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RESEARCH ARTICLE

THE REGIONAL '*ANGULATA* EVENT': A DIAGNOSTIC EPISODE OF THE LATEST DANIAN IN THE SOUTHERN TETHYS

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ABSTRACT

The diagnostic episode of tectonic activity in combination with sea-level fall after the latest Danian event (around the Danian/Selandian or Danian/Thanetian transition) was recognized and recorded from many parts of the Southern Tethys: Tunisia, Egypt, Jordan and United Arab Emirates (UAE). This episode is named here the '*angulata* Event'. This event is represented by glauconitic bed in Sidi Nasseur and Tajérouine of Tunisia, or non-depositional sediments (or eroded after deposition) in Abu Zenima section (Sinai) and Jiran El Ful section, west Cairo of Egypt, and also Tell Burma and Wadi Arab sections of Jordan, or intraformational conglomeratic bed in Malaqet section of UAE. The studied latest Danian event (*angulata* Event) in the study areas exhibits many lateral and vertical facies changes and regional pattern to the relation between litho- and biostratigraphic boundaries across the Danian/Selandian (D/S) in Tunisia, but Danian/Thanetian (D/T) succession in Egypt, Jordan and UAE. Two new species are added to the recorded assemblage: *Morozovella arabiana* and *Morozovella tunisica*. This event is the second Paleogene event of Anan, after the global *"pentacamerata* Event*'* around the Ypresian-Lutetian (Y-L) transition in the world.

KEYWORDS

Danian, Selandian, Thanetian, Paleocene, Foraminifera, Tectonic, Eustatic sea level, Conglomerate, Tethys, Tunisia, Egypt, Jordan, UAE.

1. INTRODUCTION

The lithological at the Danian-Thanetian planktic foraminiferal zones P2-P4 in the different localities in the Southern Tethys: Tunisia, Egypt, Jordan, UAE (Figure 1), are marked by different lithological remarks in Danian-Selandian (D/S) boundary, or Danian-Thanetian (D/T) boundary: a glauconitic maker bed in Tunisia, non-depositional sediments in Egypt and Jordan, or intraformational conglomeratic beds in UAE.

Figure 1: Location map of studied countries in the Southern Tethys at the K/T (Tunisia, Egypt, Jordan, UAE).

2. MATERIAL OF STUDY

The data presented here summarize the current state of knowledge on many sections from Tunisia (Sidi Nasseur and Tajérouine sections), Egypt (Abu Zenima section), Jordan (Tell Burma and Wadi Arab sections) and UAE (Malaqet section). These sections yield good examples for the D/S and D/T transition, the *angulata* Event.

3. STRATIGRAPHY

Thomsen and Heilmann-Clausen (1985) noted that the Danian and Selandian stages in the type section of Denmark are chronostratigraphically equivalent to Early-Middle Paleocene and its boundary is marked by an unconformity. In this study, the lithological and faunal changes at the P3a/P3b zonal boundary (at ~ 60.0 Ma) in Tunisia of the Southern Tethys seem to correspond to the D/S boundary in the type region in Denmark, and the historical Thanetian strata span calcareous nannofossil zones NP6-NP9 of Martini, 1971 (Figure 2).

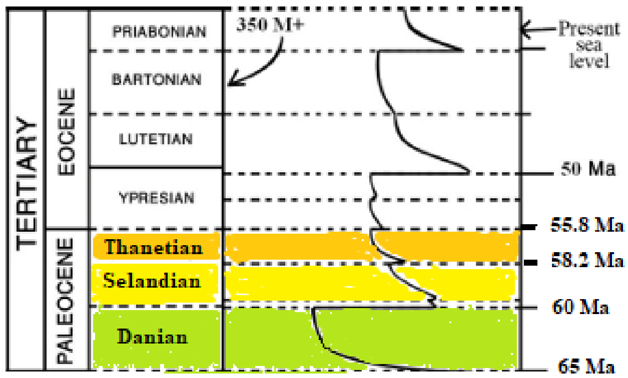

Figure 2: Global cycles of relative eustatic sea-level changes during the Paleocene: Danian, Selandian and Thanetian stages (after Vail et al., 1977).

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4. Planktic and Benthic Foraminifera

The time-interval corresponding to the planktic foraminiferal zones P3a-P3b of Olsson et al, 1999 (P3a: *Morozovella angulata-Igorina albeari* Interval Subzone, P3b: *Igorina albeari-Globanomalina pseudomenardii* Interval Subzone, or D/S transition (Early-Middle Paleocene), or D/T (Early-Late Paleocene) is marked by a regional tectono-sedimentary event with eustatic sea-level fall in Tunisia, but D/T in Egypt, Jordan and UAE of the Southern Tethys.

In Tunisia: the characteristic deep outer neritic species *Angulogavelinella avnimelechi* (Reiss, 1952) disappears just beneath the P2/P3 zonal boundary, *Anomalinoides affinis* (Hantken, 1875) and *Angulogavelinella abudurbensis* (Nakkady, 1950) gradually decrease in numbers until they disappear at the P3a/ P3b Subzonal boundary at the base of the glauconitic marker bed.

In Egypt: *Pseudoclavulina hewaidyi* Anan, *Clavulina clavata* Cushman, *Tristix aubertae* Anan, *Neoflabellina jarvisi* (Cushman), *Lagena sulcata* (Walker and Jacob), *Palmula berggreni* (Anan), *Anomalinoides leroyi* Anan, *Vulvulina colei* Cushman and *Gyroidinoides luterbacheri* Anan (2004) are disappear at D/S boundary. *Tristix aubertae* Anan, *Leroyia aegyptiaca* Anan, *Palmula salimi* Anan, *Lagena rawdhae* Anan, *Orthokarstenia nakkadyi* Anan appears at the first Selandian. *Pseudoclavulina youssefi* Anan, *Leticuzonaria hodae* Anan, *Annulofrondicularia bignoti* (Anan), *Annulofrondicularia nakkadyi* (Futyan) and *Vaginulina boukharyi* (Anan) start its appearance at the first Thanetian.

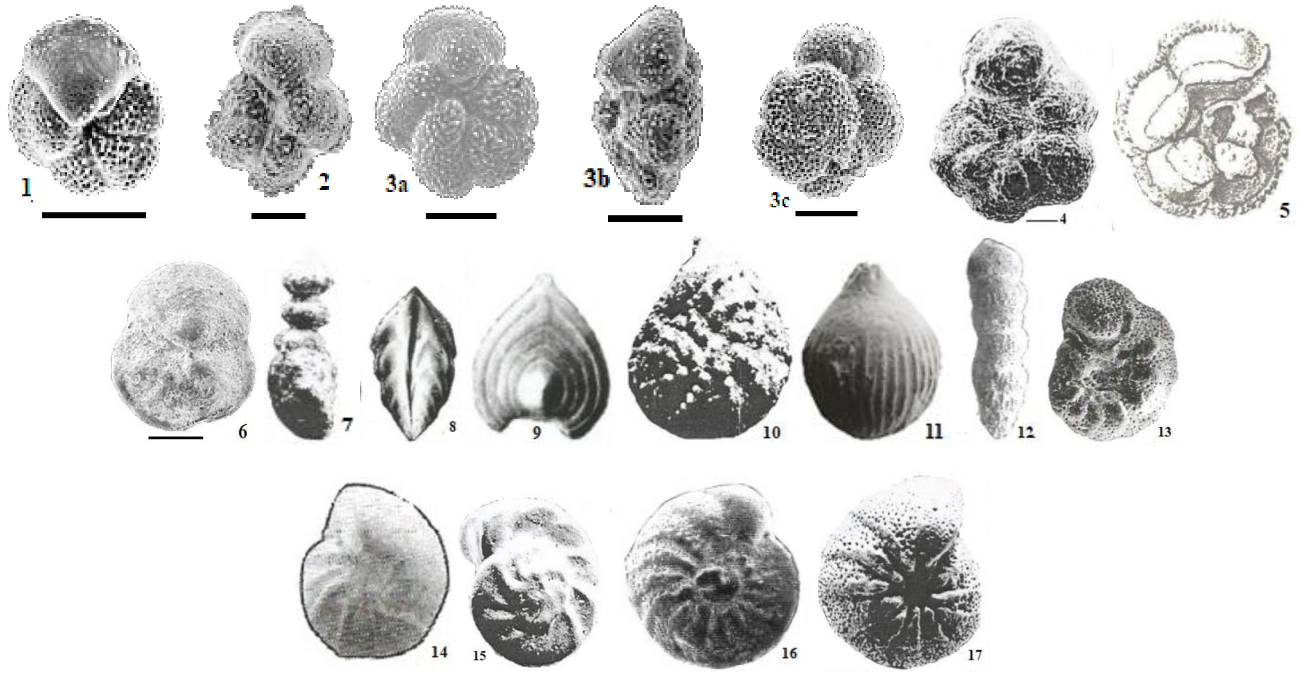
In Jordan: *Angulogavelinella bandata* Futyan (1976) starts its appearance in the Danian, while *Pseudoclavulina futyani* Anan (2021), *Lenticuzonaria hodae* Anan (2021) and *Gyroidinoides tellburmaensis* Futyan (1976) start its appearance at the first Thanetian.

In UAE: *Repmanina mazeni* Anan, *Psammolingulina bahri* Anan disappear at D/S boundary, while *Laevidentalina hudae* Anan and *Hemirobulina olae* Anan start its appearance at the first Selandian.

Some diagnostic planktic and benthic foraminiferal Paleocene species are illustrated in Plate 1, including *Morozovella tunisica* n. sp. and used to detect the D/S boundary with the LO of *P. uncinata* (Bolli).

Plate 1 (Scale bars 100 µm)

Figure 1: *Igorina albeari* (Cushman and Bermudez, 1949), **2.** *Morozovella angulata* (White, 1928), **3.** *Morozovella tunisica* n. sp., **4.** *Morozovella arabiana* Anan, n. sp., **5.** *Morozovella velascoensis* (Cushman, 1925), **6.** *Globanomalina pseudomenardii* (Bolli, 1957), **7.** *Pseudoclavulina futyani* Anan (2021), **8.** *Tristix aubertae* Anan (2002), **9.** *Annulofrondicularia bignoti* (Anan, 2002), **10.** *Lenticuzonaria hodae* Anan (2021), **11.** *Lagena rawdhae* Anan (2020), **12.** *Orthokarstenia nakkadyi* Anan (2009), **13.** *Anomalinoides leroyi* Anan (2008), **14.** *Gyroidinoides luterbacheri* Anan (2004), **15.** *Gyroidinoides tellburmaensis* Futyan (1976), **16.** *Angulogavelinella abudurbensis* (Nakkady, 1950), **17.** *Angulogavelinella bandata* Futyan (1976).



Morozovella tunisica **Anan, n. sp.** (=*Morozovella* sp. - Itterbeeck et al., 2007, p. 215, pl.1, fig. 4a-c). Pl.1, fig. 3.

Etymology: after the Republic of Tunisia (Figure 3).

Stratigraphic level: Late Danian Sidi Nasseur section, west Tunisia (Figure 4).

Diagnosis: Biconvex finally spinose trochospiral test, umbilical side distinctly convex with five subangular (nearly banana shape) chambers in the last whorl increasing gradually in size as added, depressed curved sutures, fairly open narrow deep umbilicus with low arch interiomarginal umbilical-extraumbilical aperture.

Remarks: The species *Morozovella tunisica* differs from *M. angulata* by is nearly biconvex test, more elongate curved with nearly banana shape chamber and curved sutures, than flat dorsal side, inflated triangular chambers and straight sutures of the latter species.

Morozovella arabiana **Anan, sp. nov.** (=Tansitional form between *Morozovella uncinata* and *Morozovella angulata* – Anan and Hamdan, 1993, p. 36, fig. 4. 4). Pl. 1, fig. 4.

Etymology: after the UAE (see Figure 1).

Stratigraphic level: Late Danian *Morozovella angulata* Zone (P3a) of Jabal Malaqet section (UAE), and continue to the *Globanomalina pseudomenardii* (P4a) (see Figure 11).

Diagnostic: Planoconvex finally subspinose low trochospiral test, 6-7 triangular inflated chambers gradually increased in size as added, periphery sharply angled, sutures straight and deep, fairly open wide deep umbilicus with low arch interiomarginal umbilical-extraumbilical aperture.

Remarks: The species *Morozovella arabiana* differs from *M. angulata* by its more numbers of chambers in the last whorl, and wider umbilical area.

5. The Lacuna around S/D and D/T in The Southern Tethys

The syndepositional faulting and folding that developed contemporaneously with sedimentation in the study areas, together with the continuous restrictions of the southeastern seaway that connected between the Tethyan and Indo-Pacific realms essentially have been caused the formation of this

The Paleocene "*angulata* event" in the Paleocene sequence, takes its named after the diagnostic late Danian-early Thanetian planktic foraminifera species *Morozovella angulata* (White, 1928).

Tunisia

Noted that the interval of the D/S spans part of planktic foraminiferal Zone P2, Subzone P3a and part of Subzone P3b in Sidi Nasseur section (Figure 3) (Itterbeeck et al., 2007).

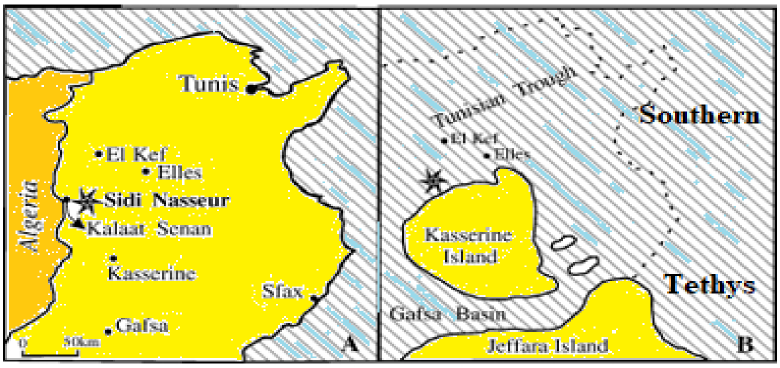
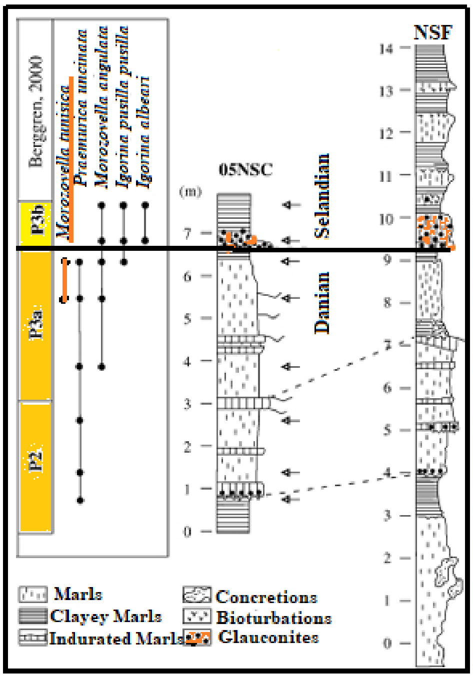


Figure 3: A) Location of the Sidi Nasseur sections, west Tunisia, **B)** Paleogeography during the Paleocene.

The lithological and faunal changes at the P3a/P3b zone boundary within the Sidi Nasseur sections (05NSC and NSF) with glauconitic maker bed seem to correspond to the D/S boundary in the type region in Danmark and are characterized by a significant hiatus. This boundary was detected by the last occurrence (LO) of the planktic *Praemurica uncinata* and first appearance (FA) of *Igorina albeari*, while *Morozovella angulata* ranged along P3a, P3b and P4a crossing the boundaries (Bolli, 1957; Cushman and Bermudez, 1949; Bolli, 1957). On the other hand, the D/S hiatus was documented by other author in Tajérouine section of Tunisia (i.e. Mtimet et al., 2013, Figures 4, 5).



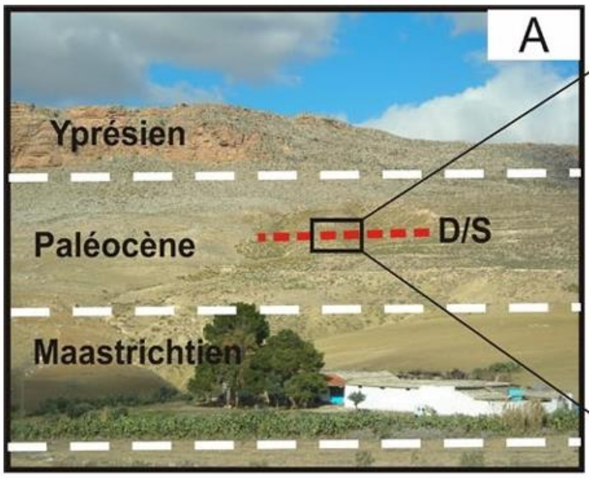


Figure 4: Stratigraphic log of the D/S in Sidi Nasseur section, west Tunisia (after Itterbeeck et al., 2007).

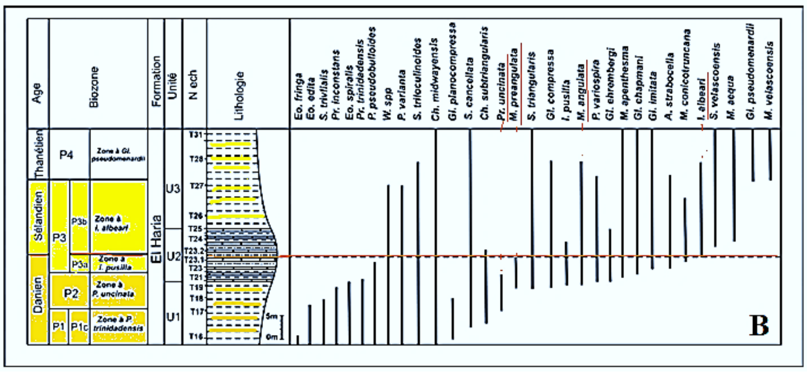


Figure 5: A) The D/S stratigraphic position of Tajérouine section, west Tunisia, **B)** Vertical distribution of planktonic foraminifera along the Danian/Selandian interval in the Tajérouine section, Tunisia (after Mtimet et al., 2013).

Egypt

The Maastrichtian-Ypresian succession (about 85 m thick) of Abu Zenima section in west Sinai, Egypt (Figure 6. A, B) consists of the following formations, from older to younger: Maastrichtian Sudr Chalk, Danian-Selandian Dakhla Shale, Thanetian Tarawan Chalk, Thanetian-Ypresian Esna Shale and Ypresian Thebes Formation (Anan, 1992). The planktonic foraminiferal zonation spanning the D/S boundary in Dakhla Shale is:

Globanomalina pseudomenardii Zone (P4) – Early Thanetian unconformity

Praemurica uncinata Zone (P2) – Late Danian

A dark layer divided the Dakhla Shale into two parts of nearly equal thickness, and represent the D/S boundary with an omission of two zones including the planktic foraminiferal zones: *Morozovella angulata* Zone and *Morozovella p. pusilla* Zone of Bolli, 1957 (=*Igorina pusilla* zone (P3a) of the upper Danian and the *Igorina albeari* zone (P3b) of Selandian) of Olsson et al., 1999; Wade et al., 2011; Mtimet et al., 2013).

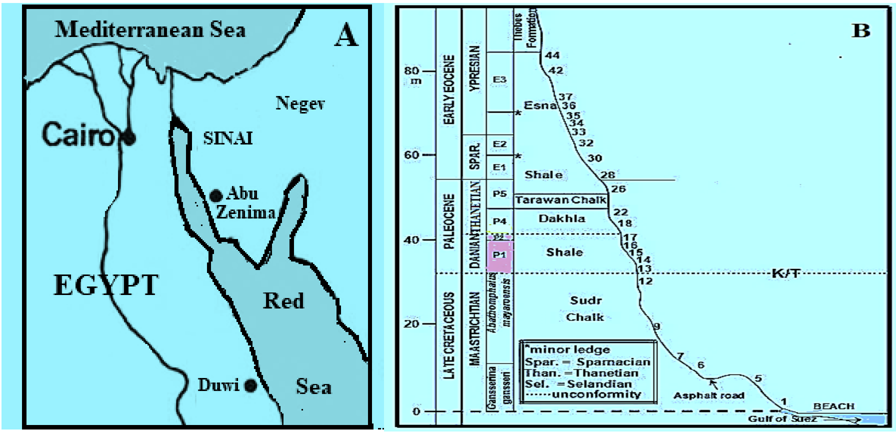


Figure 6: A) Location map, and **B)** Stratigraphy of the Abu Zenima section, Sinai, Egypt (after Anan, 1992).

Jiran El Ful section (Abu Rawash area), west Cairo of Egypt presents also the D/T boundary with an omission of Selandian (P3) and early Thanetian (P4), as follows (Figure 7):

Morozovella velascoensis Zone (P5), Unit C – Late Thanetia

Clast supported conglomerate, Unit B

Praemurica uncinata Zone (P2), Unit A – Late Danian

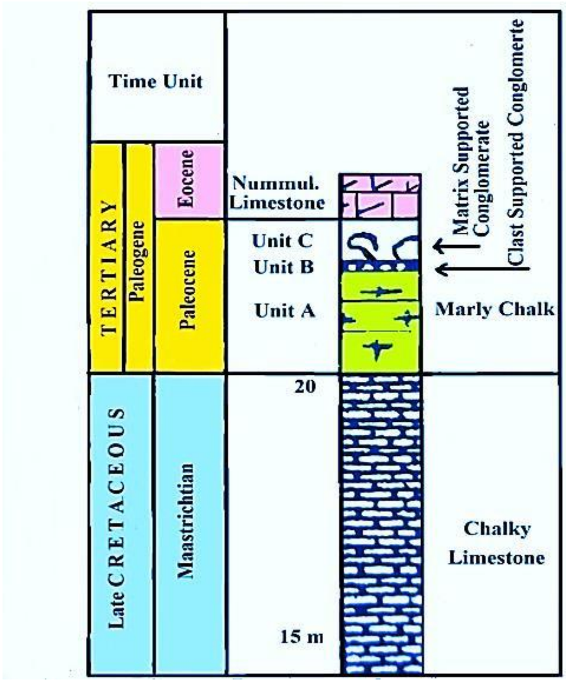


Figure 7: Maastrichtian-Ypresian stratigraphy of Jiran El Ful section, Abu Rawash area, west Cairo, Egypt (after Anan, 1987).

On the other hand, the D/S and S/T hiatus are documented by other others in many parts of Egypt (i.e. Speijer, 2003; Farouk and Faris, 2013; and Farouk, 2016, Figure 8).

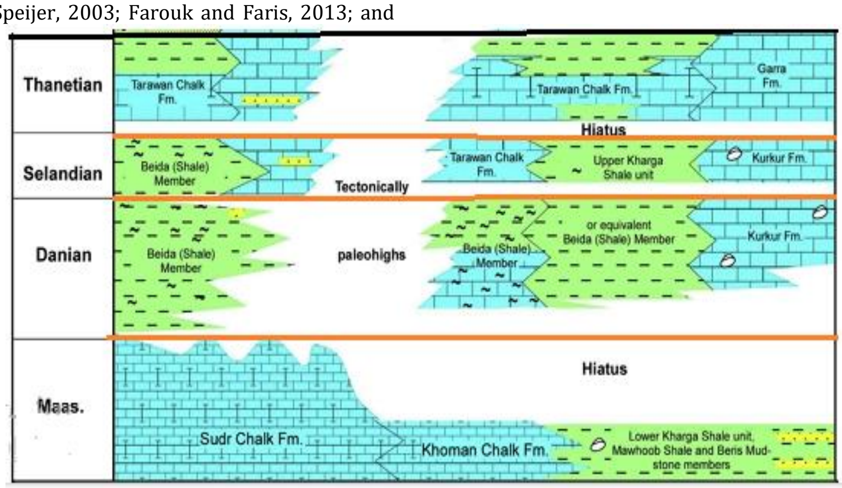


Figure 8: Hiatuses in the Paleocene succession of Egypt (after Farouk, 2016, with some modifications).

Jordan

Two sections in the north (Wadi Arab) and south Jordan (Tell Burma) present the Latest Danian Event (*angulata* Event) which exhibits many lateral and vertical facies changes across the Danian/Thanetian succession (Figures 9, 10). In these two sections, the Thanetian rocks rest unconformably on the Danian rocks (Futyan, 1976).

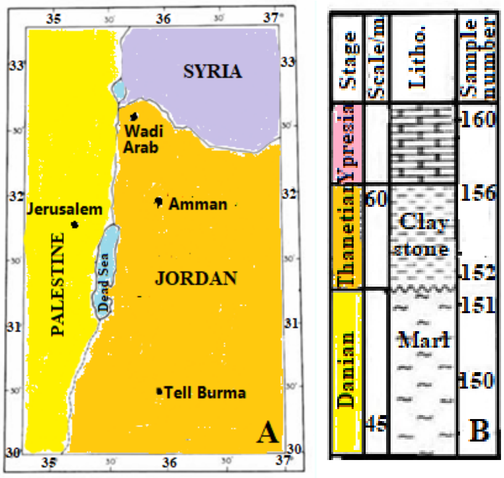


Figure 9: A) Location map of Tell Burma and Wadi Arab sections, **B)** stratigraphy of Wadi Arab section. Jordan (after Futyan, 1976).

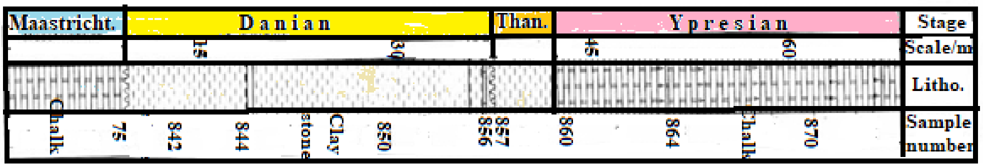


Figure 10: Stratigraphy log of Tell Burma section, South Jordan (after Futyan, 1976).

UAE

Based on the codified zones of, the *M. angulata* Zone (= *Igorina pusilla* Zone, P3a) is related to the late Danian, while the *G. pseudomenardii* Zone (P4) to the early Thanetian (Olsson et al., 1999). In Malaqet sections, the Thanetian rocks rest unconformably on the Danian rocks (Figure 11), while in Mundassa section the Selandian or Thanetian sediments ? rest unconformably on the Danian sediments (Figure 12).

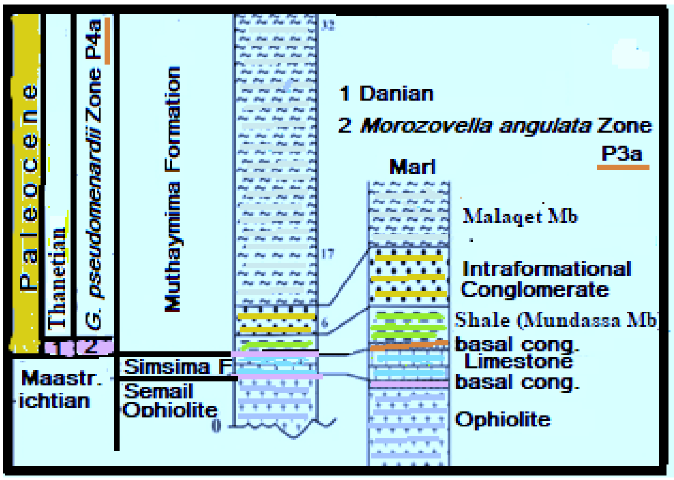


Figure 11: Litho- and biostratigraphic log of Malaqet section, Al Ain area, UAE (after Anan and Hamdan, 1992).

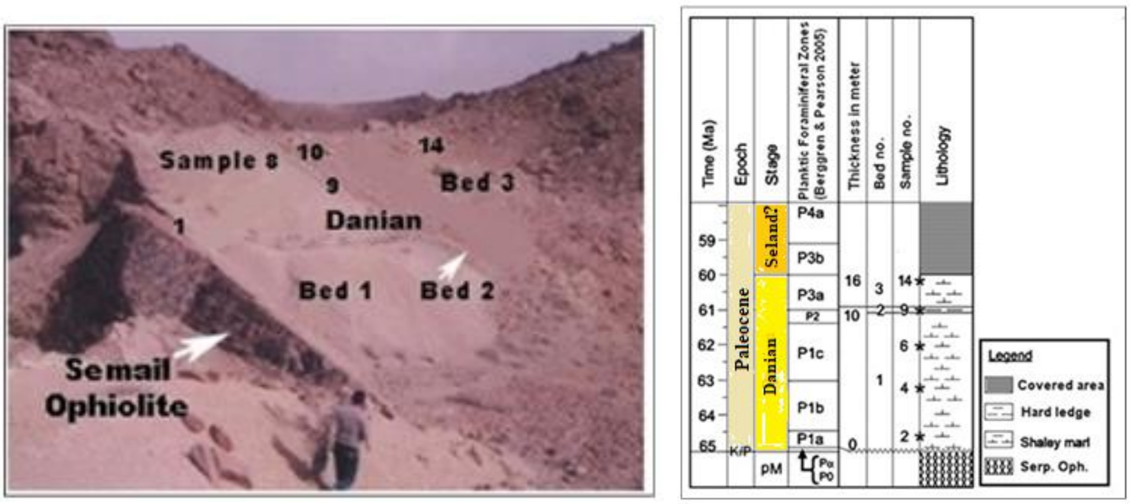


Figure 12: View anf log of the Paleocene Danian sediments of Mundassa Member of the Muthaymimah Formation, which nonconformably overly the obducted Pre-Maastrichtian Semail Ophiolite (after Anan, 2021).

6. Significant Episodes of Tectonic Events in The Southern Tethys

Tunisia: noted that the D/S boundary interval in the Sidi Nasseur section is characterized by at least two unconformities (Itterbeeck et al., 2007). The first co-occurs with the P2/P3 a subzonal boundary, coinciding with the D/S boundary. The second unconformity occurs at the base of the main glauconitic bed and coincides with the P3a/P3b subzonal boundary. Noted that the lithology of the D/S transition coincides with a level of bioturbation, rich in the glauconitic and phosphate grains, and reflecting a global event, constitutes on the field, a good marker of the D/S transition and allows correlations in small and great scale (Mtimet et al., 2013).

Egypt and Jordan: The major tectonic pulse of the Syrian Arc took place during the Campanian–Maastrichtian. Tectonics and sea-level changes played an important role in the depositional history of the eastern side of the study area in Egypt (Sinai) and Jordan (Figure 13).

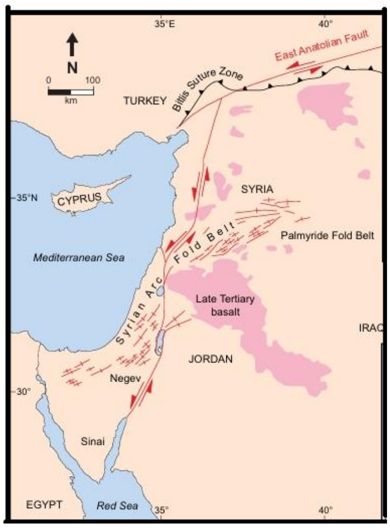


Figure 13: The Syrian Arc Fold Belt extending from northern Sinai, through the Negev and Jordan, and into central Syria, where it is known as the Palmyride Fold Belt (after Abed, 2013).

UAE: Two unconformities were recognized: basal conglomerate at the K/T boundary, and intraformational conglomerate at D/T (see Figure. 11).

7. Paleogeography

According to many authors, the Tethys had been connected from west Atlantic Ocean to east with the Indian Ocean via the Mediterranean Sea during the K/T time, including Tunisia, Egypt, Jordan, UAE in the Southern Tethys (Figure 14) (e.g. Solakius et al., 1990; Rögl 1999; Aubry et al. 2007; Abed, 2013; Anan, 2024).

Figure 14: K/T Paleogeographic maps showing the location of the study areas in the south Tethys (after Solakius et al., 1990).

8. Paleoenvironment

The D/S boundary in northern Tunisia is characterized by a regional hiatus due to erosion of the top of Subzone P3a. and transition from deep outer neritic (~175m) to shallow outer neritic (~ 125 m) deposition.

The D/S transition in Egypt is characterized by a dark brown organic-rich marl bed, similar to black shale.

The syndepositional folding that developed contemporaneously with sedimentation in J. Malaqet with the continuous restrictions of the southeastern seaway that connected between the Tethyan and Indo-Pacific realms essentially have been caused the formation of these successive conglomeratic beds in the Paleocene. Major environmental parameters affecting the abundance and distribution of foraminiferal species include: water depth, type of substrate, temperature, oxygenation, nutrition, organic matter influx on the seafloor, current patterns TCC (Figure 15).

Figure 15: The Neo-Tethys Ocean during the Late Cretaceous-Neogene times showing the open flow direction of the Tethyan Circum global Current (TCC) in all directions (after Abed, 2013).

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