

Morozovella gorrondatxensis (Orue-Etxebarria 1985) vs *M. crater* (Hornibrook 1958): taxonomy and significance for Early/Middle Eocene boundary biostratigraphy

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ABSTRACT: The Global Stratotype Section and Point for the base of the Middle Eocene Lutetian Stage has recently been defined at the calcareous nannofossil CP12a/b zonal boundary at the Gorrondatxe section (Biscay, Basque Country). In terms of planktonic foraminifera, the lowest occurrence of a species defined at this section, namely *Morozovella gorrondatxensis*, appears as one of the events that may best serve to approximate the Ypresian/Lutetian boundary, as it is only 1.2 myr younger than the calcareous nannofossil CP12a/b zonal boundary. However, *Morozovella gorrondatxensis* was recently re-categorized as being merely a junior synonym of *Morozovella crater*. In this paper we argue that *M. gorrondatxensis* is in fact a separate species, that its paleobiogeographic distribution was supra-regional, and that it therefore has a great potential for early Lutetian biostratigraphic refinements.

INTRODUCTION

An accurate and reliable time scale is fundamental in most geological disciplines. In order to improve standard time scales, the ICS (International Commission on Stratigraphy) and the IUGS (International Union of Geological Sciences) aim to define GSSPs (Global Stratotype Sections and Points) for the bases of all internationally agreed chronostratigraphic stages.

The GSSP for the base of the Lutetian Stage (Ypresian/Lutetian or Early/Middle Eocene boundary) has recently been defined at the cliff of the Gorrondatxe beach in Getxo (Biscay province, Basque Country; Lat. 43° 22' 46" N, Long. 3° 00' 51" W; text-fig. 1), in the marly bed that contains the lowest occurrence of the calcareous nannofossil *Blackites inflatus* (Molina et al. 2011), the marker taxon of Zone CP12b of Okada and Bukry (1980). In addition to this primary correlation criterion, secondary events that may help approximate the Ypresian/Lutetian boundary elsewhere were defined using other criteria (text-fig. 1b). For example, cyclostratigraphy has shown that the Ypresian/Lutetian boundary is 819 kyr (39 precession cycles) younger than the C22n/C21r Chron boundary (Payros et al. 2011), thus being dated at approximately 47.8 Ma in the Gradstein et al. (2004, 2012) timescales. In terms of planktonic foraminifera, Payros et al. (2007a, 2009a, 2009b, 2011) demonstrated that the lowest occurrence of *Turborotalia frontosa* (Subbotina 1953) is the event that lies closest to the base of Zone CP12b, the former being approximately 550 kyr (26 precession cycles) older than the latter (text-fig. 1b). However, in order to accurately delimit the Ypresian/Lutetian boundary by means of planktonic foraminifera other younger events should also be defined. According to the standard planktonic foraminiferal biostratigraphy, the Ypresian/Lutetian boundary is included in the *Turborotalia frontosa* Lowest-occurrence Subzone E7b of Wade et al. (2011), which extends from the lowest occurrence of *T. frontosa* to that of *Guembelitrionides nuttalli* (Hamilton 1953). Payros et al. (2007a) showed that the latter event is approximately 2.3 myr younger

than the base of Zone CP12b and is, unfortunately, of little help in approximating the Ypresian/Lutetian boundary. The studies carried out in Gorrondatxe (Orue-Etxebarria 1985; Orue-Etxebarria et al. 2006; Bernaola et al. 2006) determined that two planktonic foraminiferal events occur between the Ypresian/Lutetian boundary and the top of Zone E7b (text-fig. 1b), namely the approximately coeval lowest occurrences of *Morozovella gorrondatxensis* (Orue-Etxebarria 1985) and *Globigerinatheka micra* (Shutskaya 1958). Nevertheless, neither species was specifically catalogued in the Atlas of Eocene Planktonic Foraminifera (Pearson et al. 2006), as the former was included in synonymy with *Morozovella crater* (Hornibrook 1958) and the latter with *Subbotina senni* (Beckmann 1953).

The aims of this paper are twofold. Firstly, to argue that *M. gorrondatxensis* is a species in its own right and, secondly, to discuss its consequent significance in approximating the Ypresian/Lutetian boundary.

BACKGROUND

Morozovella gorrondatxensis was formally defined at the Gorrondatxe section (Orue-Etxebarria 1985). In 2011, the ICS and the IUGS selected this section as the GSSP for the base of the Lutetian Stage due to its suitability for detailed, multidisciplinary stratigraphic studies (Molina et al. 2011). A notable characteristic of the Gorrondatxe section is that it is rich in diverse and well-preserved calcareous microfossils (Orue-Etxebarria et al. 2006; Bernaola et al. 2006). Notwithstanding this attribute, the most notable characteristic of Gorrondatxe is that the Eocene sedimentary succession is highly expanded (Orue-Etxebarria et al. 1984; Orue-Etxebarria and Apellaniz 1985; Payros et al. 2006, 2009b; Orue-Etxebarria et al. 2006; Bernaola et al. 2006; Molina et al. 2011). For example, the stratigraphic thickness from the lowest occurrence of *Planorotalites palmerae* (Cushman and Bermudez 1937) to that of hantkeninids (i.e., *Hantkenina nuttalli* Toumarkine 1981; *Hantkenina mexicana* Cushman 1924) is

approximately 850 m (text-fig. 1b); this interval corresponds to the planktonic foraminiferal Zone P9 of Berggren et al. (1995, see their p.153), which was formally defined on the basis of the aforementioned two bioevents. The combination of well-preserved fossils and considerable sedimentary thickness has allowed several significant planktonic foraminiferal events to be pinpointed along Zone P9, thus leading to the definition of locally useful subzones (Orue-Etxebarria et al. 1984; Orue-Etxebarria and Apellaniz 1985; Orue-Etxebarria et al. 2006; Bernaola et al. 2006). In addition, successive biostratigraphic and magnetostratigraphic events were accurately calibrated in Gorrondatxe. This calibration led Payros et al. (2007a) to amend the standard Eocene biomagnetostratigraphic framework, mainly the planktonic foraminiferal biostratigraphic scale. One of their main amendments concerned the lowest occurrence of hantkeninids, the main criterion used to mark the Ypresian/Lutetian boundary for more than 50 years, which was actually found to be 3.1 myr younger than previously thought. The new Gorrondatxe results were later confirmed by independent studies carried out in other areas (Larrasoana et al. 2008; Ortiz et al. 2008; Jovane et al. 2010; Rögl and Egger 2010, 2011; Payros et al. 2011; Weinbaum-Hefetz and Benjamini 2011; Zakrevskaya et al. 2011; Coccioni and Bancala 2012; Pearson and Coxall, 2014) and eventually led to the revision of the standard Eocene biomagnetostratigraphic framework (Wade et al. 2011; Gradstein et al. 2012). Consequently, the planktonic foraminiferal Zone P9 was abandoned and replaced by Zone E7a, which extends up to the lowest occurrence of *T. frontosa*, and Zone E7b, as outlined above (text-fig. 1b).

The discussion above argues that the results of the stratigraphic studies carried out in Gorrondatxe are reliable, despite being at odds with previously accepted assumptions and therefore having seemed questionable when first presented. Accordingly, we think that some of the results that were initially disregarded, including the definition of *M. gorrondatxensis*, should now be re-examined. The lowest occurrence of *M. gorrondatxensis*, provided it is demonstrated to be a distinct species and its paleogeographic distribution is found to be wide, could in fact provide greater precision to the standard planktonic foraminiferal biostratigraphic scale around the Ypresian/Lutetian boundary.

TAXONOMIC DISCUSSION

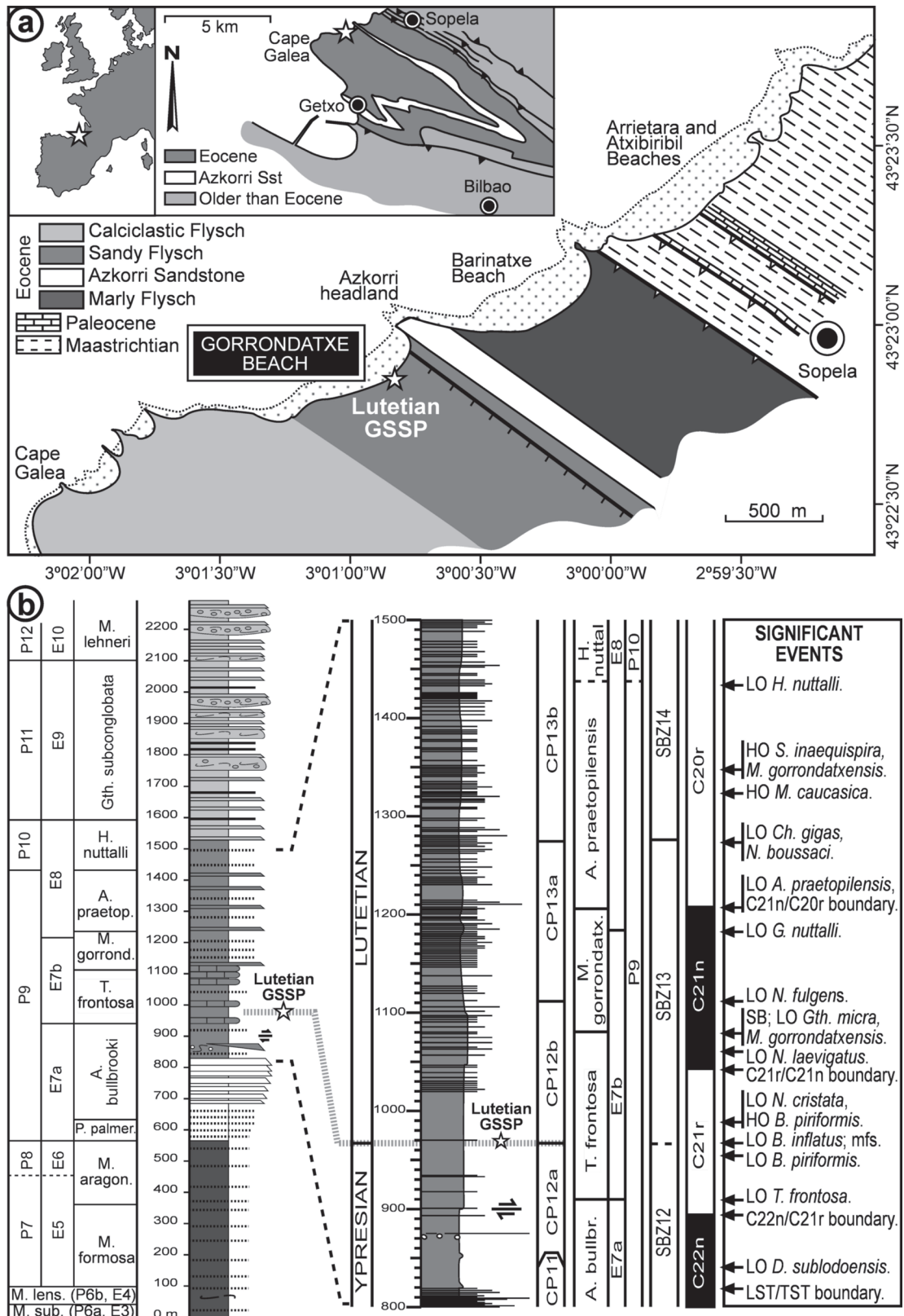
In the formal definition of *M. gorrondatxensis*, Orue-Etxebarria (1985) stated that the species is characterized by a trochospiral, plano-convex test with a lobulate equatorial outline and an angular axial outline with well-developed muricocarina (text-fig. 2a). Its spiral side is almost flat, but shows a small convexity in the first part of the spire. The umbilical side is highly convex. The test is composed of about 10 chambers arranged in two whorls, the last whorl showing 4½-5 chambers that rapidly increase in size. These chambers are imbricated on the spiral side, appear flattened and are tangentially wider than radially high; their sutures range from slightly curved to oblique. On the umbilical side, the chambers are triangular and slightly inflated, showing rounded umbilical rims; the intercameral sutures are radial and depressed. The umbilicus is relatively small, deep and open. The aperture is interiomarginal and in an umbilical-extraumbilical position. The diameter of the test ranges from 0.5 to 0.6 mm. The wall is finely perforate and its surface is generally smooth but rugose on the umbilical side. Orue-Etxebarria (1985) added that *M. gorrondatxensis* is homeomorph of *M. gracilis* (Bolli 1957), but differs in that it has fewer chambers in the last whorl and is larger in size.

Despite this apparently differentiating description, *M. gorrondatxensis* was classified as a junior synonym of *Morozovella crater* in the Atlas of Eocene Planktonic Foraminifera (Pearson et al. 2006). This may be due to the use of differing criteria when referring to *M. crater*. The taxonomic problem most likely arose from the fact that no figure, but just a brief description to distinguish *M. crater* from *Morozovella aragonensis* (Nuttall 1930), was given the first time *M. crater* was cited (Finlay 1939). Fortunately, it was mentioned that the type specimen of *M. crater* was stored “in the New Zealand Geological Survey collection, Wellington, New Zealand”. Blow (1979, p. 996) pointed out that “Hornibrook (1958) illustrated the holotype of Finlay’s taxon for the first time and the specimen is shown to possess a flat dorsal side but strongly vaulted ventral side combined with a widely open and deep umbilicus”. Pearson et al. (2006, p. 361) agreed that “the first valid reference to *M. crater* is by Hornibrook (1958, p. 33, pl. 1, figs. 3-5) in which a holotype specimen is illustrated and a more thorough description given”. The holotype specimen stored at the New Zealand Geological Survey collection was later refigured by Jenkins (1971, pl. 8, figs. 192-194; text-fig. 2b) in order to illustrate *Globorotalia (Morozovella) crater*, which Pearson et al. (2006, p. 358) considered a junior synonym of *M. crater*. According to the three illustrations by Jenkins (1971), *M. crater* has an almost flat spiral side, a wide umbilicus and a circumumbilical collar of fused muricae heavily ornamented; it shows 5 chambers in the last whorl, which only slightly increase in size (text-fig. 2b).

Taking the previous descriptions into account, we conclude that the characteristics of *M. gorrondatxensis* and *M. crater* are distinct enough to be ascribed to separate species. Firstly, the equatorial outline is more lobulate in *M. crater* than in *M. gorrondatxensis*. Secondly, the umbilical side of *M. gorrondatxensis* is lower than that of *M. crater*, whereas the spiral side is more convex in the former. Thirdly, the umbilicus is smaller in *M. gorrondatxensis* than in *M. crater*, and has a less marked muricae on the circumumbilical collar. Finally, successive chambers in the last whorl of *M. gorrondatxensis* increase in size rapidly, whereas those of *M. crater*, being essentially equidimensional, increase in size gradually. These differences clearly stand out in samples containing both species (text-fig. 3) and show in fact that the characteristics of *M. gorrondatxensis* fall outside the morphological variability of *M. crater*. It must be acknowledged, however, that younger, more evolved specimens of *M. gorrondatxensis*, such as the holotype (text-fig. 2a), are slightly larger than the more primitive specimens, have a wider umbilicus, and their muricocarina is more prominent, therefore giving an appearance morphologically closer to *M. crater*. An evolution towards progressively bigger tests with more clearly marked ornamentation is common in most planktonic foraminiferal species. Interestingly, however, the stratigraphic range of *M. crater* does not reach the stratigraphic levels containing the fully evolved morphotype of *M. gorrondatxensis*, as the disappearance of *M. crater* overlapped with the appearance of *M. gorrondatxensis* in its most primitive form.

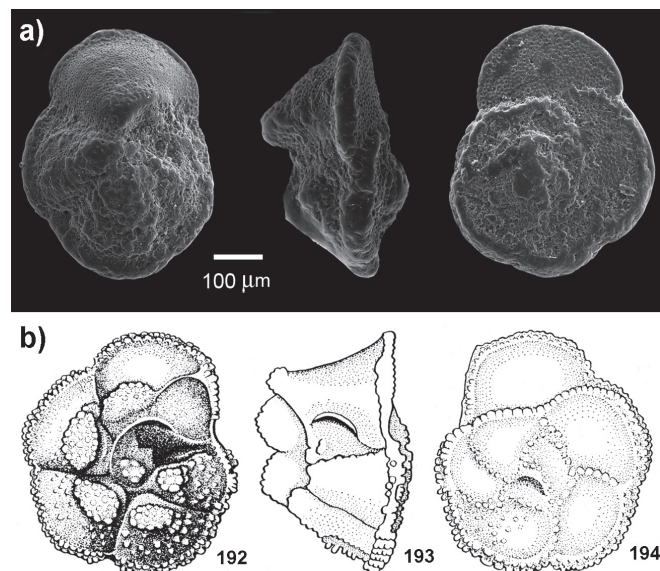
OCCURRENCE

Paleogeographically, in Lutetian times the type area of *M. gorrondatxensis* was included in the Basque basin, in the westernmost part of the Pyrenean region in northern Iberia (text-fig. 4a). *Morozovella gorrondatxensis* has also been identified in other Pyrenean areas, such as the Pamplona basin (Navarre province) and the Jaca and Ainsa basins (Huesca province). In the Pamplona basin, *M. gorrondatxensis* was found in several



TEXT-FIGURE 1

A. Location of the Gorrondatxe section, GSSP for the base of the Lutetian Stage and type area of *Morozovella gorrondatxensis* (Orue-Etxebarria 1985). B. Litholog of the Eocene succession exposed between Sopela and Cape Galea (Payros et al. 2006), with an enlargement of the Ypresian/Lutetian transition found at Gorrondatxe. The local planktonic foraminiferal biostratigraphy and its correlation with the standard P (Berggren et al. 1995) and E (Wade et al. 2011) scales is by Orue-Etxebarria et al. (1984), Orue-Etxebarria (1985), Orue-Etxebarria and Apellaniz (1985), Orue-Etxebarria et al. (2006), Bernaola et al. (2006) and Payros et al. (2009a). Calcareous nannofossil biostratigraphy (CP scale of Okada and Bukry 1980), nummulitid biostratigraphy (SBZ scale of Serra-Kiel et al. 1998) and magnetostratigraphy are from Bernaola et al. (2006). Significant events that delimit the Ypresian/Lutetian boundary are from Molina et al. (2011). LO: lowest occurrence; HO: highest occurrence; SB: sequence boundary; LST: lowstand systems tract; TST: transgressive systems tract; mfs: maximum flooding surface.



TEXT-FIGURE 2

A. *Morozovella gorrondatxensis* (Orue-Etxebarria 1985), as illustrated in the original definition of the species, showing the umbilical side (paratype), a lateral view (paratype) and the spiral side (holotype). These specimens, picked up from a sample collected 137m above the lowest occurrence of *M. gorrondatxensis* at Gorrondatxe (lower part of Zone E8), correspond to the fully evolved morphotype mentioned in the text. B. Holotype of *Morozovella crater* (Hornibrook 1958), as illustrated by Jenkins (1971, his plate 8), which was referred to as *Globorotalia (Morozovella) crater crater* Finlay. 192: Holotype (N.Z.G.S. Reg. No. TF1077/1) F 5570; x75. 193: Holotype; x75. 194: Holotype; x75.

sections (Oskia, San Gregorio, Osinaga-Aristregi, Otsakar and Anotz) that expose the 2nd calciclastic member of the Anotz Formation (Canudo 1990; Payros et al. 2006, 2007b, 2009b, 2011) and within the 2nd megabreccia cluster of the Erro Formation in the Ultzama, Erro and Urrobi sections (Payros et al. 1999, 2006). In Huesca, *M. gorrondatxensis* was found between megabreccias MT4 and MT6 of the Hecho Group at the Veral river section of the Jaca basin (Payros et al. 1999) and also at the transition between the Boltaña and Paules formations of the Boltaña-Campodarbe section in the Ainsa basin (Canudo 1990; Mochales et al. 2012). In Lutetian times, the Pyrenean basins opened northwestwards into the Atlantic Ocean at approximately 35°N paleolatitude (text-fig. 4a), therefore having Boreal paleobiogeographic affinities (Payros et al. 2009b; Molina et al. 2011).

Interestingly, *M. gorrondatxensis* has also been identified in successions from southern Iberian sedimentary basins as far apart as 1000 km. In the Subbetic Zone of the Betic Cordillera (southern Spain; text-fig. 4a) *M. gorrondatxensis* occurs at the Gor and Pedro Martínez sections (Granada province; Pujalte et al. 2012, 2014). The southern Iberian Betic basins were connected eastwards to the Tethys region, at approximately 30°N paleolatitude (text-fig. 4a). In order to better document the morphological variability of *M. gorrondatxensis* (mainly of its umbilical side, which is most relevant) and complement illustrations of specimens from the type area (Text-figs. 2a, 3; also see Orue-Etxebarria 1985, his pl. 2; Bernaola et al. 2006, their fig. 10), examples of new specimens derived from such different areas are shown in Text-figure 5.

The occurrence of *M. gorrondatxensis* in more distant areas has also been investigated. To this end, the morozovellids illustrated in

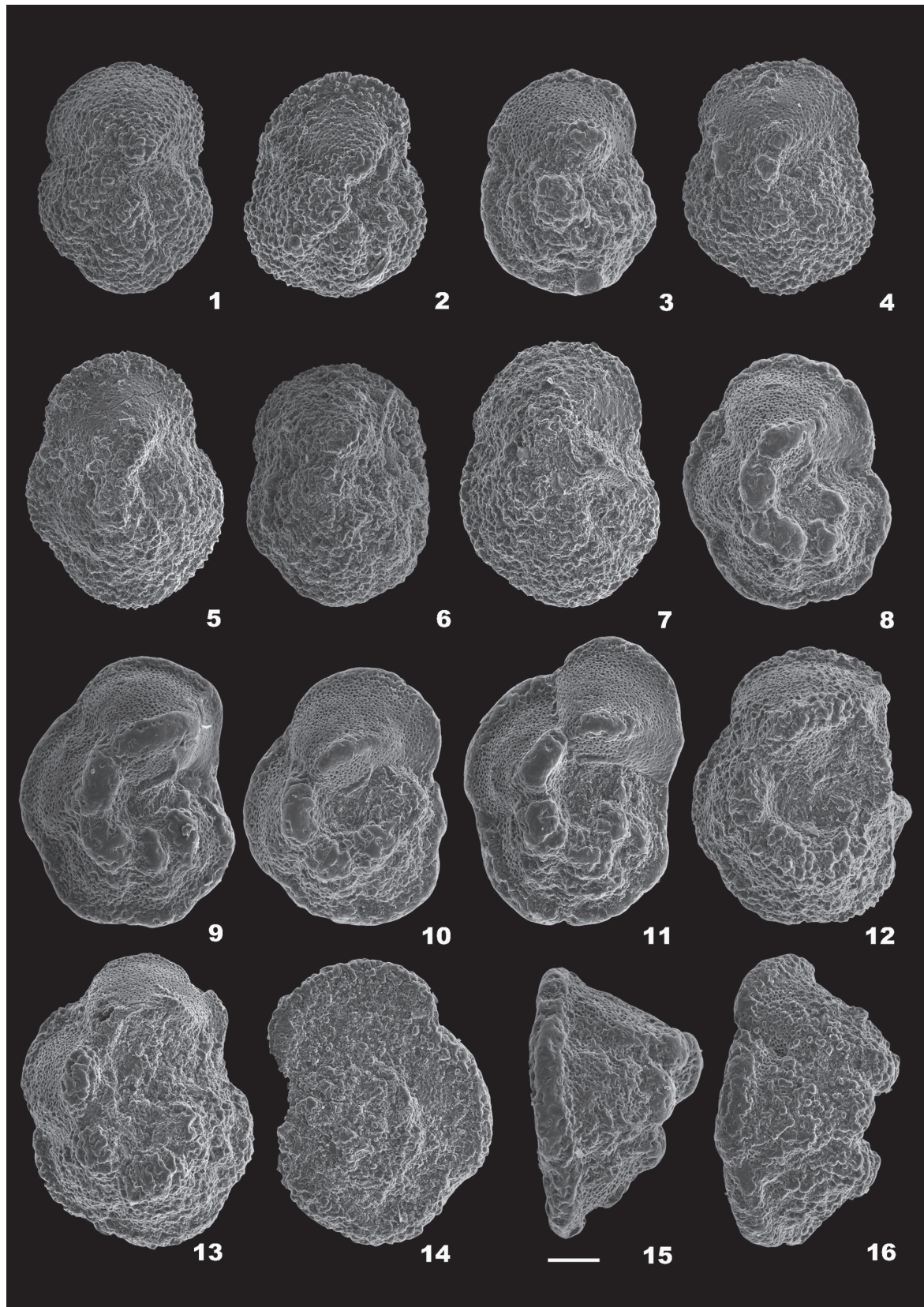
the literature were reviewed and their taxonomic classification re-assessed (Table 1). According to this survey, some morozovellids found in the Alabama coastal plain (text-fig. 4b) and classified as *Globorotalia rex* Martin 1943 [= *Morozovella subbotinae* (Morozova 1939)] by Loeblich and Tappan (1957; their pl. 60, figs. 1a-c) show characteristics that fall within the morphological variability of *M. gorrondatxensis*. Similarly, one *M. lensiformis* (Subbotina 1953) specimen found by Blow (1979, his pl. 154, fig. 1) in the Cape Verde Islands (Atlantic Ocean; text-fig. 4b) could also be re-classified as *M. gorrondatxensis*, although its umbilical side was not illustrated. However, Blow (1979) had found this specimen in deposits attributed to his P10 Zone (which is not equivalent to Zone P10 of Berggren et al. 1995, but to Zone E7b of Wade et al. 2011), an age by which *M. lensiformis* had already disappeared (Pearson et al. 2006), therefore leading to the conclusion that the specimen should not have been classified as *M. lensiformis*. Another two *M. lensiformis* specimens found by Blow (1979; his pl. 126, figs. 2 and 5) in Shatsky Rise (Pacific Ocean; text-fig. 4b) also fall within the morphological variability of *M. gorrondatxensis*; another *M. lensiformis* specimen from the same location (Pearson et al. 2006, their pl. 11.9, fig. 3) also corresponds to *M. gorrondatxensis*. Finally, the *Morozovelloides crassatus* specimens collected by Egger et al. (2011, their fig. A2.4, 1-3) in Austria (text-fig. 4a) correspond to the fully evolved morphotype of *M. gorrondatxensis*.

In conclusion, the occurrence of *M. gorrondatxensis* in different paleobiogeographic domains (text-fig. 4) shows that it was not a regionally restricted endemic species. However, independent records from other areas worldwide would be required to determine whether *M. gorrondatxensis* was more globally distributed.

STRATIGRAPHIC DISTRIBUTION

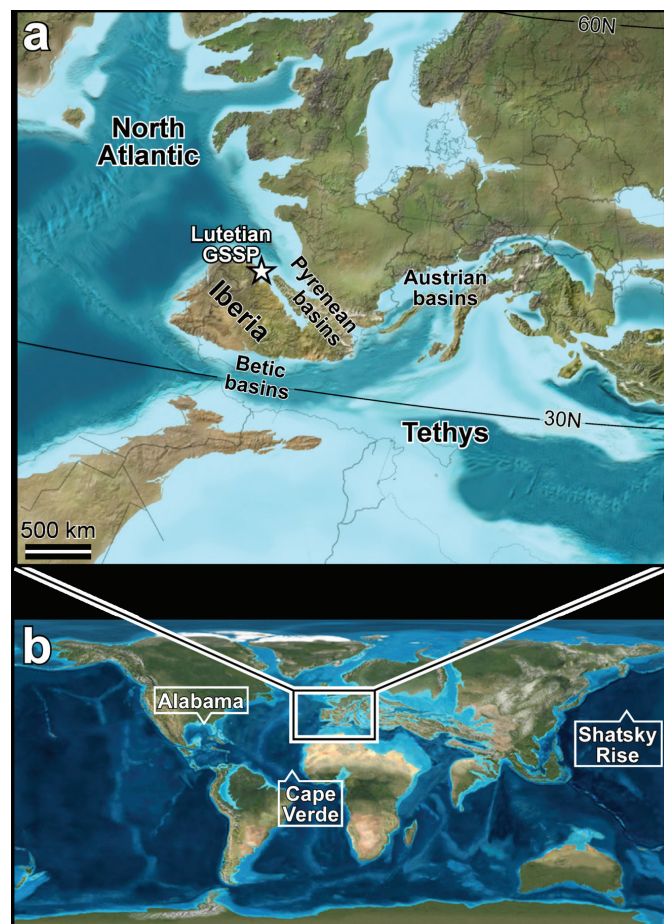
The lowest occurrence of *M. gorrondatxensis* in the Gorrondatxe section was found 115 m above the Ypresian/Lutetian boundary GSSP and its highest occurrence is 264 m higher (text-fig. 6). It extends from the upper part of the standard planktonic foraminiferal Zone E7b to the lower part of Zone E8, being therefore restricted to the lower Lutetian. According to the age model developed by Payros et al. (2007a) at Gorrondatxe, the lowest occurrence of *M. gorrondatxensis* can be dated at 46.6 Ma, being 1.2 myr younger than the Ypresian/Lutetian boundary and 1.1 myr older than the E7b/E8 zonal boundary; its highest occurrence in Gorrondatxe is estimated at 44.3 Ma, 1.2 myr after the E7b/E8 zonal boundary (text-fig. 6; note that the numerical ages by Payros et al. 2007a were calibrated to the time scale of Gradstein et al. 2004; the time scale of Gradstein et al. 2012 has identical numerical values at the base of the Lutetian Stage but they differ by up to 0.5 myr at the top of the studied interval).

In all of the Pyrenean basins, in the Cape Verde Islands and in the Austrian succession reported above *M. gorrondatxensis* occurs at the same stratigraphic interval as in Gorrondatxe (Zones E7b and E8; see Table 1 and the original references for each of the abovementioned localities). The Alabama and Pacific Ocean specimens herein re-classified as *M. gorrondatxensis* were collected from apparently older deposits, but these ages should be revisited and possibly revised in the light of the new evidence. Furthermore, in all of the continuous successions studied in the Pyrenean basins the stratigraphic range of the species can be accurately delimited between the upper part of Zone E7b and the lower part of Zone E8. However, in the Betic Cordillera the stratigraphic range of *M. gorrondatxensis* extends up to the



TEXT-FIGURE 3

Morozovella gorrondatxensis (Orue-Etxebarria 1985) and *M. crater* (Hornibrook 1958) specimens picked up from a sample collected 22m above the lowest occurrence of *M. gorrondatxensis* at Gorrondatxe (upper part of Zone E7b; scale bar: 100µm). 1-7: Umbilical views of the most primitive morphotype of *M. gorrondatxensis* (topotypes); 8-13: Umbilical views of *M. crater*; 14: Spiral view of *M. crater*; 15-16: Lateral view of *M. crater* (compare its flat spiral side with the more convex spiral side of *M. gorrondatxensis* shown in the lateral views in text-figs. 2a, 5). The morphological characteristics of *M. gorrondatxensis* do not fall within the variability of *M. crater*, showing that *M. gorrondatxensis* warrants being classified as a separate species in its own right.



TEXT-FIGURE 4

A. In addition to its occurrence in the Lutetian GSSP, *Morozovella gorrondatxensis* has been reliably identified in other Pyrenean (Boreal) and Betic (Tethyan) sedimentary basins of Iberia. *Morozovelloides crassatus* specimens from Austria (Egger et al. 2011) have been reclassified herein as *M. gorrondatxensis*. B. Other morozovellids from Alabama (Loeblich and Tappan 1957), the Cape Verde Islands (Blow 1979) and Shatsky Rise (Blow 1979; Pearson et al. 2006) have also been reclassified as *M. gorrondatxensis*, showing that the paleobiogeographic distribution of the species was supra-regional (50 Ma paleogeographic reconstructions by Ron Blakey 2011, Colorado Plateau Geosystems, Inc., available at <http://www.cpgeosystems.com>).

middle part of the late Lutetian Zone E10 (Pujalte et al. 2012, 2014). The differing stratigraphic range of *M. gorrondatxensis* in the Pyrenean and Betic basins was in all likelihood related to their distinct paleobiogeographic affinities and to the Lutetian climatic evolution. In Lutetian times, the Pyrenean basins were located at 35°N paleolatitude and had Boreal paleobiogeographic affinities, whereas the southern Iberian Betic basins were located at 30°N paleolatitude and had Tethyan affinities (text-fig. 4a). The Lutetian climate was generally characterized by a progressive cooling (Zachos et al. 2001), but morozovellids needed warm waters to thrive (Pearson et al. 2006). Therefore, it seems reasonable to conclude that the longer stratigraphic range of *M. gorrondatxensis* in the Betic basins was probably related to the prevalence of warmer conditions in the Tethyan low latitudes, whereas the Pyrenean basins became too cold for most morozovellids by late Lutetian times (Payros et al. 2006).

IMPLICATIONS FOR *M. CRATER*

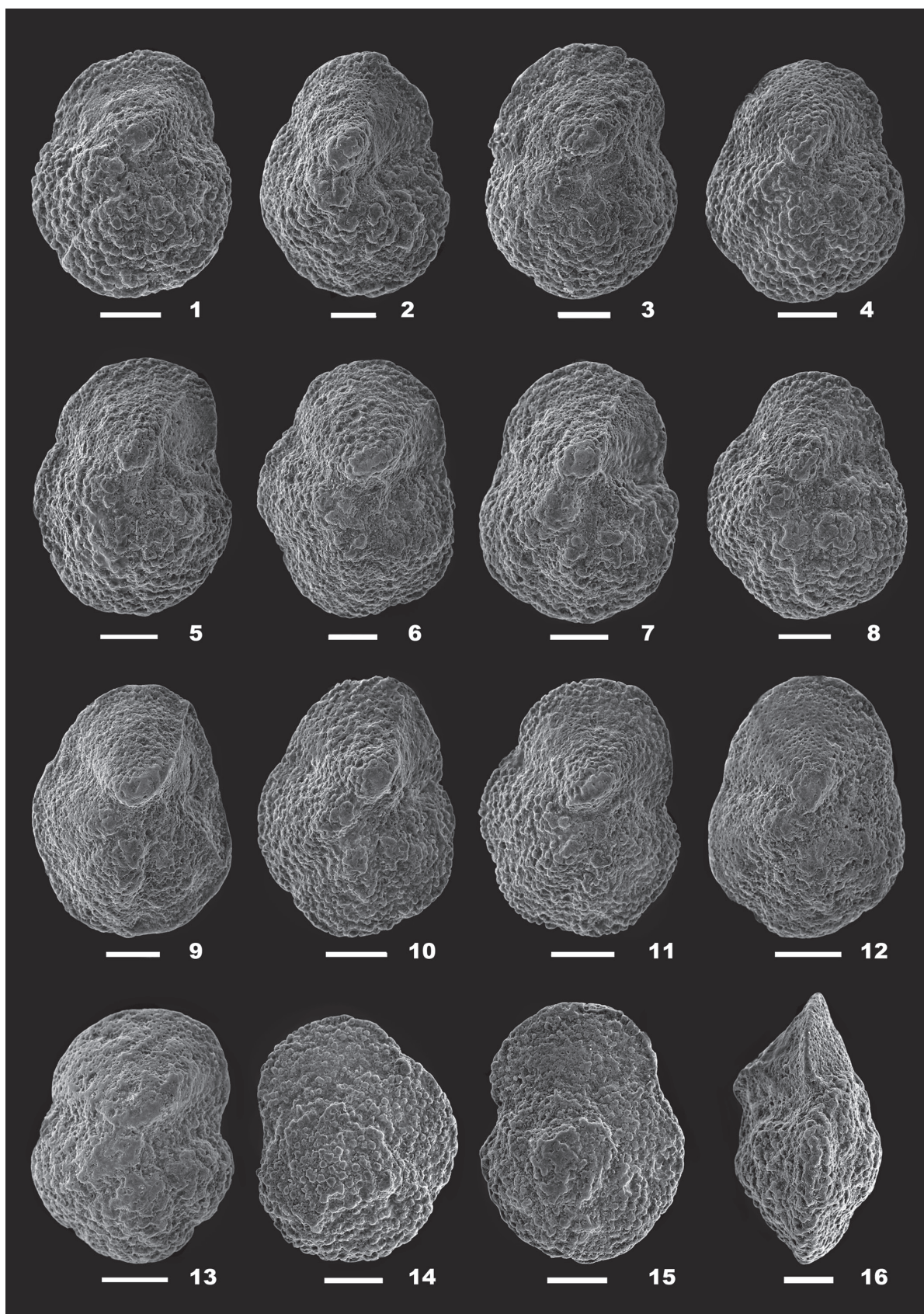
Morozovella crater and *M. gorrondatxensis* co-occur in a 60 m thick interval of the upper part of Zone E7b in the Gorrondatxe section (text-fig. 6). This interval can be dated between 46.6 Ma (marked by the lowest occurrence of *M. gorrondatxensis*) and 45.7 Ma (highest occurrence of *M. crater*). Interestingly, the stratigraphic range of *M. crater* does not reach the levels containing the fully evolved morphotype of *M. gorrondatxensis*, as *M. crater* disappears when *M. gorrondatxensis* still shows its most primitive characteristics (text-fig. 6). In all of the Iberian sections, the highest occurrence of *M. crater* can also be restricted to Zone E7b. Furthermore, Table 1 shows that true *M. crater* specimens do not extend much higher in other basins, as all certain occurrences can also be restricted to Zone E7b, except for one Austrian occurrence originally attributed to Zone E8. However, these observations differ notably from those suggested by Pearson et al. (2006), as they considered that *M. crater* extends from Zone E4 to Zone E9.

This discrepancy may have arisen from mistaking the youngest, most evolved morphotype of *M. gorrondatxensis* for *M. crater*. The underlying reason for this misclassification might be found in the fact that most Lower-Middle Eocene deep-marine sections in the world include significant stratigraphic gaps (Aubry 1991, 1995; Payros et al. 2007a, 2009b). This implies that expanded successions which extend continuously from deposits with *M. crater* to deposits with fully evolved *M. gorrondatxensis* have seldom been studied in detail. Consequently, the evolution described above, including the appearance of the primitive morphotype of *M. gorrondatxensis*, the subsequent disappearance of *M. crater* and the proliferation of the fully evolved morphotype of *M. gorrondatxensis*, has probably been overlooked. Taking everything into account, it is reasonable to conclude that specimens of the fully evolved morphotype of *M. gorrondatxensis* found in deposits younger than Zone E7 were misclassified as *M. crater*.

CONCLUSIONS

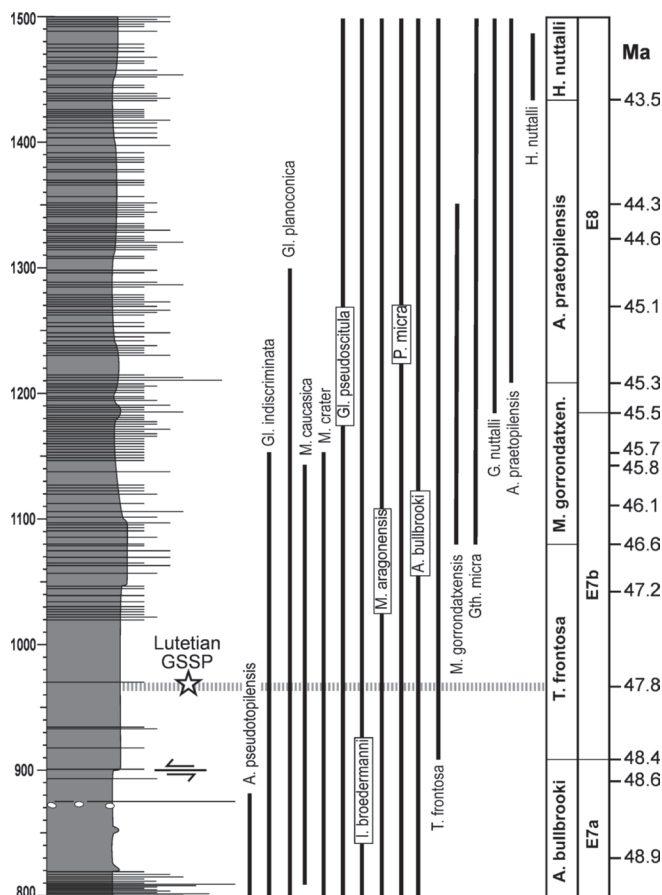
Detailed re-examination of *Morozovella gorrondatxensis* and *M. crater* descriptions and illustrations demonstrated that they have significant morphological differences. Consequently, we challenge the classification of the former as a junior synonym of the latter (Pearson et al. 2006) and argue that *M. gorrondatxensis* warrants being classified as a separate species in its own right. Although *M. gorrondatxensis* and *M. crater* partly co-occur, their stratigraphic distributions differ considerably. *Morozovella gorrondatxensis* is the planktonic foraminiferal species that first appears in the Lutetian deposits of the Gorrondatxe stratotype section. Its lowest occurrence is dated at 46.6 Ma, being 1.2 myr younger than the Ypresian/Lutetian boundary. This means that the lowest occurrence of *M. gorrondatxensis* is a valuable event to approximate the position of the Ypresian/Lutetian boundary using planktonic foraminifera. This event coincides with the lowest occurrence of *Globigerinatheka micra* (Orue-Etxebarria 1985; Orue-Etxebarria et al. 2006; Bernaola et al. 2006), but the value of the latter as a separate species still needs to be reassessed (Pearson et al. 2006; Molina et al. 2011). Taking everything into account, the planktonic foraminiferal events that best delimit the Ypresian/Lutetian boundary are the lowest occurrence of *M. gorrondatxensis* and that of *T. frontosa*, which is approximately 1.8 myr older (Payros et al. 2009a, 2011).

In addition to its occurrence in its type area, *M. gorrondatxensis* has been found in E7b-E8 deposits from other basins,



TEXT-FIGURE 5

Morozovella gorronatxensis (Orue-Etxebarria 1985). 1-11: Umbilical views; Middle Eocene, Zone E10, Gor section (Guadix Basin, Betic Cordillera, Granada); 12-13: Umbilical views, Middle Eocene, Zone E8, Osinaga section (Pamplona basin, western Pyrenees, Navarre); 14-15: Spiral views, Middle Eocene, Zone E10, Gor section (Guadix Basin, Betic Cordillera, Granada); 16: Lateral view, Middle Eocene, Zone E10, Gor section (Guadix Basin, Betic Cordillera, Granada). Scale bar: 100 μ m.



TEXT-FIGURE 6

Stratigraphic range of selected planktonic foraminiferal species in the Gorrondatxe section, showing that the distributions of *Morozovella gorrondatxensis* (Orue-Etxebarria 1985) and *Morozovella crater* (Hornibrook 1958) differ considerably. The lowest occurrence of *Morozovella gorrondatxensis*, dated at 46.6 Ma, is a valuable event to approximate the Ypresian/Lutetian and E7b/E8 zonal boundaries. Chronology is not linear due to the varying proportion of turbiditic deposits (Ma column, based on the age model of Payros et al. 2007a, which was calibrated to the times scale of Gradstein et al. 2004). The time scale of Gradstein et al. (2012) accepts the same age for the Lutetian GSSP (47.8 Ma) but suggests slightly older numerical values (by up to 0.5 myr) for the events at top of the section (see comments in Gradstein et al. 2012, p. 1097).

showing that the species was distributed at a supra-regional paleobiogeographic scale. Therefore, *M. gorrondatxensis* may prove useful to refine the standard planktonic foraminiferal biostratigraphic scale. Its lowest occurrence is 1.1 myr older than the E7b/E8 zonal boundary of Wade et al. (2011), thus allowing subdivision of Zone E7b. Its highest occurrence in Gorrondatxe is estimated at 44.3 Ma, 1.2 myr after the E7b/E8 zonal boundary. However, in Tethyan basins *M. gorrondatxensis* extends up into the late Lutetian Zone E10. The differing stratigraphic range suggests that the early disappearance of *M. gorrondatxensis* from the Pyrenean (Boreal) basins was driven by the progressively cooling Lutetian climate.

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TABLE 1

Review of morozovellids illustrated in the literature. Age according to the original reference but updated herein, if possible, to current zonal terminology (given in square brackets: P scale refers to Berggren et al. 1995 unless otherwise specified; E scale refers to Wade et al. 2011).

Reference	Locality, age	Original classification	Re-assessment (this study)
Loeblich and Tappan (1957), pl. 60, figs. 1a-c	Alabama, U.S., Early Eocene?	Globorotalia rex (=Morozovella subbotinae)	Morozovella gorrondatxensis
Mallory (1959), figs. 1a-c	Kern County, California, U.S., Early Eocene?	Globorotalia aragonensis Nutall var. twisselmanni	Morozovella crater
Samuel and Salaj (1968), pl. 11, figs. 3a-c	Slovakia, Early Eocene	Morozovella crater	Morozovella crater
Jenkins (1971), figs. 192-197	New Zealand, Early Eocene	Morozovella crater	Morozovella crater
Blow (1979), pl. 126, figs. 2, 5	DSDP 47-2/8/2/71-73 cm, Shatsky Rise, Pacific Ocean, originally assigned to Zone P8 of Blow (1979), dated as Zone E6 by Pearson et al. (2006)	Morozovella lensiformis	Morozovella gorrondatxensis
Blow (1979), pl. 154, fig. 1	KANE 9/42/95 cm, Echo Seamount, Cape Verde Islands, Atlantic Ocean, Zone P10 of Blow (1979) [=E7b]	Morozovella lensiformis	Morozovella gorrondatxensis
Nocchi et al. (1991), pl. 2, figs. 4-5	ODP 114, Southern Atlantic Ocean, Zone P9 [=Zones E7a-b]	Morozovella crater	Morozovella crater
Strong et al. (1995), fig. 6i	Mead Stream, New Zealand, Upper part of Zone P9 [=E7b]	Morozovella crater	Morozovella crater
Pearson et al. (2004), pl. 2, figs. 13-14	TDP-2, Tanzania, P9-10 transition zone [=E7b-8 transition]	Morozovella crater	Morozovella caucasica
Pearson et al. (2006), pl. 11.5, figs. 1-16	Several localities	Morozovella crater	Morozovella crater
Pearson et al. (2006), pl. 11.9, fig. 3	DSDP 47-2/8/2/71-73 cm, Shatsky Rise (Pacific Ocean), Zone E6	Morozovella lensiformis	Morozovella gorrondatxensis
Creech et al. (2010), figs. 2a-c	Waipara, New Zealand, 47-50.5 Ma	Morozovella crate	Morozovella crater
Egger et al. (2011), figs. A2.4, 1-3	Holzhäusl, Austria, Zone E8	Morozovelloides crassatus	Morozovella gorrondatxensis
Egger et al. (2011), figs. A2.4, 8-9	Holzhäusl, Austria, Zone E8	Morozovella crater	Morozovella crater
Egger et al. (2011), figs. A2.4, 12-13	Holzhäusl, Austria, Zone E8	Morozovella caucasica	Morozovella crater

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