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PALEOENVIRONMENTAL RECONSTRUCTION OF THE OLIGOCENE-MIOCENE DEPOSITS OF SOUTHERN CARIBBEAN (CARMEN DE BOLIVAR, COLOMBIA) BASED ON BENTHIC FORAMINIFERA

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ABSTRACT

The benthic foraminifera from an Oligocene-Middle Miocene stratigraphic section were used to interpret the depositional environments of these sediments. The examined stratigraphic section (Carmen de Bolivar section) located on the arroyo Alferez (Colombia) is 1950 m long and mainly consists of shale and siltstone with sandstone layers belonging to the Carmen Formation, Oligocene-Middle Miocene in age.

Paleobathymetric and paleoenvironmental interpretation were based on the foraminiferal analysis of 80 samples collected every 10-15 meters along the entire length of the section.

This study shows the results of a quantitative analysis of the benthic foraminifera greater than 63μm.

Several foraminiferal associations have been individuated within the section:

- Associations dominated by planktic foraminifera with variable percentages of benthic foraminifera either calcareous or agglutinated. These associations are interpreted as belonging to marine environment from the upper bathyal zone.
- Association dominated or totally composed by agglutinated foraminifera. The calcareous foraminifera within this association are rare and poorly preserved. The agglutinated foraminifera are abundant, finely to middle agglutinated and mainly small-sized (>63-125 μm). This association indicates a turbid water condition and suggests a organic-rich upper-middle bathyal depositional environment.

Keywords: Benthic foraminifera, Oligocene, Miocene, Colombia, paleoecology.

RECONSTRUCCIÓN PALEOAMBIENTAL DE LOS DEPÓSITOS DEL OLIGOCENO-MIOCENO DEL SURESTE DEL CARIBE (CARMEN DE BOLIVAR, COLOMBIA) BASADA EN LOS FORAMINÍFEROS BENTÓNICOS

RESUMEN

Los foraminíferos bentónicos extraídos de una sección estratigráfica del Oligoceno-Mioceno Medio fueron usados para interpretar los ambientes de depositación de dichos sedimentos. La sección estratigráfica de Carmen de Bolívar ubicada en el arroyo Alférez (Bolivar, Colombia) está compuesta principalmente de arcillolita limosa y limolitas con intercalaciones de arenitas de la Formación el Carmen (Oligoceno-Mioceno).

Las interpretaciones paleobatimétricas y paleoambientales están basadas en el análisis de 80 muestras de foraminíferos tomadas cada 10-15 metros en toda la sección.

Este estudio esta basado en el análisis cuantitativo de los foraminíferos bentónicos de tamaño >63μm.

Las siguientes asociaciones de foraminíferos bentónicos están presentes en la sección:

- Asociaciones caracterizadas de foraminíferos planctónicos con porcentajes variables de foraminíferos bentónicos calcáreos y aglutinados. Las asociaciones son características de ambiente marino batial superior.
- La asociación dominada o caracterizada exclusivamente por foraminíferos aglutinados. Los foraminíferos calcáreos son raros o mal preservados. La asociación comprende abundantes foraminíferos aglutinados de tamaño pequeño (>63-125 μm). Esta asociación se interpreta como típica de sedimentos ricos en materia orgánica y de depósitos de turbiditas de aguas profundas (ambiente batial medio-superior).

Palabras clave: Foraminíferos bentónicos, Oligoceno, Mioceno, Colombia, paleoecología.

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INTRODUCTION

Benthic foraminifera inhabit marine environment and are one of the most important components of modern and ancient benthic communities. As they live in a large enough number to be quantitatively studied in small samples they are frequently used for paleoenviromnental reconstructions. Thousands are the works in which modern distribution pattern of benthic foraminifera are used to make interpretations about the ecological preferences of fossil associations. The benthic foraminifera occurrences, frequencies and distributions are related to the physico-chemical character of the bottom water masses, the bathymetry, the kind of substrate, the supply of organic matter to the seafloor, the nutrient influx and the oxygen concentration at the sediment-water interface (Murray 1991, Sen Gupta 1993, Kaiho 1994, Leckie and Olson 2003, among others).

Benthic foraminifera are one of the most useful groups for ancient marine environment interpretation especially in studying Cenozoic deposits because the majority of Cenozoic foraminifera genera are still represented in modern associations.

The purpose of this study is to describe (with quantitative analysis) the benthic foraminiferal content of the El Carmen Formation within the stratigraphic section Arroyo Alférez (Carmen de Bolívar, Colombia (FIGURE 1) with the aim of detecting paleoenvironments and paleoenvironmental changes during the Oligocene – Lower Miocene. The paleoenvironmental interpretation this work proposes is based on quantitative analysis of either agglutinated or calcareous benthic foraminifera greater of 63µm.

The stratigranphic section (FIGURE 1), measured and sampled along the small river Alférez (starting point 9° 43' 10.77" – 75° 9' 9.50" and final point 9° 42' 41.31" – 75° 7' 3.67"), is 1900m long and mainly comprises the El Carmen Formation and at the bottom the upper interval of the San Jacinto Formation. The El Carmen Formation

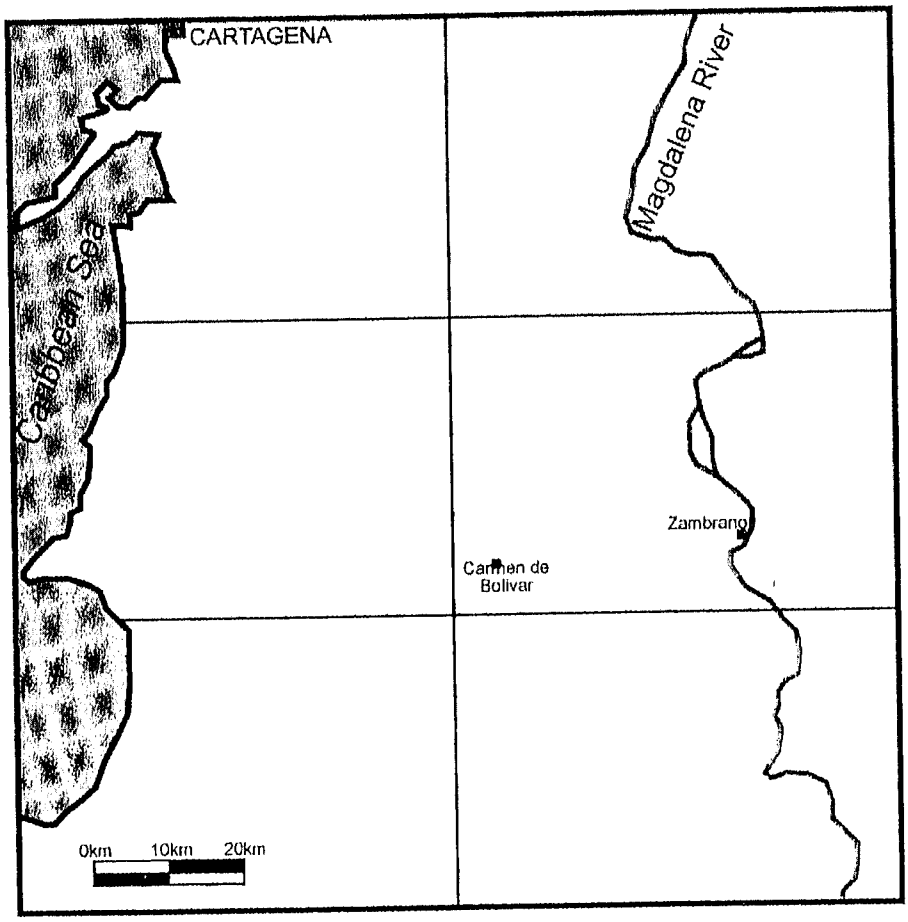

FIGURE 1. Location Map of the sampling area.

is characterized from silty-claystones or interbedded claystones, siltstones and sandstones. In some interval the Formation is characterized by sandstone with siltstone and claystone intercalations.

PREVIOUS WORKS

Little is published about Cenozoic benthic foraminifera from Northern Colombia. Moreover, benthic foraminifera occurrences and distributions have been mainly used for biostratigraphy rather than paleoecology. Particularly, the information about the paleoecology of benthic foraminifera are poor, based on qualitative analysis and often obtained using only the coarser fraction (>125μm) of the foraminiferal content which, as we can see also from this work (FIGURE 2), eliminates a large fraction of the fauna.

Petters and Sarmiento (1956) studied with qualitative analysis the foraminiferal content of El Carmen Formation in the Carmen-Zambrano area mainly to propose a zonation but also to propose a paleoenvironmental interpretation and to describe 9 new calcareous benthic species. Benthic foraminifera from deepwater Oligocene-Lower Miocene sediments are described in the nearby areas of Falcon Basin (Venezuela) and Trinidad (Bolli et al., 1994).

METHODS

Samples were collected on outcrops along Alferez river and positioned along a stratigraphic section (Rey and Ramírez, 2005).

Eighty samples collected every 10-15 meters along the entire length of the section, have been selected for micropaleontological analysis using benthic foraminifera. Samples (about 20g each) have been processed to obtain a concentrate residue of microfossils for quantitative analysis.

To achieve complete brake down, samples have been: dried at 40°C, soaked in water and washed through a sieve with 63μm mesh, treated in an ultrasonic cleaner, washed and dried again. Incompletely disaggregated samples were ultrasonically treated several times.

All the washing residual was examined for the analysis to investigate about the presence of foraminifera, other microfossils, piryrite and py tritized microfossils, oxidation and oxidized foraminifera, foraminiferal fragments, traces of dissolution, sand grains.

Benthic foraminifera where identified at the specific level (where possible) or at the generic one. Identifications relied mainly upon original descriptions (from Ellis and Messina, 1940) and also upon Petters and Sarmiento (1956), van Morkhoven et al. (1986), Loeblich and Tappan (1987), Bolli et al. (1994) and Bornmalm (1997).

After the preliminary qualitative analysis, samples were split into portion of about 300 individual foraminifera. The two fractions >63-125μm and >125μm were counted separately.

The frequencies of the recorded foraminifera or foraminiferal groups were plotted as frequency graphics (FIGURE. 3). Selected specimens were photographed with SEM (FIGURE 4).

Collection slides and washing residual of examined samples are stored at ICP Ecopetrol – Colombia.

RESULTS

All the samples collected within the fine grain sediment (claystone and siltstone) contain foraminifera. Sandy samples were barren or poor of foraminifera. In the last case foraminifera result to be oxidized and in a bad state of preservation with respect to those recovered within fine grain sediments.

Reworked specimens with filled tests, abraded surface and a red patina of hydrous iron oxide are present in the majority of the studied samples, particularly in those samples with a higher percentage of sand. The taxa that are mostly affected by taphonomic effects like abrasion, opaque tests and fracture are the calcareous ones, especially the smaller ones or the ones with more delicate test. As the fracture and dissolution affect from the 26 to the 84% of the planktic foraminifera the plankton /benthic ratio has not been used for bathymetric interpretation of the studied samples.

Pyritization is very common either in calcareous or agglutinated foraminifera. Deformation and compression

mostly affect agglutinated foraminifera with organic cement.

Planktic foraminifera are present within the fossiliferous samples of the entire section with different percentages and in different state of preservations well as benthic foraminifera. The last ones are characterized mostly by agglutinated specimens that for the majority of the analyzed samples dominate or totally compose the association. Among the agglutinated foraminifera the small-size ones >63-125μm dominate the association where either calcareous benthic foraminifera or big size agglutinated reach the lower percentages (FIGURE 2).

Benthic foraminifera recovered within the studied section have been divided in the following groups and their frequencies have been plotted in FIGURE 3:

- CALCAREOUS FORAMINIFERA Calcareous foraminifera recovered within the studied section are present with species belonging to the genera *Bulimina, Uvigerina, Siphonodosaria, Bolivina, Cibicidoides, Nodosaria, Gyroidina, Anomalina, Pullenia, Lagena, Plectrofrondicularia, Lenticulina, Sigmomorphina, Laticarinina* and *Globocassidulina*. The above mentioned genera are mainly infaunal, detritivorous and inhabit organic-rich and low-oxygen envoronment. There is a scattered occurrence of Miliolidae that are reported as rare and with a broken and pyritized test.
- *SPIROSIGMOILINELLA TENUIS* This species that was previously described as belonging to the family Miliolidae and in several works (Petters y Sarmiento, 1956; Bornmalm, 1997) is reported as *Sigmoilina tenuis* (Czjzek), occurs in the majority of the studied samples and in all the cases in relatively low percentage (<10%). *Spirosigmoilinella tenuis* presents a wall that is finely agglutinated test on an organic base, is insoluble in acid and presents an aperture that is not provided with a tooth.
- AGGLUTINATED FORAMINIFERA GROUP 1 The microfauna that characterize this group consists of big size oportunistic genera (mainly >125μm) that agglutinate coarse grain particles, mainly quartz. *Haplophragmoides* is the most represented genera of this group. Foraminifera belonging to this group are more abundant in coarse grain sediments.
- AGGLUTINATED FORAMINIFERA GROUP 2 The foraminifera that characterize this group

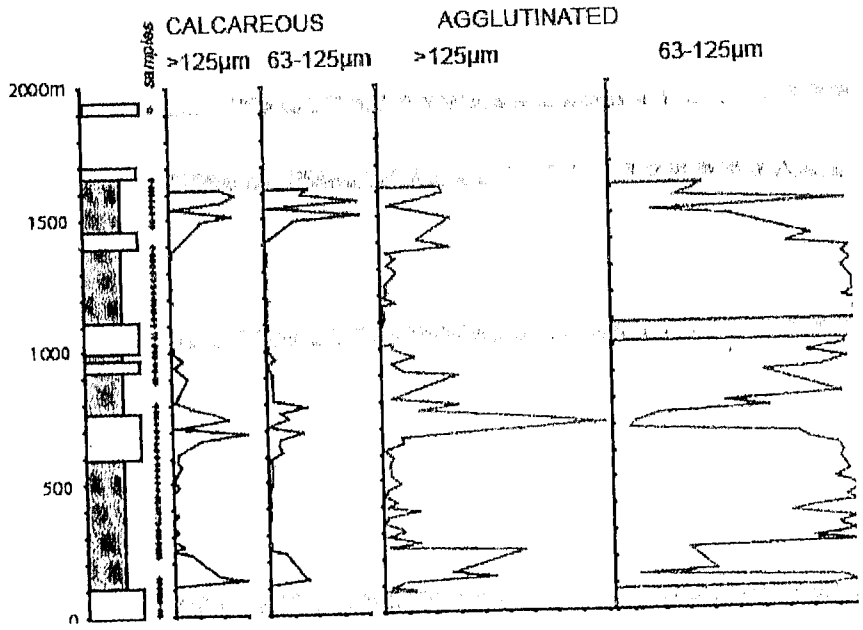

FIGURE 2. Percentages of calcareous and agglutinated benthic foraminifera. The intervals marked in pale gray result to be barren or contain poorly preserved benthic foraminifera and samples have not been considered for quantitative analysis.

are fine grain, mainly small size (>63-125μm), opportunistic, with a tapered, biserial, planispiral and trochoid coiling. They mostly are mobile or shallow infaunal and belong to the genera *Trochamina, Haplophragmoides* and *Verneulinulla.* This group very frequently charachterize the 90-100% of the benthic association.

- AGGLUTINATED FORAMINIFERA GROUP 3. It comprise not opportunistic, slow-growing, big –size, deep-infaunal mainly belonging to the genera *Schenkiella, Vulvulina* and *Martinottiella.* They occur in the section in small percentages and never characterize the association.
- AGGLUTINATED FORAMINIFERA GROUP 4. The group consists of tubular shape foraminifera or foraminiferal fragments. They manly agglutinate coarse particles (quartz). The most represented genus is *Bathysiphon* that occurs together with *Rizhammina.*
- AGGLUTINATED FORAMINIFERA GROUP 5. It comprise other benthic foraminifera (*Glomospira, Cyclammina, Recurvoides, Reticulophragmium, Ammodiscus*).

The lower part of the stratigtraphic section (from the bottom to 63.13 m) is characterized by a sandy and barren interval. Foraminifera belonging to the agglutinated group 2 occur between 82.50 and 93.38m. Between 113.63 and 231.63m the samples are sandy and contain a pyritized and oxidized association with either calcareous or agglutinated foraminifera. The interval between 246.38 and 461.63 m is composed by fine grain sediments (mainly characterized by agglutinated foraminifera of group 2) with some coarser intervals containing also calcareous foraminifera and specimens from the other agglutinated groups. From 487.63 to 663.13m the section is mainly sandy and contains mixed calcareous and agglutinated microfauna. Calcareous foraminifera from this interval are poorly preserved mainly due to pyritization and oxidation. From 687.63 and 897.63 m the samples contain sand and the association is characterized by high percentage of agglutinated foraminifera with a tubular shape, low abundance, paucity of foraminifera in the finer fraction (>63-125μm), occurrence of rare not fractured calcareous foraminifera (and among those broken test of calcareous foraminifera with a tubular shape like *Nodosaria*). From 910.88 to 1014.63m the assocaiation is mainly characterized by agglutinated foraminifera either in sandy or fine grain sediments.

Between 1038.38 and 1069.13m the section is sandy and contains few big size foraminifera: due to the low abundance and the bad preservation of the calcareous

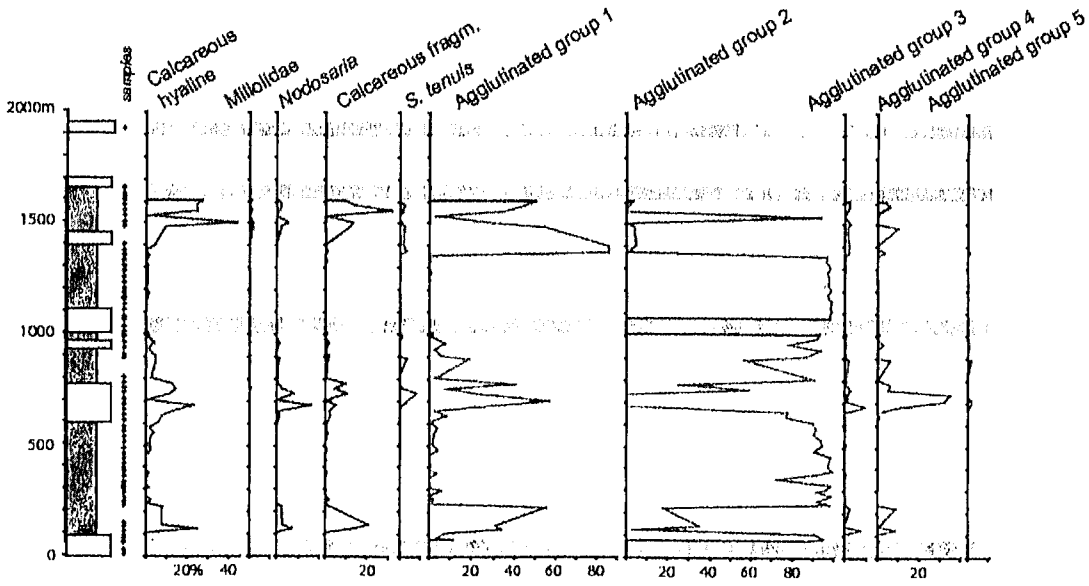

FIGURE 3. Frequency graphics of benthic foraminifera or foraminifera groups.

tests samples for this interval were not counted. From 1082.88 to 1362.85m the analyzed samples were recovered in fine grain sediments and the association is for the majority composed by abundant small-size agglutinated foraminifera belonging to group 2. From 1382.88 to 1666.88m the association contains either calcareous or agglutinated foraminifera. The first ones results mainly fractured and strongly oxidized especially in the upper part of the interval (from 1625.88m upwards) were foraminifera were not counted. The uppermost part of the section (1935.13m) results barren.

DISCUSSION

Paleoenvironmental interpretation is based on the comparison between the recovered associations and similar associations from either recent environments (several species and almost all the genera occurring in this section are still living in today's environment) or fossil associations from different areas.

Associations with abundant, small-size, opportunistic, mainly infaunal agglutinated foraminifera recovered in the majority of the fine-grain sediments is interpreted as representative of dysoxic condition in bathyal environment. Such dysoxic condition can correspond to high epipelagic productivity that produce high level of nutrient fall (organic material) and induce oxygen deficiency. The high foraminiferal abundance in this interval can be caused by the lack of predator dysoxic environments. On seasonally anoxic slope environment the foraminiferal number can reach one or two order of magnitude higher than in well oxygenated environments. (Bernhard and Reimers, 1991). Comparable associations have been reported either from modern environments like recent borderland basins of California in disoxic conditions (Kaminski et al., 1995), or from same-age sediment of different areas like in Miocene sediments from Gulf of Mexico (Green et al., 2004) and in Miocene sediments interpreted as corresponding to an oxygen minimum zone offshore Cabinda (Preece et al., 1999).

Calcareous benthic foraminifera associated with coarse grain agglutinated foraminifera mainly belonging to groups 1, 3 and 5, indicate more oxygenated upper bathyal environment. Infaunal, detritivores, calcareous taxa can tolerate changes in oxygen due to high organic matter environment. While the above mentioned association occurs in sandy sediment, it can be interpreted as indicative of turbidity current or storm induced bottom current. Stressed situations like currents, disturb the bottom sediment, decimate the benthic community, redistribute organic matter. This also explains the low abundance, the presence broken tests and the pyritization.

The association recovered in sandy sediments and containing high percentage of agglutinated foraminifera with a tubular shape (agglutinated group 4), can be considered a severely altered assemblage due to down slope selective transport caused by a turbidity current or bottom current. This can explain why where tubular shape agglutinated foraminifera are abundant also tubular calcareous foraminifera (*Nodosaria*) fragments reach the maximum abunsdance.
Spirosigmoilinella tenuis that occurs in all the above mentioned associations and never dominate the association, inhabits bathyal environments, tolerates stressed conditions and present a resistant test.

Pyritization of foraminifera and other organisms (diatoms) suggests a low oxygen and high organic carbon environment.

The dominance of agglutinated foraminifera is linked to a reduced availability of dissolved calcium carbonate typical of organic rich and low pH environments.

The oxidation of foraminiferal test in several samples (especially the ones with a sandy fraction) can be caused by weathering.

The sea water oxygen content and the oxygenation of bottom sediments are the factor that mainly controls the composition of the associations.

Some genera like *Haplophragmoides* and *Trochammina* inhabit different kinds of low oxygen environments. Using the occurrence of those genera does not allow to distinguishing which is the cause of the underoxigenation of the depositional environment.

All the section is interpreted to be deposited in a upper-middle bathyal marine environment close to a continental margin characterized by high nutrients produced by fluvial runoff, upwelling or by the 2 combined phenomena.

The main problems in using benthic foraminifera recovered in Carmen de Bolivar section for biostratigraphy are: a general dissolution that affect the most delicate calcare-

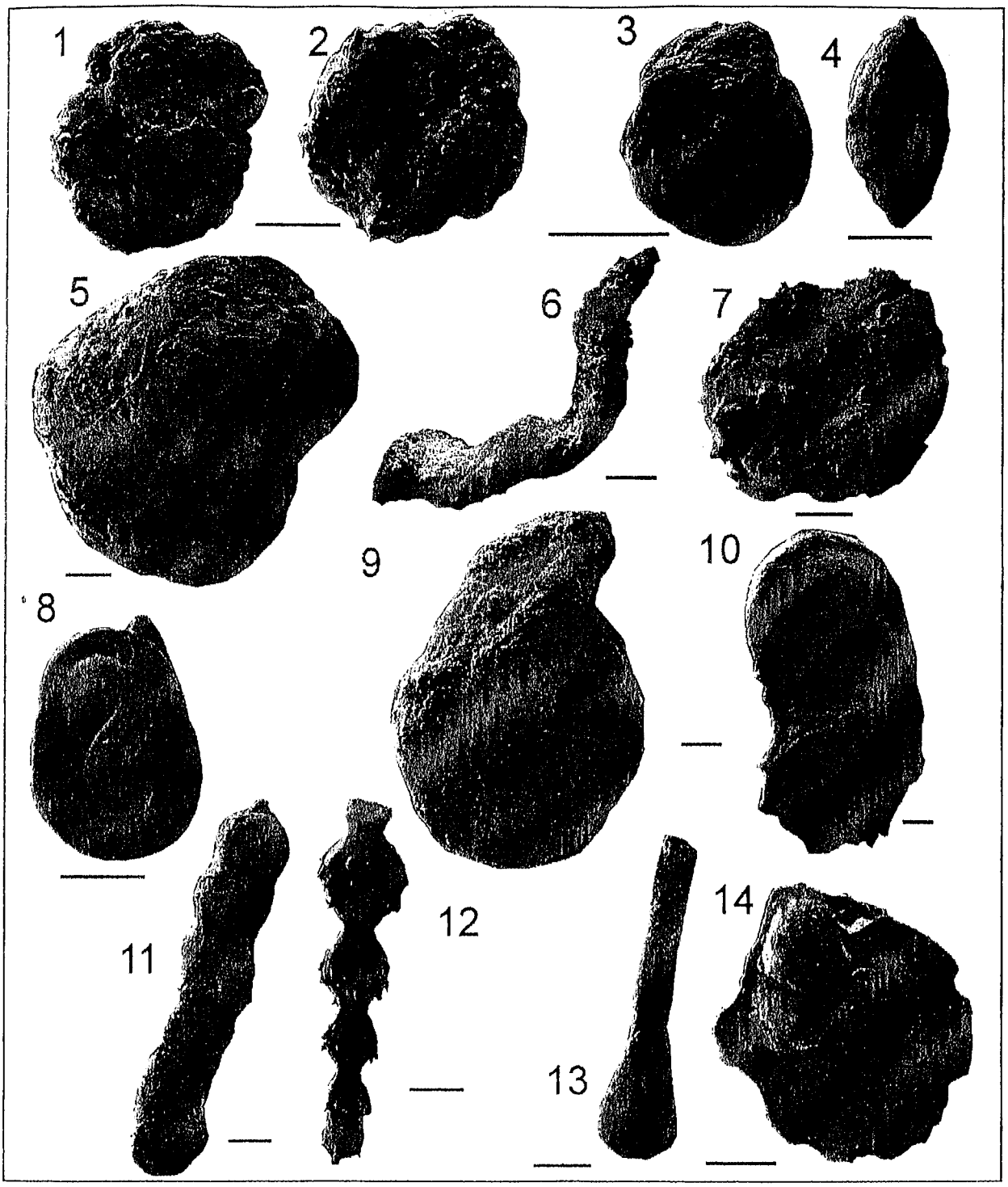

FIGURE 4. Selected illustrations of specimens from Carmen de Bolivar Section. The scale bar correspond to 100µm. 1 and 2: Trochammina sp.1 -1382.88m - dorsal (1) and ventral (2) view. 3: Haplophragmoides aff. H. narivaensis – 231.62m. 4: Spirosigmoilinella tenuis – 1410.63m. 5: Reticulophragmium rotundidorsatum – 711.63m. 6: Rhizammina sp.1 - 711.63m. 7: Haplophragmoides sp.1 - 711.63m. 8: Glomospira sp.1 – 231.63. 9: Cyclammina aff. C. cancellata – 563.63m. 10: Vulvulina stainforthi – 614.63m. 11: Schenkiella pallida – 741.38m. 12: Siphonodosaria nuttalli aculeata – 687.63m. 13: Nodosaria longiscata – 910.88m. 14: Laticarinina bulbrooki – 1590.13m.

ous tests and the difficulty on recognizing those benthic foraminifera that can be reworked or displaced by turbidity currents. Moreover, the agglutinated foraminifera that dominated the benthic association are facies-related and their occurrence or not-occurrence is related to changes of environment and not to biostratigraphic events. Finally, the majority of agglutinated foraminifera specimens is not identifiable at the specific level due to deformation and compression that characterize most of the fossil organic-cemented agglutinated foraminifera.

The fact that most of the benthic foraminifera reported in this section are strongly facies related make they a useful tool in recognizing organic matter rich sediments and deep-water turbidite deposits. The identification in the fossil record of these important associations allows characterizing depositional paleoenvironments corresponding to petroleum source rocks or reservoirs. Benthic foraminifera analysis in the Carmen de Bolivar section allow recognizing the depositional history of the examined sediments and constitute a powerful tool for an accurate facies characterization, resulting in an improved definition of sedimentary bodies.

CONCLUSIONS

• Small-size opportunistic agglutinated foraminifera are strongly facies related: for this reason they are powerful for paleoenvironmental interpretation and useless for detailed biostratigraphy.

• Agglutinated foraminifera associations allow recognizing organic matter rich sediments and deep-water turbidite deposits. The identification in the fossil record of these important associations allows characterizing depositional paleoenvironments that can correspond to petroleum source rocks or reservoirs.

• The Carmen de Bolivar section is mainly characterized by an assemblage indicative of slope (probably upper-middle bathyal) environment under the influence of dysoxic condition.

• This association comprises mainly infaunal opportunistic agglutinated foraminifera with a preference for soft (muddy) sediments.

• Sporadic events of better oxygenation and turbidity or bottom currents produce changes in the foraminiferal association (increase of calcareous and coarse grain agglutinated foraminifera) or decimate the benthic community.

• Benthic foraminifera analysis in the Carmen de Bolivar section allow recognizing the depositional history of the examined sediments and constitute a powerful tool for an accurate facies characterization, resulting in an improved definition of sedimentary bodies.

• Studying the size fraction >63-125μm is necessary to individuate those samples containing opportunistic small-size microfauna that can characterize severely stressed environmental conditions.

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