

Neogene history of the Carapita Formation, Eastern Venezuela Basin

Dennis Sanchez^{1,2}, Marie-Pierre Aubry², and Robert D. Liska³

¹PDVSA-EXPLORACIÓN, Laboratorio Geológico El Chaure,
edificio principal piso 01 oficina 03, Guanta-Anzoátegui, Venezuela

²Department of Geological Sciences, Rutgers University, Bush Campus, Wright-Rieman Laboratories,
610 Taylor Road, Piscataway, NJ 08854

³7706 Green Lawn Drive, Houston, TX 77088
email: aubry@rci.rutgers.edu

ABSTRACT: Based on the stratigraphic distribution of planktonic microfossils (mostly planktonic foraminifera) and abundance patterns of benthic foraminifera we determine the temporal completeness of one land section and three wells through the Lower and Middle Miocene Carapita Formation of eastern Venezuela, compare the extent of the hiatuses in the sections and document changes in paleodepth at these localities during the early and Middle Miocene. We determine that changes in paleodepth are associated with hiatuses, but see no relationship with the global changes in sea-level inferred from deep sea isotope records. This strongly suggests that there was a strong tectonic forcing on stratigraphic architecture at upper and middle bathyal depths, as to be expected in a tectonically active area. However, similar stratigraphic patterns are also observed elsewhere, implying that a widespread tectonic structuring of the stratigraphic architecture may have been operative. Recognition of hiatuses (not merely unconformities) as primary stratigraphic components will make possible an uninterrupted documentation of sequence boundaries from subaerial to bathyal environments, and help determine objectively the structural mechanism(s) operating on the genesis of stratigraphic sequences (*sensu* Catuneanu et al. 2009). Biostratigraphy (and biochronology) are the main tools to understanding this structuring.

INTRODUCTION

Sequence stratigraphy represents a considerable advance in the description of the stratigraphic record. Designed to interpret stratal successions within shallow water sequences as reflecting changes in relative sea level history (Vail et al. 1977), or, as recently agreed upon, changes in accommodation (Catuneanu et al. 2009) it has been less successful with the documentation of deeper water sedimentary packages at basinal locations where strata are conformable (i.e., concordant) across sequence boundaries, in particular when delineated from seismic profiles. This study is an opportunity to examine such deep-water successions and test them for stratigraphic completeness in complementarity to the sequence stratigraphic framework achieved for correlative shallower water successions.

Cropping out over a large part of eastern Venezuela are 4500 to 6000 meters of the thick Lower to Middle Miocene Carapita Formation (Hedberg 1937a; Pearson 1965) which has proved to be a critical formation for the oil industry. It constitutes an important oil reservoir in the eastern part of the Anzoátegui State and also forms a main seal rock for an Oligocene oil reservoir located in the north of Monagas State. Eastern Venezuela is a structurally complex area, with numerous thrust faults causing vertical repetitions of stratigraphic successions. To minimize risks associated with drilling in such complex terranes, and also reduce drilling time, the oil industry has relied intensely on micropaleontology, and the biostratigraphic characterization of the Carapita Formation which is a much-needed assistance in oil exploration. Despite its crucial stratigraphic position, there has been no integrated micropaleontologic study of the Carapita Formation, only narrowly focused, albeit significant, studies. The depositional history of this formation remains unknown in

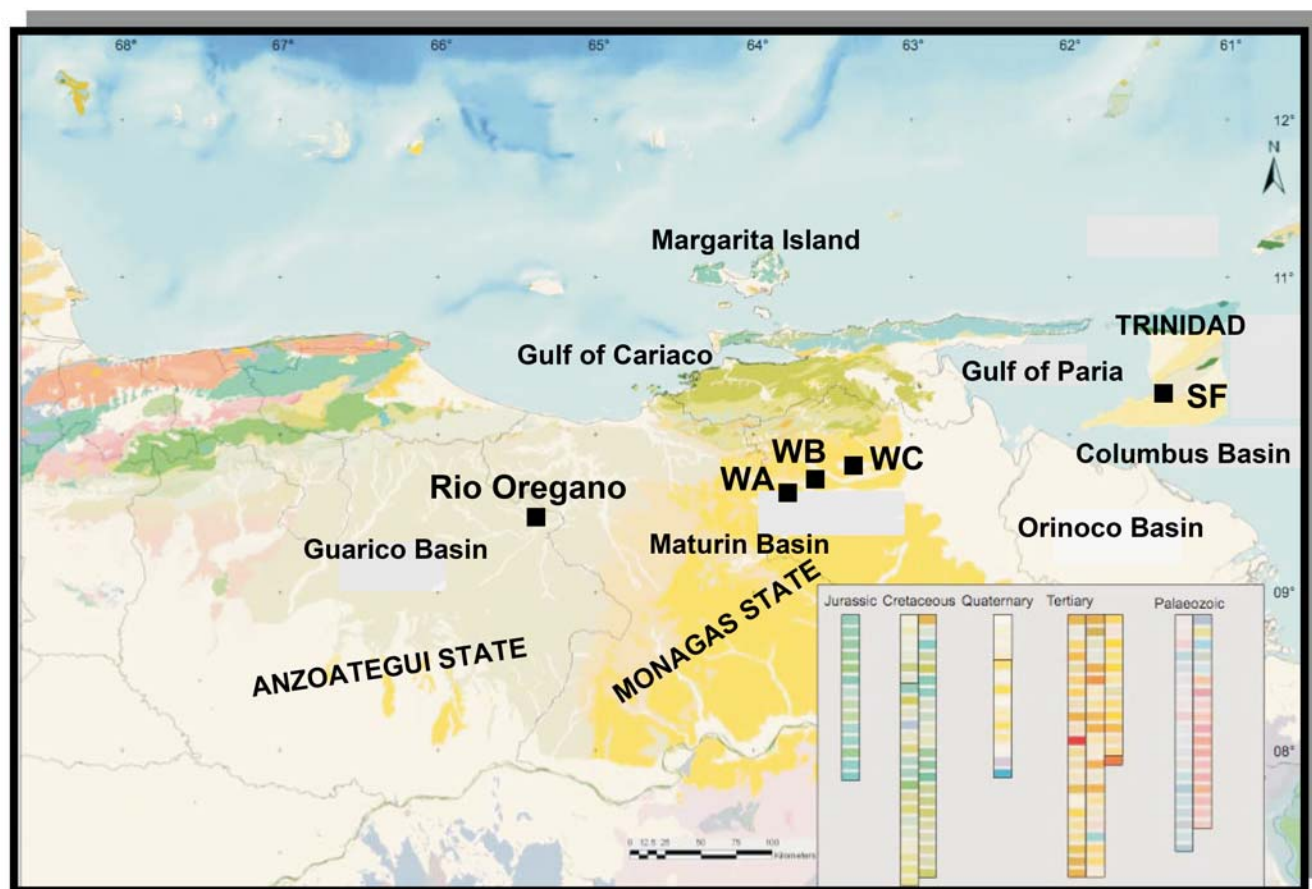
terms of temporal completeness and poorly documented with regard to bathymetry.

The objective of this study is to remedy this situation based on an integrated biostratigraphic investigation using planktonic and benthic foraminifera and complementary calcareous nannofossil data. The formation has been analyzed at three selected drilled sites and in the outcrop section along Rio Oregano (Hedberg 1937a). The microfaunas are generally poorly preserved in the Carapita Shales, particularly in the drilled material, however. We have circumvented this problem by comparing microfaunas of the Carapita Formation with foraminifera from the abundant, well-preserved microfaunas of the regionally equivalent Cipero Formation of South/central Trinidad (Sanchez et al. 2014).

In this paper we 1) discuss the stratigraphy of the Carapita Formation, 2) demonstrate the occurrence of multiple hiatuses in each section, 3) conduct a broad survey of inferred bathymetric distributions of Neogene benthic foraminifera, and 4) combine this information with the analysis of morphogroups as described by Corliss and Chen (1988) and Corliss and Fois (1991). We then integrate the paleobathymetric interpretation into the temporal framework established for the four sections. We suggest that in situ tectonics, not glacioeustasy, controlled the early Neogene sedimentary history in the eastern Venezuela Basin.

GEOGRAPHIC AND GEOLOGIC AND SETTING

The area of interest in this study is eastern Venezuela between the Gulf of Cariaco and the Gulf of Paria to the north and the Maturin Basin to the south, and the southern island of Trinidad (Text-fig. 1). This is a structurally complex area that has been



TEXT-FIGURE 1

Geographic location of the study area. Left: General location of Venezuela and Trinidad (modified from Duerto 2007). Note: color versions of this figure and others herein, are available online. In this figure, color denotes chronostratigraphic age (see inset).

extremely deformed during the oblique collision between the South American and Caribbean Plates, producing a system of blocks delineated by thrust faults (Text-fig. 2a, b). The Maturin Basin of eastern Venezuela is delineated by two east-west trending thrust systems, the Monagas Fold-Thrust belt to the south and the Pirital thrust to the north (Hung 1997; Sanchez et al. 2010). The latter divides into subparallel faults that affect south Trinidad.

The stratigraphy of the Maturin Basin (Text-figs. 3, 4) reflects four main episodes of tectonic history whose timing is debated (Eva et al. 1989; Erikson and Pindell 1993; Parnaud et al. 1995; Yoris and Ostos 1997; Di Croce et al. 1999; Jacome et al. 2003; CEV 2005; Higgs 2009). Paleozoic pre-rifting and Jurassic to Early Cretaceous rifting were followed by an episode of tectonic quiescence as a passive margin became established in the north of Venezuela during the Cretaceous. The duration of this episode is controversial, either > 140 Myr (until Eocene, Erikson and Pindell 1993) or just a few million years (Higgs 2009). The oblique collision between South American and the Caribbean plates resulted in a change of the structural regime to an active margin, resulting in early Neogene turbiditic sedimentation (Duerto 2007; Sanchez et al. 2007). The Carapita Formation, which is part of the Merecure Group, was deposited in an extensive deep-water basin during Late Oligocene to Middle Miocene (Text-figs. 5a, b). In the stratotypic area as well as in

the Maturin Basin the Carapita Formation is, essentially, a homogeneous foraminiferal shale (Hedberg 1937a, b). The shales are dark gray and ferruginous, sometimes finely micaceous and with subconchoidal fracture. The carbonate content is generally low. The formation overlies the Upper Oligocene Naricual Formation (Hedberg and Pyre 1944) and underlies the Upper Miocene La Pica Formation. The lower boundary is a transitional contact. The upper boundary is unconformable (Text-fig. 4).

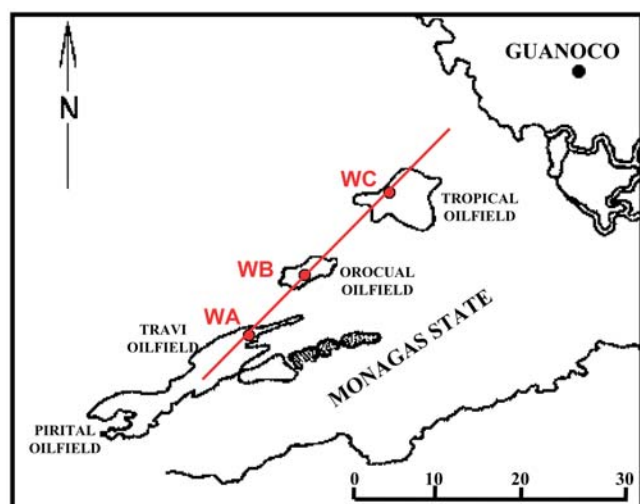
MATERIALS AND METHODS

A total of 228 samples have been examined in this study: 121 cutting samples from the Carapita Formation in exploration wells; 67 outcrop samples from the Carapita Formation; and 19 outcrop samples from the Cipero Formation for reference. All samples analyzed are listed in Table 1.

We describe below the sections analyzed in this work and the methodology used. Sample processing, taxonomic framework and biozonal characterization based on the Cipero Formation are discussed in Sanchez et al. (2014).

Sections

Three wells and one land section in the Eastern Venezuela Basin are examined here (Text-figs 1, 2a). The three PDVSA exploration wells are situated between the Pirital and Tropical Oilfields. Because well data are proprietary, neither the full names of the



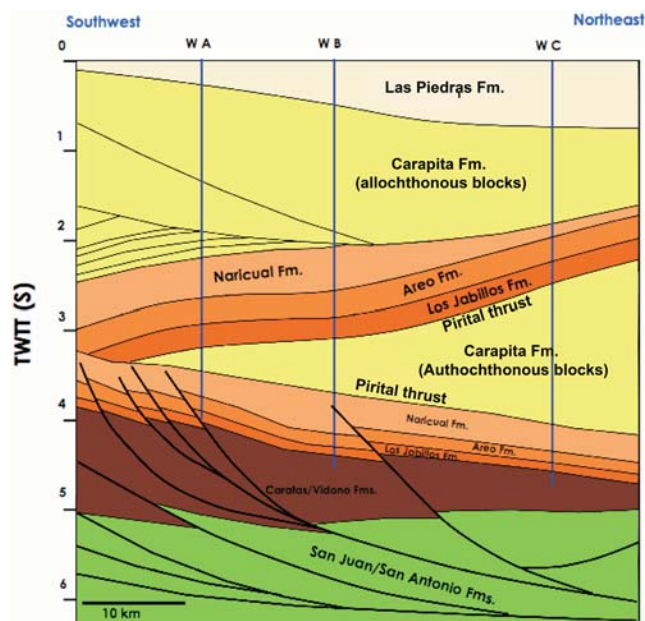
TEXT-FIGURE 2a
Location of the three wells (WA, WB, WC, Eastern Venezuela Basin. Geographical location (modified from Código Geológico de Venezuela, PDVSA-INTEVEP 2005).

wells nor their exact geographic coordinates in the northern part of the Monagas State are given. They are referred to here as Wells A, B, C.

Well A (WA) was drilled in 2004 to a total depth (TD) of 21,838ft (~6617.5m). Located 10km southwest of WA, Well B (WB) was drilled in 2008 to a TD of 16,731ft (~5070m). Well C (WC), also drilled in 2008 to a TD of 14,080ft (~4267m) is located 25km southwest of WB. The lithostratigraphic succession is the same in the three wells (Text-fig. 4) and as follows (from top to bottom): Mesa/Las Piedras (Plio-Pleistocene), La Pica (Pliocene), Carapita (Oligo-Miocene), Naricual (Oligocene), Areo (Oligocene), and Los Jabillos (Oligocene) Formations.

As a result of the Pirital thrust, the Carapita to Los Jabillos part of the succession is repeated below the Los Jabillos Formation, which is then underlain by the Vidoño (Eocene), and Caratas (Paleocene) Formations (Text-fig. 2b). The Carapita Formation is conveniently and informally subdivided into three units: Carapita 1 is the more superficial, overlying the Pirital thrust; Carapita 3 is the deepest. The shales of Carapita 2, below the Pirital thrust fault, are generally older (Zones N4-N6 [M1-3]) than those of Carapita 1 (which are essentially Zone N6 [Zone M3] and younger; see above) (PDVSA Internal Report; 2006, 2010). This study is only concerned with Carapita 1 recovered above the Pirital thrust. It is 7,735ft (~2343m) thick in WA, 9,760ft (~2957.5m) in WB, and 6,490ft (~1967m) in WC. Only cuttings samples, generally taken at intervals of ~100 feet (~30m), were available from these drilled wells (no side wall samples were taken from the Carapita Formation).

The 111m thick section that crop out along the Rio Oregano (Lat.: 10° 94' to 10° 99' N; Long.: 64° 43' W) was collected by one of us (DS, April 2009) at ~1m intervals (Text-fig. 6). The exposures are almost continuous along the river, but with two large vegetation-covered intervals, from 44 to 60m and from 64 to 70m as measured from the base of the section. The Rio Oregano section is located East of the Carapita stratotype section on Quebrada Carapita (north of Santa Ines). It is not as complete as



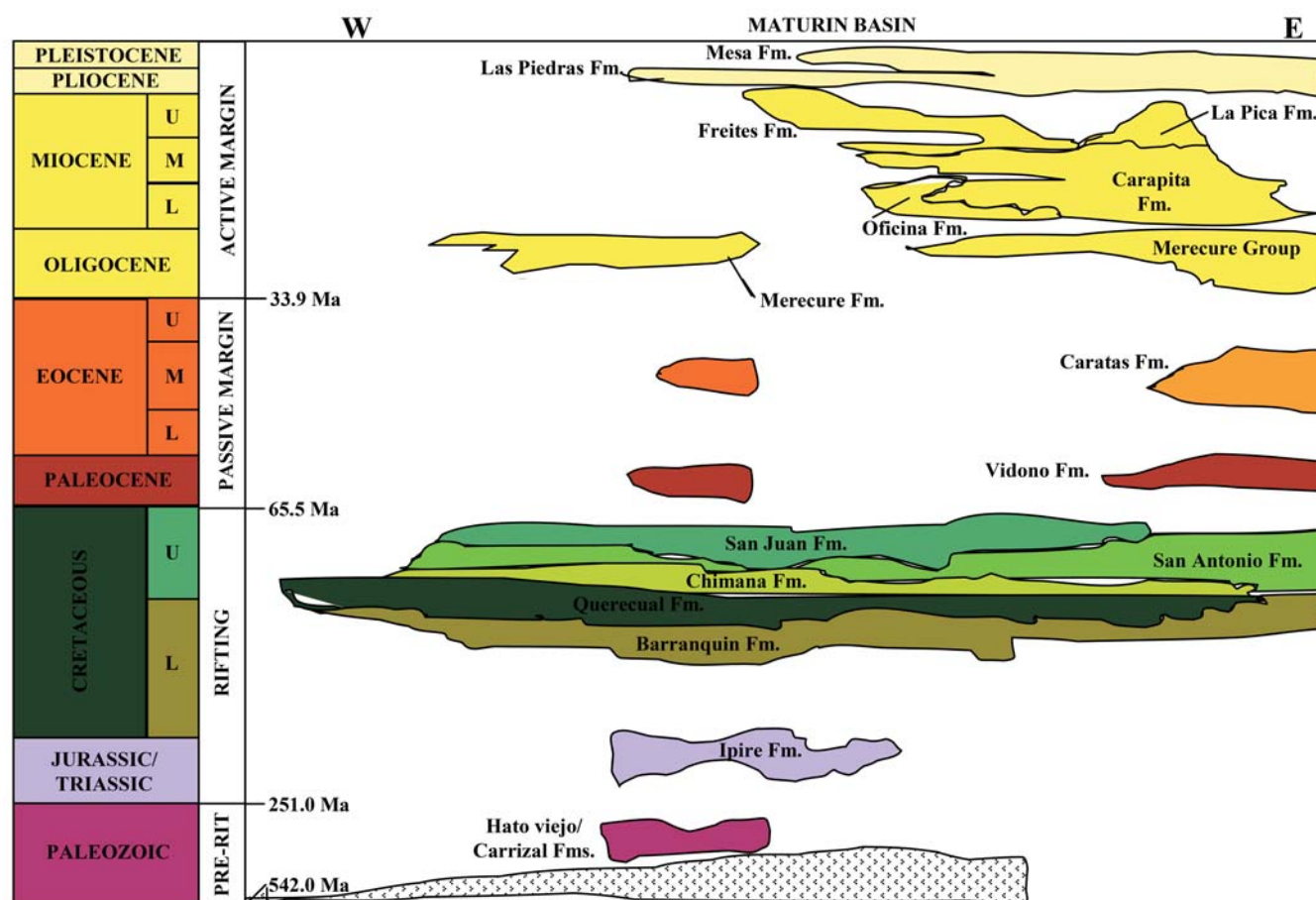
TEXT-FIGURE 2b
Location of the three wells (WA, WB, WC, Eastern Venezuela Basin. Location in a simplified structural framework of the studied area (from PDVSA, Internal Report 2009). Note the repetition of the stratigraphic succession below the Pirital thrust. In this study only the shales of the Carapita Formation overlying the Pirital thrust are considered.

the stratotype section (Hedberg 1937a, b), but access to the latter has become extremely difficult and dangerous. It was important to study a normal stratigraphic succession on land because it served as a control to assess the quality of the data in the wells (e.g., determine the absolute abundance of the foraminifera in the formation), and it strengthened our stratigraphic and temporal interpretation of the wells. Also a paleobathymetric analysis would have been meaningless using cutting samples alone.

Biozonal and biochronological framework

Planktonic and benthic foraminifera provided the main stratigraphic control in the initial study of the wells, with complementary data from calcareous nannofossil (PDVSA Internal Report; 2006, 2010). The distributions of all marker species of planktonic and benthic foraminifera identified in each well have been revised as part of this study and are documented separately (Sanchez et al. 2014; see Appendix a, b herein). Taxonomic identification was considerably aided by comparison with foraminiferal assemblages in Lower and Middle Miocene biozones from the Cipero Formation of Trinidad. Of the 19 samples carefully examined, five were selected for the high quality of preservation of their planktonic foraminiferal assemblages. They served, both, as a taxonomic and a biostratigraphic reference, each sample best representing a biozone (Text-fig. 7).

The biozonal interpretation in this study is based on the biozonal frameworks and stratigraphic ranges in Kennett and Srinivasan (1983), Bolli et al. (1985) and Berggren et al. (1995) for planktonic foraminifera, and Martini (1971) for calcareous nannofossils. In addition the Highest Occurrences (HO) and,



TEXT-FIGURE 3

Simplified chronostratigraphic chart of the Eastern Venezuela Basin (modified from Duerto 2007). Note that the Carapita/La Pica formational contact is unconformable. The hiatus is short and not represented.

when possible, the Lowest Occurrences (LO) of stratigraphically useful taxa other than the biozonal markers were carefully delineated.

The biostratigraphic resolution achieved in this study is notably greater in the Rio Oregano section (sampled at 1m interval) than in the wells (sampled at ~30m interval). Unlike outcrop samples collected at specific levels, cutting samples represent a mixture of microfaunas from the actual level being drilled and also from overlying horizons. We were therefore careful in relying mostly on the HO of taxa in these wells. The use of (admittedly approximately) LOs of *O. universa*, *O. suturalis* and *P. sicana* is based on the fact that no specimens of these taxa were found at lower depths (see below). The same stratigraphic relationship between these taxa and the HO of *S. heteromorphus* in the Rio Oregano outcrop section as in the wells supports our use of these markers. The same observation applies to the LO of calcareous nannoplankton *S. belemnus* (see below).

Interestingly, there was no indication of reworking or downhole contamination in the wells.

We apply the time scale of Berggren et al. (1995). Planktonic foraminiferal biochronology has been updated in Wade et al. (2011) but most of the Lower Miocene datums remain un-

changed (Table 2). The Neogene calcareous nannoplankton biochronology in Lourens et al. (2004) and in Gradstein et al. (2012) has been recalibrated to the GPTS of Cande and Kent (1995). Age differences between datums in the two time scales are small (<150 kyr) except for two datums used here, either because of poor calibration (*Sphenolithus belemnus*) or because of magnetostratigraphic misinterpretation (*Helicosphaera ampliaperta*).

Stratigraphic and temporal interpretations

It is well known that the stratigraphic record is highly discontinuous (e.g., Ager 1993; Miall 2010) and diverse methodologies (e.g., graphic correlation, strontium isotope stratigraphy) are available to decipher the presence of unconformities in stratigraphic sections. We use here the methodology explained by Aubry (1995) which is designed to 1) delineate unconformities, 2) date their two surfaces, and 3) determine the encompassing hiatus. Overlap between hiatuses in different sections constitutes a means of determining the timing of the causal mechanism responsible for the development of correlative unconformities thus providing a test to global mechanisms (such as glacio-eustasy) (Aubry 1991).

The methodology relies on the comparison of the thicknesses of stratigraphic units with their duration (e.g., biozones with

biochrons, magnetozone with magnetochrons, etc.). An earlier attempt at conducting magnetostratigraphy on outcrop sections in eastern Venezuela proved unsuccessful (Berggren and Kent 1995, unpublished data). Poor preservation of foraminifera prevented the application of stable isotope stratigraphy to refine the biostratigraphy on the Rio Oregano section. Therefore only biostratigraphy is available here.

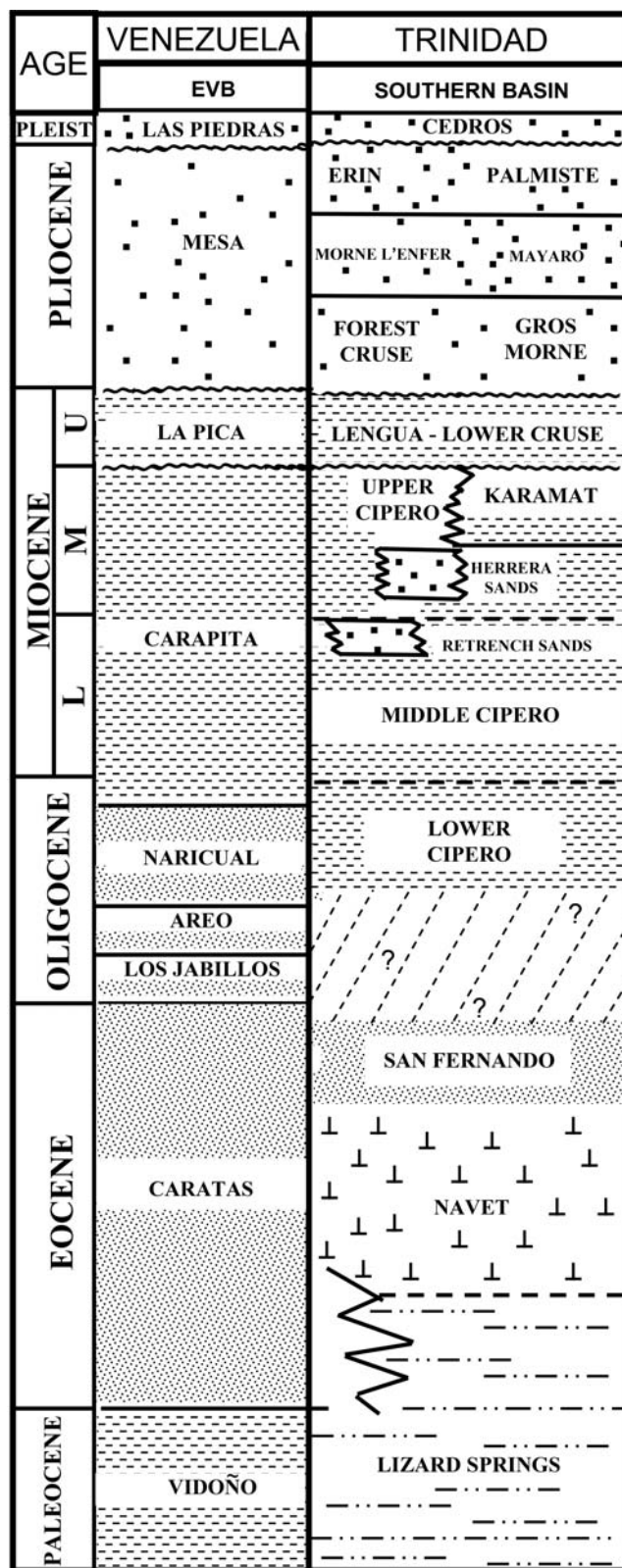
In continuous sections the thicknesses of biozones are proportional to the durations of corresponding biochrons, and evolutionary events (First Appearance Datum [FAD] and Last Appearance Datum [LAD]) are recorded sequentially in the sections. In discontinuous sections FADs and LADs that occurred hundred of thousands to million years apart are registered at the same stratigraphic level (or unrecorded when the hiatus is too long). The greater the number and diversity of bioevents the more accurate the location of unconformities is (see Aubry 1995, figs. 4, 5). Once the sedimentation rate curve is established and the rates of sedimentation determined, the ages of the unconformable surfaces can be calculated by extrapolation. However, when sections are too discontinuous or events too few, the ages of surfaces can be estimated, not calculated. This introduces a known uncertainty in the temporal interpretation. In this work we place greater confidence in the interpretation of the Middle Miocene than in the Lower Miocene interval, because a greater number of biostratigraphic data are available for the Middle Miocene than the Lower Miocene. The temporal interpretation proper consists in mapping the time represented by stratigraphic units in a given area. It is the means to truly consider time as the fourth dimension in stratigraphic analysis.

Paleobathymetry

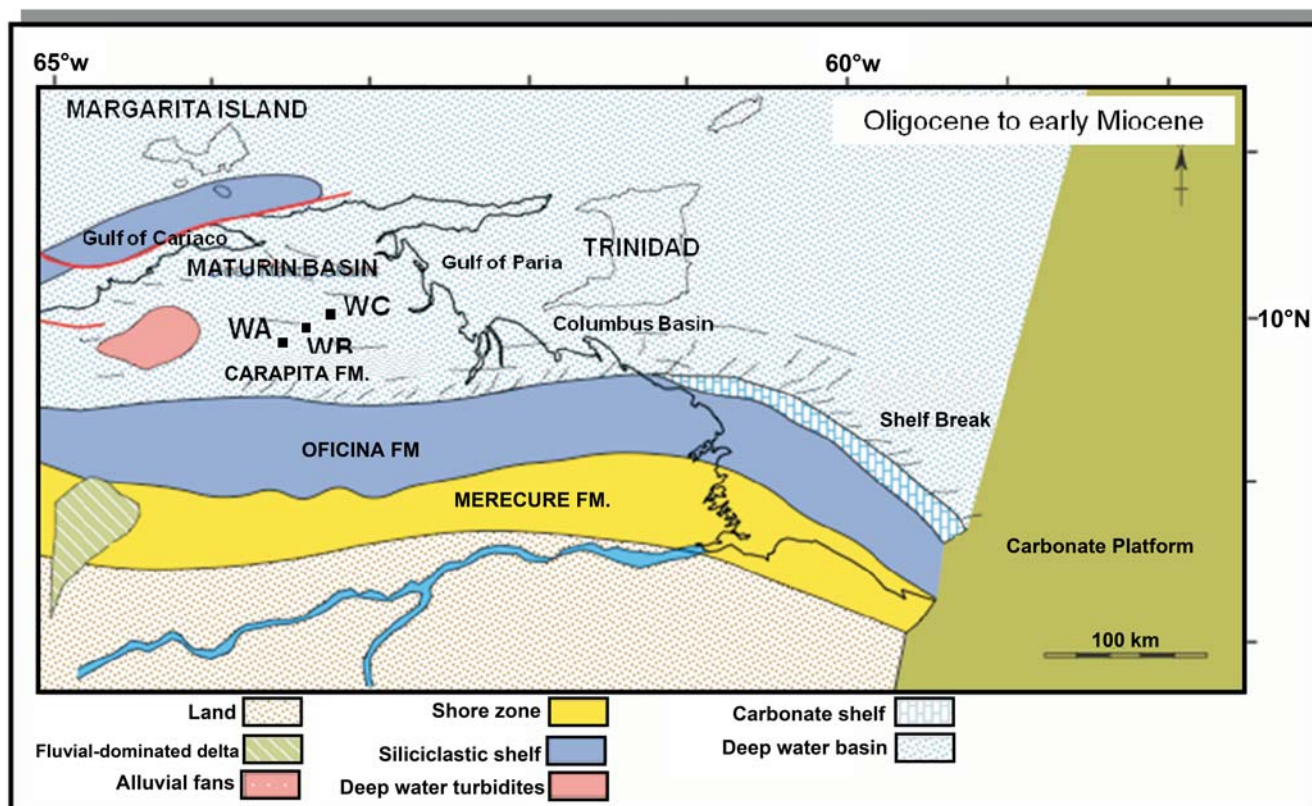
Benthic foraminifera have previously helped determine the depositional depth of the Carapita Formation (Saint Marc 1988; De Cabrera and De Macquhae 1990). From a study of thirty five (35) wells drilled in the eastern Venezuela Basin and using biofacies defined on the basis of consistently co-occurring taxa, the latter authors concluded that Early Miocene deposition occurred at middle to lower bathyal depths (600–2000m) and Middle Miocene sedimentation at upper bathyal (200–600m) depths (bathymetric zones of Van Morkhoven et al. 1986).

Several multivariate techniques such as Factor Analysis (Imbrie and Purdy 1962), Principal Components Analysis (McGowran 1968), Cluster Analysis (Bonham-Carter 1965; Parks 1966), have proven useful to manipulate large amount of data and to extract the significance of data obtained from hundreds of analyses. Benthic foraminifera are not abundant in the Carapita Formation (nor are they in the Cipero Formation). At most levels the total number of benthic foraminifera recovered from the washed residue of 100 g of rock was <100 specimens (Text-fig. 8). To obtain the 300 specimens of benthic foraminifera required for statistical analysis it would have been necessary to wash much larger amounts of rocks (~500 g) and picking would have required an inordinately long time. We thus turned to two other methodologies—a general survey of the paleobathymetry inferred in previous studies for the benthic taxa encountered in this study, and morphotype analysis of calcareous benthic foraminifera. It was also inappropriate to use Chi-square analysis for this study, because the species inventory in the Cipero and the Carapita Formations were largely different.

We also analyzed benthic foraminiferal assemblages from 19 samples from the Cipero Formation. This formation is well

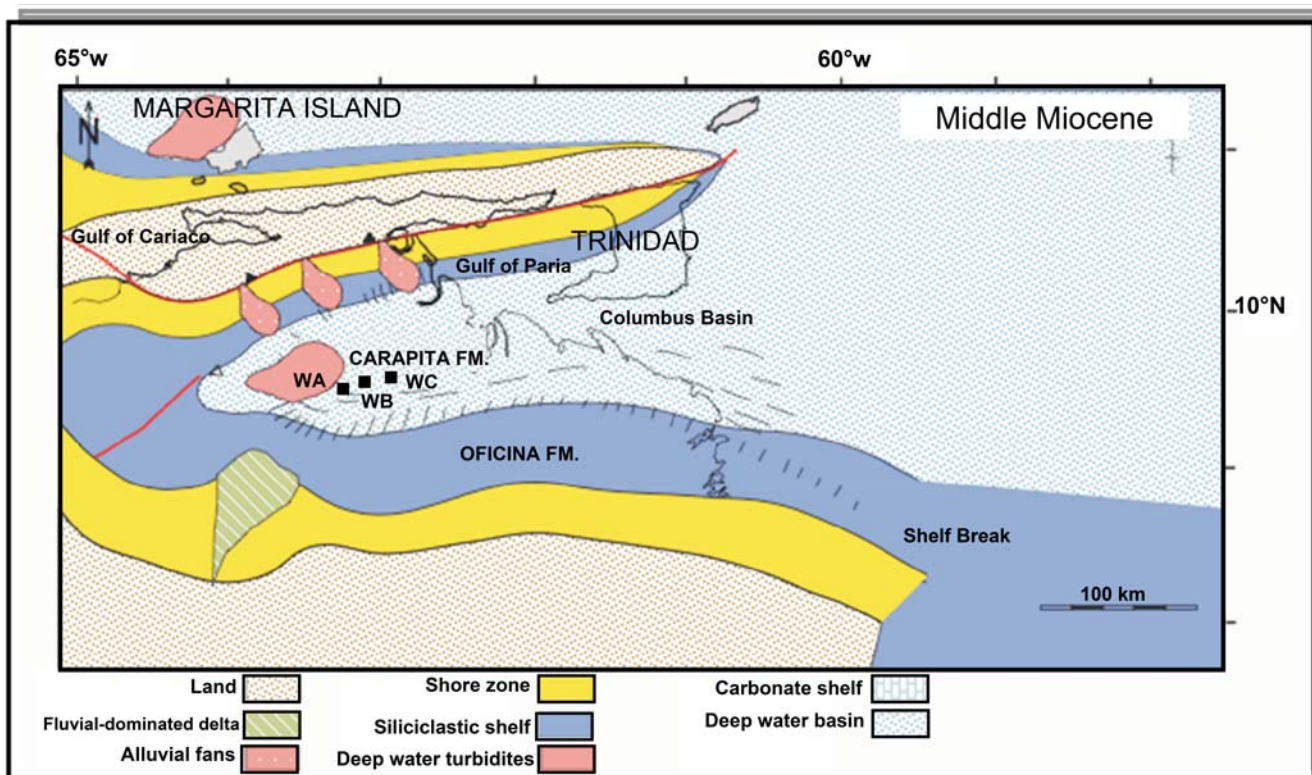


TEXT-FIGURE 4
Lithostratigraphic correlations between Eastern Venezuela and Trinidad
(modified from Algar 1991).



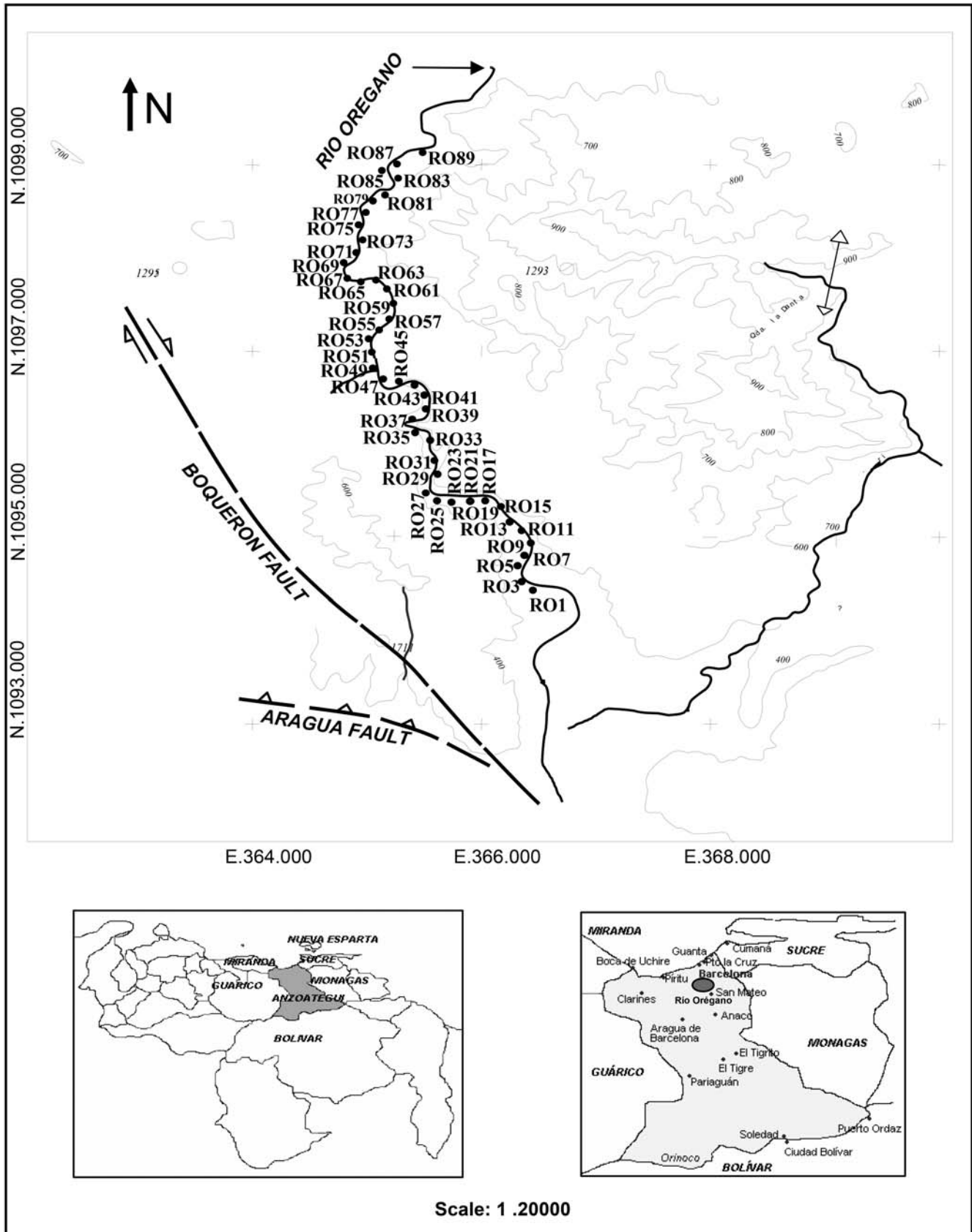
TEXT-FIGURE 5A

Paleogeographic reconstructions of the Eastern Venezuela Basin, Oligocene to Early Miocene (from Duerto 2007). Note the position of the wells.

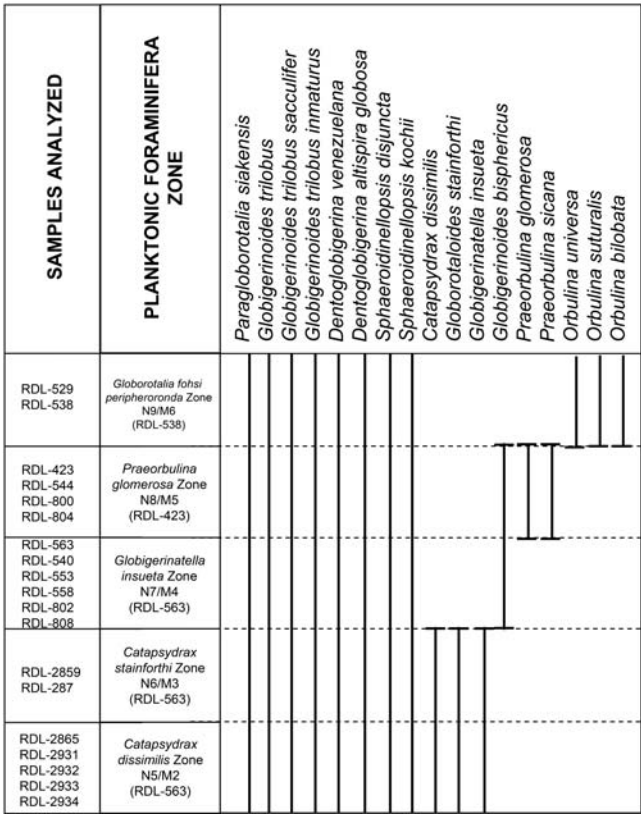


TEXT-FIGURE 5B

Paleogeographic reconstructions of the Eastern Venezuela Basin, Middle Miocene (from Duerto 2007). Note the position of the wells.



TEXT-FIGURE 6
Map of the Rio Oregano area showing approximate position of samples along the section. (see Table 1)



TEXT-FIGURE 7
Biostratigraphic ranges of selected planktonic foraminifera in the Cipero Formation, Trinidad.

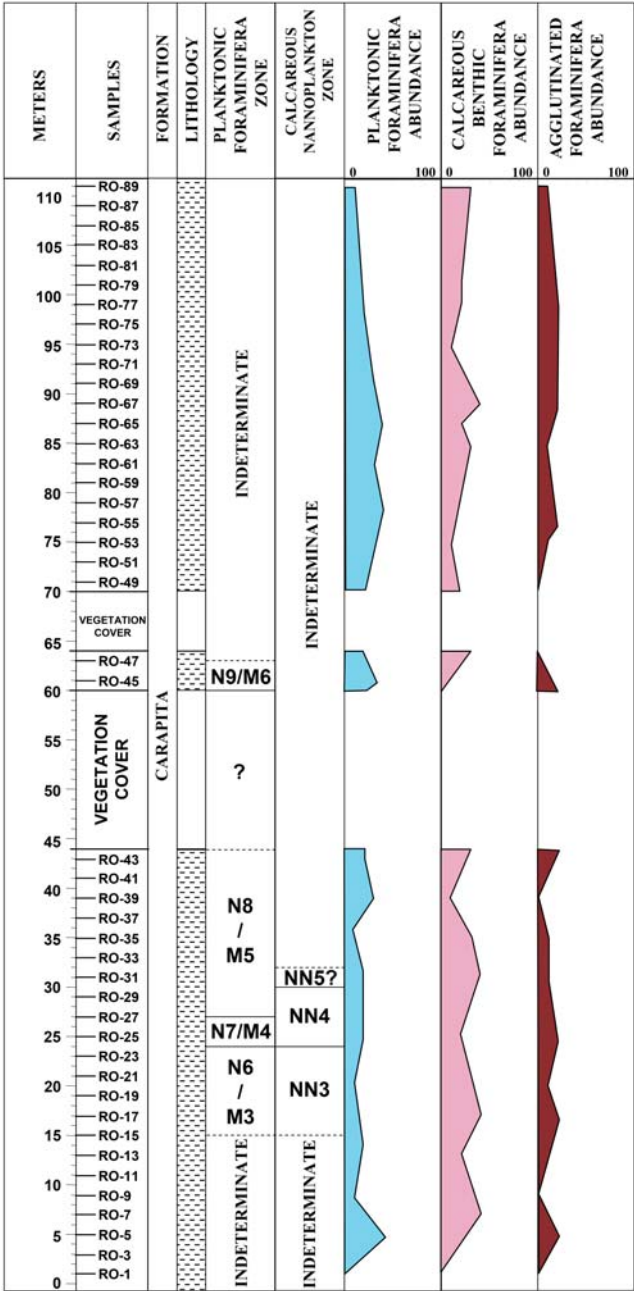
known to represent a deep-water (lower bathyal) facies (Stainforth 1948) and thus constitutes a reference against which to compare the assemblages from the Carapita Formation.

Literature survey

We used the bathymetric distributions inferred by Van Morkhoven et al. (1986) for calcareous benthic foraminifera and by Kaminski and Gradstein (2005) for agglutinated foraminifera. For taxa that were not considered in these two studies, we collected information from Hedberg (1937b), Cushman and Renz (1945), Renz (1948), Phleger and Parker (1951), Bandy (1967), Whittaker (1988), and Robertson (1988).

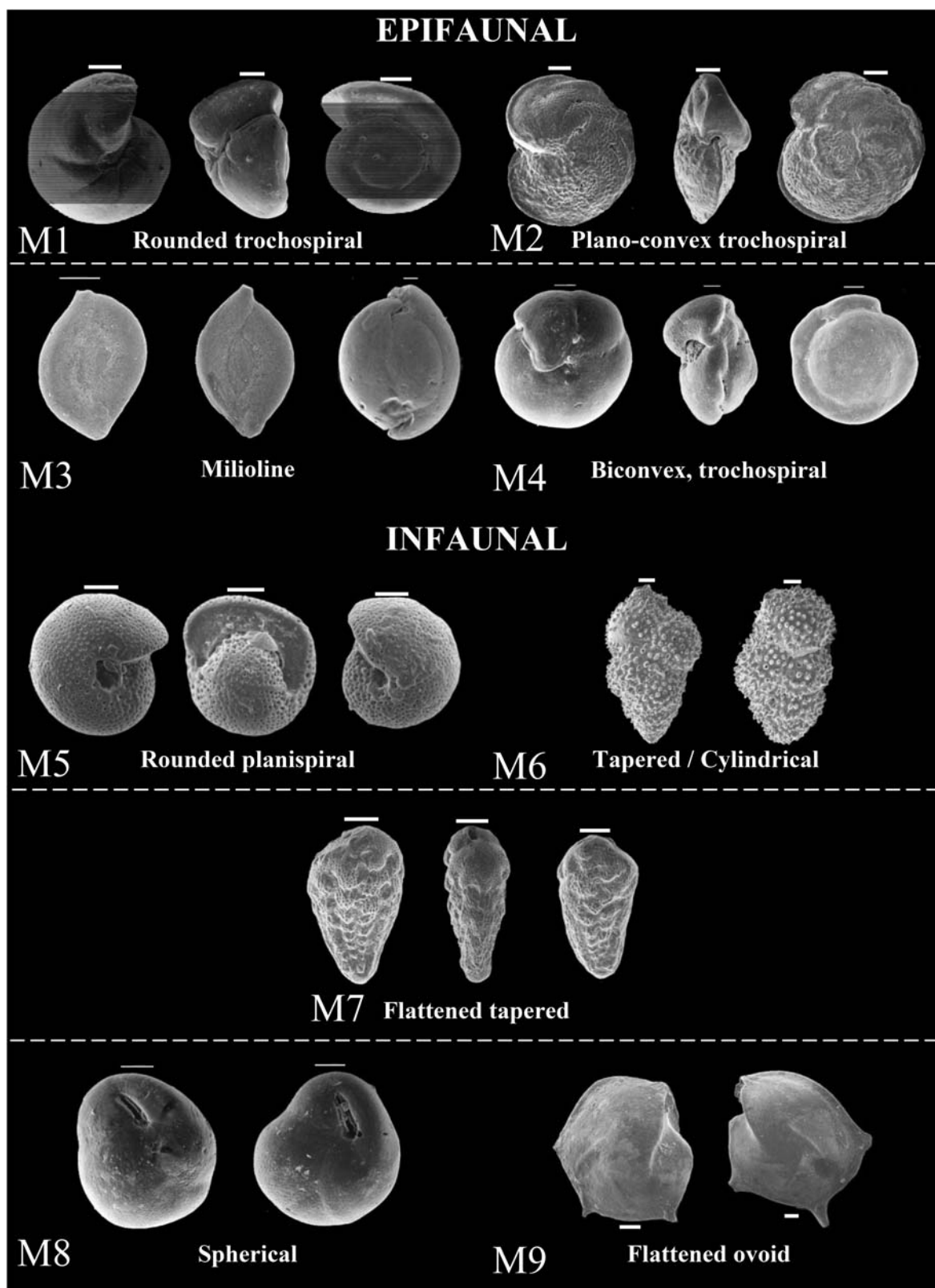
Morphotype analysis

Benthic foraminifera live both at the surface of sediments and in the sediments in which their distribution is stratified (Thiel 1975; Corliss 1985; Gooday 1986, Corliss and Emerson 1990). The shape and mode of coiling of the test and the distribution of pores on its surface (three characters that define morphotypes) were shown by Corliss and Chen (1988) to be indicative of the microhabitats in which benthic foraminifera live. These authors described four epifaunal and five infaunal morphotypes (Text-fig. 9), morphotypes that were related to water depth habitat by Corliss and Fois (1991) using the database of Recent benthic foraminifera in the Gulf of Mexico (Phleger 1951). These authors established that the percentages of different morphotypes are indicative of different depths (Table 3a, b).



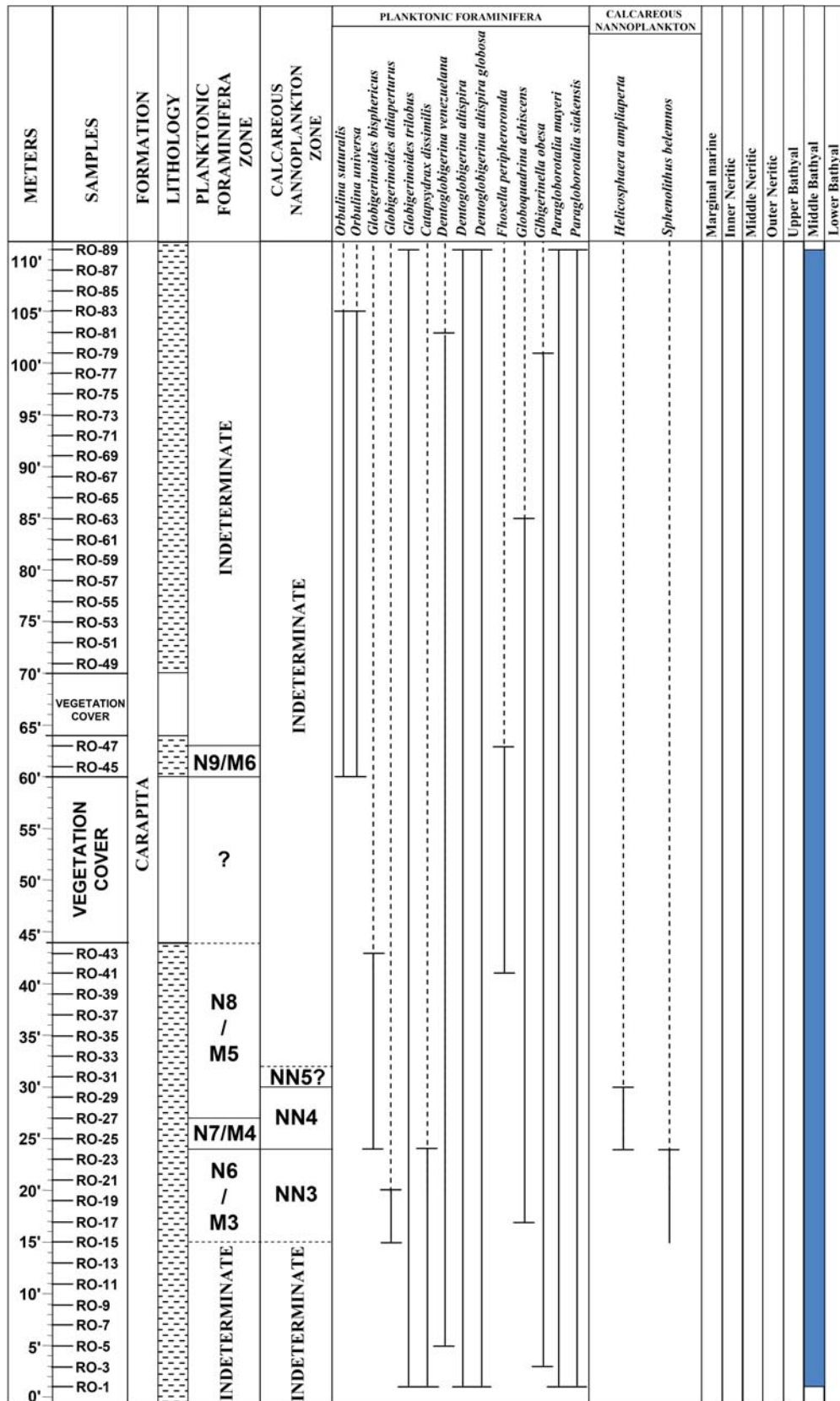
TEXT-FIGURE 8
Absolute abundance of foraminifera in 100 g-samples collected from the Carapita Formation in the Rio Oregano outcrop section. Although no samples were barren, note the low abundance of the planktonic foraminifera at all levels except at level 8m. Agglutinated foraminifera occur throughout the section but represent only a small percent of the benthic foraminifera.

Many of the species of benthic foraminifera encountered in the Carapita Formation are extant and occur in the Gulf of Mexico. This warrants our use of modern day bathymetric distribution of morphotypes to infer paleobathymetry during the early and middle Neogene in the southern Caribbean. Extinct taxa were assigned to a morphotype following the criteria delineated by Corliss and Chen (1988) (Table 3a, b). Our histograms of species composition show obvious differences between the two for-



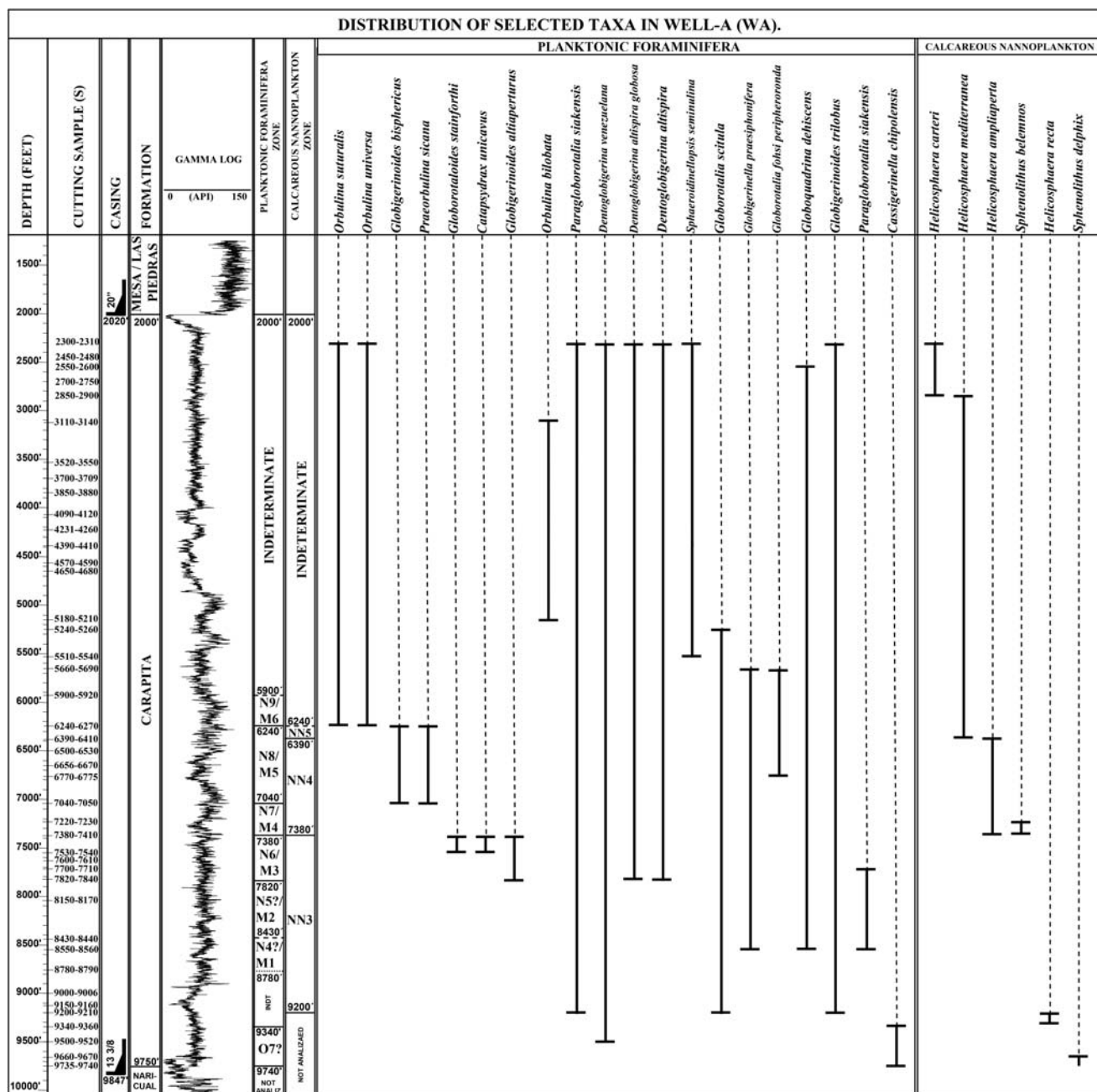
TEXT-FIGURE 9

Morphotypes recognized among the benthic foraminifera occurring in the Carapita and Ciperó Formations (the morphotypes are those described by Corliss and Chen 1988 and Corliss and Fois 1991). Epifaunal morphotypes have surface pores present only on one side of the test and the foraminifera live on or above the sediment. Infaunal morphotypes usually have pores on both sides of the test. Morphotypes are symbolized here by the following taxa: M1: *Gyroidinoides altiformis*; M2: *Planulina renzi*; M3: *Quinqueloculina seminula*; M4: *Neoeponides umbonatus*; M5: *Melonis pompilioides*; M6: *Uvigerina rugosa*; M7: *Bolivina impercata*; M8: *Globocassidulina subglobosa*; M9: *Lenticulina calcar*.



TEXT-FIGURE 10

Distribution of selected planktonic foraminiferal species in the Cipero Formation, Rio Oregano. Contacts between the Carapita Formation and the Naricual (below) and La Pica (above) Formations are not accesible in the field because of vegetation cover. Paleobathymetry is as follows: inner neritic: 0–30m; middle neritic: 30–100m; outer neritic: 100–200m; upper bathyal: 200–600m; middle bathyal: 600–1000m; lower bathyal: 1000–2000m.



TEXT-FIGURE 11

Distribution of selected planktonic foraminiferal (this work) and calcareous nannofossil (PDVSA Internal Report 2006) species in the Carapita Formation, Well A (WA).

mations considered here, and suggest significant differences in paleodepth.

RESULTS

Biostratigraphy

Rio Oregano section

Exceptionally, in order to facilitate comparison with the biostratigraphy of the wells, the biozonal contents of this land section is described in descending stratigraphic order.

Fourteen (14) species belonging to seven (7) genera of planktonic foraminifera have been recorded in the 111m thick Rio Oregano outcrop section (Text-fig. 10). Planktonic foraminifera indicative of Early Miocene to Early Pliocene ages occur throughout. These are *Globigerinella obesa*, *Paragloborotalia siakensis*, *Dentoglobigerina venezuelana*, *D. altispira*, *D. altispira globosa*, *Globoquadrina dehiscens* and *Globigerinoides trilobus*. *Globorotalia peripheroronda* occurs between 42 to 62m.

The biozonal age of the upper part of the section is indeterminate for lack of marker species. The youngest markers in the

section are the LOs of *Orbulina universa* and *O. suturalis* at 60m. These define the base of Zone N9/M6, which, because of the sampling gap between 60 and 44 m, is imprecisely positioned between these levels. The interval between 44 and 27 m, 27 and 25 m, and 25 to 15m are assigned to Zones N8/M5, N7/M4 and N6/M3, respectively.

Planktonic foraminifera exhibit poor to moderate preservation and their abundance is variable in Zone N8/M5. The LO of *Globigerinoides bisphericus* is recorded at 26m; on this basis the N7/N8 zonal boundary is placed between levels 26 and 25m (Text-fig. 10). The lower boundary of Zone N7/M4 is placed between 24 and 25m based on the HO of *Catapsydrax dissimilis* at 24m. The HO of the calcareous nannofossil *Sphenolithus belemnoides* is also located at 24 m, indicating that the NN3/NN4 zonal boundary occurs between samples 24 and 26m (O. Rodriguez, pers. communication, August 2010, and PDVSA Internal Report 2010). There is thus good agreement between planktonic foraminiferal and calcareous nannofossil biostratigraphy (Berggren, et al. 1995).

Well A (WA), Travi Oilfield

Twenty two (22) species belonging to twelve (12) genera of planktonic foraminifera were identified in WA (Text-fig. 11) between 2300 and 9740ft (~697m – ~2951.5m). Long ranging, Early Miocene to Early Pliocene planktonic foraminifera occur throughout this 7735ft (~2344m) thick section: *Globigerinella obesa*, *G. praesiphonifera*, *Paragloborotalia siakensis*, *Dentoglobigerina venezuelana*, *D. altispira*, *D. altispira globosa*, *Globorotalia scitula*, *Globoquadrina dehiscens*, and *Globigerinoides trilobus*. *Sphaeroidinellopsis seminulina* occurs between 2300 and 5510ft (~697m – ~1670m) only, and *Globorotalia peripheroronda* between 5660 and 6775ft (~1715m – ~2053m). Biozonal assignment of the Carapita Formation above 6,240ft (~1891m) is indeterminate. In general, planktonic foraminifera exhibit poor preservation and in some intervals tend to be internally pyritized (2450ft– 2900ft; ~742m – ~879) or glauconitic (4390ft – 4650ft; ~1330m – ~1409m). The HOs of *Orbulina universa* and *Orbulina suturalis* (Text-fig. 11) are located at 2300ft (~697m), and their LOs at 6240ft (~1891m). The lower boundary of Zone N9/M6 is thus placed between 6240ft and 6390ft (~1891m – ~1936m). This is well supported by the HO of (calcareous nannofossil) *Helicosphaera ampliapertura* at 6390ft (~1936m), the LAD of this taxon being very close to the FADs of *Orbulina universa* and *Orbulina suturalis* (see Berggren et al. 1995).

The formation is divided into five biozones below 6240ft (~1891m), from lower Middle Miocene Zone N8/M5 between 6240ft and 7040ft (~1891m – ~2133m) to Lower Miocene Zone N6/M3(?) between 7380ft and 7820ft (~2236m – ~2370m), Zone N5/M2 between 7820ft and 8430ft (~2370m – ~2554.5m) and (questionable) Upper Oligocene Zone O7 between 9340ft and 9740ft (~2830m – 2951.5). Abundance and preservation of planktonic foraminifera vary from poor to moderate in Zone N8/M5. The HOs of *Globigerinoides bisphericus* and *Praeorbulina sicana* are at 6390ft (~1936m), their LOs at 7040ft (~2133m). The lower boundary of Zone N8/N7 is thus placed between 7040 and 7220ft (~2133 – ~2178m). The HO of *Globorotaloides stainforthi* at 7380ft (~2236m) indicates the lower boundary of Zone N7/M4 (Text-fig. 11). Calcareous nannofossil data in this interval are very poor and indicative of a broad Early to Middle Miocene age (PDVSA Internal Report 2006). Poor preservation and few planktonic foraminifera char-

acterize the N6/M3 zonal interval. The HO of *Globigerinoides ampliapertura* is at 7380ft (~2236m) and its LO at 7820ft (~2370m). The lower boundary of Zone N6/N3 is between 7820 and 8150ft (~2370m – ~2470m; Text-fig. 11).

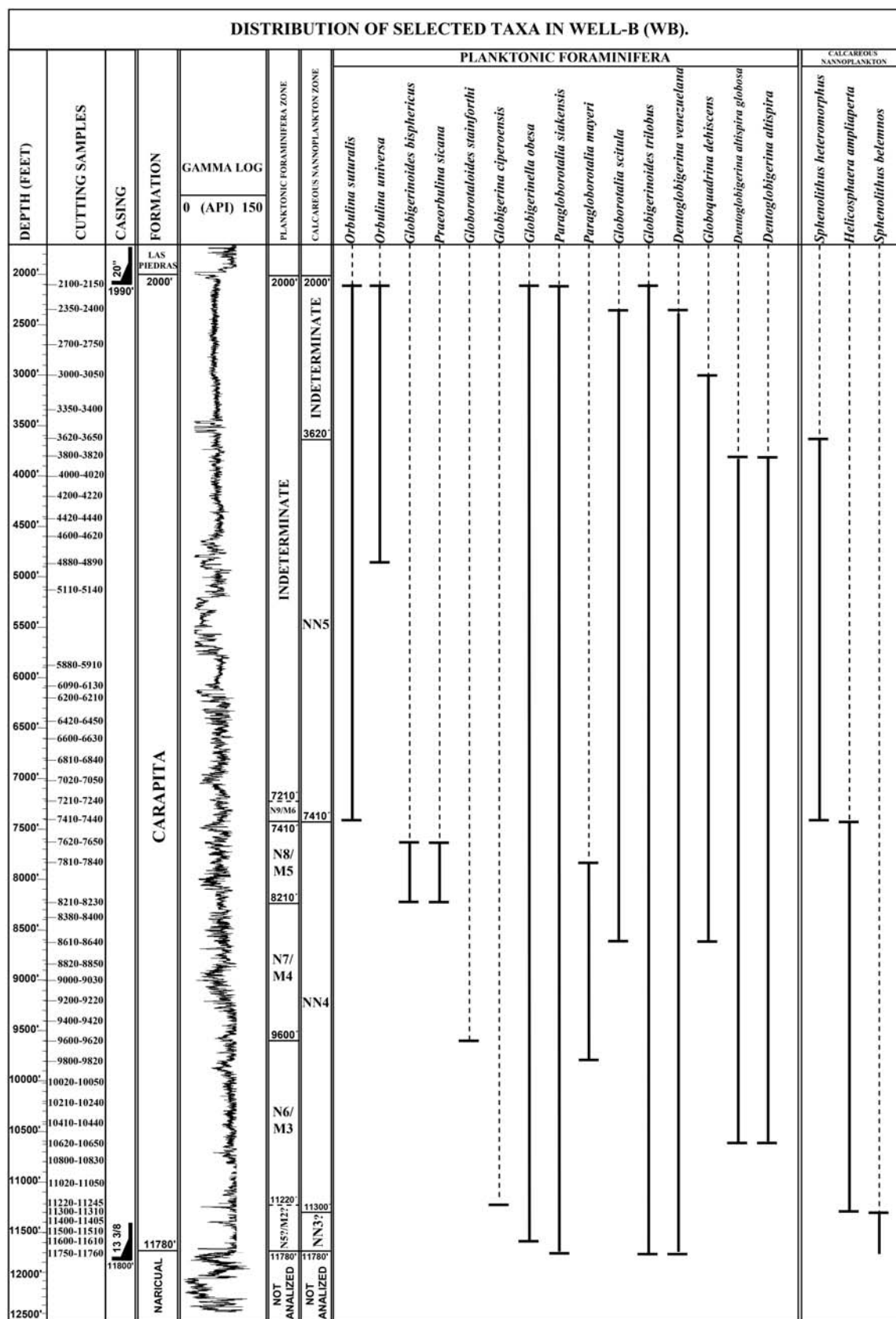
Planktonic foraminiferal assemblages are poor to moderate with low abundance and diversity in the N5/M2 zonal interval. The occurrences of *Cassigerinella chipolensis* between 9340 to 9740ft (~2830m – ~2951.5m) and *Sphenolithus delphix* at 9740ft (2951.5m) indicates that this interval is Upper Oligocene. *Cassigerinella chipolensis* was used as a datum event (FAD at 33.65 Ma) by Berggren et al (1995). Only the calcareous nannofossil *Helicosphaera recta* (Upper Oligocene to Lowermost Miocene) was reported from the interval 9200ft to 9210ft (~2788 – 2791m) (PDVSA Internal Report 2006).

Well B (WB), Orocuai Oilfield

Fourteen (14) species of nine (9) genera of planktonic foraminifera were identified (Text-fig. 12). Three (3) species of calcareous nannofossils were reported (PDVSA Internal Report 2006). Planktonic foraminifera indicative of Lower Miocene to Lower Pliocene occur between 2100 to 11310ft (~636m – ~3427m). These are *Globigerinella obesa*, *Paragloborotalia siakensis*, *Dentoglobigerina venezuelana*, *D. altispira*, *D. altispira globosa*, *Globoquadrina dehiscens* and *Globigerinoides trilobus* (Text-Fig. 12). *Globorotalia scitula* only occurs between 2350 to 8640ft (~712m – ~2618m).

No biozonal assignment is possible for the interval between 2100ft and 7410ft (~636m – ~2245m) in which planktonic foraminifera show poor preservation. The HOs of *Orbulina universa* and *Orbulina suturalis* are located at 2100ft (~636m); the LO of *O. universa* is at 7410ft (~2245m), that of *O. suturalis* at 4890ft (~1481m). The lower boundary of Zone N9/M6 is thus placed between 7410ft and 7620ft (~2245m – ~2309m). The HO of the calcareous nannofossil *Helicosphaera ampliapertura* is at 7410ft (~2245m) implying that the NN4/NN5 zonal boundary occurs between 7410 and 7610ft (~2245m – ~2307m; PDVSA Internal Report 2008), which supports our biozonal determination (see well WA, above).

The interval between 7620 and 11220ft (~2309m – ~3427m) belongs to three biozones, from lower Middle Miocene Zone N8/M5 between 7410ft and 8210ft (~2245m to ~2489m), Lower Miocene Zone N7/M4 (8210ft – 9600ft; ~2489m to ~2909m), to undifferentiated Zones N6/M3 to N5/M2 (9600ft to 11310ft; ~2909m to ~3427m). The preservation of planktonic foraminifera is poor to moderate and their abundance is variable in the N8/M5 zonal interval. The HOs of *Globigerinoides bisphericus* and *Praeorbulina sicana* are located at 7620ft (~2309m), and their LOs at 8210ft (~2489m; Text-fig. 12). The lower boundary of Zone N8/N7 is thus placed between 8210ft and 8380ft (~2489m – ~2539m). The HO of *Globorotaloides stainforthi* at 9600ft (~2909m) implies that the lower boundary of Zone N7/M4 occurs between 9600ft and 9800ft (~2909m – ~2967m; Text-fig. 12). Calcareous nannofossil data for this interval are very poor and indicative of an Early to Middle Miocene age (PDVSA Internal Report 2006). Poor to moderate preservation and low abundance of planktonic foraminifera characterize the N6/M3 zonal interval. The HO of (calcareous nannofossil) *Sphenolithus belemnoides* is at 11310ft (~3427m) implying that the NN3/NN4 zonal boundary occurs between 11310ft and 11400ft (~3427m and ~3454.5m) (see Berggren et al. 1995).

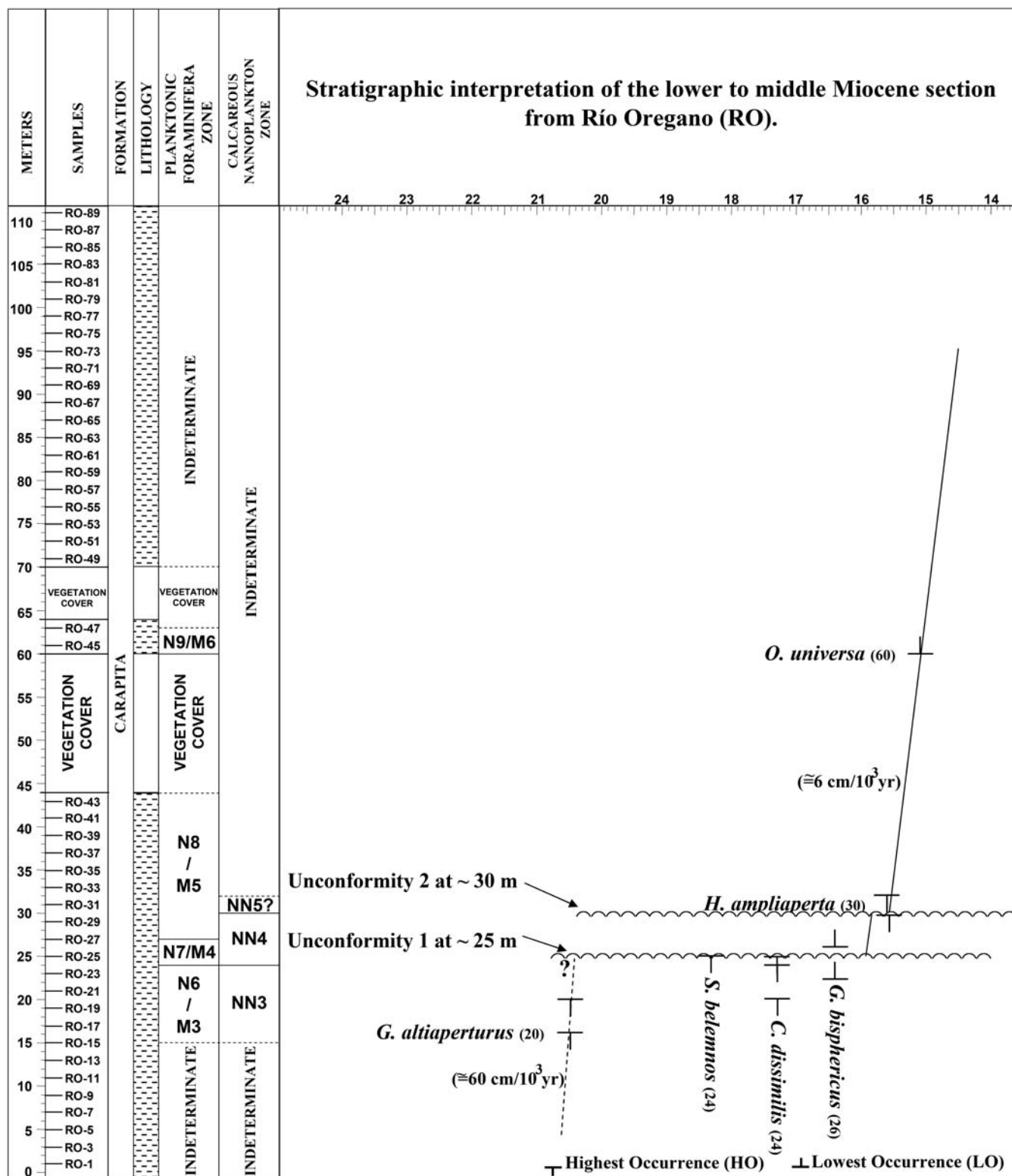


TEXT-FIGURE 12
Distribution of selected planktonic foraminifera (this work) and calcareous nannofossil (PDVSA Internal Report 2008) species in the Carapita Formation, Well B (WB).



Nine (9) genera and fifteen (15) species of planktonic foraminifera were identified in WC (Text-fig. 13). Long ranging, Early Miocene to Early Pliocene planktonic foraminifera occur in WC between 4380ft and 9200ft (~1327m – ~2788m), such as *Paragloborotalia siakensis*, *Dentoglobigerina venezuelana*, *Globorotalia scitula*, and *Globigerinoides trilobus*.

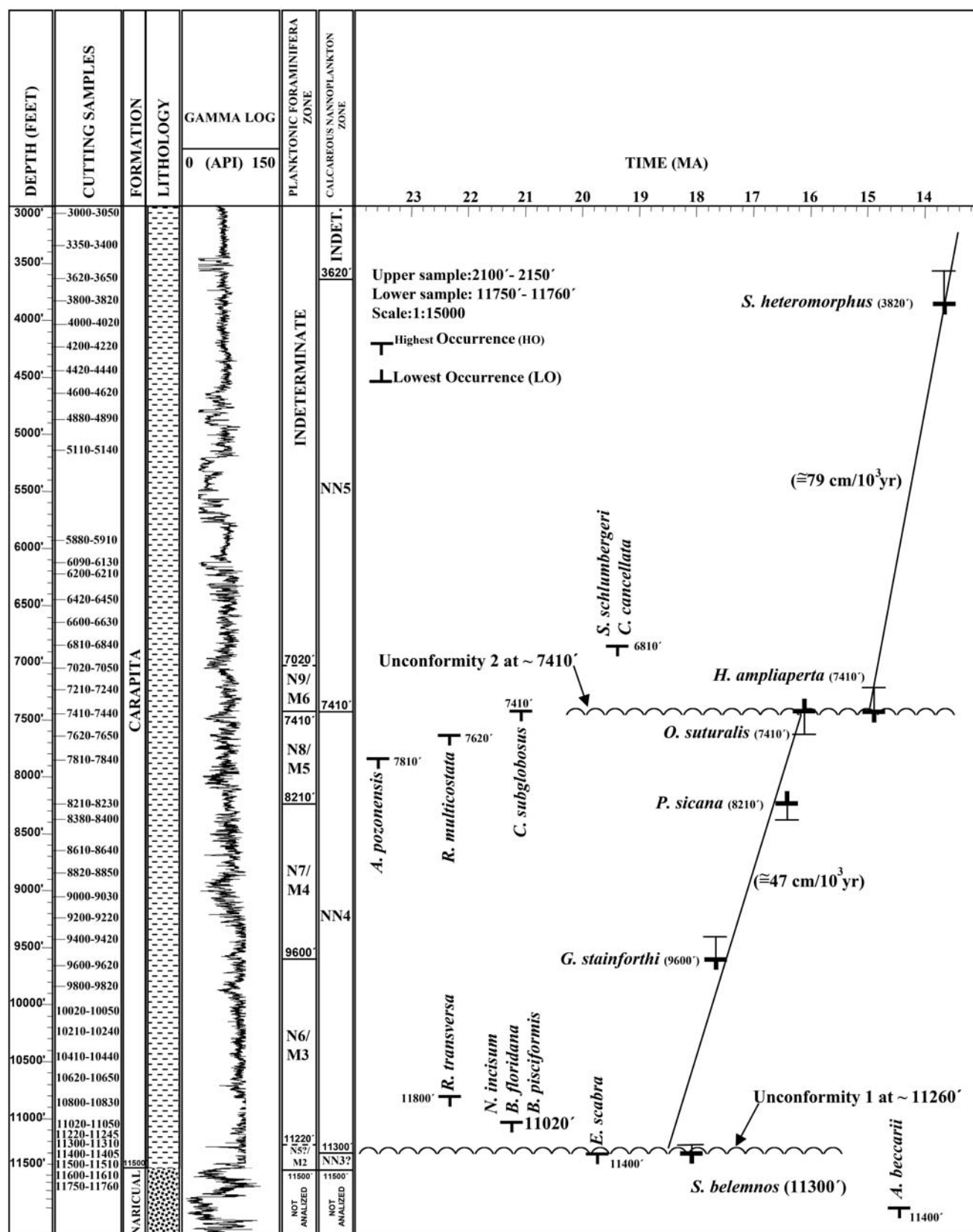
No biozonal assignment is possible for the upper part (4380ft to 7850ft; ~1327m to ~2388m) of the 6490ft (~1967m) thick section through the Carapita Formation. The HOs of *Orbulina*



TEXT-FIGURE 14

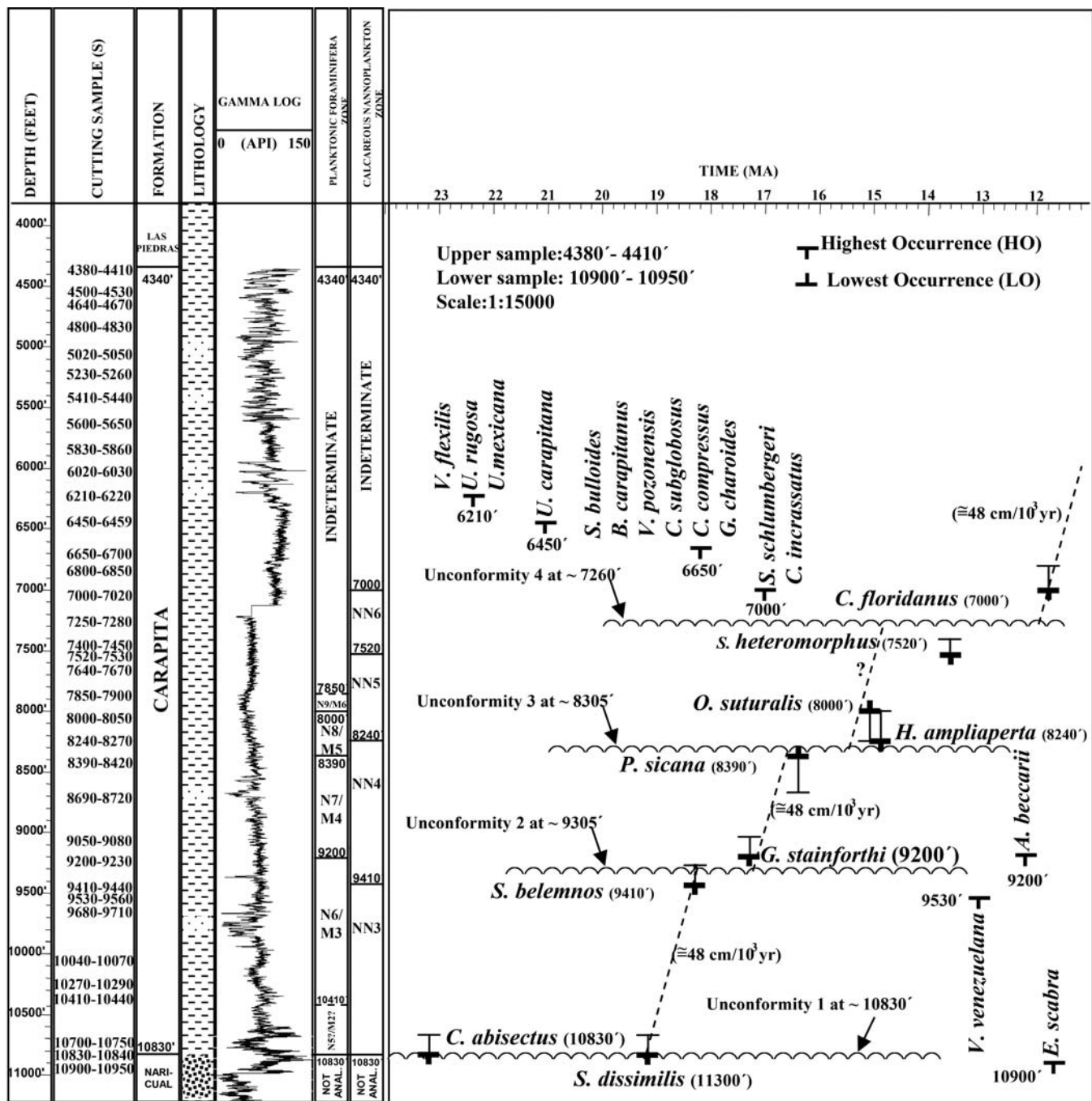
Stratigraphic interpretation of the Carapita Formation, Río Oregano outcrop section. See Text-fig. 21 for the stratigraphic ranges of benthic foraminifera.





TEXT-FIGURE 16

Stratigraphic interpretation of the Carapita Formation, Well B (WB), Orocuai Oilfield. See Text-fig. 23 for the stratigraphic ranges of benthic foraminifera.



TEXT-FIGURE 17

Stratigraphic interpretation of the Carapita Formation, Well C (WC), Tropical Oilfield. See Text-fig. 24 for the stratigraphic ranges of benthic foraminifera.

universa and *O. suturalis* are located at 5020ft (~1521m), and the LO of *O. universa* at 8000ft (~2424m). The lower boundary of Zone N9/M6 is thus placed between 8000ft and 8390ft (~2424m - ~2542m). Based on the HO of (calcareous nanno-fossil) *Helicosphaera ampliapertura* at 8240ft (~2497m), the NN4/NN5 zonal boundary occurs between 8000 and 8240ft (~2424m - ~2497m), supporting the biozonal determination based on planktonic foraminifera (see above).

The interval between 8000 and 9200ft (~2424 - ~2788m) in the well is assigned to lower Middle Miocene Zone N8/M5 (8000 - 8390ft; ~2424 - ~2542m), Lower Miocene Zone N7/M4 (8390ft - 9200ft, ~2542m - ~2788m) and Zone N6/M3? - N5/M2? (9200ft - 10410ft, ~2788m - ~3154.5m). Abundance and preservation of planktonic foraminifera vary from poor to moderate in the N8/M5 zonal interval. The HOs of *Globigerinoides bisphericus* and *Praeorbulina sicana* are located at 8000ft (~2424m), and their LOs are at 8390ft

SPECIES		BATHYMETRY						
		NERITIC			BATHYAL			ABYSSAL
		INNER	MIDDLE	OUTER	UPPER	MIDDLE	LOWER	UPPER
		30	100	200	600	1000	2000	3000
1	<i>Bolivina floridana</i>							
2	<i>Bolivina pisciformis</i>							
3	<i>Buliminella elegans</i>							
4	<i>Bulimina inflata</i>							
5	<i>Bulimina macilenta</i>							
6	<i>Bulimina pupoides</i>							
7	<i>Chilostomella ovoidea</i>							
8	<i>Cibicidoides alazanensis</i>							
9	<i>Cibicidoides compressus</i>							
10	<i>Cibicidoides crebbsi</i>							
11	<i>Cibicidoides incrassatus</i>							
12	* <i>Cyclammina cancellata</i>							
13	* <i>Dorothia brevis</i>							
14	<i>Globocassidulina subglobosa</i>							
15	<i>Guttulina irregularis</i>							
16	<i>Guttulina jarvisi</i>							
17	<i>Hanzawaia ammophila</i>							
18	<i>Hanzawaia mantaensis</i>							
19	<i>Laticarinina pauperata</i>							
20	<i>Lenticulina calcar</i>							
21	<i>Melonis pompilioides</i>							
22	<i>Planulina renzi</i>							
23	<i>Rectuvigerina multicostata</i>							
24	<i>Rectuvigerina striata</i>							
25	<i>Rectuvigerina transversa</i>							
26	<i>Siphonina pozonensis</i>							
27	<i>Sphaeroidina bulloides</i>							
28	<i>Uvigerina carapitana</i>							
29	<i>Uvigerina mexicana</i>							
30	<i>Uvigerina rugosa</i>							

TEXT-FIGURE 18

Bathymetric distribution of the benthic foraminiferal species occurring in both the Cipero and the Carapita Formations. (Bathymetry according to Van Morkhoven et al. 1986). *Agglutinated benthic foraminifera.

(~2542m). The lower boundary of Zone N8/N7 is thus placed between 8390ft and 8690ft (~2542m – ~2633m). The HO of *Globorotaloides stainforthi* at 9200ft (~2788m) characterizes the lower boundary of Zone N7/M4 between 9050ft and 9200ft (~2742m – ~2788m). Based on the HO of *Sphenolithus belemnoides* at 9410ft (~2851.5m) the NN3/NN4 zonal boundary occurs between 9210ft and 9410ft (~2791m – ~2851.5m) (Text-fig. 13), supporting as in other wells the delineation of the base of Zone N7/M4. Planktonic foraminifera are poorly to moderately preserved in the lower part of the formation. Based on the HO of *Globigerina ciperoensis* at 10410ft (~3154.5m)

the lower boundary of Zone N6/N5 is placed between 10270ft and 10410ft (3112m – ~3154.5m).

Temporal interpretations of sections

Rio Oregano section

An unconformity is clearly present at ~25m as shown by the juxtaposed HOs at 24m of *S. belemnoides* (LAD at 18.1 Ma) and *C. dissimilis* (LAD at 17.62 Ma) and the LO of *G. bisphericus* (FAD at 16.4 Ma) at 26m. The NN3/NN4 and N6/M3-N7/M4 zonal contacts are thus unconformable (Text-fig. 14). The ages

SPECIES	BATHYMETRY						
	NERITIC			BATHYAL			ABYSSAL
	INNER	MIDDLE	OUTER	UPPER	MIDDLE	LOWER	UPPER
	30	100	200	600	1000	2000	3000
1 <i>Anomalinoides globulosus</i>							
2 <i>Anomalinoides pompilioides</i>							
3 <i>Buchnerina trinitatis</i>							
4 <i>Cibicidoides havanensis</i>							
5 <i>*Eggerella bradyi</i>							
6 <i>Lenticulina adelinensis</i>							
7 <i>Lenticulina occidentalis</i>							
8 <i>Neoeponides umbonatus</i>							
9 <i>*Conglophragmium irregularis</i>							

TEXT-FIGURE 19

Bathymetric distribution of the benthic foraminiferal species occurring in the Cipero Formation and not in the Carapita Formation. (Bathymetry according to Van Morkhoven et al. 1986). *Agglutinated benthic foraminifera.

of the surfaces of the unconformity cannot be determined precisely in the absence of a sufficient number of biostratigraphic events to constrain them through sedimentation rates. The lower surface is >18.1 Ma but younger than 20.5 Ma (LAD *G. alitiaperturus*); the upper surface is <16.4 Ma (FAD *G. bisphericus*) but >14.87 Ma (LAD *H. ampliaperta*). We tentatively date the lower surface at 19 Ma and the upper surface at 16 Ma.

The absence of overlap between the upper range of *H. ampliaperta* (LAD 14.87 Ma) and the lower range of *O. universa* (FAD 15.10 Ma) implies the occurrence of an unconformity at ~30m. The lower surface is >15.10 Ma and <16.4 Ma (FAD *G. bisphericus*). The upper surface is <14.87 Ma but we have no means of determining a minimum date for it. We tentatively date the lower surface at 15.20 Ma, and arbitrarily date the upper surface at 13 Ma. This is not an entirely arbitrary determination. The cosmopolitan, solution resistant species *Sphenolithus heteromorphus* (LAD 13.49 Ma) was recovered in WB. We take its absence from the section as indicating that Zone NN5 is part of the stratigraphic gap at ~30m.

Well A (WA), Travi Oilfield

The sedimentary interval between 7380ft (~2237m) and 9200ft (~2788m) is very difficult to interpret in the absence of planktonic foraminiferal markers. The HO of the Oligocene-lowermost Miocene species *H. recta* (9200ft; ~2788m) is anomalously correlative with the base of Zone NN3 at 9200ft (~2788m). This and the juxtaposed HO of four species of benthic foraminifera at 9160ft (~2776m) (Text-fig. 15) suggest the occurrence of an unconformity between 9160ft and 9200ft (~2776m – 2788m). It is tentatively placed at 9160ft (~2776m). The hiatus is very difficult to determine. The lower surface is estimated at 23 Ma, based on the occurrence of *S. delphix* at 9660'–9670' (2927 m–2930m) (Text-fig. 11). The range of this species slightly predates the Oligocene/Miocene boundary (Shackleton et al. 2000). The upper surface is estimated at 19.5 Ma, based on the FAD of *S. belemnus* at ~19.3 Ma.

An intra Lower Miocene unconformity is inferred at level ~7380ft (~2236m) marked by the juxtaposed HO of *G. alitiaperturus* (LAD at 20.5 Ma), *G. stainforthi* (LAD at 17.62 Ma) and LO of *S. belemnus* (FAD at 18.1 Ma). The NN3/NN4 and N6/M3–N7/M4 zonal contacts are thus unconformable (Text-fig. 15). The lower surface of the unconformity is >20.5 Ma. It is arbitrarily estimated at 21 Ma. The upper surface of the unconformity is >17.62 Ma. It is estimated at 18.1 Ma.

In continuous sections an overlap occurs between the upper range of *H. ampliaperta* and the lower range of *O. suturalis*. The absence of such an overlap in Well A suggests that an unconformity between 6398ft and 6240ft truncates the ranges of the two species (as in the Oregano section). The unconformity is arbitrarily placed at 6315ft (1914m). The hiatus >230 kyr, is extremely difficult to determine. The lower surface of the unconformity is >15.10 and <16.4 Ma (FAD *P. sicana*). The upper surface is <14.74 Ma but, as in the Oregano section there is no means to constrain a minimum date. The lower surface is estimated at 15.3 Ma and the upper surface is estimated at 13 Ma based on the same logic as for the Rio Oregano.

Well B (WB), Orocual Oilfield

A Lower Miocene unconformity is inferred at ~11260ft (~3412m) from the correlation of the NN3/NN4 and M2/M3 zonal boundaries (Text-fig. 16). The hiatus is difficult to determine. The upper surface of the unconformity may be estimated at 18.6 Ma through extrapolation of a sedimentation rate of ~47cm/10³ yr calculated between the HO/LAD of *G. stainforthii* at 9600m (2909m) and the LO/FAD of *P. sicana* at 8210ft (~2489m). We recognize that this date is somewhat problematic because a surface at 18.6 Ma would be located in Zone NN3. We therefore adjust the position of the surface at 18.2 Ma. The lower surface, in Zone M2 is difficult to position. It is estimated at 19 Ma based on the occurrence of *S. belemnus* at 11310' (3427m).

A younger unconformity at 7410ft (~2245m) is inferred from the juxtaposition at this level of LO of *O. suturalis* (FAD at 15.1

SPECIES		BATHYMETRY						
		NERITIC			BATHYAL			ABYSSAL
		INNER	MIDDLE	OUTER	UPPER	MIDDLE	LOWER	UPPER
		30	100	200	600	1000	2000	3000
1	<i>*Alveovalvulinella pozonensis</i>							
2	<i>*Bathysiphon carapitanus</i>							
3	<i>Cassidulina carapitana</i>							
4	<i>*Eggerella scabra</i>							
5	<i>Fronicularia sagitula</i>							
6	<i>*Gaudryina bullbrookii</i>							
7	<i>*Glomospira charoides</i>							
8	<i>Gyroidinoides altiformis</i>							
9	<i>Gyroidinoides soldanii</i>							
10	<i>Lenticulina hedbergi</i>							
11	<i>Lenticulina subpappiliosus</i>							
12	<i>Marginulinopsis basispinosus</i>							
13	<i>Neoeponides campester</i>							
14	<i>Neoeponides parantillarum</i>							
15	<i>Nonion costiferum</i>							
16	<i>Nonion incisum</i>							
17	<i>Planorbulinella trinitatis</i>							
18	<i>Planularia venezuelana</i>							
19	<i>Pseudoglandulina comatula</i>							
20	<i>Pseudoglandulina gallowayi</i>							
21	<i>Pseudoglandulina incisa</i>							
22	<i>Pseudoglandulina laevigata</i>							
23	<i>Saracenaria italica</i>							
24	<i>Saracenaria senni</i>							
25	<i>Sigmoilopsis schlumbergeri</i>							
26	<i>*Textularia tatumii</i>							
27	<i>Vaginulinopsis superbus</i>							
28	<i>*Valvulina flexilis</i>							
29	<i>*Valvulina jarvisi</i>							
30	<i>*Valvulina spinosa</i>							

TEXT-FIGURE 20

Bathymetric distribution of the benthic foraminiferal species occurring in the Carapita Formation and not in the Cipero Formation. (Bathymetry according to Van Morkhoven et al. 1986); *Agglutinated benthic foraminifera.

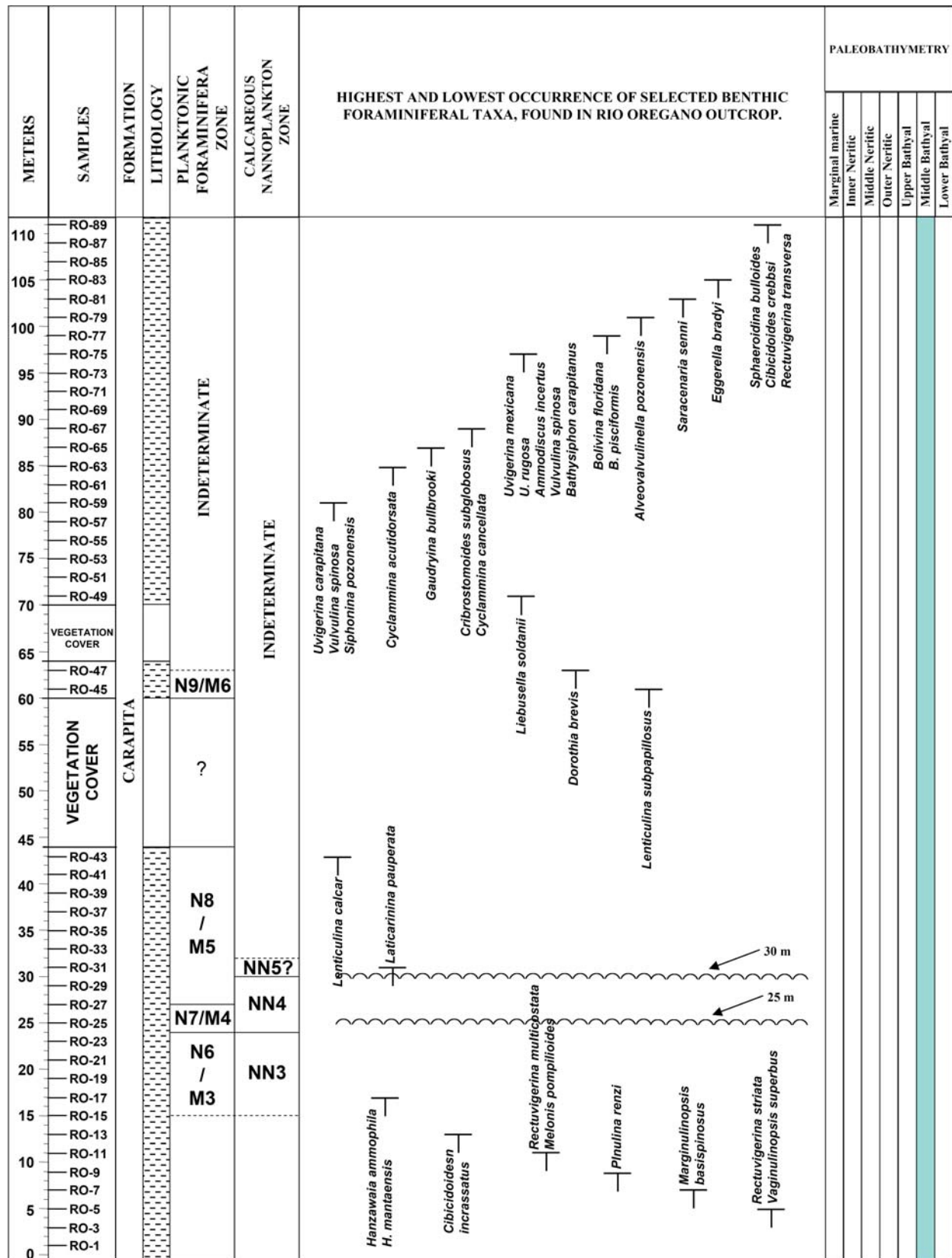
Ma) and the HO of *H. ampliapertura* (LAD at 14.87 Ma). The NN4/NN5 and N8/M5-N9/M6 zonal contacts are thus unconformable. The lower surface of the unconformity is estimated at 15.9 Ma (applying a sedimentation rate of 47cm/10³ yr). The upper surface is <14.87 Ma and > LAD *S. heteromorphus* (13.6 Ma). It is tentatively estimated as 14.5 Ma.

Well C (WC), Tropical Oilfield

An intra-lower Miocene unconformity is inferred at level ~10830ft (~3282m). It is marked by the juxtaposition of the HOs of *C. abisectus* (with LAD approximately at the

Oligocene/Miocene boundary, ~ 23 Ma) and *S. dissimilis* (with LAD in mid-NN2, ~ 2 Myr younger, although not calibrated to magnetostratigraphy). The stratigraphic gap encompasses Zones M1/N4, NN1 and almost entirely M2/N5 and NN2 (Text-fig. 17). The lower surface of the unconformity is tentatively estimated at 23.5 Ma. Its upper surface is tentatively estimated at 19.5 Ma.

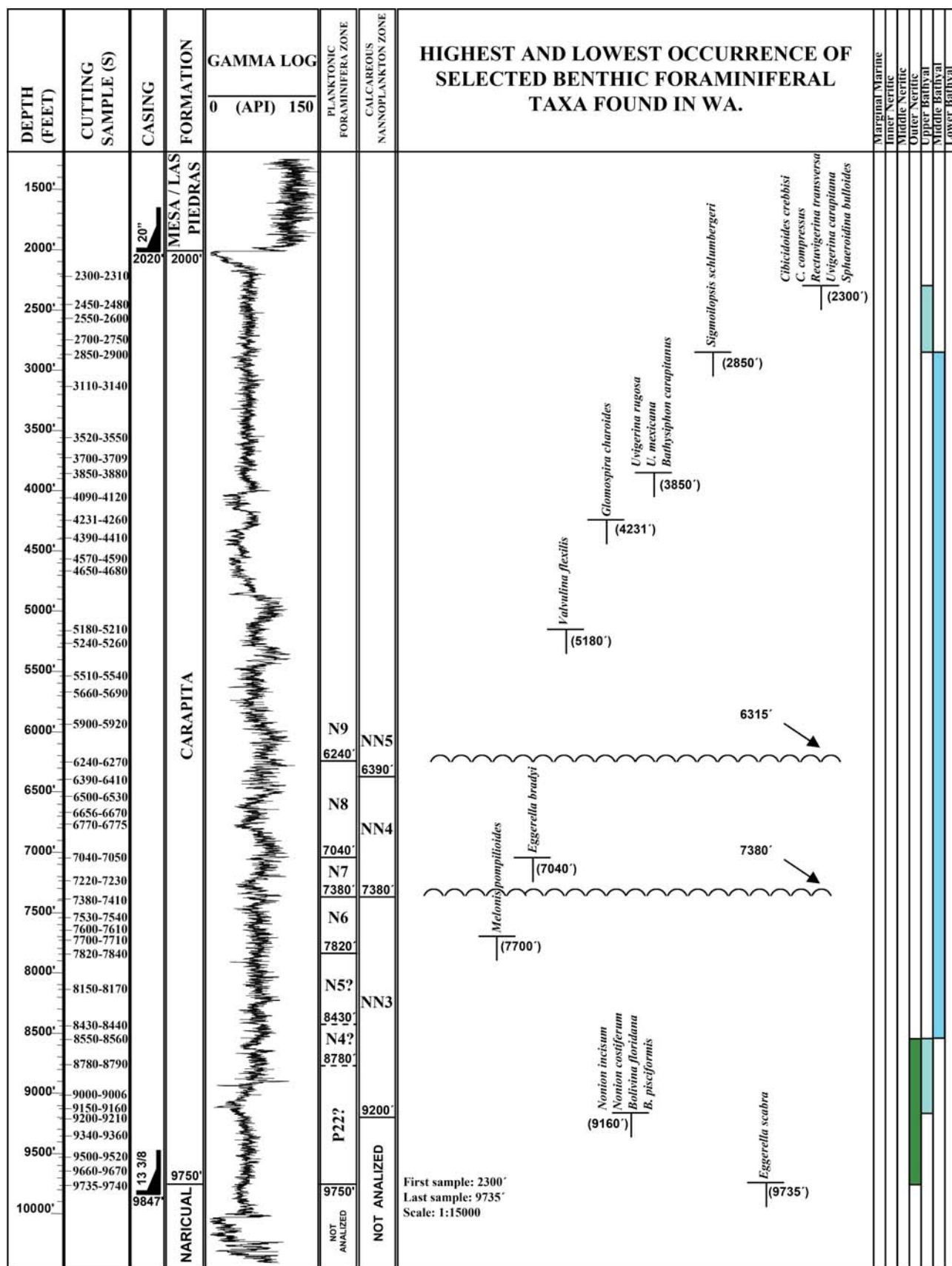
An unconformity is inferred at ~9305ft (~2820m) based on the HOs of *S. belemnoides* (9410ft, ~2851.5m; LAD at 18.1 Ma) and *G. stainforthi* (9200ft, ~2788m; LAD at 17.3 Ma). The strati-



TEXT-FIGURE 21

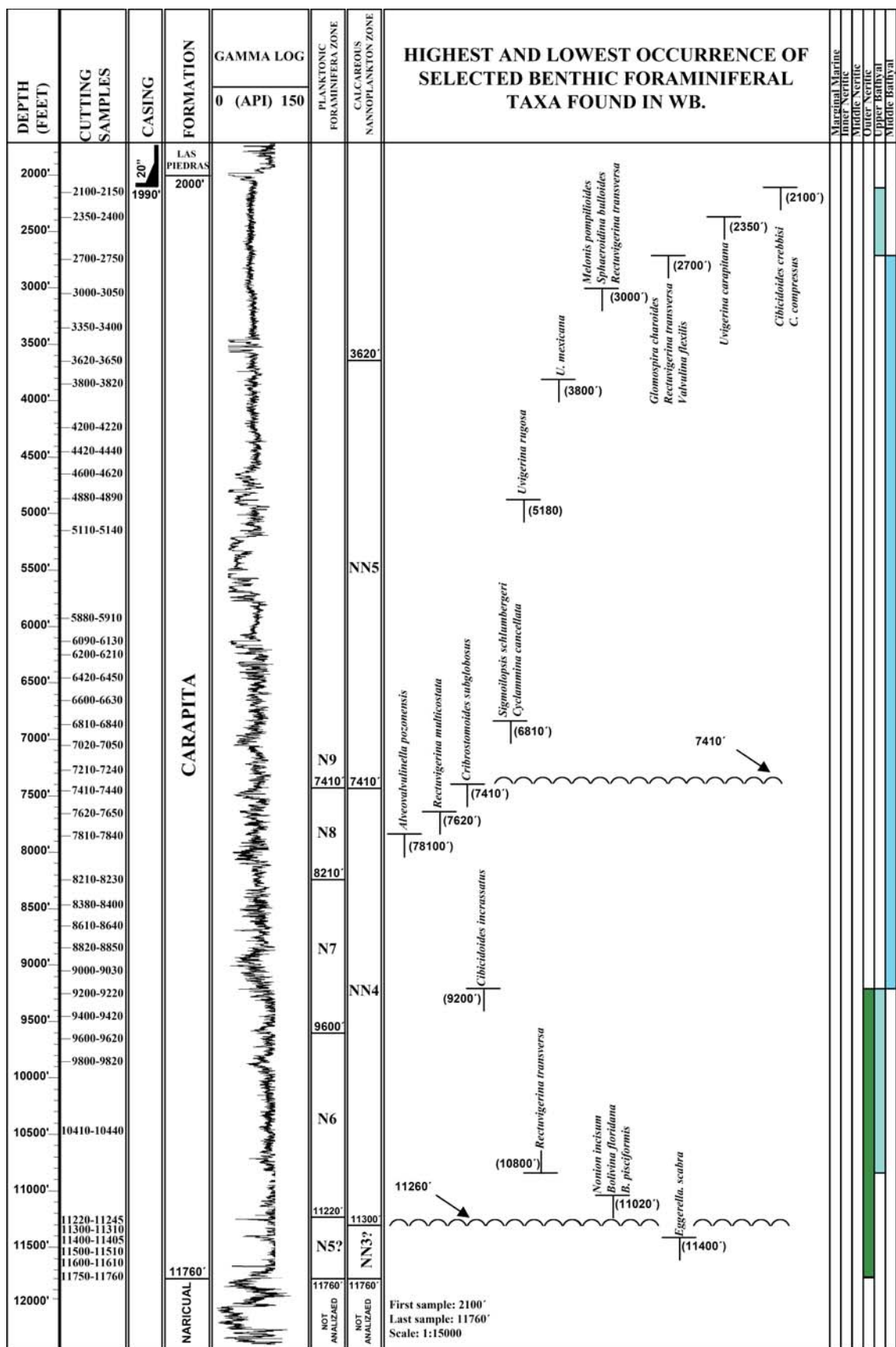
Highest and lowest occurrences of selected benthic foraminifera species recovered from the Rio Oregano outcrop section.

Paleobathymetry is as follows (as in text-figs. 22-24): inner neritic: 0-30 m; middle neritic: 30-100 m; outer neritic: 100-200 m; upper bathyal: 200-600 m; middle bathyal: 600-1000 m; lower bathyal: 1000-2000m.

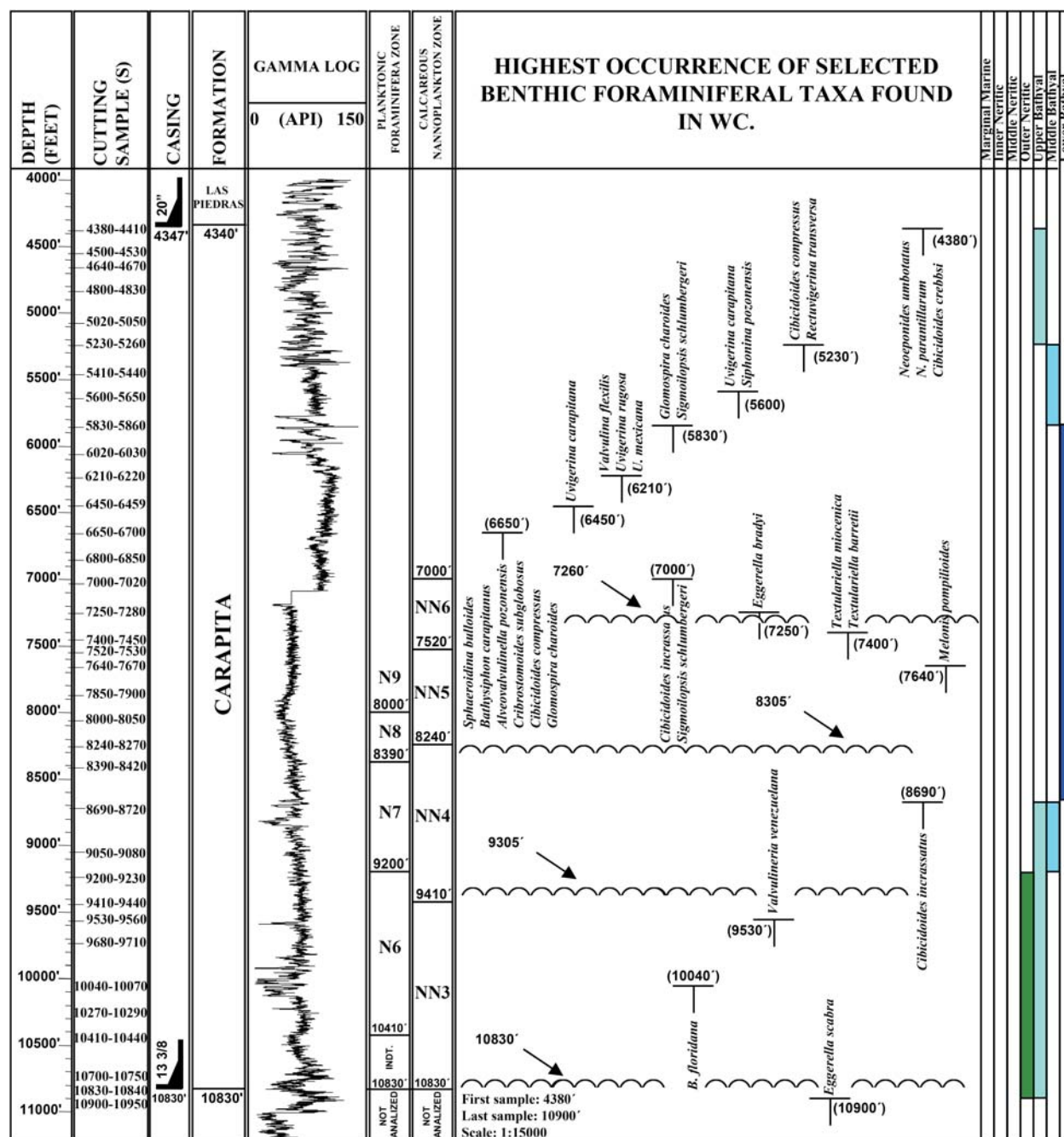


TEXT-FIGURE 22

Highest and lowest occurrences of selected benthic foraminifera species recovered from Well A.



TEXT-FIGURE 23
Highest and lowest occurrences of selected benthic foraminifera species recovered in Well B.



TEXT-FIGURE 24

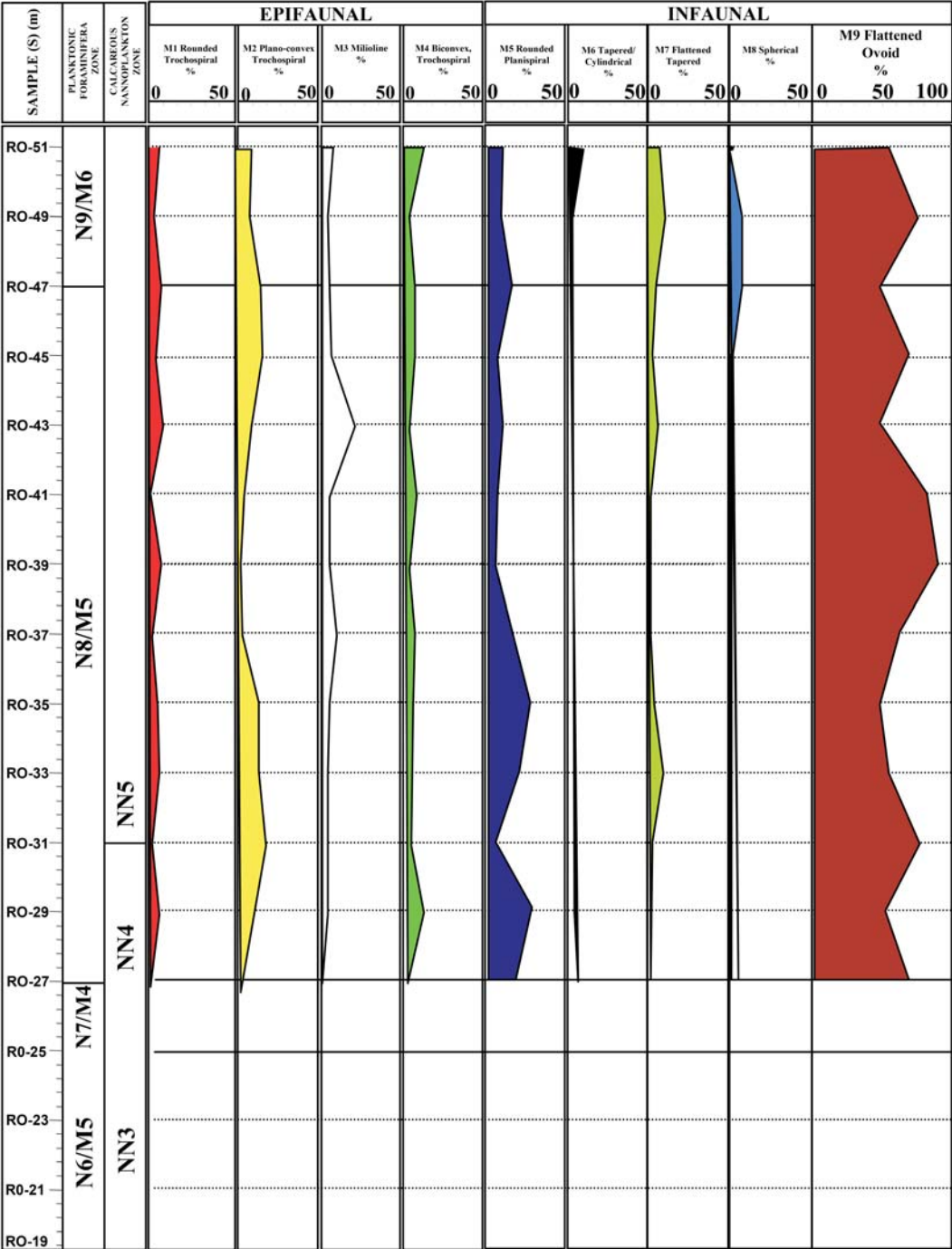
Highest and lowest occurrences of selected benthic foraminifera species recovered in Well C.

graphic gap encompasses the lowermost part of Zone NN4 and M3/N6 and the uppermost part of Zone M2/N5. The hiatus is at least 0.8 Myr. The lower surface of the unconformity is > 18.1 Ma; the upper surface is >17.62 Ma. Without sufficient means to constrain it, we estimate the lower surface of the unconformity at 18.3 Ma and the upper surface at 17.7 Ma.

An unconformity at 8305ft (~2517m) is inferred between the LO of *P. sicana* (8390ft; ~2542m; FAD at 16.4 Ma) and the HO of *H. ampliaperta* (8240ft; ~2497m; LAD at 14.87 Ma). It lies

within Zones M4/N7 and M5/N8. In the absence of additional data, we arbitrarily estimate the hiatus to be ~1.4 Myr, and arbitrarily estimate the lower surface at 16.2 Ma and the upper surface at 15.5 Ma.

As in Well A, the absence of overlap between the upper range of *H. ampliaperta* and the lower range of *O. suturalis* implies an unconformity between 8243ft and 8000ft (~2497m – ~2424m) in the lower part of Zone NN5. The lower surface of the unconformity (at ~2455m) is older than the FAD *O. suturalis*. It is es-



TEXT-FIGURE 25
Variations in abundance of the benthic foraminiferal epifaunal and infaunal morphotypes in the Carapita Formation, Rio Oregano outcrop section.

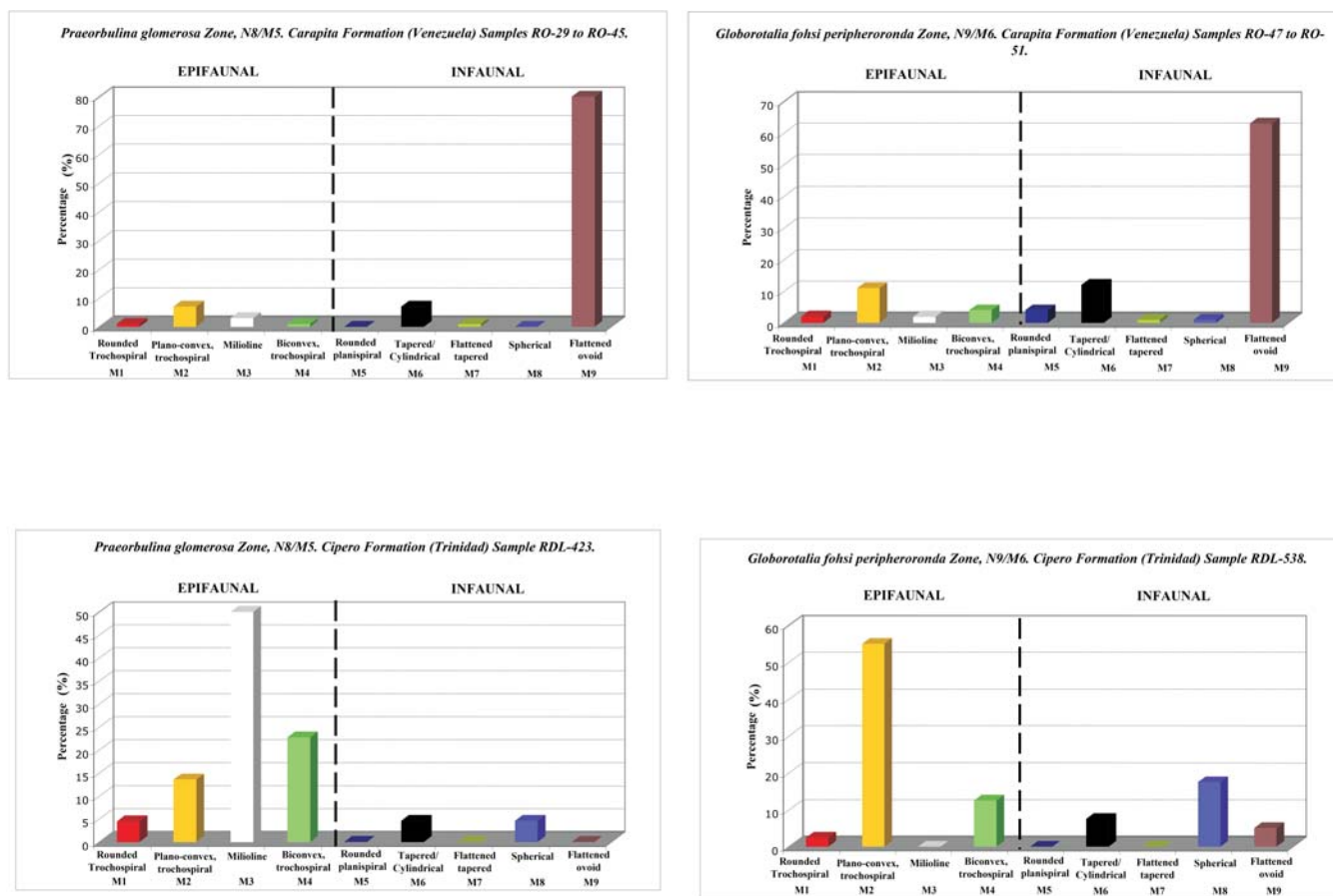
timated at 15.3 Ma. The upper surface is younger than the LAD *H. ampliaperta*, and much older than the LAD *S. heteromorphus* (13.49 Ma). It is estimated at 14.5 Ma.

A younger unconformity, arbitrarily located at ~7260ft (~2200m) is marked by the offset between the HOs of *S. heteromorphus* (7520ft, 2279m; LAD at 13.49 Ma) and *C. floridanus* (7000ft; ~2112m; LAD at 11.8 Ma). The stratigraphic gap encompasses Zones M9/N12, M8/N11 and

M7/N10. The hiatus is arbitrarily estimated at 1 Myr. The lower surface is < 13.49 and tentatively estimated at 13 Ma. The upper surface is > 11.8 Ma and tentatively estimated at 12 Ma.

Paleobathymetry

A total of 69 species of benthic foraminifera were recovered from the Cipero and Carapita Formations in outcrop sections. Thirty species are common to both the Carapita and Cipero Formations (Text-fig. 18). Nine species are restricted to the Cipero



TEXT-FIGURE 26

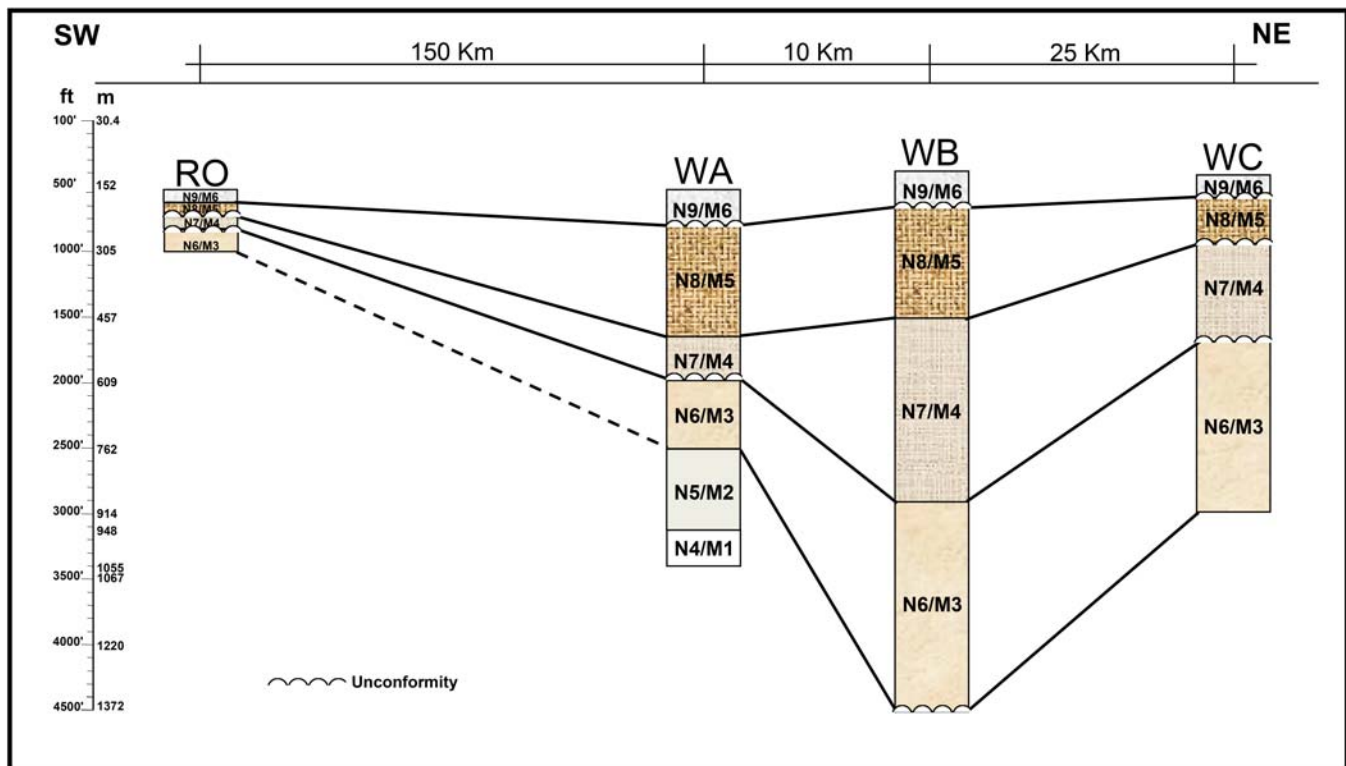
Comparison of the abundance patterns of benthic foraminiferal morphotypes in the Carapita Formation (a) and Cipero (b) Formations. In sample RDL-423 (a) from the Cipero Formation near the Lower/Middle Miocene boundary (N8/M5), the dominant morphotype (M) is M3 (~50%), followed by M4 (22.7 %) and M2 (13.6 %) whereas in sample RO-29 to RO-45 (b) of the same age but from the Carapita Formation, M9 is dominant with percent values of 80%, followed by M2 and M6 with values <10 %. In Middle Miocene (N9/M5) sample RDL-538 (c) from the Cipero Formation morphotype M2 is dominant (55%) whereas in sample RO-47 to RO-51 (d), M9 dominates (~60%) followed by M6 (10 %) and M2 (<10%). Note: the sample composition shown in (b) represents an average of the composition of all samples between RO-29 and RO-45, and the sample composition in (d) represents the average of the composition of all samples between RO-47 and RO-51.

Formation (Text-fig. 19) and thirty species are exclusive to the Carapita Formation (Text-fig. 20). Based on the bathymetric survey (see above) the species assemblages strongly suggest that both the Carapita (Rio Oregano, Eastern Venezuela Basin) and the Cipero (Trinidad) Formations were deposited at bathyal depths (Text-figs 18-20). Additionally, maximum overlap in the paleobathymetric preferences of the taxa occurring only in the Carapita Formation point to upper to middle bathyal ranges (Text-fig. 20), whereas maximum overlap for the taxa occurring only in the Cipero Formation point to deeper (middle and lower) bathyal environments. This suggests that the Cipero Formation (San Fernando area) was deposited at greater depths than the Carapita Formation (Rio Oregano area). With reference to Van Morkhoven et al. (1986) the former would have been deposited at a depth range between 500 to 2000 m, the latter between 200 to 1000m.

Based on the bathymetric survey, the distribution of the benthic foraminifera also indicate that the lower part of the Carapita Formation (Zone M3/N6) in the Rio Oregano area was deposited at middle bathyal depth (Text-fig. 21). In the area of the

wells the N4-N6/M1-M3 zonal interval was deposited at outer neritic to bathyal depth whereas the N7-N9/M4-M5 zonal interval was deposited at upper to middle bathyal depths (Text-figs. 22-24). Assemblages indicative of outer neritic to bathyal depths include *Nonion incisum*, *N. costiferum*, *Bolivina imborcata*, *B. pisciformis*, and *Eggerella scabra* (cf. Text-fig. 20). Assemblages indicative of upper to middle bathyal depths comprise *Cibicidoides crebbsi*, *C. compressus*, *C. incrassatus*, *Rectuvigerina transversa*, *R. multicostata*, *R. striata*, *Uvigerina carapitana*, *U. rugosa*, *U. mexicana*, *Melonis pompilioides*, *Siphonina pozonensis*, *Eggerella bradyi*, *Dorothia brevis*, *Cyclammina cancellata*, *Valvulina flexilis*, *Alveovalvulinella pozonensis*, *Glomospira charoides*, *Bathysiphon carapitanus*, *Sigmoilopsis schlumbergeri*, *Neoepionides umbonatus*, and *N. parantillarum* (cf. Text-figs. 17, 19).

In the Carapita Formation, the infaunal morphotypes dominate over the epifaunal ones in the *Praeorbulina glomerosa* and *Globorotalia peripheroronda* Zones (Zones N8/M5 and N9/M6) with percent values oscillating between 53.6 – 80.0 %. In contrast, in the Cipero Formation the epifaunal morphotypes



TEXT-FIGURE 27
Stratigraphic correlation between sections through the Carapita Formation across the study area.

dominate over the infaunal ones for the same zonal interval, with values oscillating between 50.0 – 55.0 %. This is well exemplified by two sets of representative assemblages from the two formations (compare Text-figs. 26a and c, and 26b and d).

The abundance patterns of the morphotypes in these assemblages is notably different from the patterns described by Corliss and Fois (1991) in benthic communities from the Gulf of Mexico. For instance, in the Gulf of Mexico, morphotype M9 reaches maximum values of 40 % (in 100 to 500m water depth) whereas in the Carapita Formation the percentage is always >50 % (compare Text-figs. 25 and 26 with Tables 4 and 5). Morphotype M2 reaches maximum values of 10 % in the Gulf of Mexico communities, but values >50 % in the Cipero Formation. In addition, different morphotypes in the same assemblage yield contradictory information. In Sample RO-47, values of morphotype M9 would indicate water depth of 100 to 500 m, but values of M6 suggest lower bathyal (1000-2000m) depths (compare Text-fig. 26a and Tables 4 and 5). Morphotype M3 with values between 5 to 10 % would indicate water depths of 500 to 1000m; this morphotype is rare or absent in water depths below 1000m (Table 4). However in sample RDL-423 (Cipero Formation), this morphotype constitutes almost 50 % of the benthic assemblage. Morphotype M2 is also highly represented in Sample RDL-538, much above a percentage of 0 to 10 %, which would indicate water depths of 100 to 1000m.

The conclusions derived from morphotype analysis of benthic foraminiferal communities in the Gulf of Mexico are clearly not applicable to the Early and Middle Miocene assemblages of the Carapita and Cipero Formations. Nevertheless the different representation between the epifauna and infauna in the two forma-

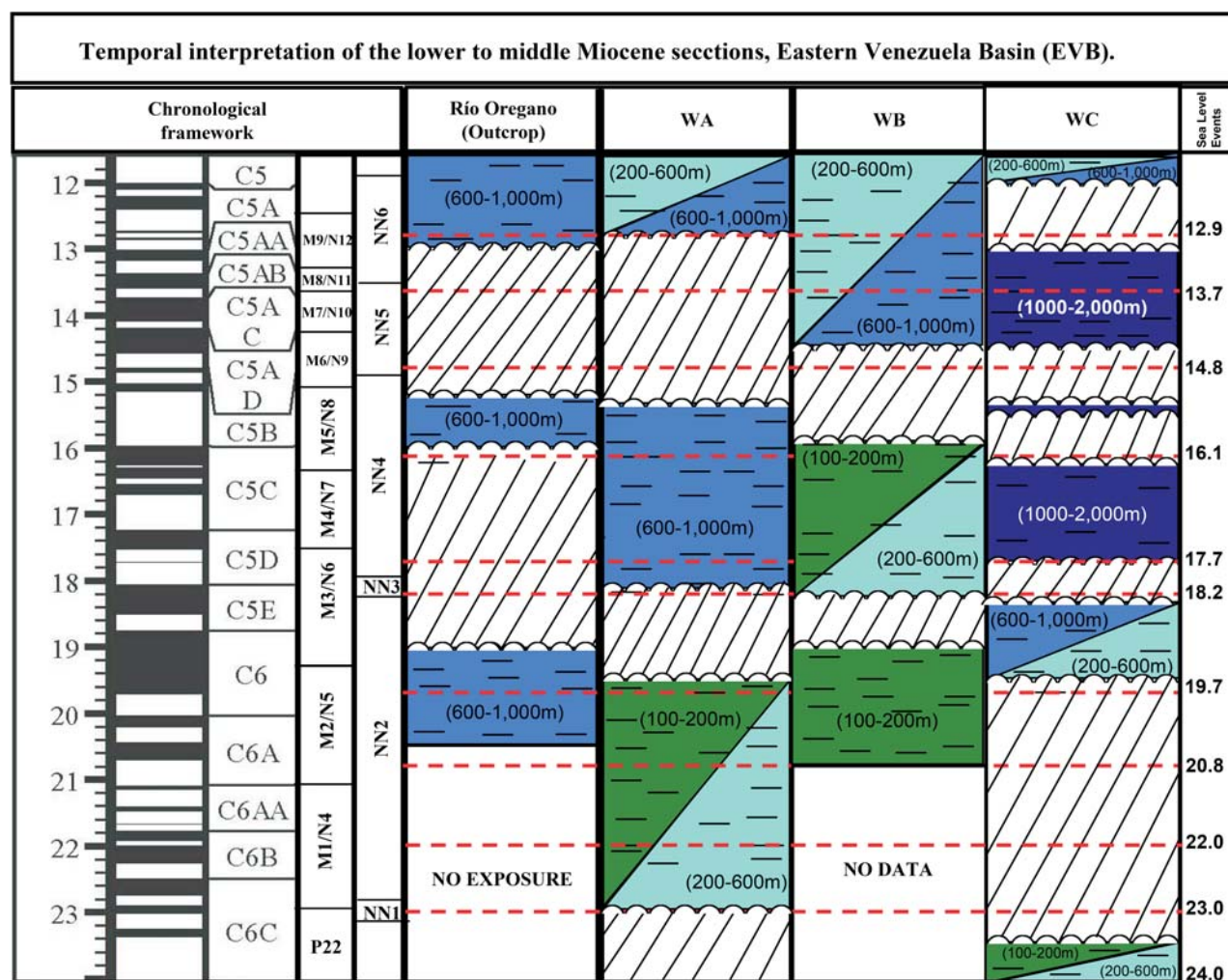
tions constitute evidence of different depositional depths, which is congruent with conclusions derived from the bathymetric survey. Remarkably, the epifaunal-infaunal patterns found in benthic foraminiferal associations of the Carapita and Cipero Formations agree well with the observation by Corliss and Fois (1991) in the Gulf of Mexico and Norwegian Sea, as a function of nutrient availability.

DISCUSSION: DEPOSITIONAL HISTORY OF THE CARAPITA FORMATION

The precise age of the Carapita Formation is established for the first time, showing it to be a lateral correlative of the Cipero Formation (see Sanchez et al., submitted). In the wells and outcrop section studied here the Carapita Formation encompasses Zones N5/M2 to N9/M6. In addition, Zone N5/M1 was questionably identified in Well A (see Text-fig. 11).

However, the precise zonal age of its upper part below the La Pica Formation (~1181m, ~1579m and ~812m in wells A, B and C, respectively) remains unknown.

The same biostratigraphic succession was recovered from the Rio Oregano outcrop section and the wells (Text-fig. 27), but with considerable differences in thickness along the transect. The succession is thickest (~2333m) in WB, but extremely thin (108m) in the outcrop. Additionally, the thicknesses of discrete biozones vary in non-linear fashion with the total thickness of the sections. The N7/M4 zonal interval is much thinner in WA than in WB (~103m versus ~421m) and of intermediate thickness in WC (~245m), whereas the N8/M5 zonal interval is as thick in WA as in WB (~242m) but only half this thickness in WC (~118m). Such differences may have two explanations, ei-



TEXT-FIGURE 28

Early to middle Miocene depositional history in the Eastern Venezuela Basin, based on the temporal interpretation the Carapita Formation at different localities.

ther change in sedimentation rates through time and/or occurrence of stratigraphic gaps (Aubry 1995). As shown by the temporal analyses, changes in sedimentation rates (over the long term) can be ruled out. Only in one section (Well B) was it possible to determine satisfactorily sedimentation rates, which were high (50 to $80\text{cm}/10^3\text{yr}$ calculated here) in agreement with previous work (De Cabrera and De Macquhae 1990). In this well, the sedimentation rate curves do not show inflexions that would support sharp changes in rates. The temporal interpretations indicate that the sections are highly discontinuous (Text-fig. 28). Although no lithological breaks were observed in the field, the Oregano section comprises at least two stratigraphic gaps. It is possible that other unconformities occur, which cannot be documented because of the two inaccessible intervals in the section (see above). The Miocene succession recovered from WA is highly discontinuous, and contains two major stratigraphic gaps (Text-fig. 15), as does the correlative succession recovered from WB in which two unconformities were inferred (Text-fig. 16). The Miocene succession recovered from WC was even more discontinuous, with four principal unconformities (Text-fig. 17).

It is important to recognize that, whereas our delineation of unconformities is strongly supported by the data, there are uncertainties on the dating of many unconformable surfaces. Only in one well (WB) was it possible to use sedimentation rates to calculate dates, rather than estimate them. We recognize that the temporal placements of some surfaces were arbitrarily estimated. However, despite the imprecision of our determinations a consistent stratigraphic pattern occurs, which is similar to patterns that have been documented elsewhere (see below).

To determine the significance of the stratigraphic gaps, it is necessary to place the sections in a paleobathymetric context. The four sections are now land sections in a strongly tectonized area; determination of paleobathymetry requires use of a proxy for water depth. Our results agree with previous interpretations that the Carapita was a bathyal deposit (see above), but, importantly, we have shown that paleodepth differed at the four locations studied here, and also changed through time at each location (Text-fig. 28).

Benthic foraminiferal distribution patterns reveal a comprehensive bathymetric history of the eastern Venezuela Basin

(Text-fig. 28). The shallower sites (WA, WB) were outer neritic to upper bathyal depths during the Early Miocene (24.0 to 20.5 Ma). They deepened to middle bathyal depths during the late Early Miocene from 18.8 to 15.5, but shallowed from middle to upper bathyal depths in the early Middle Miocene (15.0 to 11.7 Ma). The intermediate site (Rio Oregano) remained at lower bathyal depths through Early to Middle Miocene (24 to 11.7 Ma). The deeper site (WC) was at outer neritic /upper bathyal depths during the Early Miocene (24 to 23.2 Ma). It deepened to upper to middle bathyal depths between 19.0 to 18.1 Ma, further deepened to lower bathyal depths between 17.1 to 14.9 Ma, and then shallowed slightly to lower to middle bathyal depths in the early Middle Miocene (11.7 to 11 Ma).

It is remarkable that changes in water depths as determined from the benthic foraminifera (Fig. 28) are associated with stratigraphic gaps. It is unlikely that changes in water depth at upper and middle bathyal locations would have been related to global changes in sea level, i.e., from Neogene glacioeustasy inferred from deep sea oxygen isotope studies combined with the marginal record of sequence boundaries (Miller et al. 2011). In fact, there is clearly no association between inferred glacio-eustatic events (red lines in Text-fig. 28) and either changes in paleodepth or the occurrence of unconformities in the sections studied here. It is more likely that changes in paleobathymetry and developments of stratigraphic gaps were controlled by structuring in a tectonically active basin (Di Croce et al. 2000).

Without access to seismic data in the studied area, a further interpretation of our record is difficult because the wells cannot be placed in a broader stratigraphic architectural context. However, a dense seismic stratigraphic framework has been developed for the eastern Venezuela Basin, and a sequence stratigraphic framework has been established for the Carapita Formation from the study of multiple wells (Sanchez et al. 2010). Using seismic data and corelogs, it would be possible to relate the Miocene successions in our three wells to Sanchez et al.'s sequence stratigraphic framework of the same stratigraphic unit. Of fundamental interest would be to determine whether the hiatuses in our sections correlate with the sequence boundaries identified by these authors. They delineated three Lower Miocene and six Middle Miocene sequences (Sanchez et al. 2010, p. 7; although five and seven sequences, respectively, are shown in their figure 3), commenting that the Lower Miocene sequences were easily identified by means of stacking patterns whereas the Middle Miocene sequences were difficult to identify from monotonous corelogs due to their deposition at greater depths. They delineated Middle Miocene sequences based on micropaleontological data. They also noted that biostratigraphic resolution was too low to date sequence boundaries. The sequence stratigraphic work in Sanchez et al. (2010) is insufficiently detailed to be tied to our work. However, there is a strong likelihood that the unconformities delineated in our four sections correspond to some of the sequence boundaries delineated by these authors. If this is correct, a major difference is readily seen between the two works concerning the treatment of unconformities. In Sanchez et al. (2010) an unconformity is regarded as a stratigraphic feature, merely indicative of a stratigraphic gap and *without* time significance. In contrast, we recognize an unconformity as a stratigraphic feature representing a lapse of time (hiatus) between two, datable stratigraphic horizons. Without consideration of the two surfaces, there cannot be satisfactory stratigraphic *and* genetic correlation be-

tween unconformities (Aubry 1991). A next step for sequence stratigraphic investigations is to incorporate hiatuses as a true component of the stratigraphic record, i.e., to recognize equal geological significance to recorded and unrecorded time.

The occurrence of substantial hiatuses in outer neritic to middle bathyal sections has now been documented in eastern Venezuela, Jamaica, the eastern Gulf of Mexico (Aubry 1993a, b, and unpublished data). Moreover, all these records show an organized pattern, with overlapping hiatuses, and bounding surfaces of similar ages extending over long distances. If all hiatuses are related to sequence boundaries, as we suggest, there are strong reasons to suspect that tectonics play a greater role than glacioeustasy in shaping the architecture of the Neogene stratigraphic record on margins than has been acknowledged until now.

CONCLUSIONS

We have established the biostratigraphy of one land section (Rio Oregano) and three wells drilled through the Carapita Formation in the eastern Venezuela Basin. We show that the four successions belong to the same biozonal interval from Lower Miocene (?Zone N4/M1) to Middle Miocene (Zone N9/M6). We further show that the four successions are discontinuous including hiatuses > 1 Myr.

We have also determined the paleodepth at each section/well based on a literature survey of species depth preferences, and also through the comparison of abundance patterns of foraminifera as grouped by morphology. We confirm that the Carapita Formation is essentially a bathyal deposit, but that depth has changed through time at different locations varying from outer neritic (Early Miocene only) to middle bathyal.

We show that changes in paleodepth are associated with hiatuses. As no relationship is seen between Neogene glacioeustatic events and hiatuses in our sections, we conclude that tectonic forcing is at the origin of both hiatuses and changes in water depth. Comparison with other regions leads us to suggest that tectonics may have played a stronger control on stratigraphic architecture than acknowledged.

Finally this study shows once again the relevance of biostratigraphy to stratigraphic analysis, not merely as a mean to calibrate sequence boundaries to the time scale as commonly done, but as a means of assessing stratigraphic completeness, determining the hiatus between unconformable but concordant horizons, and dating these interfaces. The ubiquitous applicability of biostratigraphy makes it an ideal tool to begin to ask, in concert with other appropriate tools, one of the most fundamental questions of relevance to sequence stratigraphy—that of the relationship between subaerial unconformities (the shallow water part of sequence boundaries) and unconformities at greater depth where strata are concordant.

ACKNOWLEDGMENTS

This paper is based on an MSc thesis presented by Dennis Sanchez at Rutgers University, who thanks the Exploration Team Management Dr. Sandra Crespo de Cabrera and Mr. Orlando Chacin for the opportunity to study at Rutgers University while being supported by Petroleos de Venezuela (PDVSA). We are grateful to Olga Rodriguez who generously studied calcareous nannofossils from the outcrop section of Venezuela, to Weimin Si with whom we discussed the usefulness of statistical

TABLE 1
Samples analyzed in this study.

Well A (ft)	Well A (m)	Well B (ft)	Well B (m)	Well C (ft)	Well C (m)	Oregano section Sample meter	Ciper Sample	
2300-2310	~697 – 700	2100-2150	~636 – 651.5	4380-4410	~1327 – 1336	RO-89	111	RDL-529
2450-2480	~742 – 751.5	2350-2400	~2830 – 2836	4500-4530	~1364 – 1373	RO-87	109	RDL-538
2550-2600	~773 – 788	2700-2750	~818 – 833	4640-4670	~1406 – 1415	RO-85	107	RDL-423
2700-2750	~818 – 833	3000-3050	~909 – 924	4800-4830	~1454.5 – 1464	RO-83	105	RDL-544
2850-2900	~864 – 879	3350-3400	~1015 – 1030	5020-5050	~1521 – 1530	RO-81	103	RDL-800
3110-3140	~942 – 951.5	3620-3650	~1097 – 1106	5230-5260	~1585 – 1594	RO-79	101	RDL-804
3520-3550	~1067 – 1076	3800-3820	~1151 – 1157.5	5410-5440	~1639 – 1648	RO-77	99	RDL-563
3700-3709	~1121 – 1124	4000-4020	~1212 – 1218	5600-5650	~1697 – 1712	RO-75	97	RDL-540
3850-3880	~1167 – 1176	4200-4220	~1273 – 1279	5830-5860	~1767 – 1776	RO-73	95	RDL-553
4090-4120	~1239 – 1248	4600-4620	~1394 – 1400	6020-6030	~1824 – 1827	RO-71	93	RDL-558
4231-4260	~1282 – 1291	4880-4890	~1479 – 1481	6210-6220	~1882 – 1885	RO-69	91	RDL-802
4390-4410	~1330 – 1336	5110-5140	~1548 – 1557.5	6450-6459	~1954.5 – 1957	RO-67	89	RDL-808
4570-4590	~1385 – 1391	5880-5910	~1782 – 1791	6650-6700	~2015 – 2030	RO-55	87	RDL-2859
4650-4680	~1409 – 1418	6090-6130	~1845 – 1857.5	6800-6850	~2061 – 2076	RO-63	85	RDL-2873
5180-5210	~1570 – 1579	6200-6210	~1879 – 1882	7000-7020	~2121 – 2127	RO-61	83	RDL-2865
5240-5260	~1589 – 1594	6600-6630	~2000 – 2009	7250-7280	~2197 – 2206	RO-59	81	RDL-2931
5510-5540	~1670 – 1679	6810-6840	~2064 – 2073	7400-7450	~2242 – 2257.5	RO-57	79	RDL-2932
5660-5690	~1715 – 1724	7020-7050	~2127 – 2136	7520-7530	~2279 – 2282	RO-55	77	RDL-2933
5900-5920	~1788 – 1794	7210-7240	~2185 – 2194	7640-7670	~2315 – 2324	RO-53	75	RDL-2934
6240-6270	~1891 – 1900	7410-7440	~2245 – 2254.5	7880-7900	~2388 – 2394	RO-51	73	
6390-6410	~1936 – 1942	7620-7650	~2309 – 2318	8000-8050	~2424 – 2439	RO-49	71	
6500-6530	~1970 – 1979	7810-7840	~2367 – 2376	8240-8270	~2497 – 2506	RO-47	63	
6656-6670	~2017 – 2021	8210-8230	~2489 – 2494	8390-8420	~2542 – 2551.5	RO-45	61	
6770-6775	~2051 – 2053	8380-8400	~2539 – 2545	8690-8720	~2633 – 2642	RO-43	43	
7040-7050	~2133 – 2136	8610-8640	~2609 – 2618	8890-8820	~2700	RO-41	41	
7220-7230	~2188 – 2191	8820-8850	~2673 – 2682	9050-9080	~2742 – 2751.5	RO-39	39	
7380-7410	~2236 – 2245	9000-9030	~2727 – 2736	9200-9230	~2788 – 2797	RO-37	37	
7520-7540	~2279 – 2285	9200-9220	~2788 – 2794	9410-9440	~2851.5 – 2861	RO-35	35	
7600-7610	~2303 – 2306	9400-9420	~2848 – 2854.5	9680-9710	~2933 – 2942	RO-33	33	
7700-7710	~2333 – 2336	9600-9620	~2909 – 2915	10040-10070	~3042 – 3051.5	RO-31	31	
7820-7840	~2370 – 2376	9800-9820	~2967 – 2976	10270-10290	~3112 – 3118	RO-29	29	
8150-8170	~2470 – 2476	10020-10050	~3091 – 3045	10410-10440	~3154.5 – 3164	RO-27	27	
8430-8440	~2554.5 – 2557.5	10210-10240	~3094 – 3103	10700-10750	~3242 – 3257.5	RO-25	25	
8550-8560	~2591 – 2594	10410-10440	~3154.1 – 3164	10830-10840	~3282 – 3285	RO-23	23	
8780-8790	~2661 – 2664	10620-10650	~3218 – 3227	10900-10950	~3303 – 3318	RO-21	21	
9000-9006	~2727 – 2729	10800-10830	~3273 – 3282			RO-19	19	
9200-9210	~2788 – 2791	11020-11050	~3334 – 3348			RO-17	17	
9340-9360	~2830 – 2836	11220-11240	~3400 – 3757.5			RO-15	15	
9500-9520	~2879 – 2885	11300-11310	~3424 – 3427			RO-13	13	
9660-9670	~2927 – 2930	11400-11405	~3454.5 – 3456			RO-11	11	
9735-9740	~2950 – 2951.5	11500-11510	~3485 – 3488			RO-9	9	
		11600-11610	~3515 – 3518			RO-7	7	
		11750-11760	~3561 – 3564			RO-5	5	
						RO-3	3	
						RO-1	1	

methods for this work, and to W. A. Berggren, L. Collins and M. Katz for their helpful comments and discussion. We thank K. G. Miller and R. D. Olsson for critical review of an early version of the paper, and Carlos Jaramillo for his review of this manuscript and his thoughtful comments.

REFERENCES

- AGER, D. V., 1993. *The nature of the stratigraphical record*, 3rd Ed. New York: John Wiley & Sons.
- ALGAR, S. T., and PINDELL, J. L., 1991. Stratigraphy and sedimentology of the Toco region of the Northern Range, N. E. Trinidad. In: Gillezeau, K. A., Ed., *Transactions of the Second Geological Conference of the Geological Society of Trinidad and Tobago*, 55–69. Port of Spain: GSTT.
- AUBRY, M.-P., 1991. Sequence stratigraphy: Eustasy or tectonic imprint? *Journal of Geophysical Research*, 96(B4): 6641–6679.
- , 1995. From chronology to stratigraphy: Interpreting the stratigraphic record. In: Berggren, W. A., Kent, D. V., Aubry, M. -P., and Hardenbol, J., Eds., *Geochronology, time scales and global stratigraphic correlations*, 213–274. Tulsa: Society of Economic Paleontologists and Mineralogists. Special volume 54.
- BANDY, O. L., 1967. Benthic foraminifera as environmental indices. In: Bandy, O. L., Ingle, J. C., et al., *Paleoecology*, 1-29. Washington, D. C: American Geological Institute. Short Course Lecture Notes No. 29.
- BERGGREN, W. A., KENT, D. V., AUBRY, M. P. and HARDENBOL, J., 1995. A revised Cenozoic Geochronology and chrono-

TABLE 2

Selected planktonic foraminiferal and calcareous nannofossil datums (FAD and LAD) used in this study. from: 1-) Berggren et al. 1995; 2-) Shackleton et al. 1999; 3-) Wade et al. 2011, 4-) Aubry et al., submitted and * Gradstein et al. 2012, p. 116.

Planktonic Foraminiferal Datums	Calcareous Nannofossils	Date (Ma) -1, 2-	Date (Ma) -3-	Date (Ma) -4-	WA Ft(m)	WB Ft(m)	WC (ft)	Carapita Outcrop (m)
	LAD <i>C. floridanus</i>	11.8		11.95			7000 (~2133.6)	
	LAD <i>S. heteromorphus</i>	13.6		13.49		3620 (~157.5)	7520 (~2292.1)	
FAD <i>O. universa</i>		15.10	15.10		6240 (~1902)	7410 (~2258.6)	8000 (~2438.4)	60
	LAD <i>H. ampliapertura</i>	15.6		14.87	6390 (~1947.7)	7410 (~2245)	8240 (~2511.6)	30
FAD <i>P. sicana</i>		16.4	16.4		7040 (~2145.8)	8210 (~2502.4)	8390 (~2557.3)	
FAD <i>G. bisphericus</i>		16.4			7040 (~2145.8)	8210 (~2502.4)		26
LAD <i>G. stainforthi</i> <i>C. dissimilis</i>		17.3	17.62		7380 (~2249.4)	9600 (~2926.1)	9200 (~2804.2)	24
	LAD <i>S. belemnus</i>	~18.3		18.1	7380 (~2249.4)	11300 (~3444.2)	9410 (~2868.2)	24
LAD <i>G. altiapertura</i>		20.5	20.5		7380 (~2249.4)			20
	LAD <i>H. recta</i>	[23]			9200 (~2804.2)			
	LAD <i>C. abisecta</i>	[23]		24.87*			10830 (~3301)	
LAD <i>G. ciperoensis</i>		22.8	23.68		8780 (~2676.1)	11220 (~3419.9)	10410 (~3173)	

stratigraphy. In: Berggren, W. A., Kent, D. V., Aubry, M.-P. and Hardenbol, J., Eds., *Geochronology, time scales and global stratigraphic correlations*, 129–212. Tulsa: Society of Economic Paleontologists and Mineralogists. Special volume 54

BOLLI, H. M., SAUNDERS, J. B. and PERCH-NIELSEN, K., 1985. *Plankton stratigraphy*. Cambridge: Cambridge University Press.

BONHAM-CARTER, G. F., 1965. A numerical method of classification of quantitative and semi-qualitative data, as applied to facies analysis of Limestones. *Canadian Petroleum Geology Bulletin*, 4: 482–502.

BOULILA, S., GALBRUN, B., MILLER, K. G., PEKAR, S. F., BRWNING, J. V., LASKAR, J., and WRIGHT, J., 2011. On the origin of Cenozoic and Mesozoic “third order” eustatic sequences. *Earth-Sciences Review*, 109: 94–112.

CANDE, S. C., and KENT, D. V., 1995. Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. *Journal of Geophysical Research*, 100(B4): 6093–6095.

CATUNEANU, O., ABREU, V., BHATTACHARYA, J. P., et al., 2009. Towards the standardization of sequence stratigraphy. *Earth-Sciences Reviews*, 92: 1–33.

CÓDIGO ESTRATIGRÁFICO DE VENEZUELA, 2005. PDVSA, INTEVEP. <http://www.pdv.com/lexico>.

CORLISS, B. H., 1985. Microhabitats of benthic foraminifera within deep-sea sediments. *Nature*, 314: 435–438.

CORLISS, B. H. and CHEN, C. 1988. Morphotype patterns of Norwegian Sea deep-sea benthic foraminifera and ecological implications. *Geology*, 16: 716–719.

CORLISS, B. H., and EMERSON, S., 1990. Distribution of Rose Bengal stained deep-sea benthic foraminifera from the Nova Scotian continental margin and Gulf of Maine. *Deep-Sea Research*, 37: 381–400.

CORLISS, B. H. and FOIS, E., 1991. Morphotype analysis of deep-sea benthic foraminifera from the northwest Gulf of Mexico. *Palaos*, 5: 589–605.

CUSHMAN, J. A. and RENZ, H. H., 1947. *The foraminiferal fauna of the Oligocene Ste. Croix Formation, of Trinidad, B. W. I.* Sharon, MA: Cushman Laboratory for Foraminiferal Research. Special Publication 22, 46 pp..

DE CABRERA, S. and DE MACQUHAE, I., 1990. “Síntesis bioestratigráfica del Noreste de Anzoátegui and Norte de Monagas”. Caracas: Petroleos de Venezuela SA. Unpubl. internal report.

DI CROCE J., BALLY, A. and VAIL, P., 1999. Sequence stratigraphy of the eastern Venezuelan basin. In: Mann, P., Ed., *Caribbean basins*, 419– 476. Amsterdam: Elsevier Science. Sedimentary basins of the world.

DUERTO, L., 2007. “Shale tectonics of the eastern Venezuela Basin.” Unpubl. PhD thesis, Department of Geology, Royal Holloway University of London, 452 pp.

ERIKSON, J. and PINDELL, J., 1993. Analysis of subsidence in north-eastern Venezuela as a discriminator of tectonics models for northern South America. *Geology*, 21: 945 – 948.

EVA, A. N., BURKE, D., MANN, P. AND WADGE, G., 1989. Four-phase tectonostratigraphic development of the southern Caribbean. *Marine and Petroleum Geology*, 6: 9–21.

TABLE 3a

Classification of of benthic foraminifera from the Carapita and Cipero Formations into morphotypes based on morphotype designation by Corliss and Fois 1991. Epifaunal morphotypes.

Rounded trochospiral (M1)	Plano-convex, trochospiral (M2)	Milioline (M3)	Biconvex, trochospiral (M4)
<i>Gyroidinoides altiformis</i>	<i>Cibicidoides alazanensis</i>	<i>Quinqueloculina lamarckiana</i>	<i>Neoeponides campester</i>
<i>Gyroidinoides soldanii</i>	<i>Cibicidoides compressus</i>	<i>Quinqueloculina seminula</i>	<i>Neoeponides parantillarum</i>
	<i>Cibicidoides crebbi</i>	<i>Sigmoilopsis schlumbergeri</i>	<i>Neoeponides umbonatus</i>
	<i>Cibicidoides incrassatus</i>		
	<i>Planulina marialana</i>		
	<i>Planulina renzi</i>		
	<i>Planulina subtenuissima</i>		

TABLE 3b

Classification of of benthic foraminifera from the Carapita and Cipero Formations into morphotypes based on morphotype designation by Corliss and Fois 1991. Infaunal morphotypes.

Rounded planispiral (M5)	Tapered/cylindrical (M6)	Flattened tapered (M7)	Spherical (M8)	Flattened ovoid (M9)
<i>Melonis pompilioides</i>	<i>Buliminella elegans</i>	<i>Bolivina cuadriæ</i>	<i>Globocassidulina subglobosa</i>	<i>Cassidulina carapitana</i>
<i>Nonion costiferum</i>	<i>Bulimina inflata</i>	<i>Bolivina floridana</i>	<i>Pullenia bulloides</i>	<i>Cassidulina tricamerata</i>
<i>Nonion incisum</i>	<i>Bulimina jarvisi</i>	<i>Bolivina isidroensis</i>		<i>Lenticulina adelinensis</i>
	<i>Bulimina macilenta</i>	<i>Bolivina pisciformis</i>		<i>Lenticulina americana</i>
	<i>Bulimina pupoides</i>	<i>Bolivina simplex</i>		<i>Lenticulina calcar</i>
	<i>Marginulina subbullata</i>			<i>Lenticulina clericii</i>
	<i>Uvigerina carapitana</i>			<i>Lenticulina formosa</i>
	<i>Uvigerina mexicana</i>			<i>Lenticulina hedbergi</i>
	<i>Uvigerina rugosa</i>			<i>Lenticulina nutalli</i>
				<i>Lenticulina occidentalis</i>
				<i>Lenticulina senni</i>
				<i>Lenticulina subaculeata</i>
				<i>Lenticulina subpapillosa</i>
				<i>Lenticulina suteri</i>
				<i>Lenticulina wallacei</i>
				<i>Siphonina pozonensis</i>

GOODAY, A. J., 1986. Meiofaunal foraminiferans from the bathyal Porcupine Seabight (north east Atlantic); size structure, standing stock, taxonomic composition, species diversity and vertical distribution in the sediment. *Deep-Sea Research*, 33: 1345–1373.

GRADSTEIN, F. M., OGG, J. G., SCHMITZ, M. D., and OGG, G. M., 2012. *The geological time scale 2012*. Amsterdam: Elsevier, 1143 pp.

HEDBERG, H. D., 1937a. Stratigraphy of the Rio Querecual section of northeastern Venezuela. *Bulletin of the Geological Society of America*, 48: 1971–2024

———, 1937b. Foraminifera of the Middle Tertiary Carapita Formation of northeastern Venezuela. *Journal of Paleontology*, 11: 651–697.

———, 1950. Geology of the eastern Venezuela basin (Anzoátegui–Monagas–Sucre–eastern Guarico portion). *Geological Society of America Bulletin*, 61: 1176–1216.

HEDBERG, H. D. and PYRE, A., 1944. Stratigraphy of northeastern Anzoátegui, Venezuela. *American Association of Petroleum Geologists Bulletin*, 28: 1–28.

HIGGS, R., 2009. Caribbean–South America oblique collision model revised. In: James, K. H., Lorente, M. A., And Pindell, J. L., Eds., *The origin and evolution of the Caribbean Plate*, 613–657. London: The Geological Society. Special Publication 328.

HUNG, E., 1997. “Foredeep and thrust belt interpretation of the Maturín subbasin, Eastern Venezuela basin.” Unpubl. M.A. thesis, Rice University, Houston, 125 pp.

IMBRIE, J., and PURDY, E. G., 1962. Classification of modern Bahamian carbonate sediments. In Ham, W. E., Ed., *Classification of carbonate rocks, a symposium*, 253–272. Tulsa: American Association of Petroleum Geologists. Memoir 1

JÁCOME, M., KUSZNIR, N., AUDEMARD, F. and FLINT S., 2003. Formation of the Maturín foreland basin, Eastern Venezuela: Thrust sheet loading of subduction dynamic topography. *Tectonics*, 22: 1029–1046.

KAMINSKI, M. A. and GRADSTEIN, F. M., 2005. *Atlas of Paleogene cosmopolitan deep-water agglutinated foraminifera*. Krakow: Grzybowski Foundation, 548 pp.

KENNETT, J. P. and SRINIVASAN, M. S., 1983. *Neogene planktonic foraminifera. A phylogenetic atlas*. Stroudsburg, PA: Hutchinson Ross Publishing Company. 265 pp..

LOURENS, L., HILGEN, F., SHACKLETON, N. J., LASKAR, J., and WILSON, D., 2004. The Neogene Period. In: Gradstein, F., Ogg, J. G., and Smith, A. G., *A geological time scale 2004*, 409–452; 469–472. Cambridge: Cambridge University Press.

MARTINI, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci, A., Ed., *Proceedings II*

TABLE 4

Relationship between abundance (%) of morphotypes of benthic foraminifera and water depth habitat. (from Corliss and Fois 1991).

MORPHOTYPE		WATER DEPTHS		
		100-500 m	500-1000 m	1000-2000 m
E P I F A U N A L	M1 Rounded trochospiral	0-5 %	0-10 %	Rare or absent
	M2 Plano-convex	0-10 %	0-10 %	Rare or absent
	M3 Milioline	0-5 %	5-10 %	Rare or absent
	M4 Biconvex trochospiral	20 %	40 %	Rare or absent
I N F A U N A L	M5 Rounded planispiral	0-5 %	0-5 %	Rare or absent
	M6 Tapered/cylindrical	40-50 %	40-50 %	0-30%
	M7 Flattened tapered	0-90 %	0-90 %	> 30%
	M8 Spherical	> 10 %	> 20 %	> 10%
	M 9 Flattened ovoid	0-40 %	0-10 %	Rare or absent

TABLE 5

Abundance (%) of morphotypes in the Carapita (Rio Oregano section) and the Cipero (Trinidad) formations.

	M1 Rounded Trochospiral (%)	M2 Plano-convex Trochospiral (%)	M3 Milioline (%)	M4 Biconvex Trochospiral (%)	M5 Rounded Planispiral (%)	M6 Tapered/ Cylindrical (%)	M7 Flattened Tapered (%)	M8 Spherical (%)	M9 Flattened Ovoid (%)
<i>P. glomerosa</i> Zone (Carapita Fm)	1.0	7.0	3.0	1.0	0	7.0	1.0	0	80.0
<i>P. glomerosa</i> Zone (Cipero Fm)	4.5	13.6	50.0	22.7	-	4.6	-	4.6	-
<i>G. fohsi</i> <i>peripheroronda</i> Zone (Carapita Fm)	2.0	11.0	2.0	4.0	4.0	12.0	1.0	1.0	63.0
<i>G. fohsi</i> <i>peripheroronda</i> Zone (Cipero Fm)	2.5	55.0	-	12.5	-	7.5	-	17.5	5.0

Planktonic Conference, Rome 1970, Vol. 2, 739–785. Roma: Edizione Tecnoscienza.

MCGOWRAN, G., 1968. The dendrograph: a new tool for correlation. *Geological Society of America Bulletin*, 79: 1663–1670.

MIALL, A. D., 2010. *The geology of stratigraphic sequences*. New York: Springer-Verlag.

MILLER, K. G., MOUNTAIN, G. S., WRIGHT, J. D., and BROWN-ING, J. D., 2011. A 180 million-year record of sea level and ice-volume variations from continental margin and deep sea isotopic records. *Oceanography*, 24: 40–53.

PARKS, J. M., 1966. Cluster analysis applied to multivariate geologic data. *Geology*, 74: 703–714.

PARNAUD, F. I., GOU, J. C., PASCAL, C., TRUSKOWSKI, I., GALLANGO, O. and PASSALACQUA, H., 1995. Petroleum geology of the East Venezuela Basin. In: Tankard, A., Suarez, R. and Welsink, H. J., Eds., *Petroleum basins of South America*, 741–756. Tulsa: American Association of Petroleum Geologists. Memoir 62.

PHLEGER, F. B., 1951. *Ecology of foraminifera, northwest Gulf of Mexico. Part 1: Foraminifera distribution*. Boulder, CO: Geological Society of America. Memoir 46, Part 1, 88 pp.

PHLEGER, F. B. and PARKER, F. L., 1951. *Ecology of foraminifera, northwest Gulf of Mexico. Part 2: Foraminifera species*. New York: Geological Society of America. Memoir 46, Part 2, 48 pp.

RENZ, H. H., 1948. *Stratigraphy and fauna of the Agua Salada group, State of Falcon, Venezuela*. New York: Geological Society of America. Memoir 32, 219 pp.

ROBERTSON, B. E., 1998. *Systematics and paleoecology of the benthic Foraminifera from the Buff Bay section, Miocene of Jamaica*. New York: Micropaleontology Press. Micropaleontology 44, supplement 2, 267 pp.

SAINT MARC, P., 1988. "Claves para la identificación de foraminíferos planctónicos del Neógeno de Venezuela Oriental." Caracas: Petroleos de Venezuela SA. Unpubl. internal report.

- SANCHEZ, D., RODRIGUEZ, O., MATA-GARCIA, L. and ESPIN, M., 2007. "Estudio bioestratigráfico y sedimentológico del pozo Tropical-8." Caracas: Petroleos de Venezuela SA, unpubl. internal report.
- SÁNCHEZ, G. J., BAPTISTA, N., PARRA, M., MONTILLA, L., GUZMÁN, and FINNO, A., 2010. The Monagas fold-thrust belt of Eastern Venezuela. Part II: Structural and palaeo-geographic controls on the turbidite reservoir potential of the middle Miocene fore-land sequence. *Marine and Petroleum Geology*, 28: 70–80.
- SHACKLETON, N. J., HALL, M. A., RAFFI, I., TAUXE, L., and ZACHOS, J., 2000. Astronomical calibration of the Oligocene/Miocene boundary. *Geology*, 28: 447–450.
- STAINFORTH, R. M., 1948. Description, correlation, and paleoecology of Tertiary Cipero Marl Formation, Trinidad, B. W. I. *American Association of Petroleum Geologists*, 32: 1291–1330.
- THIEL, H., 1975. First quantitative data of Red Sea deep benthos. *Marine Ecology Progress Series*, 1: 347–350.
- VAN MORKHOVEN, F. P. C. M., BERGGREN, W. A. and EDWARDS, A. S., 1986. *Cosmopolitan Cenozoic deep-water benthic foraminifera*. Pau: Elf-Aquitaine. Centre de Recherches, Memoir 11, 421 pp.
- WADE, B. S., PEARSON, P. N., BERGGREN, W. A., and PÄLIKE, H., 2011. Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale. *Earth-Science Reviews*, 104: 111–142.
- WHITTAKER, J. E., 1988. *Taxonomy and distribution of smaller benthic foraminifera from coastal Ecuador (Late Oligocene – Late Pliocene)*. London: British Museum (Natural History), 194 pp..
- YORIS, F. and OSTOS, M., 1997. Geología de Venezuela. In: *Schlumberger Oilfield Services, Venezuela WEC 1997, evaluación de pozos*, 3–44. Caracas: Editores.

Received August 14, 2013

Accepted April 17, 2014

Published June 26, 2014

APPENDIX 1A

Species range for some of the commonly represented genera of benthic foraminifera. Ranges from Hedberg (1937), Cushman and Renz (1945), Renz (1948), Phleger and Parker (1951), van Morhoven, Berggren and Ewads (1986), Whittaker (1988) and Robertson (1988). (*) Agglutinated benthic foraminifera.

EPOCH	PLANKTONIC FORAMINIFERA ZONE	
	EARLY	LATE
PLIOCENE	EARLY	LATE
MIOCENE	EARLY	LATE
	MIDDLE	LATE
OLIGOCENE	LATE	LATE

APPENDIX 1B

Species range for some of the commonly represented genera of benthic foraminifera. Ranges from Hedberg (1937), Cushman and Renz (1945), Renz (1948), Phleger and Parker (1951), van Morhoven, Berggren and Ewads (1986), Whittaker (1988) and Robertson (1988). (*) Agglutinated benthic foraminifera.

EPOCH	PLANKTONIC FORAMINIFERA ZONE			
	PLEISTOCENE	EARLY	PT1a	
PLIOCENE	LATE	PL6		
PLIOCENE	EARLY	PL5		
PLIOCENE	EARLY	PL4		
PLIOCENE	EARLY	PL3		
PLIOCENE	EARLY	PL2		
PLIOCENE	EARLY	PL1		
MIOCENE	LATE	M14		
MIOCENE	LATE	M13b		
MIOCENE	LATE	M13a		
MIOCENE	LATE	M12		
MIOCENE	LATE	M11		
MIOCENE	LATE	M10		
MIOCENE	LATE	M9b		
MIOCENE	LATE	M9a		
MIOCENE	LATE	M8		
MIOCENE	LATE	M7		
MIOCENE	LATE	M6		
MIOCENE	LATE	M5b		
MIOCENE	LATE	M5a		
MIOCENE	LATE	M4b		
MIOCENE	LATE	M4a		
MIOCENE	LATE	M3		
MIOCENE	LATE	M2		
MIOCENE	LATE	M1b		
MIOCENE	LATE	M1a		
OOLIGOCENE	LATE	O7		

