

# Two new evolutionary lineages of the Maastrichtian-Paleogene *Gaudryina Pyramidata* and *Gaudryina Arabica* groups in the Tethys

## Abstract

The rich and well-preserved Maastrichtian-Paleogene benthic foraminiferal species of the agglutinated genus *Gaudryina* in the Tethys shows an increasing phylogenetic plasticity through the modifications of morphologic features first appearing in the ancestors. Two phylogenetic lineages are observed in some agglutinated benthic foraminiferal species throughout Maastrichtian to Lutetian in some localities in the Tethys: in the *Gaudryina pyramidata* and *Gaudryina arabica* groups. These lineages help, not only to define the major faunal changes throughout the Cretaceous-Tertiary (K-T) and the Paleocene-Eocene (P-E) boundaries, but also to emphasize the stratigraphic importance of them in different localities in the Tethys. In this study, the first lineage in *Gaudryina pyramidata* group is observed in four species throughout the time, from Maastrichtian (*G. pyramidata*) to Danian (*G. limbata*) to Ypresian (*G. speijeri*) to Lutetian (*G. ennakhali*). Another lineage in *Gaudryina arabica* group is also observed in four species, from Maastrichtian (*G. arabica*) to Paleocene (*G. salimi*) to Early Eocene (*G. ameeri*) to Middle Eocene (*G. osmani*). Four out of the identified species from the two groups are treated here to be new: *Gaudryina arabica*, *G. osmani*, *G. salimi* and *G. ennakhali*. The identified Maastrichtian-Lutetian species in this study are recognized in different localities in the Tethys: Atlantic Ocean, USA, Trinidad, Barbados, France, Spain, Italy, Tunisia, Egypt, UAE, Qatar and Iran.

**Keywords:** phylogeny, agglutinated benthic foraminifera, *Gaudryina*, Maastrichtian, Paleogene, atlantic ocean, Tethys

Volume 10 Issue 1 - 2022

**Haidar Salim Anan**

Professor of Stratigraphy and Micropaleontology, Al Azhar University-Gaza, Palestine

**Correspondence:** Haidar Salim Anan, Emeritus, Former Vice President of Al Azhar University-Gaza, Professor of stratigraphy and micropaleontology, P.O. Box 1126, Palestine, Email profanan@gmail.com

**Received:** January 08, 2022 | **Published:** January 31, 2022

## Introduction

The evolutionary patterns depend mainly on the concept of taxonomy and stratigraphy. The relatively rapid or slow observable morphological changes in the foraminiferal tests, number, size, shape and arrangement of the chambers, ornamentation, position of aperture, periphery throughout the Maastrichtian-Lutetian species over a time of some 30 m. y. (70-40 Ma) from the ancestors to the descendants, offer an opportunity to observe many evolutionary changes in two groups in this study: the *Gaudryina pyramidata* group: *G. pyramidata*, *G. limbata*, *G. speijeri* and *G. ennakhali*, and *Gaudryina arabica* group: *G. arabica*, *G. salimi*, *G. ameeri* and *G. osmani* Tjalsma & Lohmann<sup>1</sup> and Bolli et al.<sup>2</sup> noted that there is a remarkable difference in size among the specimens of *Gaudryina pyramidata* in Trinidad and other parts in the Atlantic Ocean, and the larger and smaller ones have relatively triserial or biserial chambers are often better developed. The evolutionary lineages may be produced by one of the two evolutionary models: Phyletic gradualism or Punctuated equilibrium. Most probably the first model causes the present lineages due to the open marine conditions between the different oceans throughout the Maastrichtian and Paleogene times.

## Previous studies

Many attempts have been made to interpret the phylogeny of some benthic foraminiferal species, which could have evolved from another earlier stratigraphic species. Nakkady<sup>3</sup> presented five evolutionary trends (by his own identification) of accelerated benthic foraminiferal evolution in the Maastrichtian-Paleogene transition of Egypt: (1) *Cibicides abudurbensis* Nakkady<sup>4</sup> evolved to *Anomalina pseudoacuta* Nakkady<sup>4</sup>, (2) *Siphogenerina esnehensis* Nakkady<sup>4</sup> to *Siphogenerinoides eleganta* Plummer,<sup>5</sup> (3) *Siphogenerina esnehensis*

Nakkady<sup>4</sup> to *S. higazyi* Nakkady<sup>3</sup>, (4) *Verneuilina cretacea* Karrer<sup>6</sup> to *Gaudryina pyramidata* Cushman<sup>7</sup>, (5) *Eovivigerina aegyptiaca* Nakkady<sup>4</sup> to *Gumbelina globulosa* Ehrenberg.<sup>8</sup>

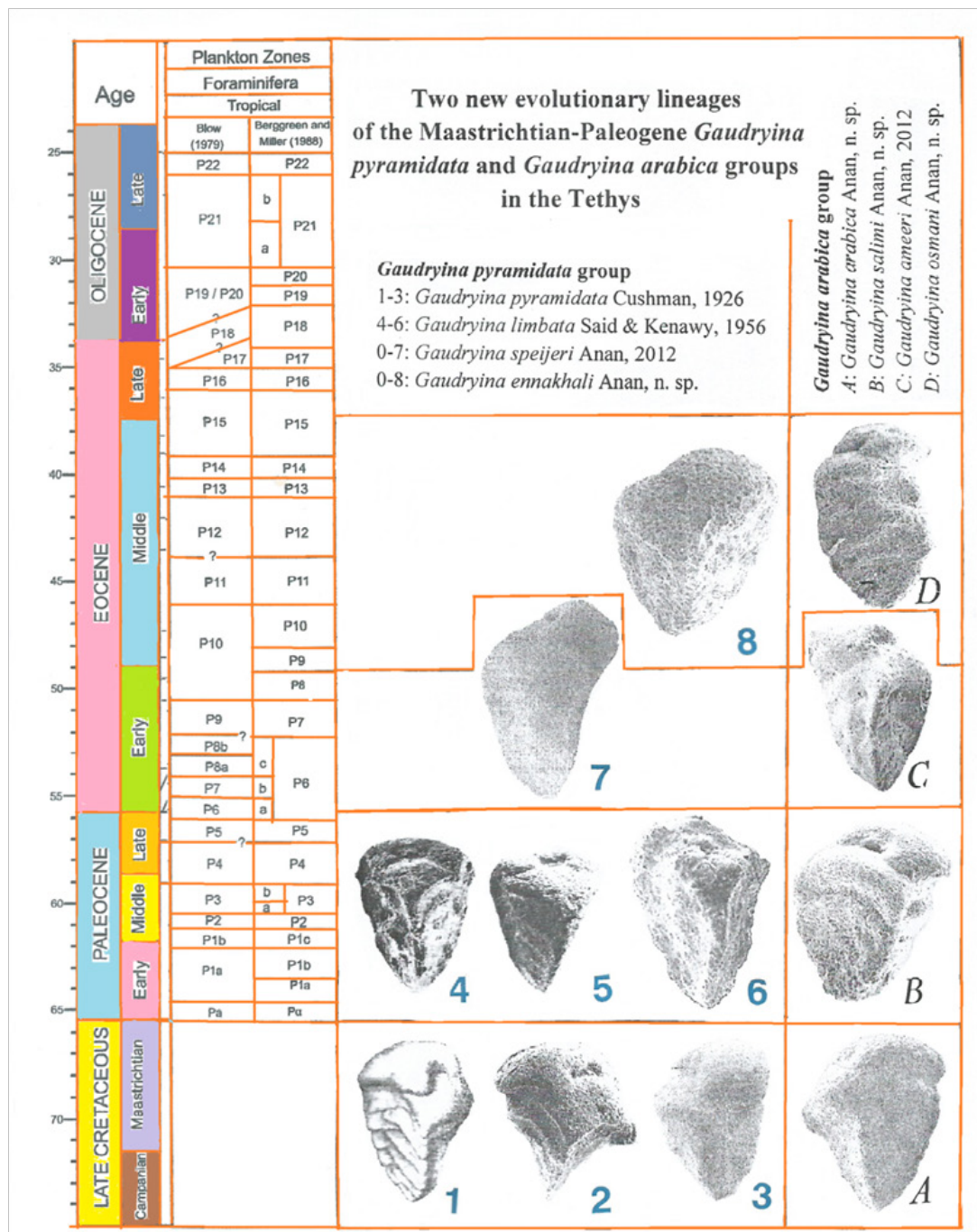
The last attempt was followed later by thirty one evolutionary trends of Anan<sup>9-14</sup>: (1) *Orthokarstenia oveyi* (Nakkady<sup>4</sup>) to *O. applinae* (Plummer)<sup>5</sup>, (2) *Discorbis p. pseudoscopos* Nakkady<sup>4</sup> to *D. p. duwi* Nakkady<sup>4</sup>, (3) *Verneuilina aegyptiaca* Said & Kenawy<sup>15</sup> to *V. luxorensis* Nakkady<sup>4</sup>, (4) *Coryphostoma incrassata* (Reuss)<sup>16</sup> to *C. midwayensis* (Cushman)<sup>17</sup>, (5) *Anomalinoides rubiginosus* (Cushman)<sup>18</sup> to *A. midwayensis* (Plummer)<sup>5</sup>, (6) *Gyroidinoides girardanus* (Reuss)<sup>16</sup> to *G. luterbacheri* Anan<sup>10</sup>, (7) *Angulogavelinella nekhliana* Said & Kenawy<sup>15</sup> to *A. avnimelechi* (Reiss)<sup>19</sup>, (8) *Cibicidoides pharaonis* (LeRoy)<sup>20</sup> to *C. farafraensis* (LeRoy)<sup>20</sup>, (9) *Bathysiphon californicus* (Martin)<sup>21</sup> to *B. paleocenicus* El Dawy<sup>22</sup> to *B. saidi* (Anan)<sup>23</sup>, (10) *Spiroplectinella knebeli* (LeRoy)<sup>20</sup> to *S. paracarinata* (Said & Kenawy)<sup>15</sup>, (11) *Gaudryina pyramidata* Cushman<sup>18</sup> to *G. ameeri* Anan<sup>12</sup> (12) *Gaudryina pyramidata* Cushman<sup>18</sup> to *G. speijeri* Anan<sup>12</sup> (13) *Bolivinoidea draco aegyptiaca* Anan<sup>13</sup> to *B. d. draco* (Marsson)<sup>24</sup>, to *B. d. dorreeni* Finlay<sup>25</sup>, (14) *Clavulina parisiensis* d'Orbigny<sup>26</sup> to *C. pseudoparisiensis* Anan<sup>27</sup>, (15) *Laevidentalina granti* (Plummer)<sup>5</sup> to *L. salimi* Anan<sup>28</sup>, (16) *Lenticulina carinata* (Plummer)<sup>5</sup> to *L. turbinata* (Plummer)<sup>5</sup> to *L. chitanii* (Yabe & Asano)<sup>29</sup>, (17) *Percultazonaria ameeri* Anan<sup>30</sup> to *P. allami* Anan<sup>30</sup>, (18) *Percultazonaria alii* Anan<sup>30</sup> to *P. longiscata* (Nakkady)<sup>4</sup>, (19) *Percultalina wadiarabensis* (Futyan)<sup>31</sup> to *Percultazonaria tuberculata* (Plummer)<sup>5</sup>, (20) *Palmata woodi undulata* Nakkady<sup>4</sup> to *P. w. woodi* Nakkady<sup>4</sup>, (21) *Gavelinella b. brotzeni* Said & Kenawy<sup>15</sup> to *Gavelinella brotzeni paleocenica* Said & Kenawy<sup>15</sup>, (22) *Siphogaudryina tellburmaensis* (Futyan)<sup>31</sup> to *S. africana* (LeRoy)<sup>20</sup>, (23) *Textularia haquei* Anan<sup>32</sup> to *T. farafraensis* LeRoy<sup>20</sup>, (24) *Pseudoclavulina barnardi* Futyan<sup>31</sup> to *P. maqfiensis* LeRoy<sup>20</sup>, (25) *Pyramidulina robinsoni* (Futyan)<sup>31</sup> to *P. leroyi* Anan<sup>32</sup>,

(27) *Frondicularia bignoti* Anan<sup>33</sup> to *F. nakkadyi* Futyan<sup>31</sup>, (28) *Frondicularia pickeringi* Futyan<sup>31</sup> to *F. gahannamensis* Ansary<sup>34</sup>, (29) *Hopkinsina arabina* Futyan<sup>31</sup> to *H. haquei* Anan<sup>32</sup>, (30) *Gyroidinoides tellburmaensis* (Futyan)<sup>31</sup> to *G. subangulata* (Plummer)<sup>5</sup>, (31) *Angulogavelinella convexa* (LeRoy)<sup>20</sup> to *A. bandata* Futyan<sup>31</sup> (1976).

### Benthic foraminiferal evolutionary trends

Minor differences in the morphology of the test, wall structure, arrangement of the chambers, position and type of aperture, stratigraphic level, size of the test and chambers are also recognized as being of the

decisive specific or subspecific value. This study represents another new attempt is made here to present two evolutionary trends marked by changes in the test morphological members of the diagnostic benthic foraminiferal genus *Gaudryina* in the Maastrichtian-Lutetian time: *Gaudryina pyramidata* group and *Gaudryina arabica* group (Figure 1). These lineages help not only to defined the major faunal changes at the K/T and through the different stages of the Paleogene, but also to emphasis the stratigraphic importance of them in different localities in the Tethys.



**Figure 1** The two phylogenetic lineages from the Maastrichtian-Paleogene of the Tethys. (1) *Gaudryina pyramidata* group (figs. 1-3: *Gaudryina pyramidata*, 4-6: *Gaudryina limbata*, 7: *Gaudryina speijeri*, 8: *Gaudryina ennakhali*) and (2) *Gaudryina arabica* group (fig. A: *Gaudryina arabica*, B: *Gaudryina salimi*, C: *Gaudryina ameeri*, D: *Gaudryina osmani*).

### **Gaudryina pyramidata lineage**

The triangular test has transverse section, early acute triserial chambers, later semi-circular final chamber in the biserial, chambers distinct and slightly inflated, truncate to subrounded periphery, sutures slightly depressed, wall agglutinated arenaceous with a smooth surface, aperture a low opening in a semicircular re-entrant of the inner margin of the last formed semi-circular chamber. The Maastrichtian *Gaudryina pyramidata* was probably ancestral of three subsequent Paleocene to Middle Eocene lineages, these are:

- 1.1 The Maastrichtian *Gaudryina pyramidata* Cushman<sup>7</sup> to the Paleocene *G. limbata* Said & Kenawy<sup>15</sup> lineage.
- 1.2 The Paleocene *Gaudryina limbata* Said & to the Early Eocene *G. speijeri* Anan<sup>12</sup> lineage.
- 1.3 The Early Eocene *Gaudryina speijeri* Anan<sup>12</sup> to the Middle Eocene *G. ennakhali* Anan (n. sp.) lineage

### **Gaudryina arabica lineage**

The triangular test has transverse section, acute triserial early chambers, later elongate tapering final chamber in the biserial stage, chambers distinct and slightly inflated, truncate to subrounded periphery, sutures slightly depressed, wall agglutinated arenaceous with a smooth surface, a large opening semicircular aperture of the inner margin of the last formed tapering chamber. The Maastrichtian *Gaudryina arabica* was probably ancestral to three subsequent Paleocene to Middle Eocene lineages, these are:

- 2.1 The Maastrichtian *Gaudryina arabica* Anan (n. sp.) to the Paleocene *G. salimi* Anan (n. sp.) lineage.
- 2.2 The Paleocene *Gaudryina salimi* Anan (n. sp.) to the Early Eocene *G. ameerii* Anan<sup>12</sup> lineage.
- 2.3 The Early Eocene *Gaudryina ameerii* Anan<sup>12</sup> to the Middle Eocene *G. osmani* Anan (n. sp.) lineage.

### **Taxonomy**

The taxonomy of Kaminski<sup>34</sup> is followed here for the recorded fauna. The *Gaudryina pyramidata* group includes four species throughout Maastrichtian to Lutetian (*G. pyramidata*, *G. limbata*, *G. speijeri* and *G. ennakhali*), but the *Gaudryina arabica* group includes another four species (*G. arabica*, *G. salimi*, *G. ameerii* and *G. osmani*), which illustrated in Plate 1. Some modern references are added to complete descriptions, synonymies, stratigraphy and new taxonomic considerations.

Order Foraminiferida Eichwald, 1830

Suborder Verneulinina Mikhalevich and Kaminski, 2004

Superfamily Verneulinioidea Cushman, 1911

Family Reophacellidae Mikhalevich and Kaminski, 2004

Subfamily Verneulininae Cushman, 1911

Genus *Gaudryina* d'Orbigny, 1839

Type species *Gaudryina rugosa* d'Orbigny, 1839

1. The *Gaudryina pyramidata* group:

***Gaudryina pyramidata* Cushman<sup>18</sup>** - (Pl. 1, figs. 1-3)

1926 *Gaudryina laevigata* Franke var. *pyramidata* Cushman<sup>18</sup>, p. 587, pl. 16, fig. 8.

1946 *Gaudryina (Pseudogaudryina) pyramidata* Cushman<sup>36</sup>, p. 36, pl. 8, fig. 14.

1953 *Gaudryina pyramidata* Cushman - LeRoy<sup>20</sup>, p. 31, pl. 1, figs. 17, 18.

1956 *Gaudryina pyramidata* Cushman - Said & Kenawy<sup>15</sup>, 124, pl. 1, fig. 26.

1978 *Gaudryina pyramidata* Cushman - Proto Decima & Bolli<sup>37</sup>, p. 793, pl. 1, fig. 6.

1983 *Gaudryina pyramidata* Cushman - Tjalsma & Lohmann<sup>1</sup>, p.12, pl. 2, fig. 4; pl. 8, fig. 1.

1988 *Gaudryina pyramidata* Cushman - Kaminski et al.<sup>38</sup>, p. 194, pl. 8, fig. 7.

1993 *Gaudryina pyramidata* Cushman - Hewaidy & Al-Hitmi<sup>39</sup>, p. 478, pl. 4, fig. 8.

1993 *Gaudryina pyramidata* Cushman - Kuhnt & Kaminski<sup>40</sup>, p. 73, pl. 6, fig. 9.

1994 *Gaudryina pyramidata* Cushman - Bolli et al.<sup>2</sup>, p. 90, fig. 24. 4 (non 5, 6).

2001 *Gaudryina pyramidata* Cushman - El-Dawy<sup>22</sup>, p. 42, pl. 1, fig. 4.

2003 *Gaudryina pyramidata* Cushman - Abdelghany<sup>41</sup>, p. 398, fig. 7. 1.

2005 *Gaudryina pyramidata* Cushman - Anan<sup>42</sup>, p. 81, pl. 1, fig. 4.

2005 *Gaudryina pyramidata* Cushman - Sztrakos<sup>43</sup>, p. 184, pl. 2, fig. 5.

2012 *Gaudryina pyramidata* Cushman - Ismail<sup>44</sup>, p. 29, pl. 1, fig. 15.

2014 *Gaudryina pyramidata* Cushman - Hewaidy et al.<sup>45</sup>, p. 22, pl. 4, fig. 6.

2016 *Gaudryina pyramidata* Cushman - VahdatiRad et al.<sup>46</sup>, p. 6, fig. 2. 17.



**Plate 1**

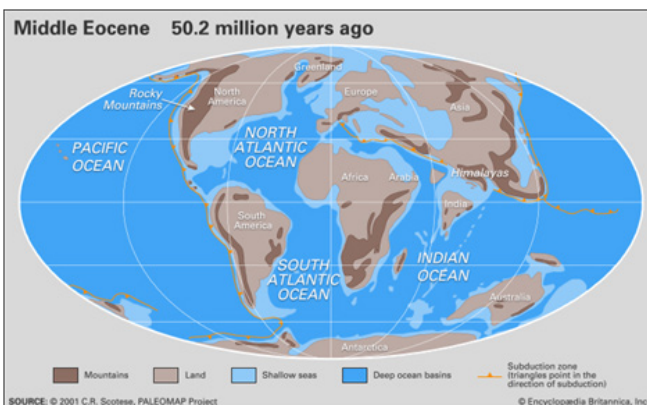
**The *Gaudryina pyramidata* group:** Fig.1-3: The Maastrichtian *Gaudryina pyramidata* Cushman (1926): 1. after Cushman (1926) x 40, 2. after Bolli et al. (1994) x 65, 3. after Anan (2005) x 100; 4-8: The Paleocene *Gaudryina limbata* Said and Kenawy (1956): 4. after Said and Kenawy (1956) x 70, 5. after Anan (1993) x 160, 6. after Bolli et al. (1994) x 50, 7. after Bolli et al. (1994) x 95, 8. after Abdelghany and Abu Saima (2013) x 70; 9. The Early Eocene *Gaudryina speijeri* Anan (2012) x 100; 10. The Middle Eocene *Gaudryina ennakhali* Anan, n. sp. x 85,

**The *Gaudryina arabica* group:** Fig. 11. The Maastrichtian *Gaudryina arabica* n. sp. x 45; 12. The Paleocene *Gaudryina salimi* Anan, n. sp. x 90; 13. The Early Eocene *Gaudryina ameerii* Anan (2012) x 85; 14. The Middle Eocene *Gaudryina osmani* Anan, n. sp. x 45.

Remarks: According to Cushman<sup>36</sup>, the test of this species somewhat longer (1.25 mm) than broad (0.09 mm), triangular in transverse section, the early chamber triserial, later biserial, angles acute, chambers distinct and slightly inflated, truncate periphery, sutures slightly depressed, wall agglutinated arenaceous with a smooth surface, aperture a low opening in a semicircular re-entrant of the inner margin of the last formed chamber. It is indicated by many authors as an index fossil for the Maastrichtian, and may range to Danian. The cosmopolitan species *Gaudryina pyramidata* was originally recorded from the Maastrichtian Velasco Shale in Mexico and occur also in USA, Trinidad, Atlantic Ocean, but later on from the Paleocene strata in many parts of the Northern Tethys (Spain, France, Italy), and Southern Tethys (Tunisia, Egypt, Qatar, Iran). It is related to Velasco-Type Fauna (VTF).



**Figure 2** The paleogeographic map of the K/T boundary showing some Tethyan localities, which including the recognized Maastrichtian members of the genus *Gaudryina* in the Tethys: Atlantic Ocean (USA, Trinidad, Barbados), Europe (Spain, France, Italy), North Africa (Tunisia, Egypt), southwest Asia (Jordan, Qatar, UAE).



**Figure 3** The paleogeographic map of the Middle Eocene showing the connections between the Pacific, Atlantic, Tethys and Indian Oceans which including the recognized Lutetian members of the genus *Gaudryina*: the Middle Eocene *Gaudryina ennakhali* Anan, n. sp. and the Middle Eocene *Gaudryina osmani* Anan, n. sp.

***Gaudryina limbata* Said & Kenawy<sup>15</sup> - (Pl. 1, fig. 4-8)**

- 1956 *Gaudryina limbata* Said & Kenawy<sup>15</sup>, p. 123, pl. 1, fig. 23.
- 1975 *Tritaxia midwayensis* (Cushman) - Berggren & Aubert<sup>47</sup>, p. 158, pl.1, fig. 1e (non 1a-d).
- 1993 *Gaudryina limbata* Said & Kenawy - Anan<sup>48</sup>, p. 314, pl. 1, fig. 6.
- 1993 *Gaudryina limbata* Said & Kenawy - Hewaidy & Al-Hitmi<sup>39</sup>, p. 478, pl. 4, figs. 6, 7.

1994 *Gaudryina pyramidata* Cushman - Bolli et al.<sup>2</sup>, p. 90, fig. 24. 4.5, 6 (non 4).

2013 *Gaudryina limbata* Said & Kenawy - Abdelghany & Abu Saima<sup>49</sup>, pl. 1, fig. 10.

2014 *Gaudryina limbata* Said & Kenawy - Hewaidy et al.<sup>45</sup>, p. 21, pl. 4, fig. 5.

2016 *Gaudryina limbata* Said & Kenawy - Anan<sup>50</sup>, p. 357, fig. 3m.

2017 *Gaudryina pyramidata* Cushman - Hewaidy et al.<sup>51</sup> p. 83, pl. 2, fig. 16.

2021 *Gaudryina limbata* Said & Kenawy - Anan<sup>52</sup>, p. 271, pl. 1, fig. 3.



**Figure 4** The three locations which the holotype species of the genus *Gaudryina* were used in this study: USA and Atlantic Ocean (*G. pyramidata*, *G. salimi*, *G. ennakhali*, *G. osmani*), Egypt=E (*G. ameerii*, *G. limbata*, *G. speijeri*) and UAE (*G. arabica*).

**Remarks:** This species has triangular transverse section, triserial early stage and later biserial, angled acute with truncated periphery and limbate sutures. Tjalsma & Lohmann<sup>1</sup> considered the *Gaudryina limbata* Said & Kenawy<sup>15</sup> is conspecific with *G. tumeyensis* Israelski<sup>53</sup> which treated by them as a synonym of Cushman. In this study, the two species are separated. The Danian *G. limbata* differs from the Maastrichtian *G. pyramidata* in being less elongated test, having sharper edges, more limbate sutures and younger stratigraphic level. In this study, the *G. pyramidata* is considered here as the ancestor of the descendent *G. limbata*. The latter species was originally recorded from the Danian of Sinai of Egypt, and later the figured forms of Anan<sup>48</sup> and Abdelghany & Abu Saima<sup>49</sup> of UAE, Bolli et al.<sup>2</sup> of Trinidad.

***Gaudryina speijeri* Anan<sup>12</sup> - (Pl. 1, fig. 9)**

- 1994 *Gaudryina cf. ellisorae* Cushman - Speijer<sup>54</sup>, p. 147, pl. 5, fig. 1.
- 2012 *Gaudryina speijeri* Anan<sup>12</sup>, p. 66, pl. 1, fig. 10.
- 2016 *Gaudryina speijeri* Anan - Anan<sup>50</sup>, p. 357, fig. 3n.
- 2019 *Gaudryina pyramidata* - Bejaoui et al.<sup>55</sup>, p. 523, pl. 11, fig. 2.
- 2021 *Gaudryina speijeri* Anan - Anan<sup>52</sup>, p. 271, pl. 1, fig. 5.

Remarks: The carinate rib is very distinct in this Early Eocene species *G. speijeri*, which exists in the triserial stage and extends to the final chamber of the biserial stage. This species differs from the Late Cretaceous *Gaudryina (Pseudogaudryina) ellisorae* Cushman in its semiglobular last chamber with more circular aperture than the triangular last chamber, and more elongate aperture than in Cushman's specimen. It seems that the illustrated side view of *G. pyramidata* in Bejaoui et al<sup>55</sup> is closely related to *G. speijeri* due to its semi-rounded final chamber, which characterized this species. In this study, the *G.*

*speijeri* more accurately was evolved from the Paleocene *G. limbata*, not directly from the Maastrichtian *G. pyramidata* as previously noted by Anan<sup>12</sup>, that the *G. speijeri* was evolved directly from the Maastrichtian *G. pyramidata*. This species was recorded from the Early Eocene in many sections in Egypt.

***Gaudryina ennakhali* Anan, n. sp.** - (Pl. 1, fig. 10)

1983 *Gaudryina pyramidata* Cushman - Tjalsma & Lohmann<sup>1</sup>, p. 12, pl. 8, fig. 1.

Holotype: Illustrated specimen in Pl. 1, fig. 10.

Dimension: Length 0.40 mm. width at top part 0.30 mm.

Etymology: After the late micropaleontologist Prof. H. El-Nakhal, Islamic University-Gaza.

Age: Middle Eocene.

Diagnosis: Test triangular in transverse section, the early chamber triserial, later biserial with more or less rounded angles, chambers slightly inflated, subrounded periphery, sutures slightly depressed, wall agglutinated arenaceous with a smooth surface, aperture a large semi-circular opening in the inner margin of the last formed chamber.

Remarks: This Middle Eocene species loose the carinate rib along the test and more or less rounded periphery. In this study, the Early Eocene *G. speijeri* is considered here as the ancestor of the descendent Middle Eocene *G. ennakhali*.

2. *Gaudryina arabica* group:

***Gaudryina arabica* Anan, n. sp.** - (Pl. 1, fig. 11)

2003 *Gaudryina pyramidata* Cushman - Abdelghany<sup>41</sup>, p. 398, fig. 7.1.

Holotype: Illustrated specimen in Pl. 1, fig. 11.

Dimension: Length 0.40 mm. width at top part 0.40 mm.

Etymology: After the United Arab Emirates (UAE).

Age: Late Maastrichtian.

Diagnosis: The early triserial stage is triangular in transverse section, the later biserial angled acute, chambers distinct and slightly inflated, truncate periphery, sutures slightly depressed, wall agglutinated arenaceous with a smooth surface, aperture a low opening in a semicircular of the inner margin of the last formed chamber.

Remarks: The front acute periphery of the test is very distinct in this Maastrichtian species, which exists along the chamber of the triserial stage, without extending to biserial stage. The elongation and tapering final chamber with semi-circular aperture at the apertural face is distinguished this species and all other species of this group.

***Gaudryina salimi* Anan, n. sp.** - (Pl. 1, fig. 12)

1983 *Gaudryina pyramidata* Cushman - Tjalsma & Lohmann<sup>1</sup>, p. 12, pl. 2, fig. 4.

Holotype: Illustrated specimen in Pl. 1, fig. 12.

Dimension: Length 0.75 mm. width at top part 0.70 mm.

Etymology: After my late son Salim Anan.

Age: Late Paleocene.

Diagnosis: Test large, triangular in transverse section, the early chamber triserial, later biserial, angles acute, chambers distinct and

slightly inflated, truncate periphery, sutures slightly depressed, wall agglutinated arenaceous with a smooth surface, aperture a large opening in a semicircular of the inner margin of the last formed chamber. It is indicated as an index fossil for the Paleocene.

Remarks: The front edge grow to produce a semi-carinate rib extends on the hole triserial portion, and extends to the pre-final chamber of the biserial stage. In this study, the Maastrichtian *G. arabica* represents the ancestor of the descendent Paleocene *G. salimi*.

***Gaudryina ameeri* Anan<sup>12</sup>** - (Pl. 1, fig. 13)

2012 *Gaudryina ameeri* Anan<sup>12</sup>, p. 63, pl. 1, fig. 7.

2021 *Gaudryina ameeri* Anan - Anan<sup>52</sup>, p. 86, pl. 1, fig. 9.

Remarks: The front carinate rib is very distinct in this Early Eocene species, which exists along the pre-final chamber of the biserial stage as well as the whole triserial portion. The elongate and tapering final chamber with semi-circular aperture at the apertural face in *Gaudryina ameeri* Anan differs from the semiglobular final chamber with circular aperture in the other *G. speijeri* Anan, and *G. ameeri* is shorter test than *G. speijeri*. The author believes that the Early Eocene *G. ameeri* was derived from the Paleocene *G. salimi* due to the growing of front edge to produce a carinate rib extends on the hole triserial portion and extends to the pre-final chamber of the biserial stage, but in another edge of the test. The second changes exist in the final chamber of *G. salimi*, which tending to be tapered through the younger time. In this study, the Paleocene *G. salimi* is considered here as the ancestor of the descendent Early Eocene *G. ameeri*.

***Gaudryina osmani* Anan, n. sp.** - (Pl. 1, fig. 14)

2003 *Gaudryina* cf. *pyramidata* Cushman - Tjalsma & Lohmann<sup>1</sup>, p. 31, fig. 8.2.

Holotype: Illustrated specimen in Pl. 1, fig. 14.

Dimension: Length 0.45 mm. width at top part 0.40 mm.

Etymology: After the micropaleontologist Prof. Osman Abdelghany, UAE University.

Age: Early-Middle Eocene.

Diagnosis: This species differs from *G. pyramidata* by its more strongly tapering initial triserial end part without carinate rib, more or less quadrate biserial part, elongate and tapering final chamber with elongate aperture at the apertural face.

Remarks: In this study, the Ypresian *G. ameeri* is considered here as the ancestor of the descendent the Lutetian *G. osmani*.

## Paleogeography

In this study, the identified Maastrichtian-Lutetian species of the two *Gaudryina* groups are recognized in different localities in the Tethys: Atlantic Ocean, USA, Trinidad, France, Spain, Italy, Tunisia, Egypt, UAE and Qatar. Haq & Aubry<sup>56</sup> noted that the North Africa and Middle East formed important parts of the Tethyan link between the Atlantic and Pacific Oceans during the K/T boundary (Fig. 2) and the Middle Eocene (Fig. 3). Abdelghany<sup>41</sup> noted that the Maastrichtian benthic foraminiferal species of Qarn El Barr section, UAE (including *Gaudryina arabica* n. sp.) and some other sections in Iraq, Jordan and Egypt are closest to the Maastrichtian fauna of Nekhl section, Sinai, Egypt (including *Gaudryina pyramidata* and *G. limbata*) (Fig. 4). The closest morphology of any recorded species from different localities in the Tethys (specimens of *G. pyramidata* from USA, Trinidad and

Egypt, Pl. 1, figs. 1-3; specimens of *G. limbata* from Egypt, UAE and Trinidad, Pl. 1, figs. 4-8) prove the open marine conditions between the different localities in different oceans throughout the Maastrichtian and Paleogene times.

## Paleoenvironment

The following is an account on the relevant paleoenvironment and interpretation in this study:

Said & Kenawy<sup>15</sup> described and recorded more than two hundred and fifty benthic foraminiferal species (including *Gaudryina limbata*) from the Maastrichtian-Paleogene strata of Sinai, Egypt. These taxa shown an affinity with Midway Type Fauna (MTF) of American Gulf Coastal Plain which documented also by Berggren & Aubert<sup>47</sup>, while Anan<sup>57</sup> (2011) noted that the probable environment for Sinai in the northern Egypt (the type locality of *Gaudryina limbata*) is outer neritic-upper bathyal (200–400 m).

Murray<sup>58</sup> noted that arenaceous foraminifera (including the genus *Gaudryina* and its members) tend to increase in cooler (usually deeper) environments. Anan<sup>59</sup> noted that the cosmopolitan cooling of the top Maastrichtian (including *Gaudryina pyramidata*) was prevailed also in Jiran El Ful section, Abu Rawash area, northern Egypt.

Tjalsma & Lohmann<sup>1</sup> recorded and described the DSDP which includes bathyal and abyssal fauna (including the Middle Eocene *Gaudryina ennakhali* and *G. osmani*) from Atlantic Legs 3,10, 14, 15, 36, 39, 40 and 44, and compared these material from the uplifted surface sections of the Paleocene (in Mexico, Trinidad) and Eocene (in Barbados).

Anan<sup>48</sup> noted that the Paleocene assemblage of benthic foraminiferal species (including *Gaudryina limbata*) in the Malaqet section (UAE) belongs to the MFT, middle to outer neritic environment (50-200 m), while the Maastrichtian species in the UAE (including *Gaudryina pyramidata*, *G. limbata*, and also *G. arabica* in this study) representing shallow to deep water environment, which may prevailed in the Arabian Gulf area in that time (Anan<sup>42</sup>).

Speijer<sup>54</sup> noted that the carinate ribs are very distinct in his Early Eocene *Gaudryina* cf. *ellisorae* (= *G. speijeri* in this study) from Wadi Nukhul (west Sinai, Egypt), and represents the deeper localities which have smooth tests, while the shallow water specimens are more coarse grained.

Gawenda et al.<sup>60</sup> noted that the turbidite sedimentation is the product of a complex interplay of tectonics, climate, production of biogenic material, and sea-level changes, and these factors control the availability and volume of detrital material transported by the gravity flows from the neritic shelf environment to adjacent basins.

Meulenkamp & Sissingh<sup>61</sup> noted that the Arabian Platform still largely covered by the sea in the Early to Middle Eocene, while it subjected to a major regression in the Middle to Late Eocene.

Bejaoui et al.<sup>55</sup> considered some agglutinated genera in Wadi Necham section, (northwest Tunisia) yields agglutinated species, such as *G. pyramidata*, of typical bathyal to upper abyssal assemblage with high terrigenous sedimentation rate and associated moderate organic flux.

Anan<sup>52</sup> considered the genus *Gaudryina* with the other genera of the family Verneuilinidae (*Plectina*, *Siphogaudryina*, *Verneuilina*) presented deep marine environments.

## Summary and conclusions

The rich and well-preserved Maastrichtian-Paleogene benthic

foraminiferal species of the agglutinated genus *Gaudryina* in the Tethys shows an increasing phylogenetic plasticity through the modifications of morphologic features first appearing in the ancestors, which made it possible to present two lineages: (1) *Gaudryina pyramidata* lineage (Maastrichtian *Gaudryina pyramidata* to Paleocene *G. limbata* to Early Eocene *G. speijeri* to the Middle Eocene *G. ennakhali*), and (2) *Gaudryina arabica* lineage (Maastrichtian *Gaudryina arabica* to the Paleocene *G. salimi* to the Early Eocene *G. ameeri* to the Middle Eocene *G. osmani*). The evolutionary lineages may be produced by one of the two evolutionary models: Phyletic gradualism or Punctuated equilibrium. Most probably the first model causes the present lineages. Four out of the recorded species from the two lineage groups are believed here to be new: *Gaudryina arabica*, *G. salimi*, *G. osmani* and *G. ennakhali*. The identified species of the two groups are recorded from wide localities in the Tethys: Atlantic Ocean, USA, Trinidad, France, Spain, Italy, Tunisia, Egypt, UAE, Qatar and Pakistan. The recorded species ranges from the middle-outer neritic, Midway Type Fauna (MTF) to bathyal environment Velasco-Type Fauna (VTF) (100-400 m depth), which also indicated an open marine conditions between the different oceans throughout the Maastrichtian and Paleogene times.

## Acknowledgments

None.

## Conflicts of interest

Authors declare that there is no conflict of interest.

## References

1. Tjalsma RC, Lohmann GP. Paleocene-Eocene bathyal and abyssal benthic foraminifera from the Atlantic Ocean. *Micropaleontology, Special Publication*. 1983;4:1–90.
2. Bolli HM, Beckmann JP, Saunders JB. *Benthic foraminiferal biostratigraphy of the south Caribbean region*. Cambridge University; 1994. 1–408 p.
3. Nakkady SE. The stratigraphic implication of the accelerated tempo of evolution in the Mesozoic-Cenozoic transition of Egypt. *Journal of Paleontology*. 1955;29(4):702–706.
4. Nakkady SE. A new foraminiferal fauna from the Esna Shale and Upper Cretaceous chalk of Egypt. *Journal of Paleontology*. 1950;24(6):675–692.
5. Plummer HJ. Foraminifera of the Midway Formation in Texas. *Bulletin University of Texas*. 1927;2644:3–206.
6. Karrer F. Ueber ein neues Vorkommen von oberer Kreideformation in Leitersdorf bei Stockerau und deren Foraminiferen Fauna. *Jahrbuch der Geologischen Bundesanstalt*. 1870;20:157–184.
7. Cushman JA. An outline of the re-classification of the Foraminifera. *Contributions from the Cushman Laboratory for foraminiferal Research*. 1927;3(1):1–105.
8. Ehrenberg CG. Über die bildung der Kreidefelsen und des Kreidemergels durch unsichtbare Organismen. *Physikalische Abhandlungen der Königlichen Akademie der Wissenschaften zu Berlin*, 1838 [1840: separate 1839], 1839;59–147.
9. Anan HS. Accelerated evolution in representatives of the genera *Orthokarstenia* and *Discorbis* (Benthic foraminifera) in the Maastrichtian and Paleocene of Egypt (Misr). *Neues Jahrbuch für Geologie und Paläontologie, Mh*. 1998;6:365–375.
10. Anan HS. A lineage phylogeny for some Maastrichtian to Ypresian benthic foraminifera in Egypt. *Egyptian Journal of Paleontology*. 2004;4:39–57.

11. Anan HS. Contribution to the Egyptian benthic foraminifera around the Paleocene/Eocene boundary in Egypt. *Egyptian Journal of Paleontology*. 2010;10:25–47.
12. Anan HS. A lineage phylogeny from some Cretaceous-Tertiary agglutinated benthic foraminiferal species in Egypt and Tethys. *Egyptian Journal of Paleontology*. 2012;12:59–72.
13. Anan HS. Evolutionary lineage of the Maastrichtian *Bolivinoidea draco* group (benthic foraminifera) in Abu Zenima section, west central Sinai, Egypt. *Arabian Journal of Geosciences*. 2017;10.431:1–7.
14. Anan HS. Punctuatedism and gradualistic evolutionary trends of eight phylogenetic lineages of Maastrichtian to Eocene and Recent benthic foraminifera from the Tethys. *Journal of Sciences*. 2020a;31(1):63–73.
15. Said R, Kenawy A. Upper Cretaceous and Lower Tertiary foraminifera from northern Sinai, Egypt. *Micropaleontology*. 1956;2(2):105–173.
16. Reuss AE. Ober die fossilen foraminiferen und Entomostraceen der Septarienthone der Umgegend von Berlin. *Zeitschrift der Deutschen Geologischen Gesellschaft*, Berlin. 1851;3(1):49–92.
17. Cushman JA. New genera and species of the families Verneuilinidae and Vulvulinidae and of the subfamily Virguliniinae. *Cushman Foundation for Foraminiferal Research, Special Publication*, 1936;6:1–71.
18. Cushman JA. The foraminifera of the Velasco Shale of the Tampico Embayment. *American Association of Petroleum Geology Bulletin*. 1926;10(6):581–612.
19. Reiss Z. Two new species of foraminifera from Israel. *Bulletin Research Council, Israel*. 1952;2:269–270.
20. LeRoy LW. Biostratigraphy of Maqfi section, Egypt. *Geological Society of American Memoir*. 1953;54:1–73.
21. Martin LT. Upper Cretaceous and Lower Tertiary foraminifera from Fresno County, California. *Jahrbuch der Geologischen Bundesanstalt Sonderband*. 1964;9:1–128.
22. El-Dawy MH. Paleocene benthic foraminiferal biostratigraphy and paleobathymetry, El Sheikh Fadl and Ras Gharib, Eastern Desert, Egypt. *Micropaleontology*. 2001;47(1):23–46.
23. Anan HS. Benthic foraminifera around Middle/Upper Eocene boundary in Egypt. *Middle East Research Center, Ain Shams University, Earth Science Series*, Cairo. 1994;8:210–233.
24. Marsson Th. Die Foraminiferen der Weissen Schreiekreide der Inseln Rügen. *Mitteilungen des Naturwissenschaftlichen Vereins für Neu-Vorpommern und Rügen in Greifswald*. 1878;10:115–196.
25. Finlay HJ. New Zealand foraminifera: Key species in stratigraphy, 4. *Transactions of the Royal Society of New Zealand*. 1940;69:448–472.
26. Orbigny AD. Tableau méthodique de la classe des Céphalopodes. *Annals des Sciences de la Naturelles*, Paris, 1826;7: 96–169, 245–314.
27. Anan HS. Littoral Recent foraminifera from the Qossier-Marsa Alam stretch of the Red Sea coast, Egypt. *Revue de Paléobiologie*. 1984;3(2):235–224.
28. Anan HS. Paleontology and stratigraphical distribution of suborder Lagenina (benthic foraminifera) from the Middle-Late Eocene Mazyad Member of the Dammam Formation in Jabal Hafit, Al Ain area, United Arab Emirates, Northern Oman Mountains. *Revue de Paléobiologie*, 2009;28(1):1–18.
29. Yabe H, Asano K. Contributions to the paleontology of the Tertiary formations of West Java. Part I. Minute foraminifera from the Neogene of West Java. *Science Reports Tohoku University Series (Geology)*. 1937;2(19):87–127.
30. Anan HS. Paleogene Lagenid Percultazonarias (Foraminifera) in Egypt: paleontology, stratigraphy, paleo-geography and some taxonomical considerations. *Egyptian Journal of Paleontology*. 2015;15:13–30.
31. Futyan AI. Late Mesozoic and Early Cainozoic benthonic foraminifera from Jordan. *Palaeontology*. 1976;19(3):517–537.
32. Anan HS. Taxonomic consideration and stratigraphic implication of the accelerated evolution of the Maastrichtian-Eocene transition of twenty benthic foraminiferal species in the Tethys. *Earth Sciences Pakistan (ESP)*. 2020b;4(1):01–06.
33. Anan H.S. Stratigraphy and paleobiogeography of some Frondiculariinae and Palmulinae benthic foraminiferal general in the Paleocene of Egypt (Misr). *Neues Jahrbuch für Geologie und Paläontologie, Mh*. 2002;10:629–640.
34. Ansary SE. Report on the foraminiferal fauna from the Upper Eocene of Egypt. *Publication de l'Institut du Desert d'Egypt*. 1955;1–160.
35. Kaminski MA. The year 2010 classification of the agglutinated foraminifera. *Micropaleontology*. 2014;60(1):89–108.
36. Cushman JA. Upper Cretaceous Foraminifera of the Gulf Coastal Region of the United States and adjacent areas. *United States Geological Survey, Professional Paper*. 1946;206:1–241.
37. Proto Decima F, Bolli HM. Southeast Atlantic DSDP Leg 40 Paleogene benthic foraminifera. In: Bolli, H.M. & Ryan, W.B.F. et al. (Eds.). U.S. Government Printing Office, Washington D.C. *Initial Report of the Deep Sea Drilling Project*. 1978;40:783–809.
38. Kaminski MA, Gradstein FM, Berggren WA, et al. Flysch-type agglutinated foraminiferal assemblages from Trinidad: Taxonomy, stratigraphy and paleobathymetry. *Geowissenschaftliche Abhandlungen, Bundesanstalt*. 1988;41:155–227.
39. Hewaidy AA, Al-Hitmi H. Cretaceous-Early Eocene foraminifera from Dukhan oil field, west Qatar, Arabian Gulf (A-Suborders Textulariina, Involutinina and Miliolina). *Al-Azhar Bulletin of Science*. 1993;4(2):469–494.
40. Kuhnt W, Kaminski MA. Changes in the community structure of deep water agglutinated foraminifera across the K/T boundary in the Basque Basin (Northern Spain). *Revista Española de Micropaleontología*. 1993;25(1):57–92.
41. Abdelghany O. Late Campanian-Maastrichtian foraminifera from the Simsim Formation on the western side of the Northern Oman Mountains. *Cretaceous Research*. 2003;24(4):391–405.
42. Anan HS. Maastrichtian agglutinated foraminifera in Egypt and other Tethyan countries. *Egyptian Journal of Paleontology*. 2005;5:75–92.
43. Sztrákos K. Paleocene and lowest Eocene foraminifera from the north Pyrenean trough (Aquitaine, France). *Revue de Micropaléontologie*. 2005;48:175–236.
44. Ismail AA. Late Cretaceous-Early Eocene benthic foraminifera from Esh El Mallaha area, Egypt. *Revue de Paléobiologie*. 2012;31(1):15–50.
45. Hewaidy AA, Farouk S, Aly HA, et al. Maastrichtian to Paleocene agglutinated foraminifera from the Dakhla Oasis, Western Desert, Egypt. *Egyptian Journal Paleontology*. 2014;14:1–38.
46. VahdatiRad M, Vahidinia M, Sadeghi A. Early Eocene planktonic and benthic foraminifera from the Khangiran formation (northeast of Iran). *Arab Journal of Geosciences*. 2016;9:677.
47. Berggren WA, Aubert J. Paleocene benthonic foraminiferal biostratigraphy, paleobiogeography and paleoecology of Atlantic-Tethyan regions: Midway-type fauna. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 1975;18:73–192.
48. Anan HS. Paleocene benthonic foraminifera of Jabal Malaqet, Al Ain region, United Arab Emirates. *Al-Azhar Bulletin of Society*. 1993;4(1):293–320.
49. Abdelghany O, Abu Saima M. Stratigraphy of the Early Paleogene Muthaymimah Formation exposed on the western flank of the Northern Oman Mountains. *Historical Geology*. 2013;23(5-6):629–642.

50. Anan HS. Early Paleogene agglutinated foraminifera from the Middle East (Egypt and Arabia) and its distribution in the Tethys. *Spanish Journal of Paleontology*. 2016;31(2):353–368.
51. Hewaidy AA, Farouk S, EL-Balkiemy AF. Foraminiferal Biostratigraphy, Stages Boundaries and Paleocology of the Uppermost Maastrichtian-Lower Eocene Succession at Esh El-Mellaha Area, North Eastern Desert, Egypt. *Journal of American Science*. 2017;13(5):74–113.
52. Anan HS. Representatives of some diagnostic agglutinated foraminiferal genera of the Suborder Verneulinina (*Plectina*, *Gaudryina*, *Siphogaudryina*, *Verneulina*) in the Southern Tethys. *International Journal of Innovative Science, Engineering and Technology*. 2021;8(6):269–281.
53. Israelski MC. Foraminifera of the Lodo Formation Central California, Arenaceous Foraminifera. *Geological Survey, Professional Paper*. 1951;240-A:1–59.
54. Speijer RP. Extinction and recovery patterns in benthic foraminiferal paleocommunities across the Cretaceous/Paleogene and Paleocene/Eocene boundaries. *Geologica Ultraiectina, Universiteit Utrecht*. 1994;124:1–191.
55. Bejaoui A, Saïdi E, Zaghbib-Turki D. Small benthic foraminiferal biostratigraphy and paleoecology during the Campanian-Maastrichtian transition in north-western Tunisia. *Turkish Journal of Earth Sciences*. 2019;28:500–530.
56. Haq BU, Aubry MP. Early Cenozoic calcareous nannoplankton biostratigraphy and palaeobiogeography of North Africa and the Middle East and Trans-Tethyan correlations. The Geology of Libya (1). 2<sup>nd</sup> Symposium Geology of Libya: Tripoli; 1980. 271–304 p.
57. Anan HS. Paleontology, paleoenvironments, palaeogeography and stratigraphic value of the Maastrichtian-Paleogene and Recent foraminiferal species of Anan in the Middle East. *Egyptian Journal of Paleontology*. 2011;11:49–78.
58. Murray JW. Distribution and ecology of living benthic foraminiferids. Crane Russak and Co.: New York; 1973. 274 p.
59. Anan HS. Biostratigraphy and paleoecology of Maastrichtian and Paleocene benthonic foraminifera from Jiran El Ful section, Abu Rawash area, Egypt. *Middle East Research Center, Ain Shams University, Earth Science Series*. 1987;1:207–227.
60. Gawenda P, Winkler W, Schmitz B, et al. Climate and bioproductivity control on carbonate turbidite sedimentation (Paleocene to earliest Eocene, Gulf of Biscay, Zumaia, Spain). *Journal of Sedimentary Research*. 1999;69(6):1253–1261.
61. Meulenkamp JE, Sissingh, W. Tertiary paleogeography and tectonostratigraphic evolution of the Northern and Southern Peri-Tethys platforms and the intermediate domains of the African-Eurasian convergent plate boundary zone. *Palaeogeography, Palaeoclimatology, Palaeogeography*. 2003;196:209–228.