

# OLIGOCENE BENTHIC FORAMINIFERA FROM THE FUENTE CALDERA SECTION (SPAIN, WESTERN TETHYS): TAXONOMY AND PALEOENVIRONMENTAL INFERENCES

RAQUEL FENERO<sup>1,2,5</sup>, ELLEN THOMAS<sup>3,4</sup>, LAIA ALEGRET<sup>1</sup> AND EUSTOQUIO MOLINA<sup>1</sup>

## ABSTRACT

The effects of Oligocene paleoclimatic and paleoenvironmental events at lower latitudes have not been well defined, and the timing and extent of a proposed warming period in the late Oligocene are not clear. The study of benthic foraminifera from the upper bathyal Fuente Caldera section in southern Spain may help reconstruct the Oligocene paleoenvironmental turnover in the western Tethys. Rupelian and Chattian sediments from Fuente Caldera consist of hemipelagic marls intercalated with turbiditic sandstones. Based on a closely spaced sample collection, we present a quantitative analysis of benthic foraminiferal assemblage changes, and a detailed taxonomic study of 19 of the most abundant and paleoenvironmentally important species, belonging to the asterigerinids, rosalinids and bolivinids.

The Fuente Caldera sediments contain abundant reworked neritic foraminifera (asterigerinids, rosalinids, *Cibicides* spp.), including epiphytes and species that commonly bear symbionts or kleptochloroplasts from the photic zone, that may have been transported downslope by turbidity currents or attached to floating plant material. The high relative abundance of bolivinid taxa in the autochthonous assemblages suggests a high food supply, probably at least in part consisting of refractory organic matter supplied by downslope turbidity currents. The benthic foraminifera indicate that water temperatures were several degrees warmer than today, as inferred from the common occurrence of warm-water taxa such as *Nodobolivinella jhingrani*, *Rectobolivina costifera* or *Tubulogenerina vicksburgensis*. Nevertheless, further paleotemperature studies are needed to test our conclusion that warm conditions prevailed in this part of the western Tethys during the Oligocene, even during colder intervals (Oi-events).

## INTRODUCTION

The Oligocene epoch was marked by abrupt climate changes, including intense cooling at high latitudes (Liu and others, 2009) and the establishment of a continent-sized ice sheet in the earliest Oligocene (e.g., Zachos and others, 2001; Coxall and others, 2005; Ivany and others, 2006; Katz and others, 2008). The development of the south polar ice

sheet has been explained as resulting from the opening of tectonic gateways around Antarctica (Tasmanian gateway, Drake passage) and subsequent thermal isolation of the continent (e.g., Kennett, 1977), but more recently declining levels of atmospheric CO<sub>2</sub> have been considered a more probable cause (De Conto and Pollard, 2003; Pagani and others, 2005; Thomas and others, 2006). The establishment of the Antarctic ice sheet was followed by fluctuations in its volume and related changes in eustatic sea level, with short-term fluctuations between warmer and colder intervals occurring at orbital frequencies and with some of the more extreme cold events occurring at low obliquity (e.g., Oi-events; Wade and Pälike, 2004; Coxall and others, 2005; Pälike and others, 2006). The effects of the paleoclimatic and paleoenvironmental variability at lower latitudes have not been well defined, and the extent and timing of the proposed warming in the late Oligocene is not clear (e.g., Cramer and others, 2009). During the late Eocene and Oligocene, the Fuente Caldera section was located at lower latitudes, between 30–40°N (Fig. 1). Geologically, it belongs to the external zones of the Betic Cordillera within the median Subbetic realm, which was a subsiding marine trough during the Oligocene.

The taxonomic and quantitative study of benthic foraminifera from the Fuente Caldera section allowed us to reconstruct the Oligocene paleoenvironments of this part of the western Tethys. Foraminifera are the most diverse, abundant, and widely distributed marine protozoa, with benthic forms occurring from the intertidal zone to the deepest trenches (e.g., Gooday, 2003; Jorissen and others, 2007; Pawlowski and Holzmann, 2008; Gooday and Jorissen, 2011). Benthic foraminifera are excellent indicators of paleodepth (Fig. 2), oceanic productivity, and/or oxygenation at the sea floor (e.g., Jorissen and others, 2007; van der Zwaan and others, 1999). They generally have short generational times of weeks to a few years (e.g., Murray, 1991; Gooday, 2003), and thus are able to react rapidly to local and global environmental changes (e.g., Gooday and others, 2009a, 2009b; Gooday and Jorissen, 2011). These organisms have long stratigraphic ranges and cosmopolitan occurrences (e.g., Thomas, 2007; Gooday and Jorissen, 2011), and their assemblages can be used to reconstruct changes of geologic time-scale magnitude in global oceans (e.g., Thomas, 2007; Gooday and others, 2009a) and short-term changes caused by human activities, such as pollution and eutrophication (Alve, 1995; Gooday and others, 2009b).

The comparison of fossil and Recent communities of benthic foraminifera in morphotype analysis (e.g., Jones and Charnock, 1985; Corliss and Chen, 1988; Mackensen and others, 1995) may allow us to infer general microhabitat species preferences, specifically an epifaunal of infaunal mode of life. The relative abundance of the

<sup>1</sup> Departamento de Ciencias de la Tierra and Instituto Universitario de Investigación en Ciencias Ambientales de Aragón, Universidad Zaragoza, Pedro Cerbuna 12, E-50009 Zaragoza, Spain

<sup>2</sup> Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510 México D.F., México

<sup>3</sup> Department of Earth and Environmental Sciences, Wesleyan University, Middletown, CT 06459-0139, U.S.A.

<sup>4</sup> Department of Geology and Geophysics, Yale University, New Haven, CT 06520-8109, U.S.A.

<sup>5</sup> Correspondence author. E-mail: rfenero@unizar.es

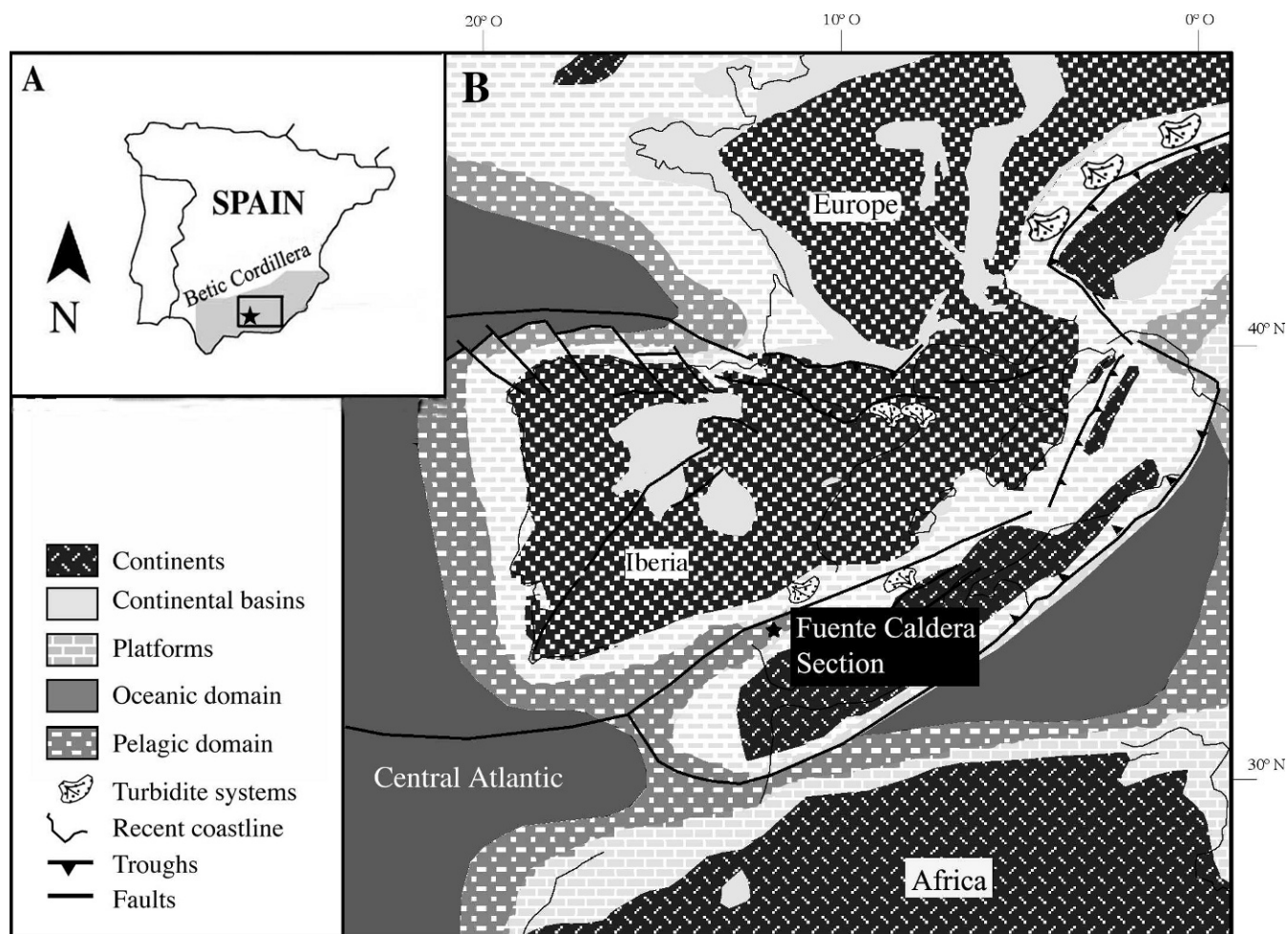


FIGURE 1. **A** Location of the Fuente Caldera section in the Betic Cordillera of southern Spain. **B** Paleogeographic reconstruction of the European continent during the Eocene-Oligocene transition, modified from Andeweg (2002).

morphotypes can be used as a proxy for environmental parameters such as the nutrient supply to the seafloor and bottom-water oxygenation (e.g., Bernhard, 1986; Jorissen and others, 1995, 2007). We must be careful in these analyses, because microhabitats of extinct foraminifera can only be inferred from data on Recent foraminifera (e.g., Jorissen and others, 2007), whose ecology is complex and not fully understood (e.g., Murray, 2006; Jorissen and others, 2007). In fact Buzas and others (1993) estimated that proposed relationships between Recent test morphologies and microhabitats may be accurate only about 75% of the time, yet we do not know to what extent Oligocene faunas were non-analog to living faunas (e.g., Lagoe, 1988; Thomas, 2007). Therefore, only major changes in percentages of morphogroups are likely to be significant for paleoenvironmental reconstructions (Gooday, 2003).

Ours is the first taxonomic study of the most important groups of benthic foraminifera of the Fuente Caldera section in the western Tethys. We focused specifically on the taxonomic revision of asterigerinids, rosalinids, and bolivinids, because of their abundance and paleoecological and/or paleobathymetrical importance.

## MATERIAL AND METHODS

The Fuente Caldera section (Molina and others, 2006; Alegret and others, 2008) is situated in northern Granada province, southern Spain, with UTM coordinates at the base and top of the section of 30SVG836571 and 30SVG835575, respectively. It exposes Oligocene beds of the Cañada Formation of the Cardela Group (Comas, 1978; Comas and others, 1984–85; Fig. 1), which show sea-level and foraminiferal assemblage changes possibly related to cooling and tectonic events (Alegret and others, 2008).

The section consists of a 370-m-thick sequence of hemipelagic marls interbedded with turbiditic sandstones, spanning the Rupelian-Chatian stages (Figs. 3, 4). The hemipelagic marls are rich in planktonic foraminifera and calcareous nannofossils, and contain common small benthic foraminifera, rare ostracodes, and rare echinoid and mollusc fragments (Molina, 1986; Monechi, 1986). The foraminifera were sampled from the autochthonous marls, and are adequately preserved to detect diagnostic morphological features (Figs. 5–7), although preservation varies from sample to sample. The calcareous sandstones contain abundant larger foraminifera, probably reworked by

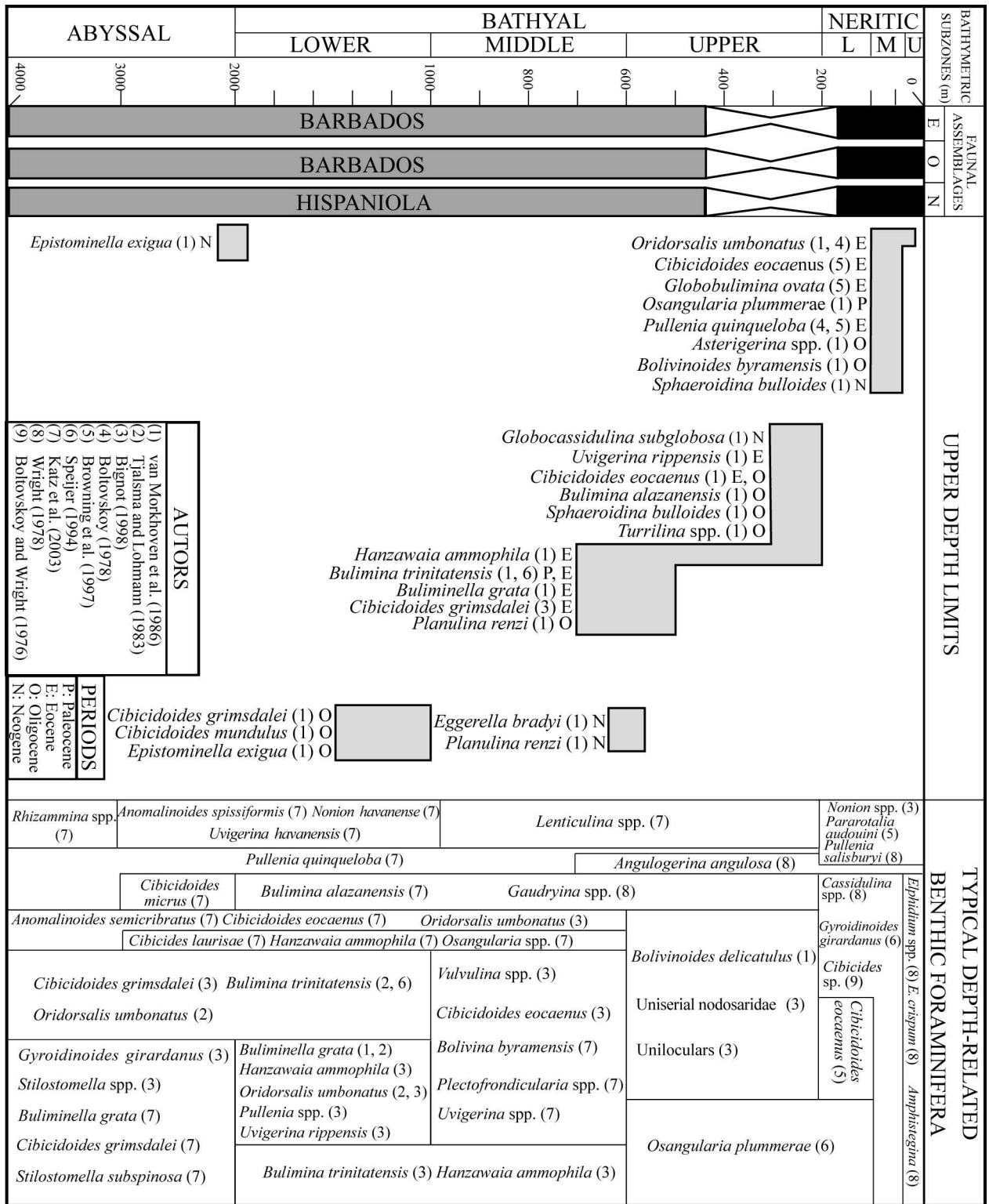


FIGURE 2. Upper depth limits and common paleobathymetric distribution of selected foraminifera found in the Fuente Caldera section. Faunal Assemblages—E: Eocene, O: Oligocene, N: Neogene.

turbidity currents and transported downslope from the shallow neritic environments.

Benthic foraminifera were reexamined for taxonomic and paleoenvironmental studies from the samples of Alegret and others (2008). The reexamination allowed us to justify

the hypothesis of the occurrence of a climatic change at the 127–166 m interval on the basis of the stratigraphic and sedimentological data. Eleven new samples were analyzed in the Fuente Caldera section (Appendix 1) including the 127–166 m interval, from all of which we recalculated

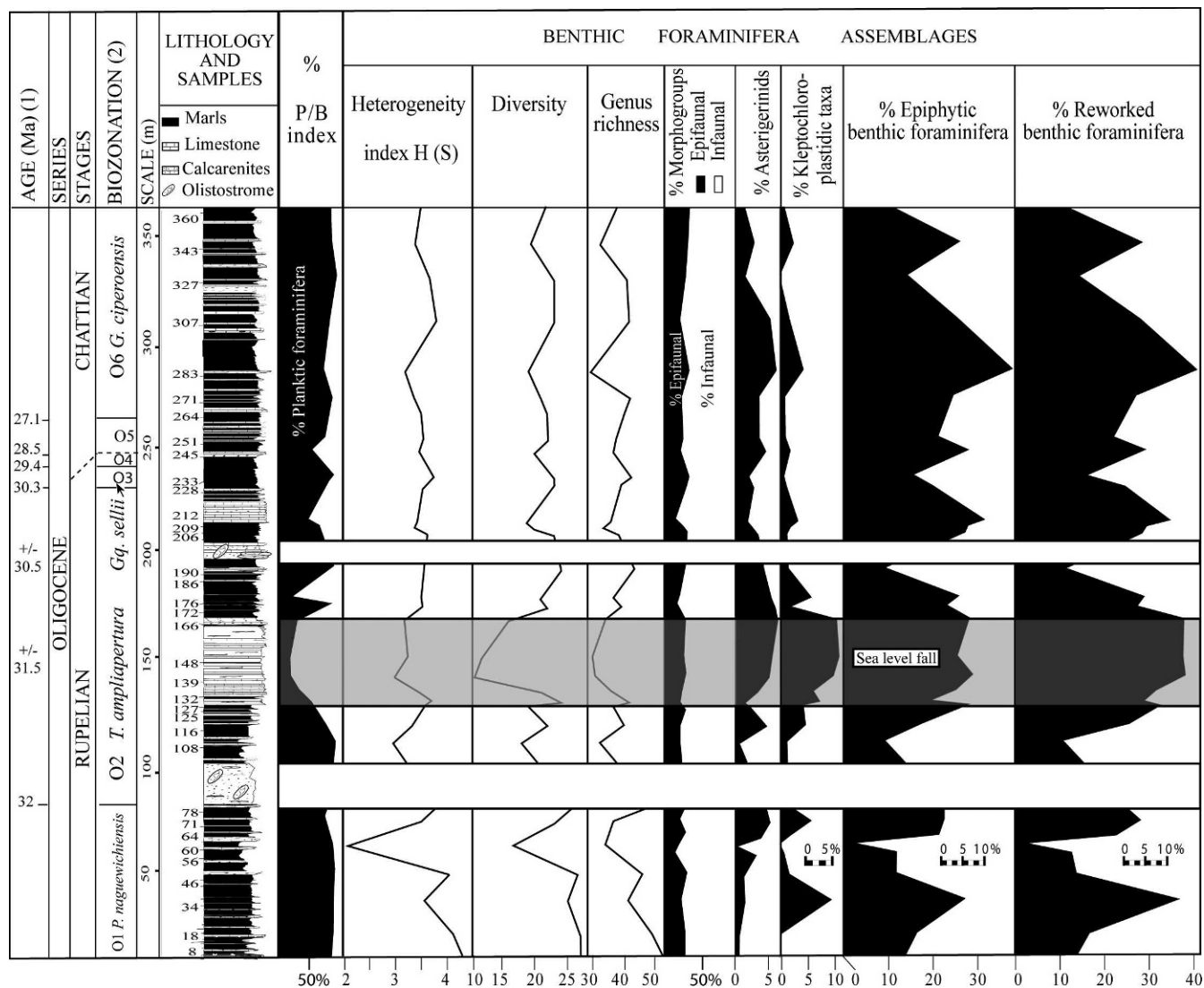


FIGURE 3. Planktic/benthic index, benthic foraminiferal indices, and relative abundance of infaunal/epifaunal morphogroups, asterigerinids (*Asterigerina campanella*, *Asterigerinoides subacutus*), kleptochloroplastidic taxa, epiphytic benthic groups (asterigerinids, *Cibicides lobatulus*, *C. refulgens*, *Rosalina globularis*, *Neoconorbina terquemi*), and relative abundance of reworked benthic foraminifera across the Oligocene at the Fuente Caldera section. 1: Age of biozone boundaries, after Berggren and Pearson (2005). 2: Biozones of Berggren and Pearson (2005), after Alegret and others (2008). Biozones: O4—*Globigerina angulisurealis/Chiloguembelina cubensis*, O5—*Paragloborotalia opima*.

faunal indices and percentages of benthic foraminiferal groups. Samples were disaggregated in water with diluted H<sub>2</sub>O<sub>2</sub>, washed through a 100-µm sieve, and dried at 50°C. We used a methylene blue staining solution after each wash to recognize possible contamination during the sample processing, and excluded stained specimens from the analyses. The quantitative and taxonomic studies were based on representative splits of ~300 specimens of the >100-µm fraction, obtained with an Otto microsplitter. The remaining residue was searched for rare species. All representative specimens were mounted on microslides for identification and repositied in the Department of Earth Sciences, University of Zaragoza, Spain.

Paleobathymetric estimates are based on the occurrence and abundance of depth-dependent species and on comparisons to benthic foraminiferal assemblages at different sites (Fig. 2). We calculated the percentage of planktonic species to estimate depositional depths (e.g., van der Zwaan

and others, 1990; Hayward, 2004) that fall within the following bathymetric zones: neritic (<200 m), upper bathyal (200–600 m), middle bathyal (600–1000 m), lower bathyal (1000–2000 m) and abyssal (>2000 m) (van Morkhoven and others, 1986).

PALEOBATHYMETRY

Paleodepth inferences were based on the upper-depth limits and total-depth distribution ranges of benthic foraminifera as compiled in Figure 2. Autochthonous benthic foraminiferal assemblages at Fuente Caldera are dominated by bolivinids (*Bolivina*, *Brizalina*, and *Bolivinoides*), asterigerinids (*Asterigerina* and *Asterigerinoides*), and rosalinids (*Neoconorbina* and *Rosalina*) (Fig. 4 and Appendix 1). In general, abundant bolivinids occur in the present oceans at lower-shelf–upper-slope depths (e.g.,

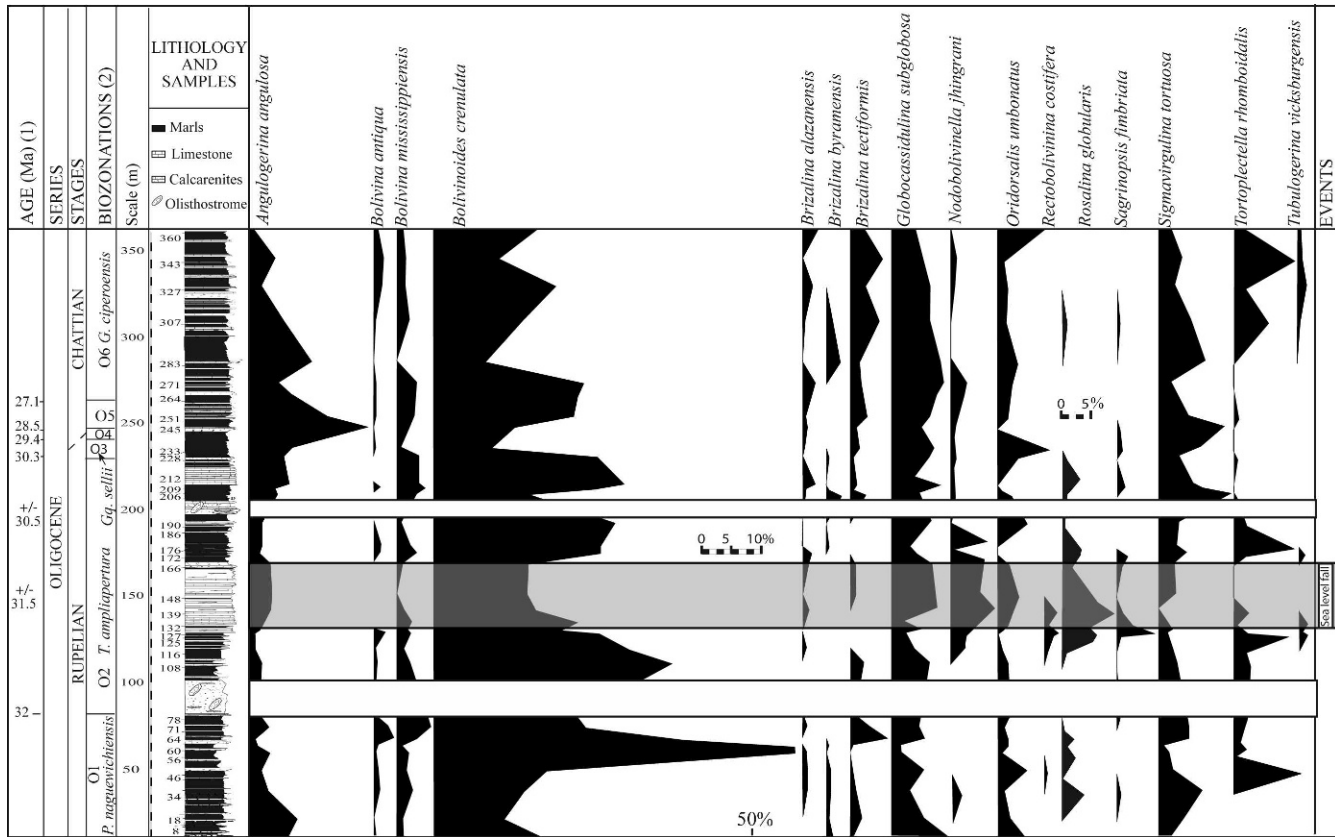


FIGURE 4. Distribution and relative abundance of benthic foraminiferal species across the Oligocene section at Fuente Caldera. 1: Age of biozone boundaries, after Berggren and Pearson (2005). 2: Biozones of Berggren and Pearson (2005), after Alegret and others (2008). Biozones: O4—*Globigerina angulifurcata*/*Chiloguembelina cubensis*, O5—*Paragloborotalia opima*.

Murray, 1991). Agglutinated species are scarce (1–5%), and dominated by uniserial taxa [e.g., *Rhabdammina cylindrica* (Glaessner, 1937)] and species of the genera *Karriella* and *Vulvulina*, generally described from bathyal depths (Kaminski and Gradstein, 2005; Fenero, 2010). Typical depths for these taxa may have been different during the Oligocene (Lagoe, 1988).

Many typically bathyal species occur abundantly in our samples. These include *Bulimina alazanensis* (Cushman, 1927), *B. macilenta* (Cushman and Parker, 1939), *B. trinitatis* (Cushman and Jarvis, 1928), *Brizalina tectiformis* (Cushman, 1926), *Cibicidoides eoaeus* (von Gümbel, 1868), *C. mundulus* (Brady, Parker, and Jones, 1888), *Hanzawaia ammophila* (von Gümbel, 1868), and *Buliminella grata* (Parker and Bermúdez, 1937) (e.g., Tjalsma and Lohmann, 1983; Wood and others, 1985; Nocchi and others, 1988; Katz and others, 2003; Fig. 2), and one, *Bulimina semicostata* (Nuttall, 1930), has a depth range of 1000–3200 m (Katz and others, 2003). We also identified rare taxa generally considered to live at abyssal depths, such as *Cibicidoides grimsdalei* (Nuttall, 1930) and *Vulvulina spinosa* (Cushman, 1927) (e.g., van Morkhoven and others, 1986; Fig. 2).

Upper-neritic taxa occur at variable relative abundances (Fig. 3, Appendix 1), including epiphytic species that live on aquatic vegetation in the photic zone such as *Cibicides lobatulus* (Walker and Jacob, 1798), *C. refulgens* (de Montfort, 1808), *Asterigerina campanella* (Gümbel, 1868),

*Asterigerinoides subacutus* (Cushman, 1922), *Neoconorbina terquemi* (Rzehak, 1888), and *Rosalina globularis* (d'Orbigny, 1826), symbiont- and kleptochloroplast-bearing species limited to the photic zone such as the larger foraminifera *Amphistegina radiata* (Fichtel and Moll, 1798), and other species such as *Elphidium advenum* (Cushman, 1922), *E. ancestrum* (Le Calvez, 1950), *E. macellum* (Fichtel and Moll, 1798), *Elphidium* sp. A, *Pararotalia audouini* (d'Orbigny, 1850), and *Protelphidium laeve* (d'Orbigny, 1826). The genera *Amphistegina*, *Cibicides*, and *Elphidium* have their upper-depth limits in the inner-neritic zone (e.g., Wright, 1978; Murray, 1991; Hayward, 2004).

The planktonic/benthic foraminiferal ratio (P/B) varies between 21–95%, with the lowermost values in samples from 132–166 m above the base of the section (*Turborotalia ampliapertura* Biozone, Rupelian; Fig. 3), where neritic species are most abundant. The generally high P/B ratios (>90%), the high diversity and heterogeneity of the benthic assemblages, and the most abundant species indicate deposition at upper-bathyal depths, with variable input of neritic taxa either by turbidity currents (which were active to some extent also during deposition of the hemipelagic marls) and/or as epiphytic taxa that may have been transported by floating plant material. The resulting assemblages thus consist of a mixture of autochthonous and allochthonous foraminifera (Figs. 3, 4), consistent with the paleogeographical location of Fuente Caldera in a

narrow arm of the ocean (Fig. 2) on a steep continental slope close to coastal photic zones (Alegret and others, 2008; Fenero, 2010).

#### PALEOECOLOGY AND PALEOENVIRONMENTS

Benthic foraminiferal assemblages are diverse (34–90 species and 27–55 genera/ sample; Fischer- $\alpha$  values between 12–28) and heterogeneous (Shannon-Weaver index values generally between 3.2–4.0) (Fig. 3). These values reflect typical deep-sea populations, with few dominant species and many with low abundance (e.g., Gooday, 2003). Benthic foraminiferal assemblages are dominated by calcareous taxa (95–99%), and there is no evidence of carbonate dissolution, indicating deposition well above the calcite compensation depth.

Assemblages are dominated by infaunal taxa (65–85%), and bolivinid species are abundant in many samples. Recent bolivinids prefer a shallow, infaunal microhabitat, and opportunistically dominate in environments with combined sediment instability and rich organic matter (Hess and Jorissen, 2009). They occur in environments with low oxygenated bottom waters and/or high organic-carbon flux rates to the seafloor (e.g., Fontanier and others, 2005; Jorissen and others, 2007). We have not found independent evidence for low-oxygen conditions (e.g., laminated sediments, high organic-carbon content) and suggest that the high bolivinid abundance resulted from a high flux of low-quality, refractory organic matter to the seafloor (e.g., Koho and others, 2008; Hess and Jorissen, 2009). This organic matter may have been transported from shallow areas to deeper parts of the basin by turbidity currents (as observed in the recent Bay of Biscay by Hess and Jorissen, 2009) and during flooding of the shelf. The abundance of bolivinids, together with the low percentage of epifaunal benthic foraminifera (15–35%), indicates eutrophic to mesotrophic conditions. The refractory organic matter may have been fully consumed by the benthic population before it could degrade and create dysoxic conditions at the seafloor, inferring that bottom waters at Fuente Caldera were well oxygenated.

Alegret and others (2008) documented two olistostrome levels within the Rupelian sediments at Fuente Caldera (Figs. 3, 4), and suggested that they possibly correlated with cold intervals. In addition, they inferred a sea-level fall in the middle part of the *Turborotalia ampliapertura* Biozone (130–166 m above base of section) that might correspond to the Oi-2 event (Wade and Pälike, 2004; Pälike and others, 2006). Our new data show very low P/B values, low diversity, and abundant reworked neritic benthic foraminifera in this interval (Fig. 3), thus supporting correlation with the glacio-eustatic sea-level fall that has been globally recognized at the Oligocene Glacial Maximum and marine isotope Zone Oi-2, although that event is now recognized as less pronounced (Browning and others, 2008; Kominz and others, 2008) than argued by Haq and others (1987). The cold intervals at Fuente Caldera have higher relative abundances of reworked neritic foraminifera (Figs. 3, 4), mixed with the autochthonous bathyal forms. Intense reworking occurred during overall low sea-level stands, with sediments deposited in upper-neritic settings during

warmer periods of higher sea level being eroded and transported downslope.

The common occurrence of reworked but well-preserved tests of epiphytic species suggests that the plants on which these species were living may to some extent also have been transported to deeper settings, adding to the benthic food supply by lateral transport, possibly through canyons, as seen in oceans today (e.g., Bay of Biscay; Fontanier and others, 2005). The good preservation of the epiphytic specimens may point to synsedimentary transport and deposition, rather than reworking of significantly older material. The rapid transport and deposition of rafted epiphytic species are consistent with a very steep continental-slope setting (Alegret and others, 2008; Fenero, 2010).

Reworked neritic foraminifera include larger foraminifera and abundant autochthonous smaller benthic foraminifera [e.g., *Nodobolivinella jhingrani* (Kalia, 1981; Fig. 4)]. In the modern oceans, nodobolivinellid species live in inner-neritic, relatively high-energy environments of normal salinity in tropical to warm-temperate seas that never drop below 12–15°C (Hayward, 1990). *Globocassidulina subglobosa* (Brady, 1881), which is abundant at Fuente Caldera (Fig. 4), is listed as a cold-temperate to temperate species in modern faunas, occurring in water masses between 4–20°C (Murray, 1991); however, in the Oligocene this species preferred warmer conditions (e.g., Corliss, 1981; Wood and others, 1985). These occurrences, together with those of common, shallow, warm-water species such as *Rectobolovina costifera* (Cushman, 1936) and *Tubulogenerina vicksburgensis* (Howe, 1930) (Alegret and others, 2008; Fig. 4), point to overall warm conditions at Fuente Caldera, even during the intervals correlated with the colder Oi-events. Nevertheless, further multidisciplinary studies are needed to confirm the potentially warm paleotemperatures at Fuente Caldera during the Oligocene.

#### TAXONOMY

##### BACKGROUND

Generic determinations and suprageneric classification followed Loeblich and Tappan (1987) except for *Nodobolivinella* that was classified according to Hayward (1990). Species identifications were based on numerous taxonomic studies including Tjalsma and Lohmann (1983), van Morkhoven and others (1986), Bolli and others (1994), Alegret and Thomas (2001), Holbourn and others (2005), and Ortiz and Thomas (2006). After preliminary analysis, all samples were reexamined, and the best preserved benthic specimens were selected for species description and SEM study. Our material was compared to type specimens deposited in the Cushman (CC) and National Museum of Natural History (USNM) collections, Smithsonian Institution, Washington D.C., and checked against the original species descriptions in the Ellis and Messina catalogue (online version, <http://www.microspress.org/em>). Genera are presented in alphabetical order within their suprageneric categories, and occurrences of individual taxa are listed by samples (Appendix 1) located stratigraphically in Figures 3 and 4.

## BOLIVINIDS

There is considerable taxonomic confusion in assigning species to the related genera *Bolivina*, *Bolivinoidea*, and *Brizalina* that are mainly differentiated by overall shape, combined with peripheral shape and surface ornamentation. *Bolivina* is distinguished by its ovoid to triangular test outline, more rounded in cross section than that of *Bolivinoidea*, with a surface ornamentation of irregularly anastomosing, imperforate costae. Occasionally coarse pores occur between the costae, and retral processes are present.

*Bolivinoidea* is distinguished by its robust, rhomboidal, flaring test outline, subrhomboidal shape compressed in cross section, with ornamentation of pronounced tubercles and longitudinal, commonly bifurcating costae. *Brizalina* is distinguished from the other genera by its lanceolate test outline, acute to carinate periphery, with a smooth surface or a surface ornamented by low and narrow, imperforate, longitudinal costae, most prominent on the early half of the test.

Other genera in this section are *Sigmavirgulina*, which is distinguished by a sigmoid alignment of chambers, an acutely angled or carinate periphery, and slightly depressed sutures. *Nodobolivina* is distinguished by an ornamentation dominated by strong sutural beads and absent or weak medial ribs. *Rectobolivina* is distinguished by an early biserial stage followed by a rectilinear uniserial stage, and by an elongate test which is oval in cross section. *Tubulogenerina* is distinguished by its elongate, subconical test, rounded to oval in cross section, with an early short triserial stage, followed by biserial and uniserial stages. *Sagrinopsis* is distinguished by an early triserial chamber arrangement followed by biserial and rectilinear uniserial stages, and it is circular to subcircular in cross section.

Order FORAMINIFERIDA Eichwald, 1830  
Suborder ROTALIINA Delage and Hérouard, 1896  
Superfamily BOLIVINACEA Glaessner, 1937  
Family BOLIVINIDAE Glaessner, 1937  
Genus *Bolivina* d'Orbigny, 1839  
Type species: *Bolivina plicata* d'Orbigny, 1839

*Bolivina antiqua* d'Orbigny, 1846  
Fig. 5.1

*Bolivina antiqua* d'Orbigny, 1846, p. 240, pl. 14, figs. 11–13; Cushman, 1937, p. 77, pl. 9, figs. 15, 16.

**Description.** Chamber arrangement biserial with 8–10, low, broad chamber pairs in the early part of the test, increasing slightly in height as added. Test elongate, compressed, rapidly tapering in the early portion, with almost parallel sides. Periphery subacute, slightly lobate. Wall smooth, perforate. Sutures strongly limbate and oblique, slightly curved. Aperture elongate, broadest at the upper end, narrow at the base of the inner margin of the last chamber.

**Remarks.** *Bolivina antiqua* is distinguished from all other species of *Bolivina* in our material by its limbate and oblique sutures, and almost parallel sides of the test in outline.

**Stratigraphic range.** This species is rare throughout most of the studied section at Fuente Caldera, although it is common in the *Pseudohastigerina naguewichiensis* Biozone (64 m above base of section, Fig. 4).

*Bolivina mississippiensis* Cushman, 1922

Figs. 5.2, 5.3

*Bolivina mississippiensis* Cushman, 1922, p. 92, pl. 15, fig. 5; Cushman, 1937, p. 69, pl. 8, fig. 16; Bandy, 1949, p. 125, pl. 25, fig. 4; Todd, 1952, p. 28, pl. 4, fig. 23.

**Description.** Chamber arrangement biserial with 6–8 pairs of chambers, which are slightly more broad than low, especially in the last two chambers. Test compressed, rapidly tapering in the early portion. Periphery subacute; wall smooth, perforate. Sutures strongly oblique, limbate, curved, and slightly crenulated. Aperture elongate, at the base of the last chamber.

**Remarks.** *Bolivina mississippiensis* is characterized by its distinctive sutures. Some specimens are slightly twisted around the vertical axis of the test.

**Stratigraphic range.** This species is rare to common in the Fuente Caldera section, and its highest percentage is reported from the top of the *Pseudohastigerina naguewichiensis* Biozone (lower Rupelian, Fig. 4).

Genus *Brizalina* Costa, 1856

Type species: *Brizalina aenariensis* Costa, 1856

*Brizalina reticulata* (Hantken, 1875)

Fig. 5.7

*Bolivina reticulata* Hantken, 1875, p. 65, pl. 15, fig. 6; Cushman, 1937, p. 50, pl. 6, figs. 24–27; Hayward and Buzas, 1979, p. 43, pl. 6, fig. 72; Sztrákos, 1982, pl. 29, fig. 5; Hayward, 2004, fig. 2T.

*Bolivina anastomosa* Finlay. Hornibrook, 1961, p. 72, pl. 10, fig. 188; Hornibrook, 1968, p. 63, fig. 10.

*Bolivina (Latibolivina) reticulata reticulata* (Hantken). Hofmann, 1971, p. 304, pl. 13, figs. 1, 3, 8, 9, 11.

**Description.** Chamber arrangement biserial with indistinct chambers, increasing rather regularly in size, width > height, separated by oblique and curved sutures. Test elongate, about three times as long as broad, slightly compressed. Periphery acute to carinate. Wall calcareous, finely perforate, ornamented with regular fine costae, which are reticulate and cover the chambers and the sutures. A narrow aperture is present on the ventral margin of the last chamber.

**Remarks.** *Brizalina reticulata* is distinguished by its regular, reticulate ornamentation. It is very similar to *Bolivina retifera* (Hantken, 1875), and they might be synonymous. It differs from *Brizalina byramensis* (Cushman, 1923) in being less compressed, lacking a keel, and developing more numerous and broad costae.

**Stratigraphic range.** This species is very rare at Fuente Caldera.

*Brizalina alazanensis* (Cushman, 1926)

Fig. 5.8

*Bolivina alazanensis* Cushman, 1926, p. 82, pl. 12, fig. 1; Nuttall, 1932, p. 20, fig. 1; Cushman, 1937, p. 63, pl. 8, figs. 6, 7; Bandy, 1949, p. 125, pl. 25, fig. 9; Bolli and others, 1994, p. 339, pl. 78, fig. 3, pl. 53, figs. 2, 3.

**Description.** Chamber arrangement biserial; chambers in the earlier part of the test indistinct, curved, broader than high, increasing in size rapidly. Test elongate in outline, compressed and tapering with a narrow keel around the periphery, rhomboid in cross section, thicker in the middle, and thinning toward the periphery. Wall calcareous, surface smooth, finely perforate. Sutures limbate, curved and oblique. Aperture elongate and narrow, at the base of the last chamber.

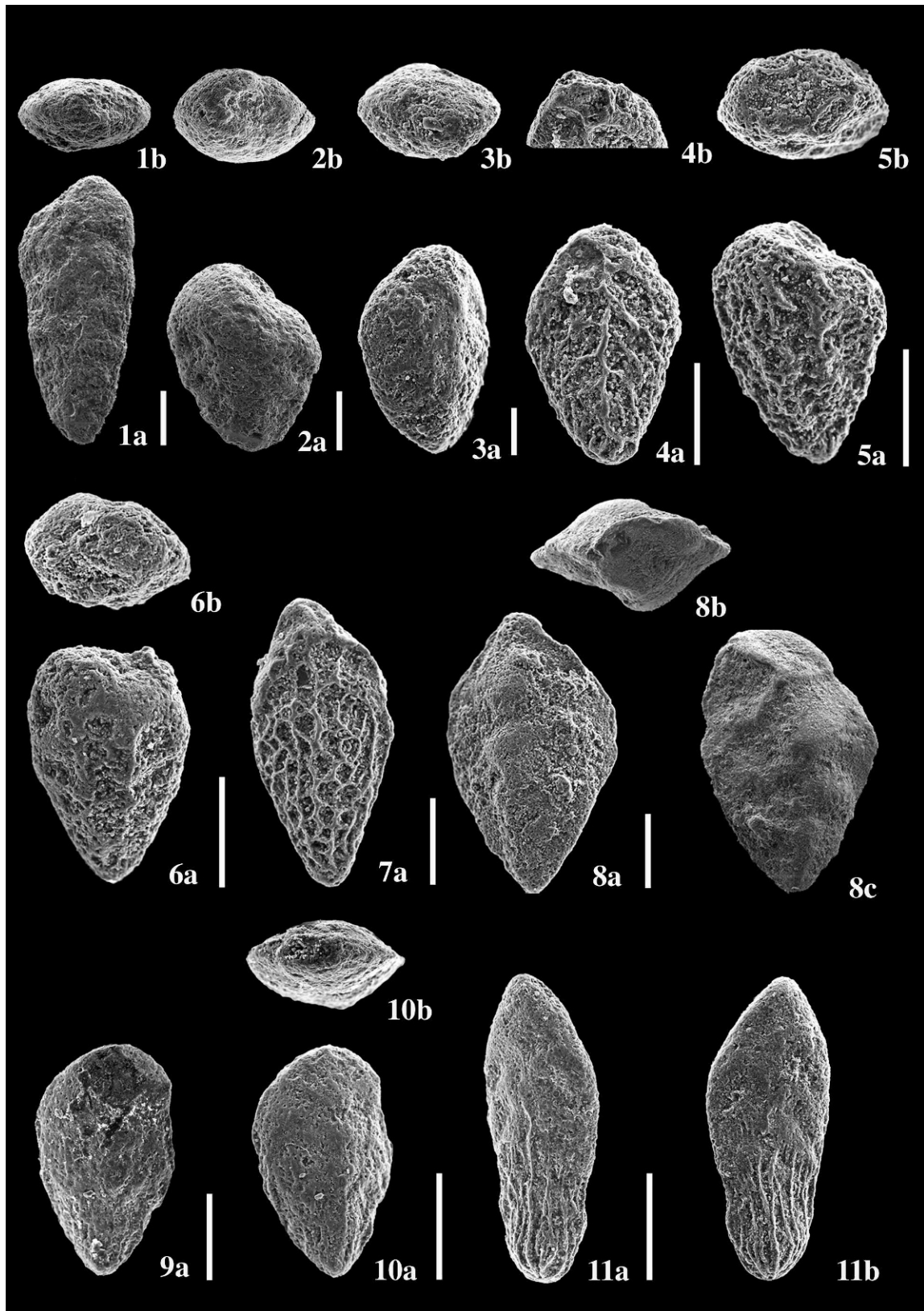


FIGURE 5. Scanning electron micrographs (scale bars = 100  $\mu$ m). **1** *Bolivina antiqua* d'Orbigny, 1846, sample no. FC-03-64. **2, 3** *Bolivina mississippiensis* Cushman, 1922, sample nos. FC-03-08, FC-03-34, respectively. **4** *Brizalina byramensis* (Cushman, 1923), sample no. FC-03-08. **5, 6** *Bolivinoides crenulata* (Cushman, 1936), sample nos. FC-03-64, FC-03-08, respectively. **7** *Brizalina reticulata* (Hantken, 1875), sample no. FC-03-08. **8** *Brizalina alazanensis* (Cushman, 1926), sample no. FC-03-172. **9, 10** *Brizalina carinata* (Terquem, 1882), sample nos. FC-03-08, FC-03-18, respectively. **11** *Brizalina tectiformis* (Cushman, 1926), sample no. FC-03-18.



*Remarks.* We examined the holotype (USNM 353840) and the plesiotype of *B. alazanensis* (CC 4801), and found them consistent with our material.

*Stratigraphic range.* This species is very rare to rare throughout the section.

*Brizalina byramensis* (Cushman, 1923)

Fig. 5.4

*Bolivina caelata* var. *byramensis* Cushman, 1923, p. 19, pl. 2, fig. 2.

*Bolivina caelata* Cushman, 1929, p. 93, pl. 13, fig. 28; Nuttall, 1932, p. 20, pl. 5, fig. 3.

*Bolivina byramensis* Cushman. Cushman, 1937, p. 69, pl. 8, figs. 18–20; Bermúdez, 1949, p. 187, pl. 12, fig. 29; Todd, 1952, p. 28, pl. 4, fig. 22; Tjalsma, 1983, p. 739, pl. 1, fig. 1; van Morkhoven and others, 1986, p. 209, pl. 71, figs. 1, 2; Bolli and others, 1994, p. 340, pl. 78, fig. 20; Molina and others, 2006, pl. 1, fig. 2.

*Brizalina byramensis* (Cushman). Whittaker, 1988, p. 93, pl. 11, figs. 24–26.

*Description.* Chamber arrangement biserial with 7–8 broad, low chamber pairs, increasing rapidly in size. Test compressed, lanceolate to subrhomboidal in outline. Periphery acute. Sutures oblique and curved. Wall calcareous, finely perforate, ornamented by irregular, longitudinal, anastomizing, curved costae. Aperture narrow, elongate, loop shaped, extending from the base of the last chamber.

*Remarks.* *Brizalina byramensis* is distinguished from other species in our material by its ornamentation, lanceolate to subrhomboidal outline, and acute periphery. This species is very similar to *Bolivina retifera* Bandy (1949), but the latter has a more carinate periphery, more elongate form, and finer reticulation. We placed *B. byramensis* within *Brizalina* because the species has a more acute periphery and is less robust in cross section than *Bolivinoidea*s and *Bolivina*.

*Stratigraphic range.* Very rare in the Fuente Caldera section.

*Brizalina carinata* (Terquem, 1882)

Figs. 5.9, 5.10

*Bolivina carinata* Terquem, 1882, p. 148, pl. 15, fig. 19; Cushman, 1937, p. 46, pl. 6, figs. 14–16; Todd, 1957, pl. 66, fig. 12; Kaasschieter, 1961, p. 193, pl. 9, figs. 12–14; Setiawan, 1983, p. 108, pl. 7, fig. 10.

*Brizalina carinata* (Terquem). Ortiz and Thomas, 2006, p. 113, pl. 4, fig. 11.

*Description.* Chamber arrangement biserial, with 6–8 pairs of chambers, which are oblique, curved, and increase in size rapidly. Test elongate in outline, compressed, tapering to somewhat subrounded. Periphery keeled. Wall calcareous, finely perforate. Sutures distinct, limbate, strongly oblique, and more depressed towards the apertural part of the test. Aperture loop shaped, extending up from the base of the last chamber.

*Remarks.* We studied the plesiotypes of *B. carinata* (USNM 623778, CC 5326 and 22061), which are consistent with our material. We include this species within *Brizalina* because of its keeled periphery.

*Stratigraphic range.* Very rare in the Fuente Caldera section.

*Brizalina tectiformis* (Cushman, 1926)

Fig. 5.11

*Bolivina tectiformis* Cushman, 1926, p. 83, pl. 12, figs. 6a, b; Galloway and Herminway, 1941, p. 491, pl. 31, fig. 2; Bermúdez, 1949, p. 195, pl. 12, fig. 47; Tjalsma, 1983, p. 739, pl. 1, figs. 3a, b.

*Bolivina* cf. *tectiformis* Cushman. Beckmann, 1953, pl. 21, figs. 16, 17. *Bolivina antegressa* Subbotina, 1953, p. 226, pl. 10, figs. 11–16; Miller and others, 1985, pl. 4, fig. 11; Miller and Katz, 1987a, p. 121, pl. 1, fig. 4; Miller and Katz, 1987b, p. 279, pl. 2, figs. 1, 2; Premoli Silva and others, 1988, pl. 2, figs. 3, 4; Müller-Merz and Oberhänsli, 1991, p. 156, pl. 2, fig. 2.

*Brizalina antegressa* (Subbotina). Molina and others, 2006, pl. 1, fig. 5.

*Description.* Chamber arrangement biserial, with 8–10 pairs of oblique or slightly curved chambers. Test elongate in outline, flat and compressed. Sites are almost parallel and subrounded to nearly pointed in cross section. Periphery acute. Wall calcareous, finely perforate, the earlier portion with an ornamentation of slightly oblique longitudinal channels and ridges that become most distinct on the thickened sutures in the central part of the test, lacking in later chambers. Sutures thickened, fusing in the median line into an almost straight, sometimes zigzag ridge. Aperture elongate, terminal, extending up from the base of the last chamber.

*Remarks.* *Brizalina tectiformis* is distinguished from other *Brizalina* species by its compressed, flat test, early chamber ornamentation, very thick sutures, and a thick ridge along the median line on its earlier chambers.

The holotype of *B. tectiformis* (USNM 353841) is very similar to the description of *Bolivina antegressa*. Since both species have the same ornamentation, with a very thick central ridge lacking in the later chambers, we consider them synonymous.

*Stratigraphic range.* This species is common in the Chattian, and rare in the rest of the section (Fig. 4).

Family BOLIVINOIDIDAE Loeblich and Tappan, 1984

Genus *Bolivinoidea* Cushman, 1927

Type species: *Bolivina draco* Marsson, 1878

*Bolivinoidea crenulata* (Cushman, 1936)

Figs. 5.5, 5.6

*Bolivina crenulata* Cushman, 1936, p. 50, pl. 7, fig. 13; Cushman, 1937, p. 53, pl. 6, figs. 33, 34; Cushman, 1951, p. 43, pl. 12, fig. 14 (not fig. 13); Kaasschieter, 1961, p. 194, pl. 9, figs. 15–17; Murray and Wright, 1974, pl. 6, fig. 12; Sztrákos, 1982, pl. 28, fig. 7; Mathelin and Sztrákos, 1993, p. 78, pl. 32, fig. 7 (not fig. 6).

*Bolivina pseudoplicata* Heron-Allen and Earland. Murray, 1971, p. 107, pl. 43, figs. 1–7; Wright, 1978, p. 711, pl. 2, figs. 6, 7; Boltovskoy and others, 1980, p. 18, pl. 3, figs. 4–8.

*Bolivinoidea crenulata* (Cushman). Molina and others, 2006, pl. 1, fig. 3; Ortiz and Thomas, 2006, p. 113, pl. 4, figs. 9, 10.

*Description.* Chamber arrangement biserial, with 7–8, broad, low chamber pairs, gradually increasing in size. Test elongate in outline, subrhomboidal in cross section, tapering, thickening rapidly at the middle part of the test toward the apertural end where breadth is greatest. Periphery subacute, slightly lobulate. Wall finely perforate with longitudinal, crenulated ridges. Sutures are sigmoid, with reentrants in longitudinal rows parallel to longitudinal ridges. Aperture an elongate narrow loop at the base of the last chamber.

*Remarks.* *Bolivinoidea crenulata* is characterized by its crenulated sutures, subrhomboidal cross section, and distinctive ornamentation. Its holotype and paratypes (CC21497, 21450) are very similar to *Bolivina floridana* Cushman, 1918 (USNM 325334, CC 977), *B. obscuranta* Cushman, 1936 (CC 21879, 21880), *B. plicatella* Cushman, 1930 (USNM 371074, CC 10916), *B. plicatella* var. *mera*

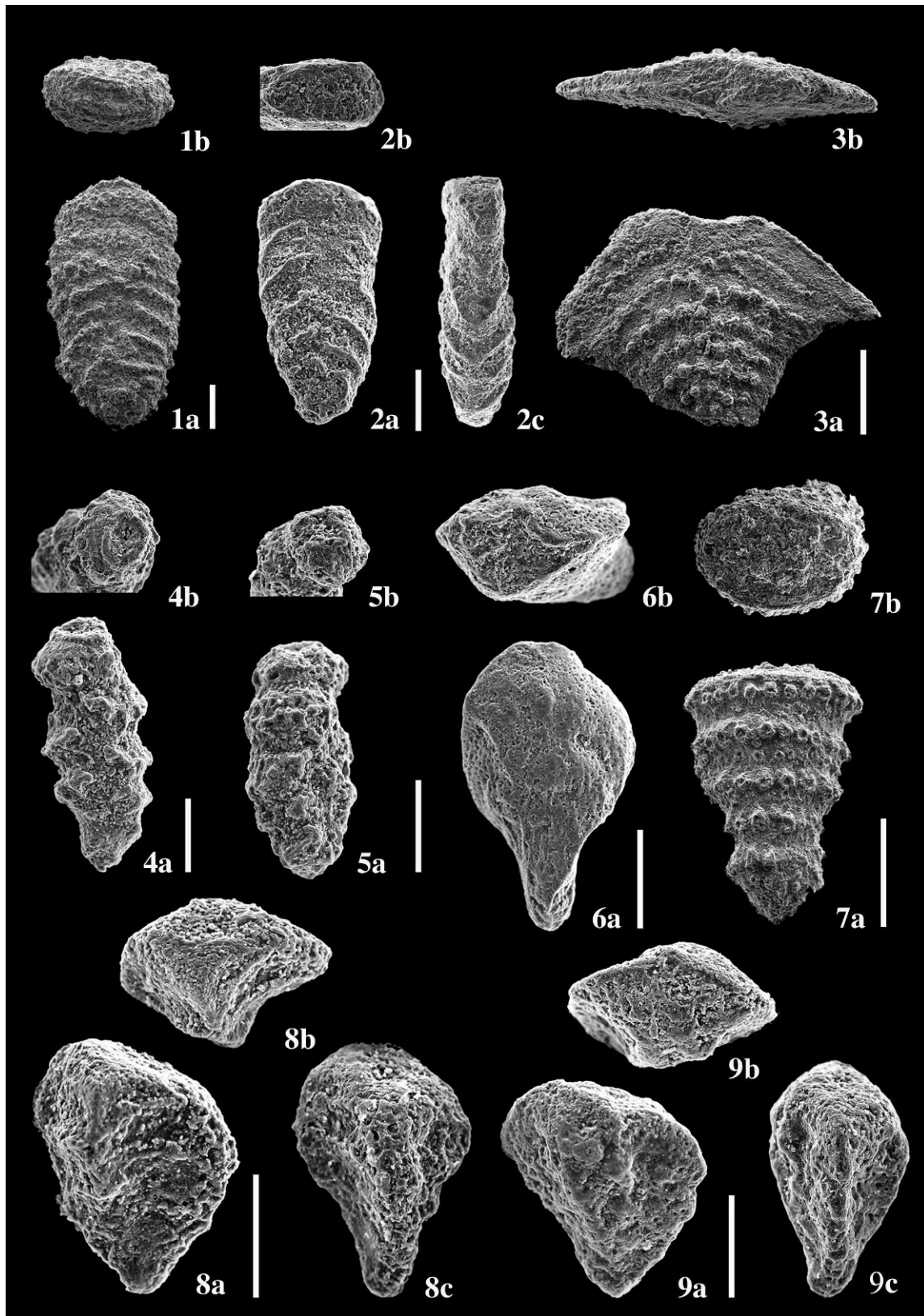


FIGURE 6. Scanning electron micrographs (scale bars = 100  $\mu$ m). 1, 2 *Rectobolivina costifera* (Cushman, 1936), sample nos. FC-03-127, FC-03-125, respectively. 3 *Nodobolivina jhingrani* (Kalia, 1981), sample no. FC-03-139. 4, 5 *Sagrinopsis fimbriata* (Millett, 1990), sample nos. FC-03-127, FC-03-132, respectively. 6 *Sigmavirgulina tortuosa* (Brady, 1881), sample no. FC-03-34. 7 *Tubulogenerina vicksburgensis* Howe, 1930, sample no. FC-03-125. 8, 9 *Tortolpectella rhomboidalis* (Millett, 1899), sample no. FC-03-172.

Cushman and Poton, 1932 (CC 16320, 18470), and *B. pseudoplicata* Heron-Allen and Earland, 1930. The latter three could possibly be synonyms, but we cannot decide this until we have studied the type material.

*B. crenulata* differs from *B. floridana* because the latter's chambers are oval in cross section rather than subrhomboidal, and *B. obscuranta* has more oblique and distinct sutures. We consider specimens described as *Bolivina pseudoplicata* by Murray (1971), Wright (1978), and Boltovskoy and others (1980) to be synonymous with *B. crenulata*. They differ only in their more pronounced crenulations, most likely attributable to different preservation of the foraminiferal tests. We have not studied the type material of *B. pseudoplicata* Heron-Allen and Earland, and thus cannot judge whether the species is synonymous, in which case *B. crenulata* would be the junior synonym.

**Stratigraphic range.** The species is very abundant throughout the section.

Superfamily BULIMINACEA Jones, 1875

Family SIPHOGENERINOIDIDAE Saidova, 1981

Subfamily SIPHOGENERINOIDINAE Saidova, 1981

Genus *Rectobolivina* Cushman, 1927

Type species: *Sagrina bifrons* Brady, 1881

*Rectobolivina costifera* (Cushman, 1936)

Figs. 6.1, 6.2

*Geminaricta virgata* var. *costifera* Cushman, 1936, p. 62, pl. 8, fig. 19; Cushman, 1937, p. 209, pl. 23, figs. 33, 34; Poignant, 1972, p. 4, pl. 1, figs. 5–7.

*Rectobolivina costifera* (Cushman). Hayward and Poignant, 1985, p. 252, pl. 1, figs. 7–13; Hayward and Poignant in Poignant, 1999, p. 141, pl. 1, figs. 18, 19.

**Description.** Chamber arrangement initially biserial with 5–6 chamber pairs followed by uniserial chambers, slightly arched at the midline of the test. Test elongate, compressed subcylindrical; width ~twice the thickness throughout. Peripheral margins subparallel, lobular to weakly spinose in biserial and uniserial parts of the test. Wall calcareous, finely perforate, especially in those areas with costae ornamentation. Sutures curved gently towards periphery, ornamented with coarse ribs in the biserial portion, arched and depressed in the uniserial stage. Aperture terminal, elliptical, surrounded by a rounded lip.

**Remarks.** The holotype of *R. costifera* (CC 21904) is consistent with our material. The holotype of *R. spinata* (Cushman, 1936) (CC 21903) is similar to our specimens, although at the end of the early portion of the test it has short and blunt spines.

**Stratigraphic range.** This species is rare at Fuente Caldera, and its last occurrence has been recorded in the lower part of the *Turborotalia ampliapertura* Biozone (Rupelian).

Subfamily TUBULOGENERININAE Saidova, 1981

Genus *Sagrinospis* Sellier de Civrieux, 1969

Type species: *Siphogenerina advena* Cushman, 1922

*Sagrinospis fimbriata* (Millett, 1900)

Figs. 6.4, 6.5

*Bigenerina fimbriata* Millett, 1900, p. 6, pl. 1, figs. 2–4.

*Bifarina fimbriata* (Millett). Cushman, 1937, p. 200, pl. 23, figs. 3–5; Montaggioni and Vénec-Peyré, 1993, pl. 1, fig. 18.

*Sagrinospis fimbriata* (Millett). Loeblich and Tappan, 1994, p. 122, pl. 239, figs. 1–10.

**Description.** Chambers initially arranged in an indistinct triserial pattern, then biserial with 5–7 chamber pairs, and finally a uniserial rectilinear stage. The biserial chambers are broad, low, and strongly oblique; the uniserial ones are circular in cross section. Test elongate, compressed, subcylindrical to cylindrical. Wall calcareous, finely perforate with pustulose surface. Sutures strongly limbate, oblique, and straight in the early stage, ornamented with coarse ribs on biserial portion of the test, gently curved in the uniserial stage. Aperture terminal, elliptical, with an imperforate border around its margin.

**Remarks.** This species is generally not well preserved in our material. The last chambers are broken off in some specimens, so the aperture cannot be clearly seen. We distinguish this species by its ornamentation and suture and chamber shape.

**Stratigraphic range.** This species is common in the *Turborotalia ampliapertura* Biozone (Rupelian, 127 m above the base of the section), and rare in the rest of the section (Fig. 4).

Genus *Tubulogenerina* Cushman, 1927

Type species: *Textularia (Bigenerina) tubulogenerina* Parker and Jones, 1863

*Tubulogenerina vicksburgensis* Howe, 1930

Fig. 6.7

*Tubulogenerina vicksburgensis* Howe, 1930, p. 331, pl. 27, fig. 3; Sztrákos, 1982, pl. 16, fig. 16; Gibson, 1987, p. 235, pl. 2, figs. 1–5.

**Description.** Initial chambers rather indistinct triserial, rapidly becoming biserial, and finally uniserial for most of the test. Chambers moderately inflated, subcircular in cross section. Test elongate, subconical. Wall calcareous, smooth, with 1–2 rows of tubulopores. Sutures depressed, horizontal, and slightly oblique toward periphery. A simple, arcuate, elongate aperture is present in the middle of a flattened, terminal, convex apertural face.

**Remarks.** The holotype of *T. vicksburgensis* (USNM 416086) is consistent with our material. This is the only species with tubulopores at Fuente Caldera.

**Stratigraphic range.** This species is very rare to rare in the reworked material (olistostrome intervals) in the middle part of the *Turborotalia ampliapertura* Biozone (Rupelian).

Superfamily LOXOSTOMATACEA Loeblich and

Tappan, 1962

Family BOLIVINELLIDAE Hayward and Brazier, 1980

Genus *Nodobolivinella* Hayward, 1990

Type species: *Nodobolivinella nodosa* Hayward, 1990

*Nodobolivinella jhingrani* (Kalia, 1981)

Fig. 6.3

*Bolivinella interrupta* Howe. Sztrákos, 1979, p. 81, pl. 15, fig. 16.

*Bolivinella jhingrani* Kalia, 1981, p. 245, pl. 1, figs. 14, 16.

*Nodobolivinella jhingrani* (Kalia). Hayward, 1990, p. 57, pl. 5, fig. 12, pl. 12, figs. 6–15.

*Nodobolivinella* sp. in Cicha and others, 1998, p. 113, pl. 45, fig. 1.

**Description.** Chamber arrangement biserial; numerous chambers are broad and low, curved down toward medial line and periphery, straightening slightly near periphery. Test compressed, triangular in outline, initially flaring rather narrowly. Periphery acute to acutely rounded. Wall calcareous, smooth, with sutures ornamented by spherical to subspherical beads that become smaller and disappear

toward the periphery and the aperture. No medial rib or furrow. Medial line marked by a zigzag line of beads following the sutures. Aperture cribrate, situated around the base of the last two chambers.

*Remarks.* This species differs from others species of *Nodobolivinella* in its beaded suture ornamentation that becomes less prominent and disappears toward the periphery and aperture.

*Stratigraphic range.* This species is very rare in the Fuente Caldera section, except for the *Turborotalia ampliapertura* Biozone (Rupelian), in which it is abundant (Fig. 4).

Family TORTOPLECTELLIDAE Loeblich and Tappan, 1985  
Genus *Tortoplectella* Loeblich and Tappan, 1985

Type species: *Textularia crispata* Brady, 1884

*Tortoplectella rhomboidalis* (Millett, 1899)  
Figs. 6.8, 6.9

*Textularia rhomboidalis* Millett, 1899, p. 559, pl. 7, fig. 4.

*Bolivina rhomboidalis* (Millett). Cushman, 1937, p. 138, pl. 18, fig. 7; Cushman, 1942, p. 19, pl. 6, figs. 6, 7; Todd, 1957, pl. 89, fig. 18; Sellier de Civrieux, 1976, p. 19, pl. 16, figs. 1–8; Buzas and others, 1977, p. 74, pl. 2, figs. 3, 4.

*Abditodentrix rhomboidalis* (Millett). Cimerman and Langer, 1991, p. 60, pl. 61, figs. 4–6.

*Tortoplectella rhomboidalis* (Millett). Loeblich and Tappan, 1994, p. 113, pl. 216, figs. 1–6.

*Description.* Chamber arrangement biserial, with ~8 slightly inflated chambers pairs that increase in size rapidly from an initially pointed to a broad end; the last few chambers are more inflated than earlier ones. Test triangular in outline, rhomboidal in cross section, increasing in size rapidly from the initially pointed to the broad end. Periphery acute, obliquely truncate. Wall calcareous, coarsely perforate. Sutures slightly depressed. Aperture oval, extending from the base of the rhomboidal apertural face.

*Remarks.* This species differs from other biserial species by its pronounced rhomboidal cross section, triangular outline, and truncate periphery.

*Stratigraphic range.* This species is common in the Fuente Caldera section, and abundant in the *Pseudohastigerina naguwichiensis* and *Globigerina ciperoensis* biozones (Fig. 4).

Superfamily FURSENKOINACEA Loeblich and Tappan, 1961

Family FURSENKOINIDAE Loeblich and Tappan, 1961  
Genus *Sigmavirgulina* Loeblich and Tappan, 1957

Type species: *Bolivina tortuosa* Brady, 1881

*Sigmavirgulina tortuosa* (Brady, 1881)  
Fig. 6.6

*Bolivina tortuosa* Brady, 1881, p. 57; Brady, 1884, p. 420, pl. 52, figs. 31, 32 (not figs. 33, 34); Egger, 1893, p. 298, pl. 8, figs. 43, 44 (part); Cushman, 1924, p. 18, pl. 5, figs. 4, 5; Cushman, 1937, p. 133, pl. 17, figs. 11–19; Cushman, 1942, p. 20, pl. 7, fig. 1; Todd, 1952, p. 30, pl. 4, fig. 35; Todd and Post, 1954, p. 353, pl. 87, figs. 45–47; Todd, 1957, pl. 89, fig. 19; Todd and Low, 1970, p. 31, pl. 2, fig. 9; Boltovskoy and others, 1980, p. 18, pl. 3, figs. 14–17; Jones, 1994, pl. 52, figs. 31–34.

*Sigmavirgulina tortuosa* (Brady). Loeblich and Tappan, 1957, p. 227, pl. 73, figs. 1, 2, 30; Buzas and others, 1977, p. 103, pl. 8, figs. 9–12; Burke, 1981, p. 19, pl. 137, pl. 9, figs. 4, 8; Loeblich and Tappan, 1987, p. 531, pl. 579, figs. 1–5; van Marle, 1988, p. 149, pl. 5, fig. 9; Montaggiioni and Vénec-Peyré, 1993, pl. 1, fig. 19.

*Description.* Chamber arrangement biserial with 6–8 chamber pairs, slightly inflated in the center of the test, and flattening toward the periphery. Specimens strongly vary in length. Test twisted rhomboidal in outline, compressed, tapering, early portion with a strongly twisted axis. Periphery acute to carinate. Wall calcareous, with rather coarse punctae. Sutures depressed, wide, and oblique. Aperture terminal, elongate, elliptical, narrow, located at the inner margin of the final chamber.

*Remarks.* *Sigmavirgulina tortuosa* differs from other biserial species by its pronounced twisted test. We think that the subspecies, *Sigmavirgulina tortuosa* var. *atlantica* (Cushman, 1936) and *S. tortuosa* var. *lissa* (Redmond, 1953), could possibly be synonyms, but we cannot decide this until studying the type material.

*Stratigraphic range.* This species is common to abundant at the Fuente Caldera section, and the highest percentages have been recorded at 206 and 245 m above the base of the section, close to the Rupelian/Chatian boundary.

#### ASTERIGERINIDS AND ROSALINIDS

There is considerable confusion in the literature in assigning species to the genera *Asterigerina*, *Asterigerinata*, *Asterigerinoides*, *Neoconorbina*, and *Rosalina*. These genera are mainly differentiated by overall shape, presence or absence of chamberlets, and shape of the periphery and aperture. The first three genera have subdivided chambers, visible on the involute side as a star-shaped form where the suture of the flap dividing the chamber into chamberlets is visible. The three are included in the Asterigerinacea (Loeblich and Tappan, 1987), and differ from each other by their evenly biconvex or unequally biconvex–planoconvex shape and by the position of the supplementary chamberlets on the highly convex or flat side of the test. *Asterigerinoides* is asymmetrically biconvex. *Asterigerina* is unequally biconvex with secondary chamberlets on the highly convex, involute side, whereas the flat side shows the evolute spiral. *Asterigerinata* has a planoconvex test, but the secondary chamberlets are present on the flat to slightly convex involute side, whereas the highly convex side exhibits the evolute spiral.

*Neoconorbina* and *Rosalina* are placed in the superfamily Discorbacea (family Rosalinidae), because they do not have supplementary chamberlets. Both genera are planoconvex to concavoconvex, with the flat to concave side involute, and the aperture covered by a flap. *Neoconorbina* has a rather flat-cone shape and few, lunate chambers/whorl so that its final chamber occupies most of the periphery, which is acute to carinate. *Rosalina* has a rounded to subacute periphery, and the spiral side is coarsely perforate.

Superfamily ASTERIGERINACEA d'Orbigny, 1839

Family ASTERIGERINIDAE d'Orbigny, 1839

Genus *Asterigerina* d'Orbigny, 1839

Type species: *Asterigerina carinata* d'Orbigny, 1839

*Asterigerina campanella* (von Gümbel, 1868)

Fig. 7.1

*Rotalia campanella* von Gümbel, 1868, p. 650, pl. 2, fig. 86.

*Rotalina campanella* (von Gümbel). Terquem, 1882, p. 74, pl. 7, figs. 1–4.

*Asterigerina campanella* (von Gümbel). Hofker, 1959, p. 252, figs. 10–12.

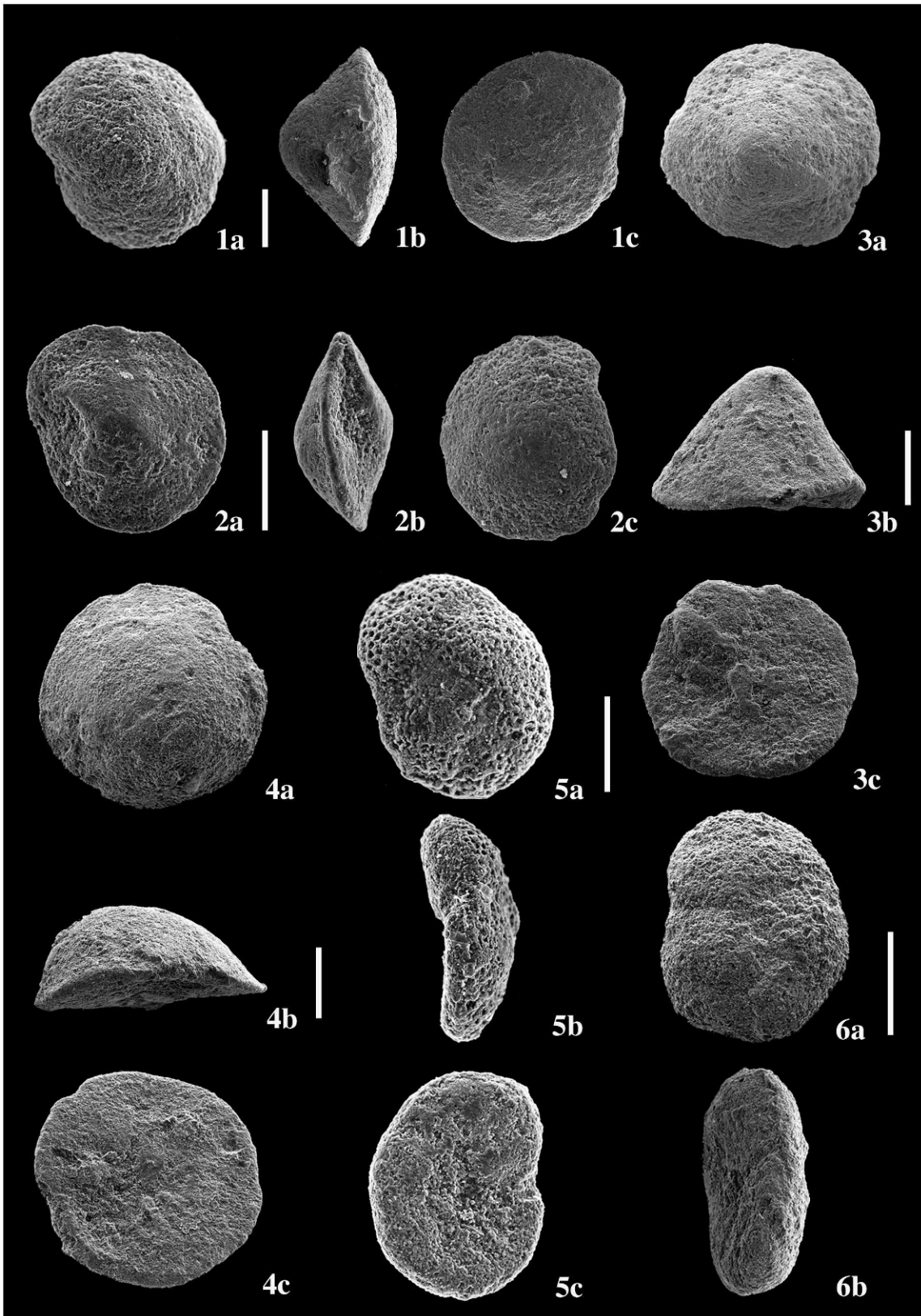


FIGURE 7. Scanning electron micrographs (scale bars = 100  $\mu\text{m}$ ). 1 *Asterigerina campanella* (von Gümbel, 1868), sample no. FC-03-34. 2 *Asterigerinoides subacutus* (Cushman, 1922), sample no. FC-03-64. 3 *Neoconorbina* sp. A, sample no. FC-03-139. 4 *Neoconorbina terquemi* (Rzehak, 1888), sample no. FC-03-139. 5, 6 *Rosalina globularis* d'Orbigny, 1826, sample no. FC-03-176.

*Description.* Chamber arrangement trochospiral, with 8 chambers visible in the last whorl; supplementary chamberlets elongate, visible in well-preserved specimens. Test plano-convex to unequally biconvex, with overall conical shape and subacute periphery. Ventral side involute, more elevated than dorsal side, with a prominent central boss; sutures radial and straight. Dorsal side flattened with oblique and slightly curved sutures. Wall calcareous, finely perforate. Aperture is a narrow, intracameral and elongate slit on the ventral margin of the last chamber.

*Remarks.* This species, recognized by its prominent boss in the center of the ventral side, can be confused with *Asterigerina fimbriata* Todd, 1957 (USNM 623799), which, however, has a keel and more limbate spiral sutures.

*Stratigraphic range.* Abundant in the middle part of the *Turborotalia ampliapertura* Biozone (Rupelian), but otherwise rare to common at Fuente Caldera.

Family ASTERIGERINATIDAE Reiss, 1963

Genus *Asterigerinoides* Bermúdez, 1952

Type species: *Discorbina guerichi* Franke, 1912

*Asterigerinoides subacutus* (Cushman, 1922)

Fig. 7.2

*Asterigerina subacuta* Cushman, 1922, p. 100, pl. 24, figs. 1–3; Cushman and Todd, 1946, p. 101, pl. 16, fig. 27; Todd, 1952, p. 42, pl. 6, fig. 2; Hofker, 1959, p. 253, fig. 15; Seiglie and Bermúdez, 1965, pl. 1, fig. 5; Nuglisch and Spiegler, 1991, p. 224, pl. 12, fig. 1.

*Description.* Chamber arrangement trochospiral, with ~8 chambers in the last whorl; supplementary chamberlets elongate, visible in well-preserved specimens. Test unequally biconvex, with keel and subacute periphery. Ventral side involute with a central boss and curved sutures, more elevated than dorsal side which is slightly convex with oblique, curved sutures. Wall calcareous, finely perforate. Aperture is a narrow, intercameral, elongate slit on the ventral margin of the last chamber.

*Remarks.* *Asterigerinoides subacutus* is characterized by a small keel and a more convex dorsal side.

*Stratigraphic range.* These specimens are very abundant in the middle part of the *Turborotalia ampliapertura* Biozone (Rupelian) and common to abundant elsewhere at Fuente Caldera.

Superfamily DISCORBACEA Ehrenberg, 1838

Family ROSALINIDAE Reiss, 1963

Genus *Neoconorbina* Hofker, 1951

Type species: *Rosalina orbicularis* Terquem, 1876  
(non *Rosalina orbicularis* d'Orbigny, 1850)

*Neoconorbina terquemi* (Rzehak, 1888)

Fig. 7.4

*Rosalina orbicularis* Terquem, 1876, p. 75, pl. 9, figs. 4a, b.

*Discorbina terquemi* Rzehak, 1888, p. 228.

*Neoconorbina terquemi* (Rzehak). Sztrákos, 1982, p. 24, pl. 31, fig. 2; Loeblich and Tappan, 1987, p. 560, pl. 609, figs. 8–10; van Marle, 1989, pl. 1, figs. 8, 9; Cimerman and Langer, 1991, p. 66, pl. 70, figs. 5–7; Cicha and others, 1998, p. 112, pl. 59, figs. 10, 11; Abu-Zied and others, 2008, pl. 2, figs. 26, 27.

*Description.* Chamber arrangement trochospiral. Test plano-convex and triangular in peripheral view, periphery subacute. Evolute dorsal side, with about 3.5 visible whorls and long chambers, increasing rapidly in size. Involute ventral side; chambers subtriangular to rectangular. Sutures curved

slightly backwards and weakly depressed on both sides of the test. Wall calcareous, finely perforate, with a smooth surface. Aperture elongate, interiomarginal, and extraumbilical.

*Remarks.* A hypotype of *N. terquemi* (USNM 211372) at the Smithsonian Institution is consistent with our material.

*Stratigraphic range.* This species is common to abundant in the Fuente Caldera section, and its highest percentage comes from the *Pseudohastigerina naguwichiensis* Biozone (Rupelian).

*Neoconorbina* sp. A

Fig. 7.3

*Description.* Chamber arrangement trochospiral. Test plano-convex to slightly concavo-convex; shape triangular with subacute periphery. Dorsal side evolute, convex, and conic with about 3–3.5 chambers in the last whorl that has depressed, curved sutures. Involute, ventral side plano-concave; chambers subtriangular to rectangular with slightly curved, depressed sutures. Wall calcareous, finely perforate, with a smooth surface. Aperture elongate, interiomarginal, and extraumbilical.

*Remarks.* This species is distinguished from *N. terquemi* by its completely triangular shape and more convex spiral side.

*Stratigraphic range.* This species is rare in the Fuente Caldera section.

Genus *Rosalina* d'Orbigny, 1826

Type species: *Rosalina globularis* d'Orbigny, 1826

*Rosalina globularis* d'Orbigny, 1826

Figs. 7.5, 7.6

*Rosalina globularis* d'Orbigny, 1826, p. 271, pl. 13, figs. 1–4; Murray, 1971, p. 135, pl. 56, figs. 1–6; Buzas and others, 1977, p. 86, pl. 4, figs. 10–12; Hageman, 1979, p. 106, pl. 9, fig. 9; Buzas and Severin, 1982, p. 35, pl. 6, figs. 7, 8; Loeblich and Tappan, 1987, p. 561, pl. 610, figs. 1–5, pl. 611, figs. 1–6; Javaux and Scott, 2003, p. 20, pl. 5, figs. 3, 4.

*Tretomphalus bulloides* (d'Orbigny). Cushman, 1934, p. 86, pl. 11, fig. 2.  
*Tretomphalus myersi* Cushman, 1943, p. 26, pl. 6, figs. 4–6.

*Description.* Chamber arrangement in a low trochospiral. Test plano-convex; periphery rounded, circular to oval in outline. Dorsal side evolute and convex with 1.5 visible whorls; sutures depressed and curved. Ventral side involute, concave, generally with five large triangular, somewhat overlapping chambers visible; sutures weakly depressed and curved backwards. Wall calcareous, coarsely perforate on the dorsal side. Aperture is an elongate, interiomarginal slit, which extends towards the umbilicus.

*Remarks.* The three hypotypes (USNM 211184, 211361, 310240) of *R. globularis* examined at the Smithsonian Institution were consistent with our material. Douglas and Sliter (1965) pointed out the considerable morphological variability within the species that is reflected in our specimens. Donnici and others (1997) figured this species with a globular floating chamber on the umbilical side, representing a phase in its reproductive cycle.

*Stratigraphic range.* This species is rare to common at Fuente Caldera, and its highest percentage is reported at 139 m in the Rupelian *Turborotalia ampliapertura* Biozone (Fig. 4).

## SUMMARY AND CONCLUSIONS

A detailed taxonomic and quantitative study of benthic foraminifera in the western Tethys at the Fuente Caldera

section (Betic Cordillera, Spain) makes it possible to reconstruct local Oligocene paleobathymetry and paleoenvironments. Our findings are based on the occurrences of bolivinid, asterigerinid and rosalinid species, 19 of which we describe in detail and compare to type material in the Smithsonian Institution.

The autochthonous assemblages indicate upper-bathyal deposition along a very steep slope close to coastal photic zones. This setting may explain the occurrence of abundant allochthonous taxa such as asterigerinids and rosalinids, which were probably transported downslope by turbidity currents or attached to floating plant material that decayed offshore. We suggest that the high abundance of bolivinids throughout the section resulted from a high flux of low-quality, refractory organic matter to the seafloor.

The common occurrence of shallow-water, warm species points to overall warm conditions at Fuente Caldera, even during intervals that have been correlated with colder Oligocene events.

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#### APPENDIX 1

Benthic foraminiferal counts from Oligocene (Rupelian and Chattian stages) samples at the Fuente Caldera section (southern Spain). This table can be found on the Cushman Foundation website in the JFR Article Data Repository (<http://www.cushmanfoundation.org/jfr/index.html>) as item number JFR\_DR2012010.