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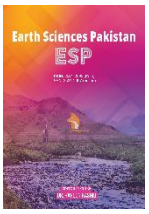

RESEARCH ARTICLE

STRATIGRAPHY, TAXONOMICAL CONSIDERATION AND EVOLUTIONARY TRENDS OF FUTYAN BENTHIC FORAMINIFERAL JORDANIAN SPECIES

Haidar Salim Anan

Emeritus, Prof. of stratigraphy and micropaleontology, former Vice President of Al Azhar University-Gaza, Gaza, P. O. Box 1126, Palestine.
****Corresponding Author Email: profanan@gmail.com***

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ABSTRACT

Two hundred and twenty-seven Maastrichtian-Early Paleogene benthic foraminiferal species were recorded from three widely separated surface Jordanian sections: Wadi Arab in the north, Muwaqqar in the center, and Tell Burma in the south. Forty-two species and subspecies were listed. Fifteen diagnostic species of them are treated by him as new species, which recorded and illustrated in this study. The paleogeographic distribution of them in some other countries in the Southern Tethys are recorded: United Arab Emirates (UAE), Egypt, Tunisia, Tanzania and Angola. One of the original species of Futyan: *Siphogenerinoides elnaggari* is considered here as a junior synonym of another species *Orthokarstenia higazyi* (Nakkady). The paratype of the recorded species *Vaginulinopsis wadiarabens*is Futyan is considered recently, by the present author, as a new genus and species: *Lenticuzonaria hodae*, while the holotype of it was regarded to be the holotype of the new genus *Percultalina*. As a token of appreciation of his outstanding career and faunal contributions, one species was recently erected: *Pseudoclavulina futyani*. Most of the recorded species (10 species) are endemic to Jordan, while others were recorded in other countries in the Southern Tethys. Most of these species are used to introduce an evolutionary trend marked by changes in the morphology and other characters of these benthic foraminiferal test. The Jordanian assemblage indicates an open marine environment, which represents middle-outer neritic environment (100 m ~ 200 m depth) and shows an affinity with Midway-Type Fauna (MTF).

KEYWORDS

Benthic foraminifera, Maastrichtian, Eocene, Jordan, Futyan, Tethys.

1. INTRODUCTION

Fifteen diagnostic species of Maastrichtian-Early Paleogene benthic foraminiferal species and subspecies were listed from three Jordanian sections: Wadi Arab (in north), Muwaqqar (in the center), and Tell Burma (in the south) (Figure 1) are described and illustrated in Plate 1 (Futyan, 1976). This assemblage was used to establish the stratigraphy of the studied sections, which represents the Middle and Late Maastrichtian, Paleocene and Early Eocene. The Maastrichtian-Paleocene (K/T) boundary has an unconformity in the three sections and is marked by a distinct lithologic and microfaunal break (Figure 2). In Tell Burma section the Thanetian rest unconformably on the Danian, but in Muwaqqar section the Thanetian rest unconformably on the Maastrichtian, while in Wadi Arab section the Thanetian rest unconformably on the Danian. The Paleocene in the three sections is quite distinct lithologically and faunally from the overlying Early Eocene.

2. STRATIGRAPHY

The stratigraphic position of the unconformities in the three sections is variable, which is explained by the fact that the orogenic movement of the Syrian Arcs was intermittent. According to the degree of unconformity was governed by two factors: the amount of uplift (as a result of which localities that represented big structural highs show the most marked unconformities), and the position relative to the highs (crest or flank) (Said and Kenawy, 1956). In the three Jordanian studied sections, Futyan recorded *Coryphostoma incrassata* together with many species belong to *Orthokarstenia oveyi,* (*elnaggari=higazyi*) and *l* or *applinae* as a mixed ecozones like Esh El Mallaha section in Egypt (no. 3, in Figure 3) (Futyan, 1976). Anan noted that the Maastrichtian chalks are exposed in different localities in Sinai (northern Egypt), yield diagnostic representatives of the genera as *Bolivinoides* and *Coryphostoma*, so far only from the north of Lat. 27° N, but the Maastrichtian rocks in central and southern Egypt predominantly clastic (Dakhla Shale), yield another genus: *Orthokarstenia* and its representatives (Anan, 1994).

3. TAXONOMY

The taxonomy of is followed here (Loeblich and Tappan, 1988). The recorded species of Futyan and other related species are illustrated in Plate 1.

4. PALEOGEOGRAPHY

Ten of the recorded species are endemic to Jordan, while other two species *Annulofrondicularia nakkadyi* and *Percultazonaria jordanensis* are recorded from Jordan and Egypt; *Pyramidulina robinsoni* from Jordan, Egypt and Tanzania; *Gyroidinoides tellburmaensis* from Jordan and Tunisia; and *Valvulineria pseudotumeyensis* from Jordan and Angola. Futyan noted that the Late Maastrichtian-Early Paleogene succession (K/T) in the three studies section in Jordan yield rich benthic and planktic foraminiferal species (two hundred and twenty-seven species) (Futyan,

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1976). The Jordanian faunal assemblage is predominantly considered here to be related to MTF (middle-upper neritic environment, 50-200 m). Aubert and Berggren considered the Tunisian Paleocene benthic foraminiferal assemblage (in the Southern Tethys, like Jordanian sections) is largely of Midway Type Fauna (MTF), middle-outer neritic environment (50-200 m) (Aubert and Berggren, 1976). After the Maastrichtian time, the Paleocene appears to have begun with a minor transgression that continued, with minor regressions throughout the period. Around the K/T time, the paleogeographic maps of some authors show that the ancestral Tethys is connected with the ancestral Atlantic and Indian Oceans via Mediterranean Sea (Figure 4) (i.e. Solakius et al., 1990; Culver, 2003). The east, west and north Africa and the southwest Asia showing possible migration routes (Jordan and Angola) during the Thanetian-Ypresian throughout the Trans-Saharan passage Figure 6 (Morsi et al., 2008).

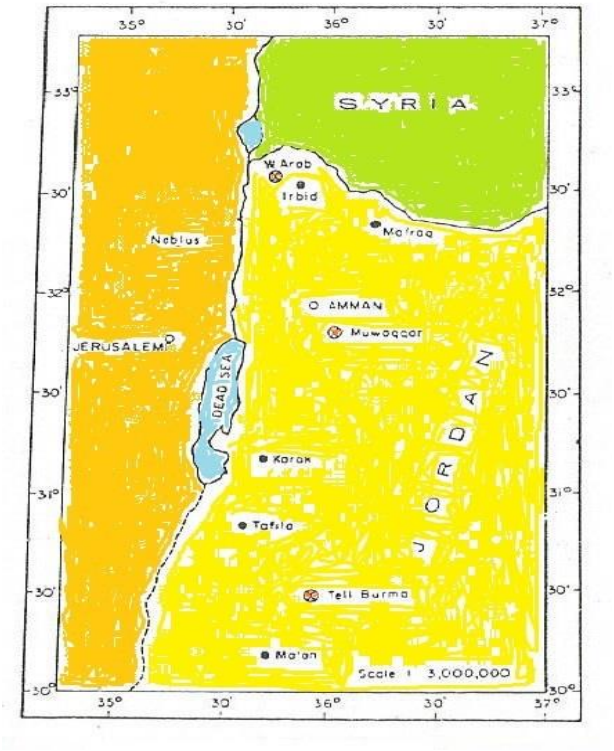


Figure 1: Location map of the three studied sections in Jordan: Wadi Arab section (in the north), Muwaqqar section (in the center) at south Amman, Tell Burma section (in the south), (Futyan, 1976).

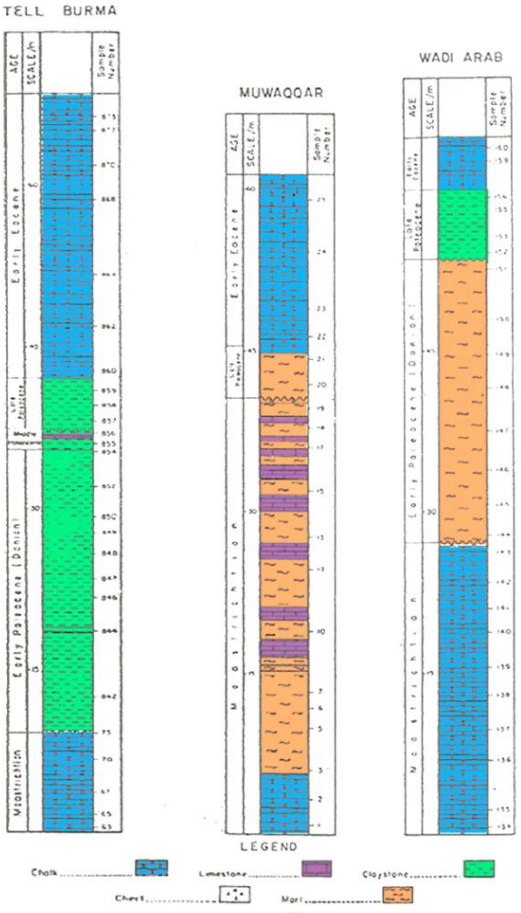
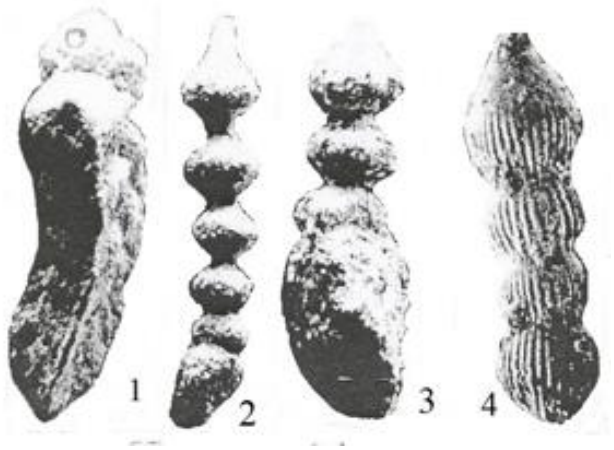
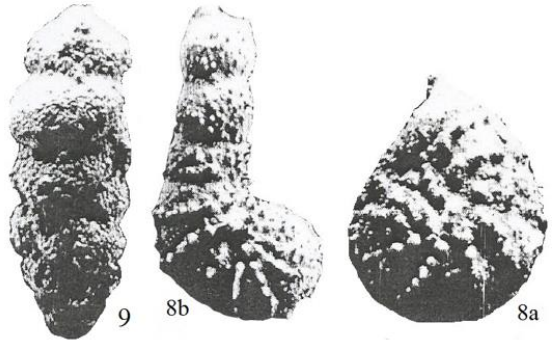
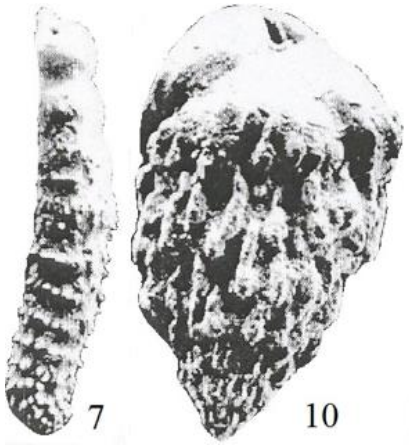


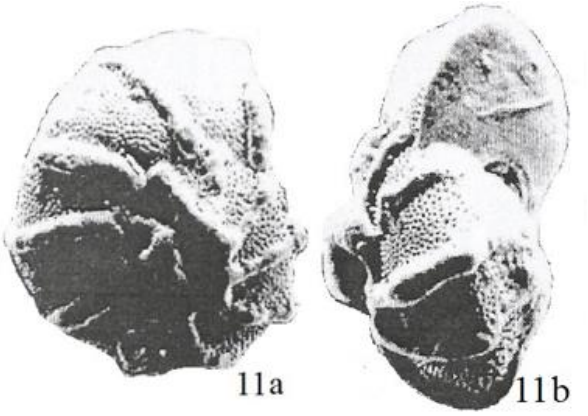
Figure 2: Stratigraphic logs of three studied sections, Jordan (Futyan, 1976).

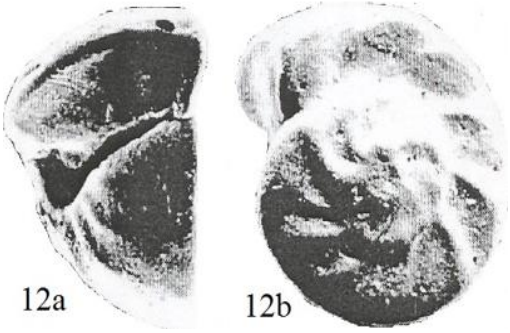
Figure 3: Geographic map of some Middle East countries (Egypt, Jordan, UAE), including the locations of some studied sections in Jordan (1. Wadi Arab, 2. Tell Burma sections) and Egypt (3. Esh El Mallaha section).

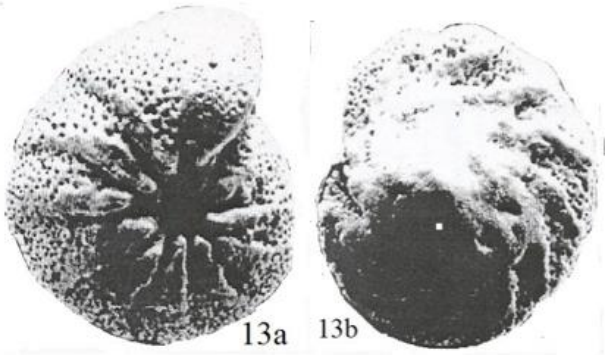












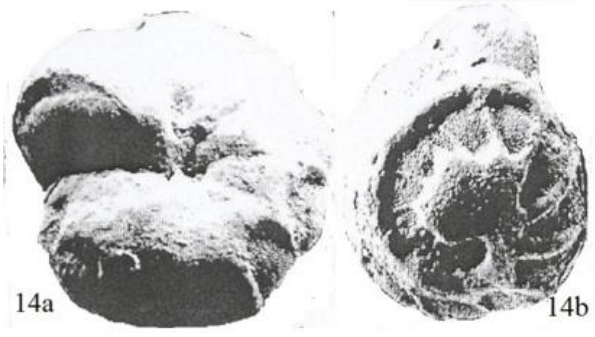


Plate 1: Figure 1. *Siphogaudryina tellburmaensis* (Futyan) x 40, **2.** *Pseudoclavulina barnardi* (Futyan) x 48, **3.** *P. futyani* Anan, 2021 x 45, **4.** *Pyramidulina robinsoni* (Futyan) x 57, **5.** *Annulofrondicularia nakkadyi* (Futyan) x 20, **6.** *Frondicularia pickeringi* Futyan x 30, **7.** *Percultazonaria jordanensis* (Futyan) x 25, **8a**. *Lenticuzonaria hodae* Anan x 35, **8b.** *Percultalina wadiarabensis* (Futyan) x 25, **9.** *Hopkinsina arabina* Futyan x 150, **10.** *Bulimina leroyi* Futyan x 95, **11a, b**. *Valvulineria pseudotumeyensis* Futyan, a: dorsal side, b: side view x 65, **12a, b** *Gyroidinoides tellburmaensis* Futyan, a: side view, b: dorsal view x 75, **13a, b** *Angulogavelinella bandata* Futyan, a: ventral side, b: dorsal side x 85, **14a, b**. *Gavelinopsis baylissi* Futyan, a: ventral side, b: dorsal side x 85.

Order Foraminiferida Eichwald, 1830
Suborder Textulariina Delage & Hérouard, 1896
Genus *Siphogaudryina* Cushman, 1938

***Siphogaudryina tellburmaensis* (Futyan, 1976) - (Pl. 1, figure 1)**

1976 *Gaudryina soldadoensis tellburmaensis* Futyan, p. 521 pl. 81, figures 1, 2.
2016 *Gaudryina tellburmaensis* Futyan - Anan, p. 357, figure 3ñ.
2020a *Siphogaudryina tellburmaensis* Futyan - Anan, p. 3, pl. 1, figure 2.

Remarks: This Late Paleocene-Early Eocene species belongs here to the genus *Siphogaudryina* due to its subterminal aperture on the apertural face of the last formed chamber. The Jordanian *S. tellburmaensis* differs from the Pakistanian *S. elongata* in its curved, not straight test (Haque, 1956, p. 35, pl. 9, figure 5). Anan introduced an evolutionary trend marked by changes in the morphology and other characters of the benthic foraminiferal test in the Maastrichtian-Eocene transition in the Tethys: The Late Paleocene-Early Eocene *Siphogaudryina tellburmaensis* → Early-Middle Eocene *S. africana* lineage (Anan, 2020a; Futyan, 1976; LeRoy, 1953). This lineage is supported by the high degree of morphological relationship, especially in chamber arrangement of the test (triserial to biserial) and the terminal aperture of the last formed chamber, but, however, differs in having curved test and rounded terminal aperture than straight test, and elongate aperture of the last chamber of *S. africana*. It is, so far, recorded in Jordan and UAE.
Genus *Pseudoclavulina* Cushman, 1936

***Pseudoclavulina barnardi* (Futyan, 1976) - (Pl. 1, figure 2)**

1976 *Clavulina barnardi* Futyan, p. 522, pl. 81, fig. 3 (*non* fig. 4).
2016 *Clavulina barnardi* Futyan - Anan, p. 361, fig. 3ab.
2020a *Pseudoclavulina barnardi* Futyan - Anan, p. 3, pl. 1, fig. 7.

Remarks: This Danian species belongs here to the genus *Pseudoclavulina* due to its terminal aperture of the last formed chamber but without tooth, as in *Clavulina*. The triserial part is small, and the uniserial part has slightly irregular five to eight flask-shaped chambers, with deeply excavated sutures. Anan introduced an evolutionary trend in the Maastrichtian-Eocene transition in the Tethys: the Danian *P. barnardi* (Futyan) → Ypresian *P. maqfiensis* LeRoy lineage (Anan, 2020a). The Jordanian *P. barnardi* and the Egyptian form have sharply pyramidal triserial portion followed by five flask-shaped uniserial portions with deeply sutures. The former species *P. barnardi* differs from the latter *P. maqfiensis* by its more elongated test and chamber numbers of the uniserial portion than the latter. It is, so far, recorded from Jordan and UAE.

***Pseudoclavulina futyani* Anan, 2021 - (Pl. 1, figure 3)**

1976 *Clavulina barnardi* Futyan, p. 522, pl. 81, fig. 4 (*non* fig. 3).
2021b *Pseudoclavulina futyani* Anan, p. 87, pl. 1, fig. 16.

Remarks: *Pseudoclavulina futyani* differs from *P. barnardi* (Futyan) in its larger triserial portion of one-half of the entire test, and three uniserial chambers in the former instead of one-fifth of the test size, and five to eight chambers in the latter. It is, so far, an endemic to Jordan.
Suborder Lagenina Delage & Hérouard, 1896
Genus *Pyramidulina* Fornasini, 1894

***Pyramidulina robinsoni* (Futyan, 1976) - (Pl. 1, figure 4)**

1976 *Nodosaria robinsoni* Futyan, p. 525, pl. 82, figs. 5,6.
2006 *Nodosaria* sp. Pearson et al, p. 307, pl. 4, fig. 11.
2016 *Nodosaria limbata* d'Orbigny - Orabi & Zaky, p. 188, pl. 3, fig. 1.
2020a *Pyramidulina robinsoni* (Futyan) - Anan, p. 3, pl. 1, fig. 9.

Remarks: *P. robinsoni* differs from *P. leroyi* in its inflated shape, lesser test-size and number of the uniserial chambers (Anan, 2020a). The inflated semi-globular chambers in the former are changed to elongate extremely long chambers in the latter. Anan also introduced another evolutionary trend: The Middle Paleocene *Pyramidulina robinsoni* (Futyan) → Late Paleocene-Early Eocene *P. leroyi*. Moreover, *P. robinsoni* is considered here as the ancestor of the descendent *P. leroyi* due to high degree of morphological relationship, especially in the distinct more than twenty closed spaced fine longitudinal ribs in the two species. *P. robinsoni* was recorded, so far, from Jordan, Egypt and Tanzania (Anan, 2020a).
Genus *Annulofrondicularia* Gerke, 1961

***Annulofrondicularia nakkadyi* (Futyan, 1976) - (Pl. 1, figure 5)**

1976 *Frondicularia nakkadyi* Futyan, p. 528, pl. 82, fig. 1.
2012 *Frondicularia nakkadyi* Futyan - Youssef & Taha,59 pl. 3, fig.10.
2020a *Frondicularia nakkadyi* Futyan - Anan, p. 4, pl. 1, fig. 12.

Remarks: This Late Paleocene species differs from the Paleocene *F. phosphatica* Russo in its lacking the central raised ridge which extends from proloculus to the aperture. Anan also introduced another evolutionary trend: Thanetian *F. bignoti* Anan → Thanetian-Ypresian *F. nakkadyi* Futyan lineage (Anan, 2020a). The morphological characters of the Thanetian *A. bignoti* with its moderate smooth test and large proloculus, four-five uniform chambers and the first one surrounding the proloculus is considered here as the ancestor of the descendent Thanetian-Ypresian *A. nakkadyi* throughout changing to a larger test, more number uniserial chambers and smaller proloculus size. It was described from Jordan and Egypt (Figures 4, 5).

***Frondicularia pickeringi* Futyan, 1976 - (Pl. 1, figure 6)**

1976 *Frondicularia pickeringi* Futyan, p. 526, pl. 82, fig. 2.
2020a *Frondicularia pickeringi* Futyan - Anan, p. 4, pl. 1, fig. 13.

Remarks: This Paleocene species differs from Late Eocene Palmula *gahannamensis* by clearly coiled initial portion with numerous coarse spaced ribs extending right across the test surface (Ansary, 1955). Anan also introduced another evolutionary trend: The Late Paleocene *Frondicularia pickeringi* Futyan → Late Eocene *F. gahannamensis* Ansary lineage The former species *F. pickeringi* has larger and much compressed rhomboidal test, and two-five fine ribs in initial portion (Anan, 2020a). It differs from the descendent *F. gahannamensis* by its numerous fine spaced ribs extending right across the surface test. It seems that *F. pickeringi*, so far, is endemic to Jordan.
Genus *Percultazonaria* Loeblich and Tappan, 1986

***Percultazonaria jordanensis* (Futyan, 1976) - (Pl. 1, figure 7)**

1976 *Marginulina jordanensis* Futyan, p. 525, pl. 81, figs. 5,6.
1976 *Marginulinopsis* aff. *tuberculata* (Plummer) - Aubert & Berggren, p. 416, pl.3, fig. 7.
2015 *Percultazonaria jordanensis* (Futyan) - Anan, p. 21, pl. 1, fig. 11.

Remarks: The Paleocene *jordanensis* species belongs to the genus *Percultazonaria P. jordanensis* was from Jordan, and also in Egypt and Tunisia (Anan, 2015).

Genus *Lenticuzonaria* Anan, 2021

***Lenticuzonaria hodae* Anan, 2021 - (Pl. 1, figure 8a)**

1976 *Vaginulinopsis wadiarabensis* Futyan, p. 524, pl. 81, fig. 7, the paratype (*non* figs. 8, 9, the holotype)
2021a *Lenticuzonaria hodae* Anan, p. 34, pl. 1, fig. 3.
Remarks: The paratype of the *V. wadiarabensis* Futyan was treated by as a separate new lagenid genus *L. hodae* (Anan, 2021a). This species differs from the other Lagenid forms by its sharp spinose periphery and surface, and elevated sutures with a row of tubercles. The other species *L. misrensis* Anan is characterized by its ornamented surface with a row of tubercles or broken into a row of nodes and elevated sutures with a row of tubercles, which lacks the spinose periphery and surface as existed in *L. hodae* Anan. It seems that this Thanetian species, tell now, is endemic to Jordan.
Genus *Percultalina* Anan, 2022

***Percultalina wadiarabensis* (Futyan, 1976) - (Pl. 1, figure 8b)**

1976 *Vaginulinopsis wadiarabensis* Futyan, p. 524, pl. 81, figs. 8, 9 the holotype (*non* fig. 7, the paratype).
2015 *Percultazonaria wadiarabensis* (Futyan) - Anan, p. 24, pl. 2, fig. 15.
2022 *Percultalina wadiarabensis* (Futyan) - Anan, p. 31, pl. 1, fig. 1.
Remarks: Anan was introduced another evolutionary trend: The

Thanetian *P. wadiarabensis* (Futyan) → the Thanetian -Ypresian *P. tuberculata* (Plummer) lineage (Anan, 2020b). The former differs from the latter by its larger coiled initial portion, stouter and flanged test, spinose periphery, and surface, 2-3 inflated uniserial chambers instead of 4-6 laterally compressed chambers, which are longer than high. It was recorded, so far, from Jordan.
Suborder Rotaliina Delage and Hérouard, 1896
Genus *Hopkinsina* Howe and Wallace,1932

***Hopkinsina arabina* Futyan, 1976 - (Pl. 1, figure 9)**

1976 *Hopkinsina arabina* Futyan, p. 529, pl. 82, figs. 7-9.
2020a *Hopkinsina arabina* Futyan - Anan, p. 4, pl. 1, fig. 15.

Remarks: Anan also introduced another evolutionary trend: The Maastrichtian *Hopkinsina arabina* Futyan → Ypresian *H. haquei* Anan lineage, which the former differs from the latter by its smooth surface and elongate wide opening terminal aperture bounded by lip (Anan, 2020a). It is, so far, an endemic to Jordan.
Genus *Bulimina* d'Orbigny,1826

***Bulimina leroyi* Futyan, 1976 - (Pl. 1, figure 10)**

1976 *Bulimina leroyi* Futyan, p. 530, pl. 82, figs. 11, 12.
Remarks: The Ypresian *B. farafraensis* differs from *B. leroyi* by its well-defined low costae extending full length of the test below last two chambers which are smooth (LeRoy, 1953). It is, so far, an endemic to Jordan.
Genus *Valvulineria* Cushman,1926

***Valvulineria pseudotumeyensis* Futyan, 1976 - (Pl. 1, figure 11a,b)**

1976 *Valvulineria pseudotumeyensis* Futyan, p. 531, pl. 83, figs. 4-6.
1990 *Valvulineria tumeyensis* Cushman & Simonson - Saman & Al-Harithi, p. 7, pl. 1, figs. 11-14.
2007 *Valvulineria pseudotumeyensis* Futyan - Kender, p. 193, pl. 19, figs. 12-15.
Remarks: This Ypresian species differs from the Late Eocene-Oligocene *V. tumeyensis* Cushman & Simonson in having thick raised sutures on both sides of the test. The former most probably evolved to the latter. It was recorded, so far, in Jordan and Angola (Trans-Saharan Seaway, Figures 5, 6).

Genus *Gyroidinoides* Brotzen,1942

***Gyroidinoides tellburmaensis* Futyan, 1976 - (Pl. 1, figs. 12a,b)**

1976 *Gyroidinoides tellburmaensis* Futyan, p. 532, pl. 81, figs. 10-12.
1994 *Gyroidinoides tellburmaensis* Futyan - Speijer, p. 62, pl. 3, fig.1.
Remarks: Anan also introduced another evolutionary trend: The Maastrichtian-Danian *G. tellburmaensis* (Futyan) → Thanetian-Ypresian *G. subangulata* (Plummer) lineage. *G. tellburmaensis* differs from *G. subangulata* (Plummer) by its more acute periphery, more whorls, wider umbilicus and limbate sutures on spiral side (Anan, 2020a). It differs also from *G. girardanus* (Reuss) by its more angular periphery, raised limbate sutures on the spiral side, and deeply limbate sutures on the ventral side. It is recorded, so far, from Jordan and Tunisia.
Subfamily Gavelinellinae Hofker, 1956
Genus *Angulogavelinella* Hofker,1957
Type species *Discorbina gracilis* Marsson,1878

***Angulogavelinella bandata* Futyan, 1976 - (Pl. 1, fig. 13a,b)**

1976 *Angulogavelinella bandata* Futyan, 534, pl. 83, figs 1-3.
2020a *Angulogavelinella bandata* Futyan - Anan, p. 4, pl. 1, figs. 23-25.
Remarks: This Middle Danian species differs from *A. avnimelechi* (Reiss) by having strongly limbate, broad raised sutures on the spiral side and a more open umbilicus. Anan also introduced another evolutionary trend: The Maastrichtian-Paleocene *A. convexa* (LeRoy) → Danian *A. bandata* Futyan lineage (Anan, 2020a). The former differs from the latter by its unequally biconvex trochospiral test, with strongly limbate raised curved spiral sutures. It is, so far, an endemic to Jordan.
Genus *Gavelinopsis* Hofker, 1957

***Gavelinopsis baylissi* Futyan, 1976 - (Pl. 1, figs. 14a,b)**

1976 *Gavelinopsis baylissi* Futyan, p. 534, pl. 83, figs. 7-9.
Remarks: *Gavelinopsis baylissi* Futyan is similar in shape with *Valvulineria pseudotumeyensis* Futyan, but differs in its high spiral biconvex test, less involute spiral side and slit aperture extending from near the periphery to the umbilicus. It is, so far, an endemic to Jordan.

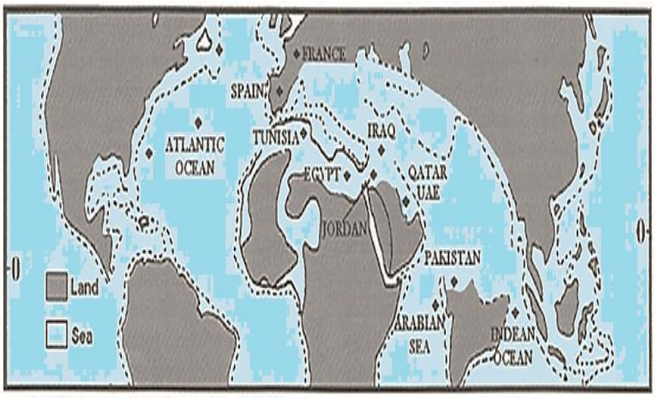


Figure 4: Paleogeographic map of Maastrichtian showing locations of some countries in the Tethys, Tunisia, Egypt (North Africa), Jordan, UAE (Southwest Asia) (after Solakius et al., 1990).

Figure 5: The geographic locations of the North Africa (Tunisia, Egypt), southwest Africa (Angola), southeast Africa (Tanzania), southwest Asia (Jordan, UAE).

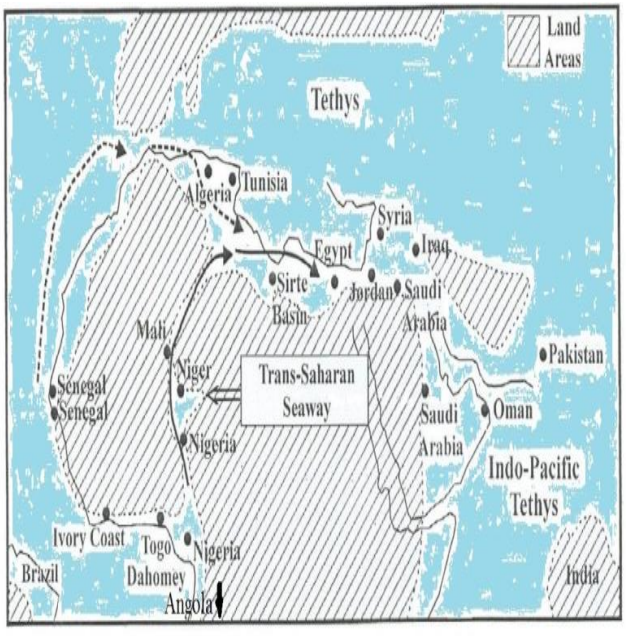


Figure 6: Paleogeographic map of Africa and the Middle East showing possible migration routes (between Jordan and Angola) during the Late Paleocene-Early Eocene Trans-Saharan passage (solid arrow), West African passage (dashed arrow), (after Morsi et al., 2008).

5. Conclusion

Forty-two Maastrichtian and Early Paleogene benthic foraminiferal species and subspecies were recorded from three widely separated Jordanian surface sections: in north (Wadi Arab), central (Muwaqqar) and south (Tell Burma). The Maastrichtian-Paleocene boundary in the three

studied sections of Jordan is an unconformable and marked by a distinct lithologic and microfossil break. In the Tell Burma and Wadi Arab the Thanetian (Late Paleocene) rest unconformably on the Danian (Early Paleocene), while in the Muwaqqar section the Thanetian rest unconformably on the Maastrichtian. The stratigraphic positions of the unconformities in the three sections are variable, due to the orogenic movement of the Syrian Arcs. The degree of unconformity was governed by two factors: the amount of uplift (as a result of which localities that represented big structural highs show the most marked unconformities), and the position relative to the highs and lows (crest or flank). Fifteen diagnostic species are described according to the modern consideration and presented in Plate 1. Most of the recorded species are endemic to Jordan, while others were recorded in UAE, Qatar, Egypt, Tunisia, Tanzania or Angola. Some of these species are used to introduce an evolutionary trend marked by changes in the morphology and other characters of these benthic foraminiferal test. From the forty-two recorded species, a remarkable increase in abundance of benthic foraminifera take place from the chalk Maastrichtian rocks 11 species (about 26 %), while to the upper Paleocene-Early Eocene marl and shale rocks 31 species (about 74 %) in the study Jordanian sections. Three of the identified Jordanian species are recorded abroad, in some Tethyan countries: *Annulofrondicularia nakkadyi, Percultalina wadiarabensis* and *Leticuzonaria hodae* (=holotype and paratype of *V. wadiarabensis* of Futyan, 1976, successively) in both Jordan and Egypt. One of the identified Jordanian species *Percultazonaria jordanensis* is recorded from three Tethyan countries: Jordan, Egypt and Tunisia. *Pyramidulina robinsoni* is recorded from three localities: Jordan, Egypt and Tanzania (Figure 5). *Orthokarstenia higazyi* of Nakkady (= *Siphogenerinoides elnaggari* of Futyan) is recorded in three countries: Egypt, Jordan and UAE. *Valvulineria pseudotumeyensis* is recorded from two localities: in west Asia (Jordan) and west Africa (Angola) through Trans-Saharan passage (Figure 6). One of the identified Jordanian species *Gyroidinoides tellburmaensis* is recorded in Jordan and Tunisia. The existence of this Jordanian species in many localities in the Southern Tethys prove again that these wide provinces are connected in an open sea water in the Maastrichtian-Paleogene times. The Jordanian faunal assemblage is predominantly considered here to be related to MTF (middle-upper neritic environment, 100-200 m).

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