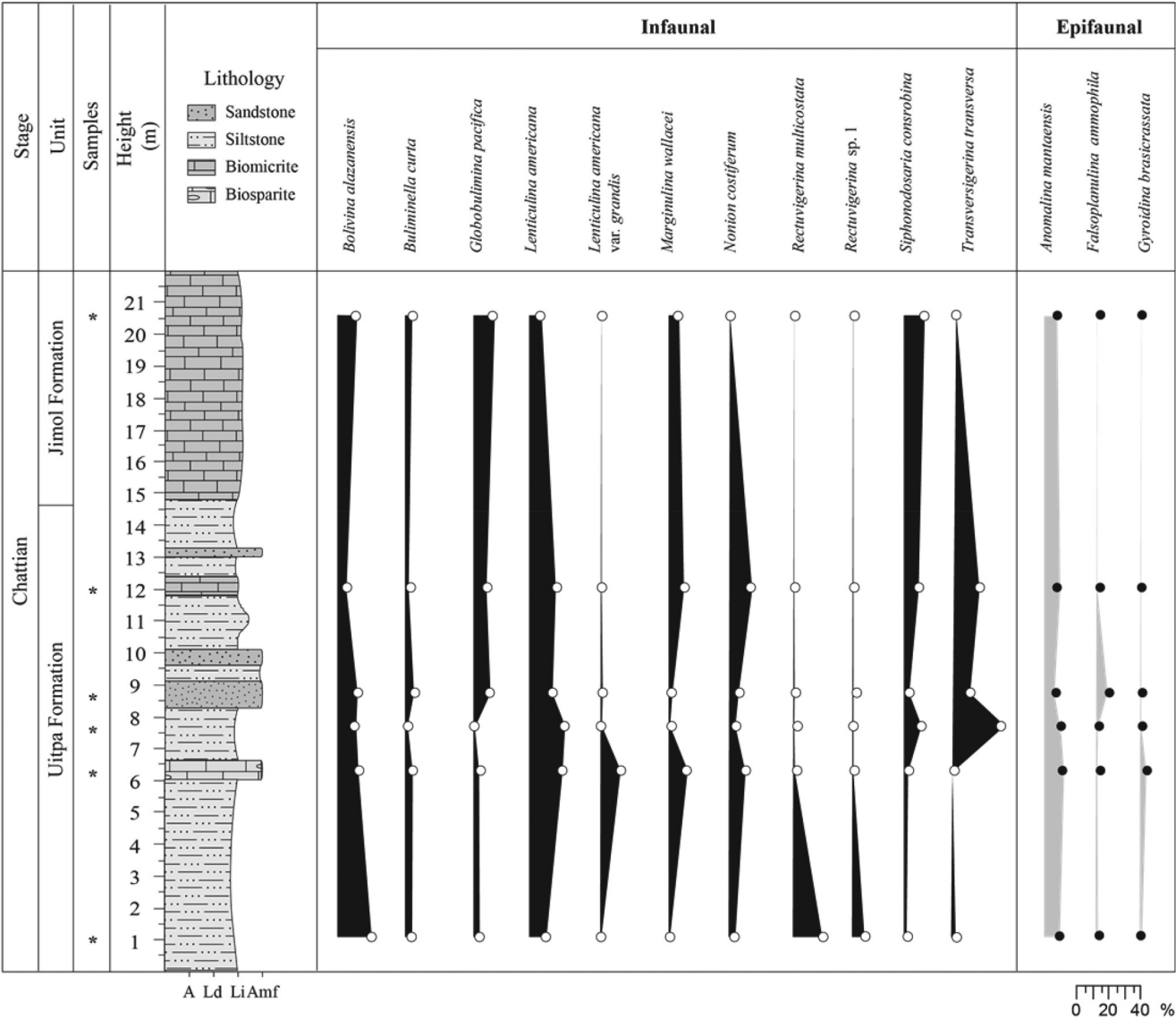
In the Jososuwou creek section (text-fig. 5), the occurrences of *Trilobatus primordius* on samples CN-6IID-034 and CN-6IID-036, and *Dentoglobigerina tapuriensis* in sample CN-6IID-034 correspond to a Chattian age, in biozones O6 to O7 (P22 and N4a following the former P zonation) (text-fig. 3). It is not possible to assign a more accurate age in this section due to the lack of more restricted biostratigraphic markers.

Benthic foraminifera

In this study, 42 genera and 67 species of benthic foraminifera were identified. In the Pisülü hill 60 species were recognized while in the Jososuwou creek section 18 species are reported.



TEXT-FIGURE 6
Fisher and Shannon indexes and stress taxa variations of the Pisülü hill section.



TEXT-FIGURE 7
Relative abundances of selected benthic foraminifera of the Pisulü Hill Section.

The qualitative and quantitative analyses of the recovered microfauna were used to propose a paleoenvironmental reconstruction for the Uitpa Formation in the upper Guajira area, and benthic foraminiferal assemblages representing different environmental conditions were identified for both localities.

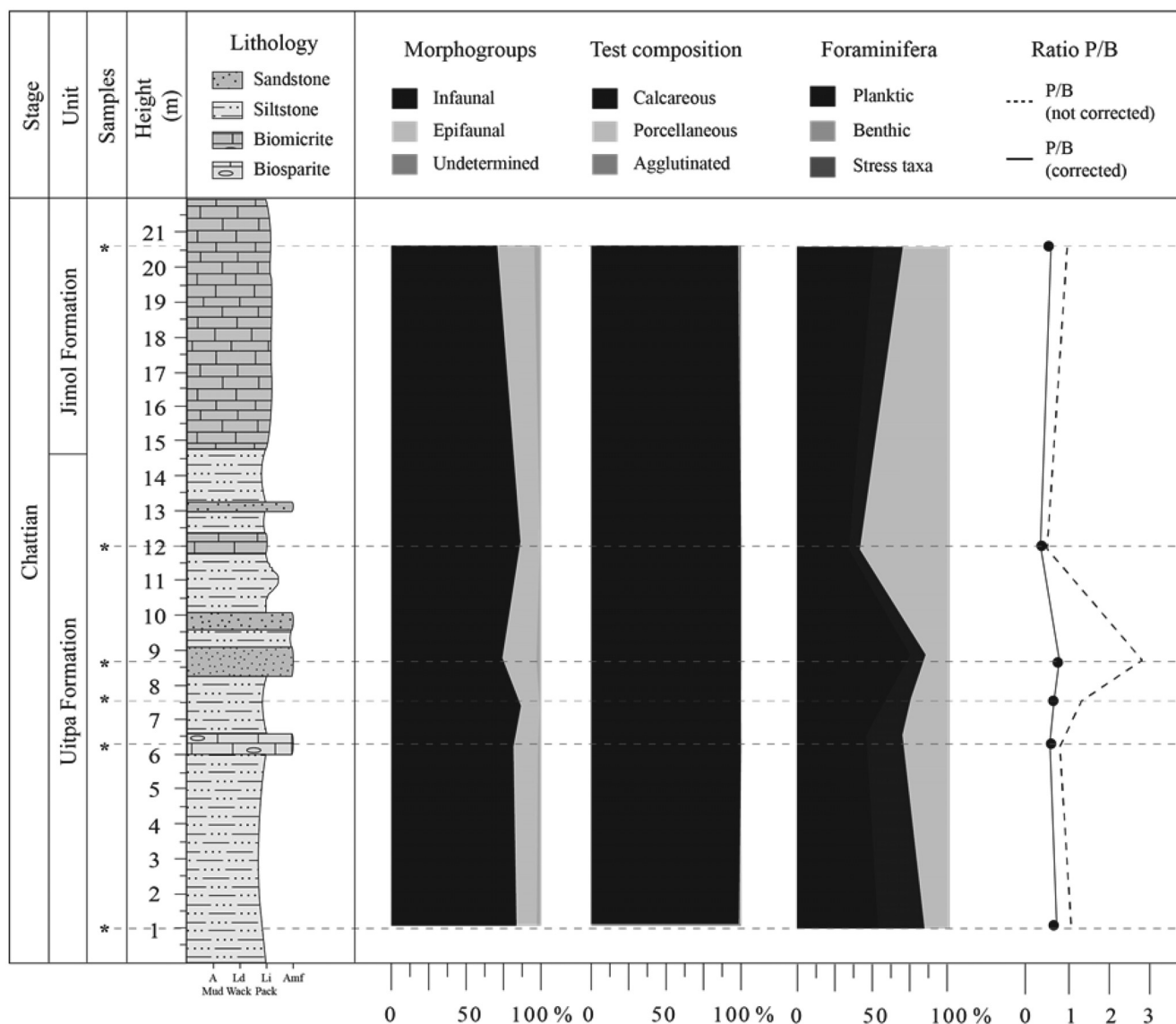
Paleoenvironmental interpretation of the Pisulü Hill Section

In the Pisulü Hill Section the benthic foraminifera fauna is moderately diverse (Fisher Index between 4.9–10.1) and heterogeneous (Shannon between 2–3). The diversity indexes remain relatively constant throughout the whole section, indicating environmental stability, but towards the middle part a slight increase in both indexes is observed (text-fig. 6).

In this section buliminids represent 20 to 45% of the association and stress taxa 8.5 to 30.9% (text-fig. 6), indicating oxygenated conditions throughout all the studied interval with relatively

lower levels in the lower – middle part of the section (samples CN-6IID-001 and CN-6IID-002).

Dominating the assemblage are *Lenticulina americana* (Cushman 1918) (15.1%), *Bolivina alazanensis* (Cushman 1926) (12.3%) and *Transversigerina transversa* (Cushman 1918) (11.1%) and in lower proportions *Anomalina mantaensis* Galloway and Morrey 1929, *Siphonodosaria consorbina* (d’Orbigny 1846), *Nonion costiferum* (Cushman 1926) and *Globobulimina pacifica* Cushman 1927 (text-fig. 7). The distribution of the above-mentioned species, specifically *Globobulimina pacifica*, *Transversigerina transversa*, *Anomalina mantaensis* and the occurrence of others like *Rectuvigerina multicostata* Cushman and Jarvis 1929, *Melonis pompilioides* (Fichtel and Moll 1798) and *Globocassidulina subglobosa* (Brady 1881) correspond to an upper bathyal paleodepth (Table 2).



TEXT-FIGURE 8

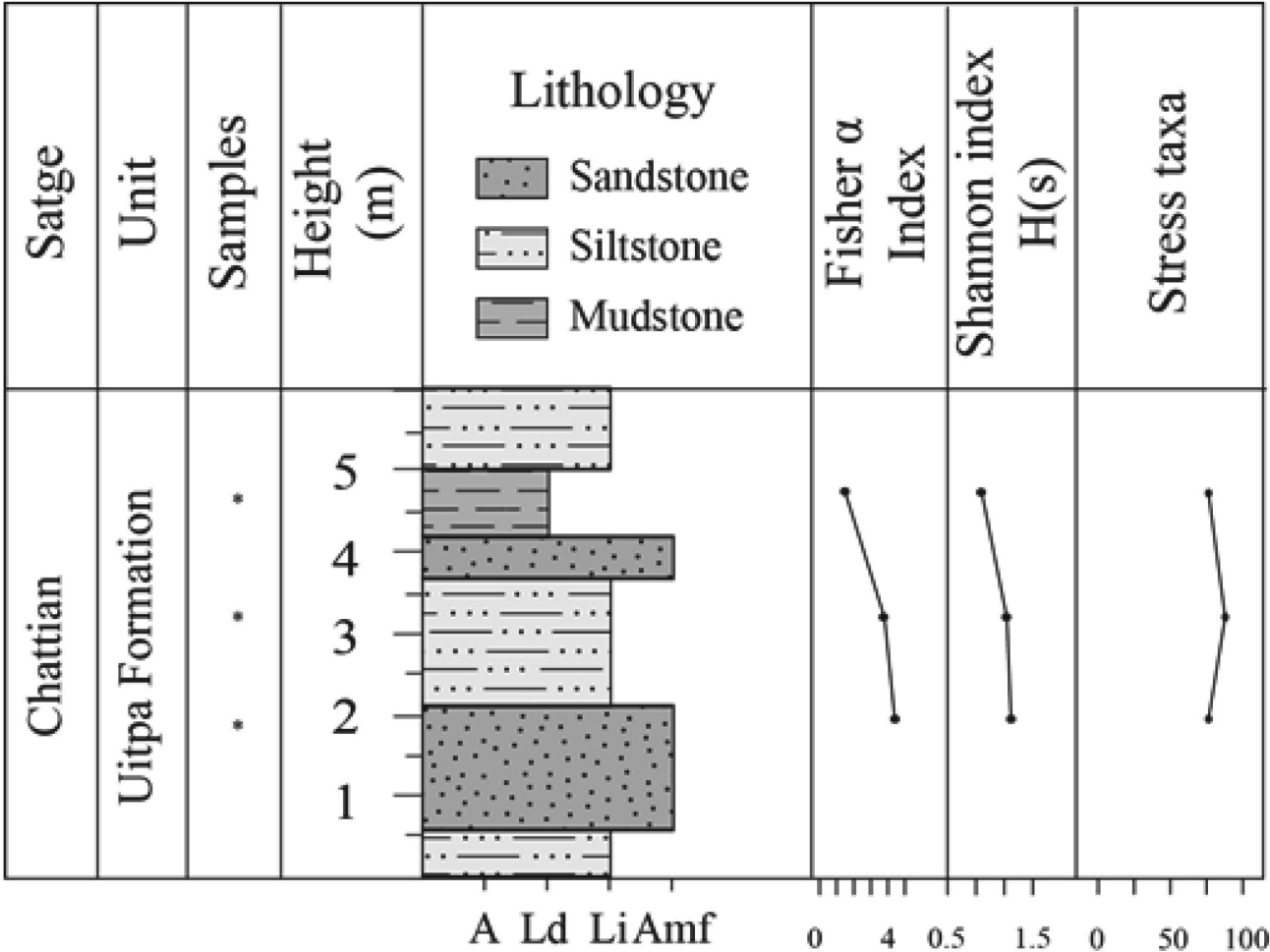
Benthic foraminifera morphogroups and test composition proportions, foraminifera types proportions and P/B ratios in the Cerro Pisülü Section.

The fauna is mainly calcareous indicating marine environments of normal salinity. Infaunal morphogroups predominate (70.6 to 86.5%) representing eutrophic conditions with high organic matter input (text-fig. 8). In this section, P/B ratio remains constant (0.4–0.8) with a minor increase in sample CN-6IIID-004. The calculated P/B ratio following van der Zwaan et al. (1990) and van Hinsbergen et al. (2005) correction was plotted against the P/B ratio uncorrected (text-fig. 8) to compare them. In this section, stress taxa proportions are relatively high and affect the calculation of the usual P/B ratio, specifically for sample CN-6IIID-004 where the P/B ratio corrected and uncorrected is different. If this correction is not made, we could be erroneously interpreting this change as only a variation in paleodepth when in reality it can be also associated with changes in paleoenvironmental conditions as clearly shown by the decrease of stress taxa (text-fig. 5).

Paleoenvironmental interpretation of the Jososuwou creek Section

In the Jososuwou creek section a low diversity and homogeneous benthic foraminifera association was recognized (Fisher index from 1.5–4.4; Shannon from 1.1–1.6) indicating stress environments. In contrast with the Pisülü hill section, the Jososuwou creek section presents variations in diversity decreasing notably to the upper part of the studied interval. The buliminids (41.9–65.1%) and stress taxa (74.5–89.7%) are abundant (text-fig. 9) a typical indicator of low oxygenation.

The faunal assemblage in the Jososuwou creek section is characterized by the high abundance of *Bolivina alazanensis* var. *venezuelana* Hedberg 1937 (47.3%) and *Uvigerina isidroensis* Cushman and Renz 1941 (31.9%); in lower proportions occurs *Nonion costiferum* (text-fig. 10). The presence of *Uvigerina*



TEXT-FIGURE 9
Fisher and Shannon indexes and stress taxa variations of the Jososuwou creek section.

isidroensis and other species like *Bulimina striata* d'Orbigny 1826 and *Globobulimina pacifica* indicates a depth of deposition of lower neritic to upper bathyal (Table 2).

The association in the Jososuwou creek section is purely calcareous (text-fig. 11) typical of normal marine environments, and infaunal morphogroups predominate (94.1–97.5%) in strong eutrophic conditions. From the benthic foraminifera assemblage, 70% of the taxa correspond to high productivity associations species representing low oxygen environments. The P/B ratio is relatively constant (0.2–0.3) showing no paleodepth changes throughout the studied interval. Also, these values are lower than those calculated for the Pisülü hill section samples.

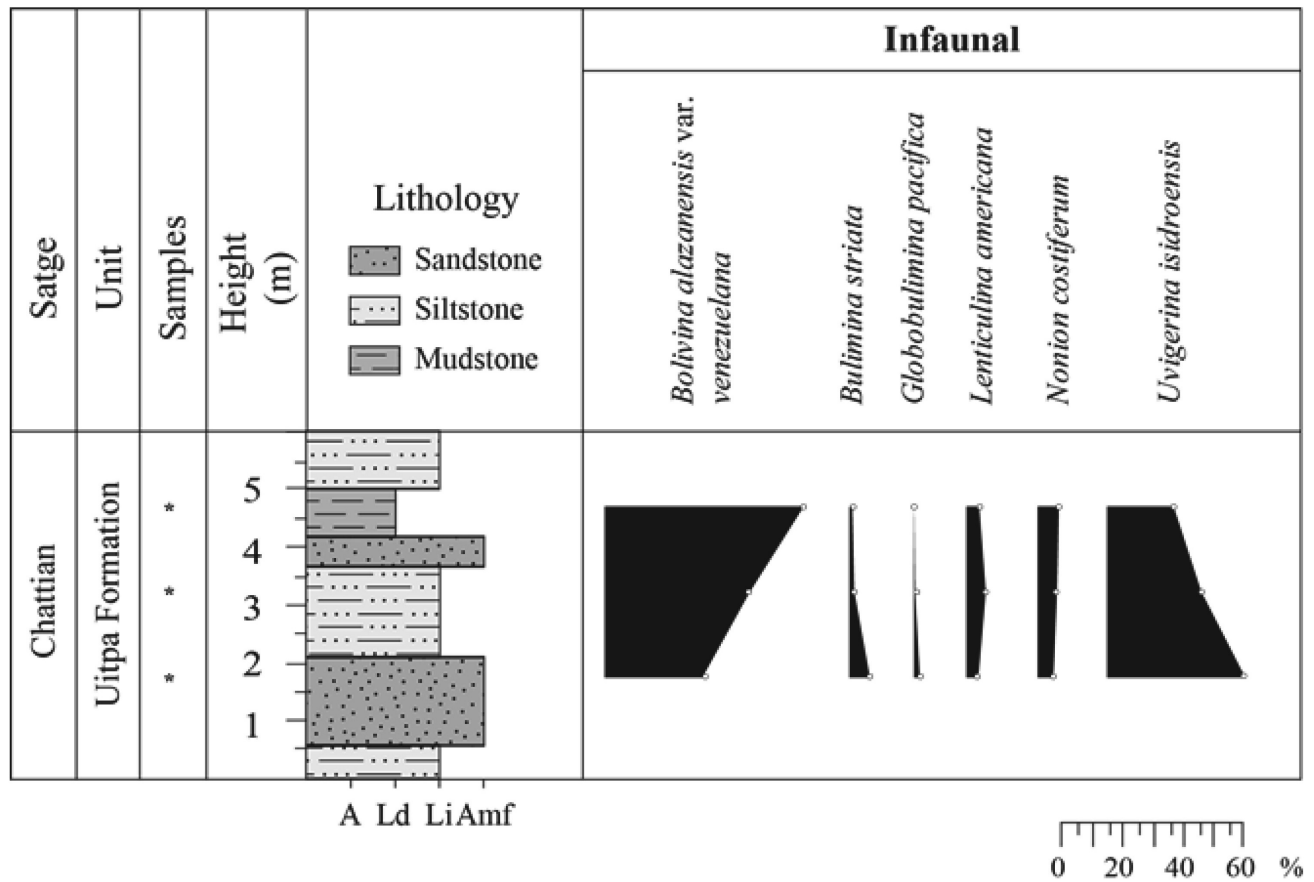
Benthic foraminifera associations

The benthic foraminifera associations, were identified using multivariate analyses carried on relative abundances of the identified species. The data matrix was processed using PAST software, in which the data was grouped using Cluster analysis R-mode and principal component analysis (PCA) to observe how different the identified associations are (Hammer et al. 2013).

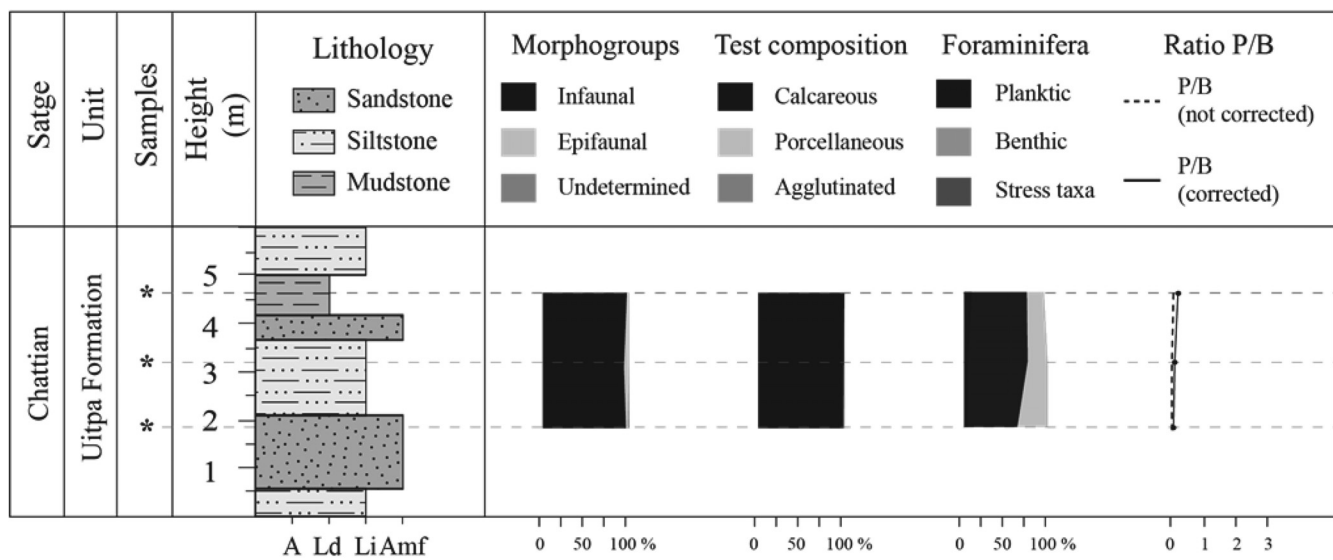
For these analyses only the species with relative abundances of more than 1% in more than one sample were used. The percentages were transformed using the formula to standardize the data (Collins 1993).

The cluster analysis made using the Ward algorithm classified the species in 3 groups (text-fig. 12). Group 1 corresponds to the assemblage *Bolivina alazanensis* var. *venezuelana* and *Uvigerina isidroensis* from the Jososuwou creek section. The second group, corresponds to the assemblage *Rectuvigerina multicostata*, *Lenticulina americana* var. *grandis* (Cushman 1920) and *Falsoplanulina ammophila* (Gümbel 1870), characteristic of the lower – middle part of the Pisülü Hill section in samples CN-6IID-001 and CN-6IID-002. Group 3 corresponds to the occurrence of *Lenticulina americana*, *Transversigerina transversa*, *Nonion costiferum*, *Buliminella curta* Cushman 1925, *Globobulimina pacifica*, *Bolivina alazanensis*, *Anomalina mataensis* and *Siphonodosaria consorbina*, present in samples CN-6IID-003, CN-6IID-004, CN-6IID-005 y CN-6IID-006.

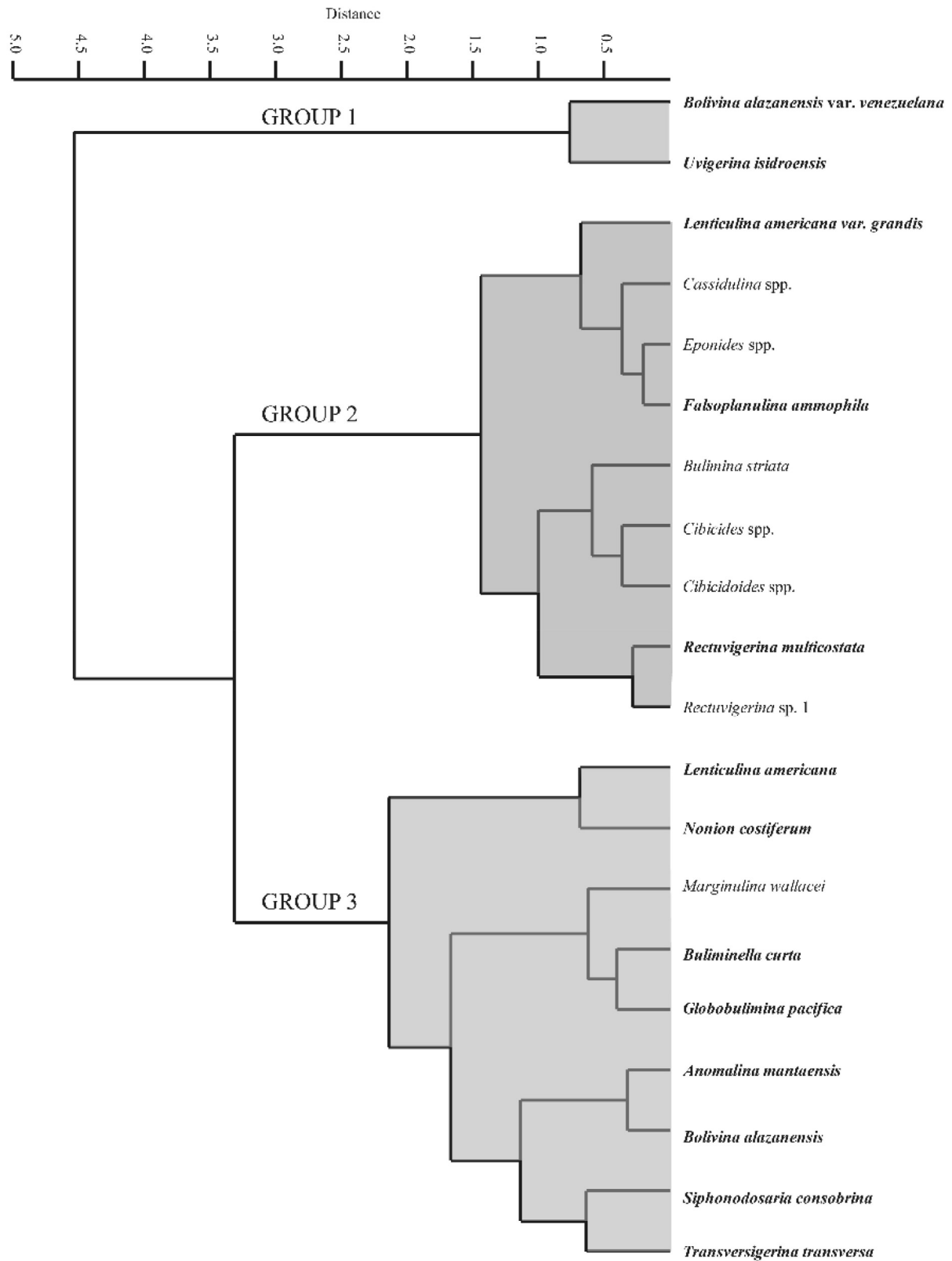
PCA showed the same three groups previously classified by the cluster analysis (text-fig. 13), confirming the associations above



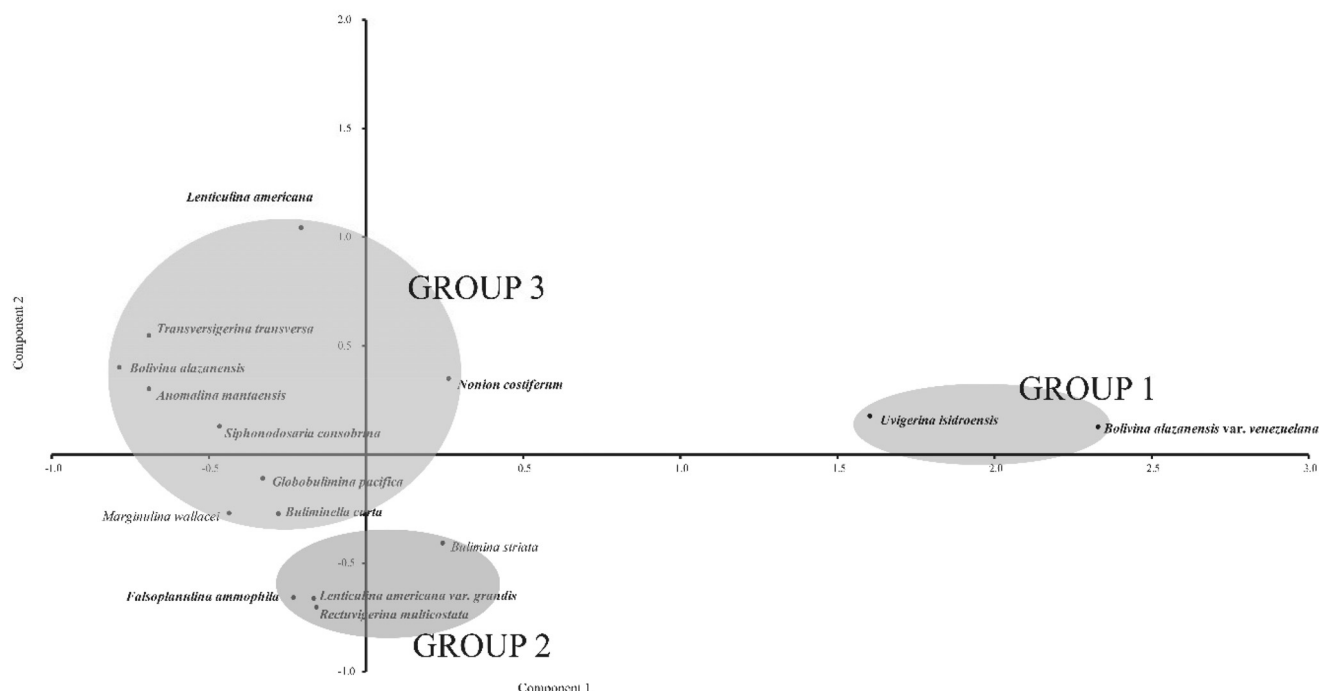
TEXT-FIGURE 10
Relative abundances of selected benthic foraminifera of the Jososuwou creek Section.



TEXT-FIGURE 11
Benthic foraminifera morphogroups and test type proportions of the Jososuwou creek section.



TEXT-FIGURE 12
R-mode cluster analysis using selected benthic foraminifera species from the Uitpa Formation.



TEXT-FIGURE 13

Principal Component Analysis (PCA) using selected benthic foraminifera species from the Uitpa Formation.

described. A marked separation between group 1 (Jososuwou creek section) and groups 2 and 3 (Pisülü hill section) is observed and it responds to the different paleoenvironmental conditions interpreted for the two sections.

Summarizing, association 1 represents outer neritic to upper bathyal environments with low oxygen levels and eutrophic conditions, while groups 2 and 3 are related to assemblages of the upper bathyal zone, with oxygenated bottom waters and higher trophic levels.

Relation with other benthic foraminiferal faunas of the Caribbean

The benthic and planktic foraminifera fauna identified in the Uitpa Formation at the upper Guajira area, is similar to the one reported by Renz (1948) in the Agua Salada Group of the state of Falcon in Venezuela. As already noticed by Becker and Dusenbury (1958), the benthic foraminifera biozones *Lenticulina wallacei* and *Transversigerina transversa* of the Agua Salada Group also occur in the upper Guajira area, and at the same time are correlatable with the ones reported in the Carapita Formation in eastern Venezuela by Hedberg (1937).

During this research, the biozone *Robulus wallacei* of Renz (1948) was identified, represented by *Bolivina alazanensis* at the Jososuwou creek section and by *Bolivina alazanensis* var. *venezuelana*, *Marginulina wallacei* and *Transversigerina transversa* at the Pisülü hill section. These similarities with other faunas of the Caribbean from the same age elevate the correlative value of this paleoenvironmental analysis.

CONCLUSIONS

In this study a report of the abundant foraminifera fauna in the Uitpa Formation from northeastern Colombia is made, a paleoenvironmental interpretation based on quantitative and qualitative analysis of benthic foraminifera species is proposed, and age determinations are made using planktic foraminifera.

The age of the studied unit at the Pisülü hill section is interpreted as Chattian (late Oligocene) specifically at the top of the biozone O7 (N4a following the former P zonation), based on the occurrence of biostratigraphic markers *Paragloborotalia mayeri* and *Dentoglobigerina tapuriensis*. As for the Jososuwou creek section, the interpreted age corresponds also to Chattian, but within the biozones O6 to O7 (P22 and N4a following the former P zonation). It was not possible to assign a more exact age in this last section due to the lack of more restricted biostratigraphic markers. As previous researchers have proposed an age of Aquitanian (early Miocene), the calibrations and taxonomic identifications of planktic foraminifera biostratigraphic markers presented here indicate an age no younger than Chattian. This new data, should be considered for future studies concerning the Uitpa Formation.

The Pisülü creek section contains two benthic foraminifera assemblages: the first, containing *Rectuvigerina multicostata*, *Lenticulina americana* var. *grandis* and *Falsoplanulina ammophila* and it is present in the lower-middle part of the section; and the second coincides with the occurrence of *Lenticulina americana*, *Transversigerina transversa*, *Nonion costiferum*, *Buliminella curta*, *Globobulimina pacifica*, *Bolivina alazanensis*, *Anomalina mataensis* and *Siphonodosaria consorbina*.

This section contains a moderately diverse and heterogeneous assemblage deposited in marine settings from the upper bathyal zone, as seen by the presence of *Transversigerina transversa*, *Anomalina mantaensis*, *Globobulimina pacifica*, *Rectuvigerina multicostata*, *Melonis pompiloides* and *Globocassidulina subglobosa*. The studied fauna is mainly calcareous proper of normal salinity and although the predominance of infaunal morphogroups indicates eutrophic conditions, oxygenation levels were high as seen by the low percentage of stress species, which favored the presence of a more diversified association.

Further west in the Jososuwou creek section, the assemblage *Bolivina alazanensis* var. *venezuelana* and *Uvigerina isidroensis* occur in marine settings from the outer neritic to upper bathyal zone, as seen by the presence of *Uvigerina isidroensis*, *Bulimina striata* and *Globobulimina pacifica*. The conditions were eutrophic but with higher organic matter input. Oxygenation was very low, probably because of reduced circulation and subsequent accumulation of organic matter in the environment. This interpretation is supported by the low diversity and homogeneity of the benthic foraminifera association, indicating that this stressed environment affected the distribution of these organisms during the Chattian at least in this area.

Although both sections were deposited close to one another, belong to the same lithostratigraphic unit, and contain deposits of similar ages, they present different paleoenvironmental conditions that respond to changes in oxygenation of bottom waters. In the Jososuwou creek section, high environmental stress con-

ditions with low oxygenation existed while in the Pisülü hill section high diversity assemblages were favored by oxygenated environments. This difference in oxygen levels cannot be associated with differences in the trophic levels or paleodepths, in turn they can be associated with changes in the circulation of bottom waters. Circulation must have been higher at the Pisülü hill area and low in the Jososuwou creek area, notably affecting benthic foraminifera faunal distribution.

The importance of identifying benthic foraminifera associations representing certain paleoenvironmental conditions, lies in the correlative potential they may have in future studies. For the Colombian Caribbean, several of the species here reported have been identified in other sites in similar ages, and if benthic foraminifera studies like this one were carried out in such sites, it will be possible to identify comparable paleoenvironmental conditions to the ones observed in the Uitpa Formation of the upper Guajira.

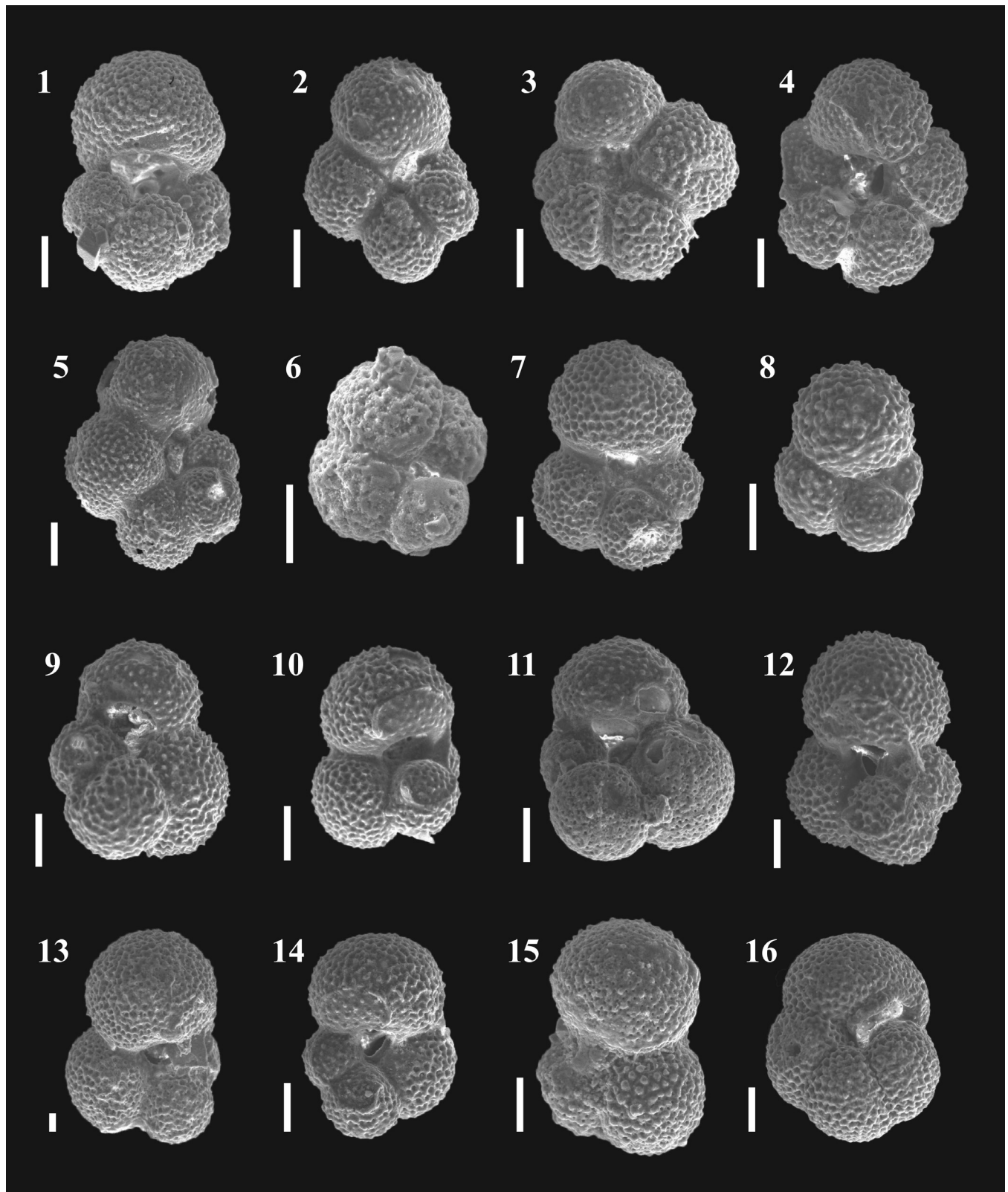
ACKNOWLEDGMENTS

We thank the National University of Colombia for making possible the realization of this research. Special thanks to Victoria Elena Corredor and Alejandro Numpaque of the Colombian Geological Survey for kindly providing the samples and stratigraphy of the studied area, and to Sebastián Aviles of the National University of Colombia for his help with the planktic foraminifera picking. And finally to Erik Isasmendi of the Universidad del País Vasco/Euskal Herriko Unibertsitatea for his valuable comments and observations.

PLATE 1

Scale: 50 µm.

- | | |
|--|--|
| 1 <i>Turborotalia</i> cff. <i>Ampliapertura</i> Bolli 1957 | 9 <i>Globigerina bulloides</i> d'Orbigny 1826 |
| 2 <i>Ciperoella anguliofficialis</i> (Blow 1969) | 10 <i>Globigerina bulloides</i> d'Orbigny 1826 |
| 3 <i>Ciperoella angulisuturalis</i> (Bolli 1957) | 11 <i>Globigerina bulloides</i> d'Orbigny 1826 |
| 4 <i>Ciperoella angulisuturalis</i> (Bolli 1957) | 12 <i>Globigerina bulloides</i> d'Orbigny 1826 |
| 5 <i>Ciperoella ciperoensis</i> (Bolli 1954) | 13 <i>Globigerina bulloides</i> d'Orbigny 1826 |
| 6 <i>Paragloborotalia nana</i> (Bolli 1957) | 14 <i>Globigerina bulloides</i> d'Orbigny 1826 |
| 7 <i>Globigerina bulloides</i> d'Orbigny 1826 | 15 <i>Globigerina bulloides</i> d'Orbigny 1826 |
| 8 <i>Globigerina bulloides</i> d'Orbigny 1826 | 16 <i>Paragloborotalia nana</i> (Bolli 1957) |



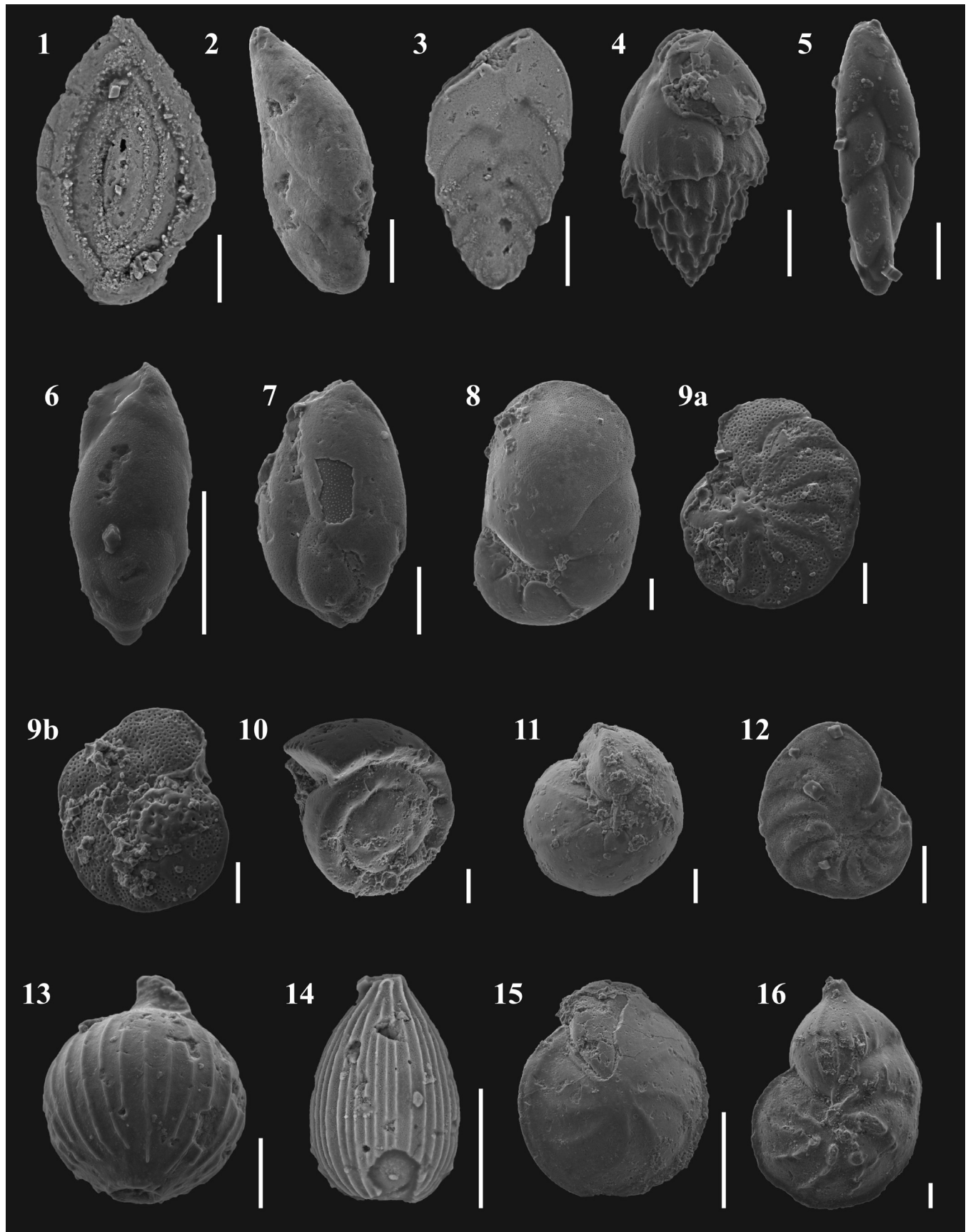
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PLATE 2

Scale: 100 µm

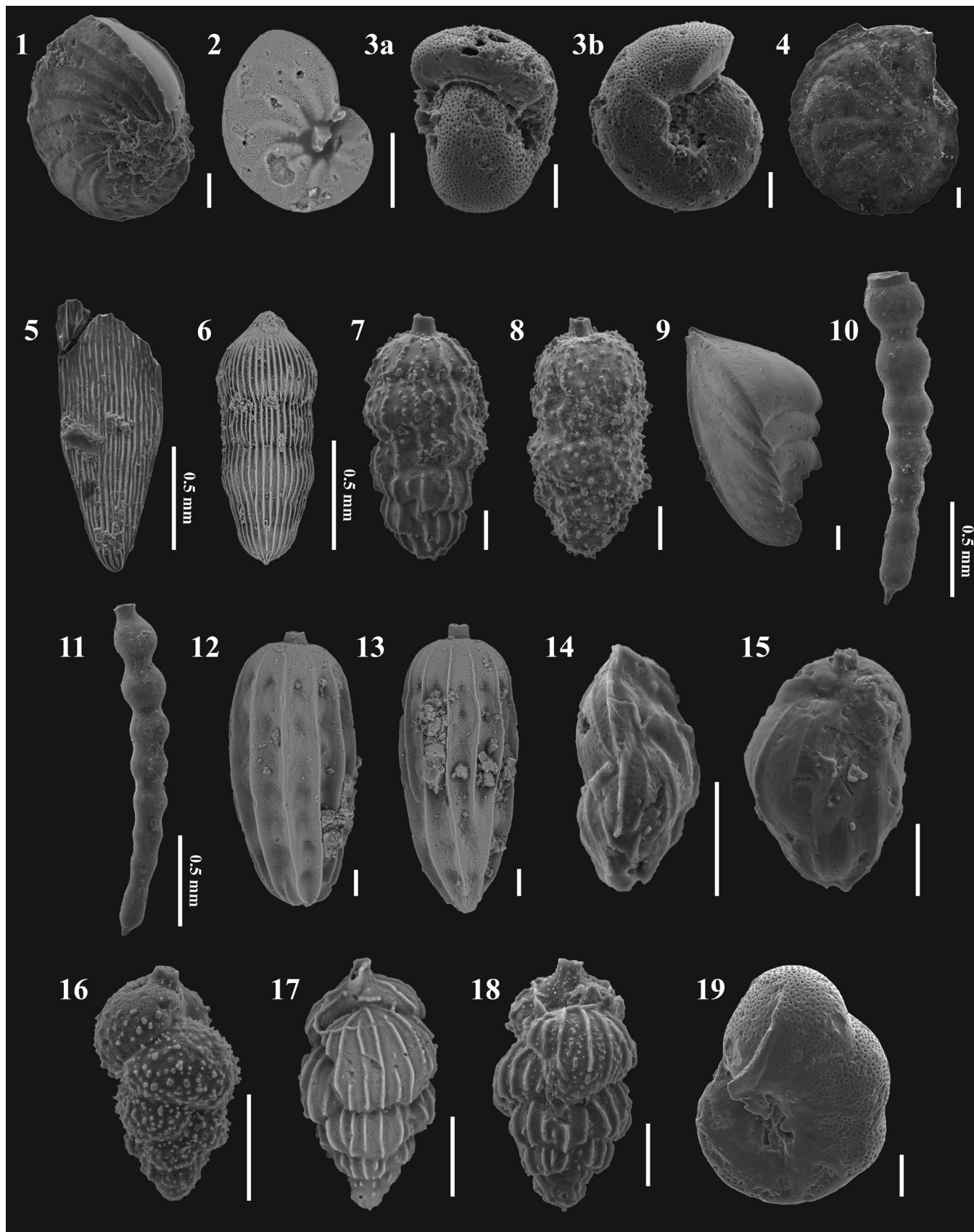
- | | |
|--|---|
| 1 <i>Spiroloculina</i> sp. d'Orbigny 1826. Sample CN-6IIID-006. | 9 <i>Cibicides neocompressus</i> Hofker 1958. Sample CN-6IIID-006, a. dorsal view, b. umbilical view. |
| 2 <i>Astacolus</i> sp. Montfort 1808. Sample CN-6IIID-006. | 10 <i>Gyroidinoides altispira</i> (Cushman and Stainforth 1945). Sample CN-6IIID-005. |
| 3 <i>Bolivina alazanensis</i> Cushman 1926. Sample CN-6IIID-004. | 11 <i>Gyroidina mauryae</i> Bermudez 1949. Sample CN-6IIID-006. |
| 4 <i>Bulimina striata</i> d'Orbigny 1826. Sample CN-6IIID-006. | 12 <i>Falsoplanulina ammophila</i> (Gümble 1870). Sample CN-6IIID-004. |
| 5 <i>Virgulina pontoni</i> Cushman 1932. Sample CN-6IIID-006. | 13 <i>Lagena acuticosta</i> Renz 1862. Sample CN-6IIID-035. |
| 6 <i>Buliminella curta</i> Cushman 1925. Sample CN-6IIID-035. | 14 <i>Lagena striata</i> (d'Orbigny 1839). Sample CN-6IIID-006. |
| 7 <i>Globobulimina pacifica</i> Cushman 1927. Sample CN-6IIID-004. | 15 <i>Lenticulina americana</i> var. <i>grandis</i> (Cushman 1920). Sample CN-6IIID-002. |
| 8 <i>Cancris nuttalli</i> (Palmer and Bermudez 1936). Sample CN-6IIID-006. | 16 <i>Marginulina wallacei</i> Hedberg 1937. Sample CN-6IIID-002. |



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PLATE 3

- 1 *Nonion costiferum* (Cushman 1926). Sample CN-6IIID-005. Scale: 100 µm.
- 2 *Nonion incisum kernensis* Kleinpell 1938. Sample CN-6IIID-034. Scale: 100 µm.
- 3 *Melonis pompiloides* (Fichtel and Moll 1798: a. vista lateral, b. vista umbilical. Sample: CN-6IIID-003. Scale: 100 µm.
- 4 *Planulina renzi* Cushman and Stainforth 1945. Sample CN-6IIID-006. Scale: 100 µm.
- 5 *Mucronina striata* (d'Orbigny 1826). Sample CN-6IIID-006. Scale: 0.5 mm
- 6 *Pseudonodosaria comatula* (Cushman 1923). Sample CN-6IIID-003. Scale: 0.5 mm
- 7 *Rectuvigerina multicostata* (Cushman and Jarvis 1929). Sample CN-6IIID-034. Scale: 100 µm.
- 8 *Rectuvigerina spinosissima* Boersma 1984. Sample CN-6IIID-001. Scale: 100 µm.
- 9 *Saracenaria senni* Hedberg 1937. Sample CN-6IIID-006. Scale: 100 µm.
- 10 *Siphonodosaria consorbina* (Schwager 1866). Sample CN-6IIID-003. Scale: 0.5 mm.
- 11 *Siphonodosaria consorbina* (Schwager 1866). Sample CN-6IIID-006. Scale: 0.5 mm.
- 12 *Transversigerina transversa* (Cushman 1918). Megalospheric form. Sample CN-6IIID-006. Scale: 100 µm.
- 13 *Transversigerina transversa* (Cushman 1918). Microspheric form. Sample CN-6IIID-006. Scale: 100 µm.
- 14 *Angulogerina illingi* Cushman and Renz 1941. Sample: CN-6IIID-002. Scale: 100 µm.
- 15 *Uvigerina adelinensis* Palmer and Bermudez 1949. Sample: CN-6IIID-034. Scale: 100 µm.
- 16 *Siphouvigerina hispida* (Schwager 1866). Sample CN-6IIID-034. Scale: 100 µm.
- 17 *Uvigerina isidroensis* Cushman and Renz 1941. Sample CN-6IIID-034. Scale: 100 µm.
- 18 *Uvigerina isidroensis* Cushman and Renz 1941. Sample CN-6IIID-035. Scale: 100 µm.
- 19 *Valvulineria* spp. Cushman 1926. Sample CN-6IIID-035. Scale: 100 µm.



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TAXONOMIC LIST OF BENTHIC FORAMINIFERA IDENTIFIED IN THIS STUDY

†extinct species

Alabamina sp. Toulmin 1941
Angulogerina illingi Cushman and Renz 1941 †
Anomalina mantaensis Galloway and Morrey 1929 †
Anomalinoides incrassatus (Fitchell and Moll 1978)
Arenobulimina spp. Cushman 1927 †
Astacolus sp. Montfort 1808
Bolivina alazanensis Cushman 1926 †
Bolivina alazanensis var. *Venezuelana* Hedberg 1937
Bolivina caudriae Cushman and Renz 1941 †
Bulimina sp. d'Orbigny 1826
Bulimina striata d'Orbigny 1826
Buliminella curta Cushman 1925 †
Cancris auricula (Fichtel and Moll 1798)
Cancris nuttalli (Palmer and Bermúdez 1936)
Cassidulina sp. d'Orbigny 1826
Cibicides compressus Hofker 1958
Cibicides sp. Montfort 1808
Cibicides yaquensis Bermúdez 1949 †
Cibicidoides sp. Thalmann 1939
Dentalina sp. Risso 1826
Elphidium lens Galloway and Hemingway, 1971 †
Eponides sp. Montfort, 1808
Falsoplanulina ammophila (Gümbel 1870) †
Fursenkoina bradyi (Cushman 1922)
Glandulina laevigata (d'Orbigny 1826)
Globobulimina pacifica Cushman 1927
Globocassidulina subglobosa (Brady 1881)
Gyroidina altiformis Stewart and Stewart 1930
Gyroidina basicrassata Bermúdez 1949 †
Gyroidina cibaoensis Bermúdez 1949 †
Gyroidina maurayae Bermúdez 1949 †
Gyroidina sp. d'Orbigny 1826
Gyroidinoides altispira (Cushman and Stainforth 1945)
Gyroidina parva Cushman and Renz 1941 †
Gyroidinoides sp. Brotzen 1942
Gyroidinoides venezuelana Renz 1948 †
Hazawaia sp. Asano 1944
Homalohedra acuticosta (Reuss 1862)
Islandiella californica (Cushman and Hughes 1925)
Lagena sp. Walker and Jacob 1798
Lagena acuticosta Reuss 1862
Lagena striata (d'Orbigny 1839)
Lenticulina americana (Cushman 1918) †
Lenticulina americana var. *grandis* (Cushman 1920) †
Lenticulina americana var. *spinosus* (Cushman 1918) †
Lenticulina convergens (Bornemann 1855)
Lenticulina cristobalensis (Bermúdez 1949) †
Lenticulina falcifer (Stache 1865) †
Lenticulina nuttalli (Cushman and Renz 1941) †
Lenticulina torrida Cushman 1923
Lenticulina rotulata (Lamarck 1804)
Lenticulina sp. Lamarck 1804
Lenticulina subpapillosus (Nuttall 1932) †
Lenticulina suteri (Cushman and Renz 1941)
Marginulina wallacei Hedberg 1937 †
Melonis pompiloides (Fichtel and Moll 1798)
Mucronina longistriata (d'Orbigny 1826) †
Mucronina vaughani (Cushman 1927) †

Nodosaria sp. Lamarck 1816
Nonion costiferum (Cushman 1926) †
Nonion incisum kernensis Kleinpell 1938 †
Nonion sp. Montfort 1808
Planulina renzi Cushman and Stainforth 1945
Pseudonodosaria comatula (Cushman 1923) synonym of
Pyramidulina comatula (Cushman 1923)
Pullenia sp. Parker and Jones in Carpenter et al. 1862
Pyramidulina raphanistrum var. *caribbeana* (Hedberg 1937)
Rectuvigerina multicostata (Cushman and Jarvis 1929)
Rectuvigerina nodifera (Cushman and Kleinpell 1934)
Rectuvigerina sp. 1
Rectuvigerina spinosissima Boersma 1984
Saracenaria italica var. *carapitana* Franklin 1944 †
Saracenaria senni Hedberg 1937 †
Siphonodosaria consobrina (d'Orbigny 1846) †
Siphonodosaria lepidula (Schwager 1866) †
Siphonovigerina hispida (Schwager 1866)
Spiroloculina sp. d'Orbigny 1826
Stilostomella paleocenica (Cushman and Todd 1946) †synonym of *Ellipsonodosaria paleocenica* Cushman and Todd 1946 †
Stilostomella spinescens (Reuss 1851)
Tortoplectella rhomboidalis (Millett 1899)
Transversigerina senni (Cushman and Renz 1941) † synonym of *Siphogenerina senni* Cushman and Renz 1941 †
Transversigerina sp. Matthews 1945 †
Transversigerina sp. 1
Transversigerina transversa (Cushman 1918) †
Trifarina sp. Cushman 1923
Uvigerina adelinensis Palmer and Bermúdez 1949 †
Uvigerina isidroensis Cushman and Renz 1941 †
Uvigerina mexicana Nuttall 1932 †
Uvigerina sp. d'Orbigny 1826
Valvulineria sp. Cushman 1926
Virgulina pontoni Cushman 1932 synonym of *Fursenkoina pontoni* (Cushman 1932)

TAXONOMIC LIST OF PLANKTIC FORAMINIFERA IDENTIFIED IN THIS STUDY

Catapsydrax dissimilis Cushman and Bermúdez 1937
Catapsydrax sp. Loeblich and Tappan 1957
Catapsydrax unicavus Loeblich and Tappan 1957
Ciperoella ciperoensis (Bolli 1954)
Ciperoella angulisuturalis (Bolli 1957)
Ciperoella anguliofficialis (Blow 1969)
Dentoglobigerina tapuriensis (Blow and Banner 1962)
Dentoglobigerina tripartita (Koch 1926)
Globigerina bulloides d'Orbigny 1826
Globigerina eamesi Blow 1959
Globigerina falconensis (Blow 1959)
Globigerinoides sp. Cushman 1927
Globorotalia sp. Cushman 1927
Globoturborotalita brazieri (Jenkins 1966)
Globoturborotalita euapertura (Jenkins 1960)
Globoturborotalita woodi Jenkins 1960
Paragloborotalia mayeri (Cushman and Ellisor 1939)
Paragloborotalia nana (Bolli 1957)
Trilobatus primordius (Blow and Banner 1962)
Trilobatus sp. Spezzaferri et al. 2015
Turborotalia cff. *Ampliapertura* Bolli 1957