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Biostratigraphy of the Upper Paleocene-Lower Eocene succession of Gebel El Aguz, northeastern Kharga Oasis, Western Desert, Egypt

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Abstract

Seven Upper Paleocene-Lower Eocene sections are investigated for the first time from Gebel El Aguz which is located midway between Naqb Assist and Gebel Ghanayim along the eastern escarpment of Kharga oasis. At this locality the lower part of the Esna Shale (The El Hanadi Member), which belongs to the Upper Paleocene, forms isolated hills composed of alternating highly fossiliferous calcareous shale, marly shale and marl belonging to Subbiozone P4c and Biozone P5. It is underlain by the Tarawan Chalk whose contact is well developed on the surface (~ one meter below Subbiozone P4c) and unconformably capped with a distinct erosional contact by a horizontal carbonate bed ranging in thickness from 0.9 m to 2.2 m. The carbonate bed which is here named as the El Aguz Limestone forms a conspicuous mapable unit extending for a long distance along the northeastern escarpment of Kharga Oasis. It starts at base with a thin (20 cm thick) indurated, limestone which is partly flinty, almost unfossiliferous and with bioturbations, then followed by a thick highly fossiliferous calcarenite which grades upward into limestone of variable fossil content. The common occurrence of excursion planktonic foraminifera fauna (PFEF) which is characteristic of the Paleocene-Eocene Thermal Maximum (PETM) as well as the sequential bioevents in the calcarenite strongly supports its correlation with the higher transgressive levels (Bed 4 and/or Bed 5) of the Dababiya Quarry Member at Dababiya, along the southern Nile Valley which belongs to the upper part of Biozone E1 and the lower part of Biozone E2.

It is, thus, apparent that the earliest part of the Eocene, (corresponding to the lower part of Biozone E1) which is represented in the Nile Valley by Beds 1, 2, and 3 of the Dababiya Quarry Member is missing in northeast Kharga Depression. So, a complete record of the biotic events that occurred during the PETM as exemplified in the DBH section which represents the Global Stratotype Section and Point (GSSP) of the P/E boundary at Dababiya Village, southern Nile Valley cannot be established in G. El Aguz. The El Aguz Limestone, thus, represents the invasion of the Tethyan flood during subsequent decrease of temperature and continuously increased faunal densities as a result of gradual increase in content of dissolved oxygen at the close of the PETM. It spans in G. El Aguz the top of the PETM (E1/E2 zonal boundary) and rests unconformably over the Hanadi Member (Subbiozone P4c and Biozone P5). The contact between the El Aguz limestone and the overlying El Mahmiya Member is synchronous with the top of the Dababiya Quarry Member in the southern Nile Valley.

Keywords: Kharga Oasis, G. El Aguz, Upper Paleocene-Lower Eocene biostratigraphy, planktonic foraminifera.

1. LOCATION AND REGIONAL STRATIGRAPHY

The Kharga Oasis is an open depression which extends in north-south direction between Latitudes 24° 32’ and 26° 0.5’N, and Longitudes 30° 25’ and 30° 50’ (Fig. 1). The depression is bounded on the north and east by a limestone plateau, whereas westwards the depression is bounded by a chalky plateau with a few outliers of the overlying sediments forming a few isolated hillocks on top (Awad & Ghobrial, 1965). This chalky plateau swerves westwards at Um Dabadib, thus leaving the depression open to the south and southwest. The average elevation of these plateaus is about 400 m above sea level. The descent from these plateaus to the desert floor (from ~100 m to 4 m) is along very steep escarpments which can be delineated as the eastern, western, northern and Umm El Dabadib escarpments. Easier paths along the eastern escarpment are used for transport where they called “Naqb” and provide a connection between the Oasis and the Nile Valley. Among these paths are the Naqb Assiut and Naqb El Rofouf which was crossed by the ancient railway road (Fig. 1). To the east of cultivation and very near the eastern plateau, there are three isolated hillocks. From south to north they are Gebel Ghaneemah, Gebel Umm el Ghanayem and Gebel El Aguz (Fig. 1).

The G. El Aguz lies at Latitude 25° 50’ 14.7” N and

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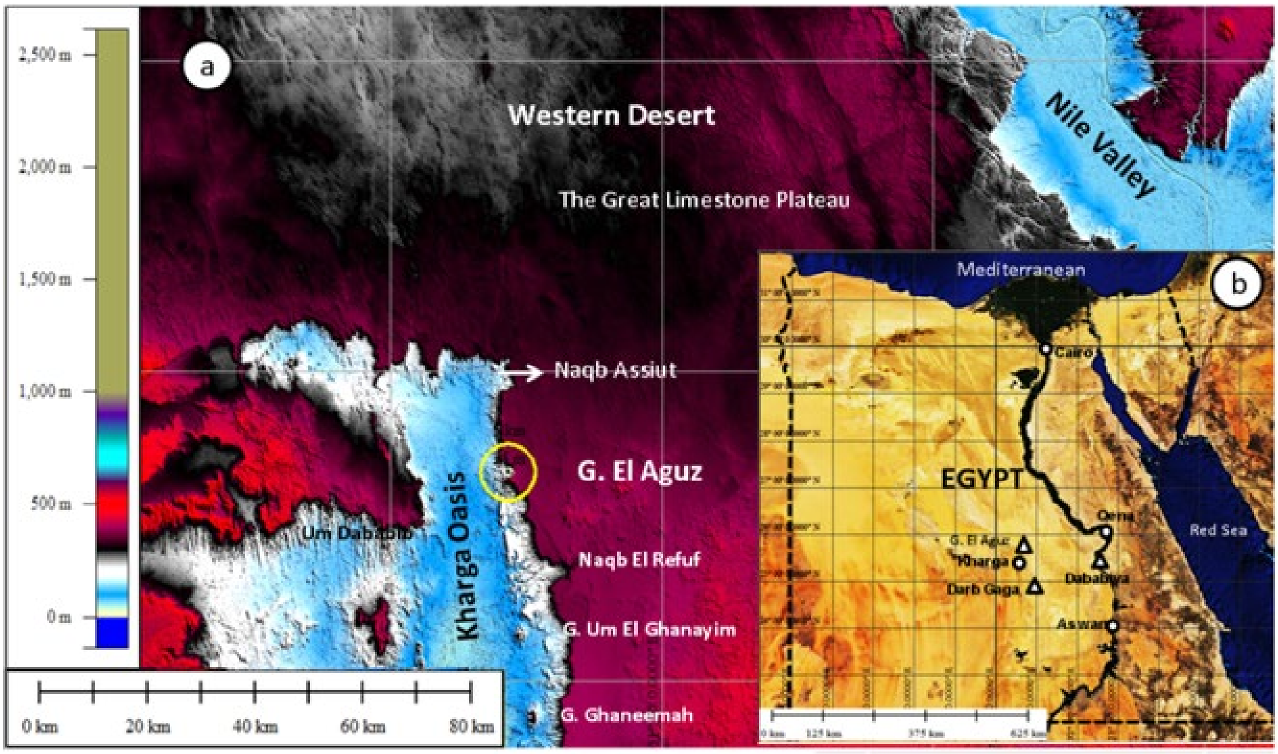


Fig. 1a-b: (a) SRTM topographic map of southern Egypt showing the location of G. El Aguz, along the northeastern escarpment of Kharga Oasis, Western Desert, Egypt. (b) Satellite imagery of Egypt from Google showing the location of G. El Aguz with respect to Dababiya, the GSSP of the P/E boundary, southern Nile Valley and comparable sections at Darb Gaga, southeastern escarpment of Kharga Oasis.

Longitude 30° 43' 5.8" E, midway between Naqb Assist and Gebel Ghanayim along the eastern escarpment. The Nubia Sandstone (Taref Formation of Awad and Ghobrial, 1965) constitutes the floor of the depression and the foothills of this escarpment (Fig. 2). It is overlain by the Quseir Shale (Youssef, 1960), which consists of unfossiliferous gray to greenish gray shale with thin bands of brown and purple clays. This is followed eastward by the Maastrichtian Duwi Formation (Youssef, 1957) which contains continuous thin beds of phosphate, shale and fossiliferous mudstone of 4 m thick, outcropping along the foothills of the escarpment, followed by ~94 m thick Dakhla Shale, the uppermost part of which spans the K/Pg boundary.

The Dakhla Shale of Said (1961) is directly overlain by the Tarawan Chalk (Awad & Ghobrial, 1965). The latter unit extends over a considerable distance and is composed of 10-11 m thick of white chalky, fossiliferous limestone changing in some localities into siliceous limestone or marly limestone. It is followed eastward by the Esna Shale which is a thick succession of shale varying into marl and marly shale in its lower part and intercalated with nummulitic limestone in its upper part. The Esna Shale (Beadnell, 1905; Said, 1960) forms the upper part of the escarpment between the underlying Tarawan Chalk and the overlying Thebes limestone, attaining a total thickness of 88-90 m.

The lower (Paleocene) part of the Esna Shale (El Hanadi Member of Abdel Razik, 1972, emended by Aubry *et al.,* 2007) forms isolated hills ranging in thickness from 8 m to 11.3 m and is mainly composed of alternating calcareous shale, marly shale and marl. It is underlain by the Tarawan Chalk whose contact is well developed on the surface and unconformably capped with a distinct erosional contact by a calcareous bed ranging in thickness from 0.9 m to 2.2 m (Fig. 3). The calcareous bed is defined here as El Aguz Limestone. It begins at the base with 20 cm of a hard, flinty unfossiliferous limestone with bioturbations filled with calcarenite, dispersed glauconite and coprolites intruded during sedimentation from the overlying calcarenite. The limestone is directly overlain by a calcarenite bed (with pelagic oozes) varying in thickness from 0.3 m to 1.1 m and passing conformably upward into a poorly to unfossiliferous limestone devoid of coprolites. The El Aguz Limestone extends for a long distance along the eastern escarpment of Kharga Oasis between Naqb Assiut and Naqb El Rofouf where it overlies unconformably the El Hanadi Member.

The contact between the El Aguz Limestone and the overlying El Mahmiya Member is sharp and comparable

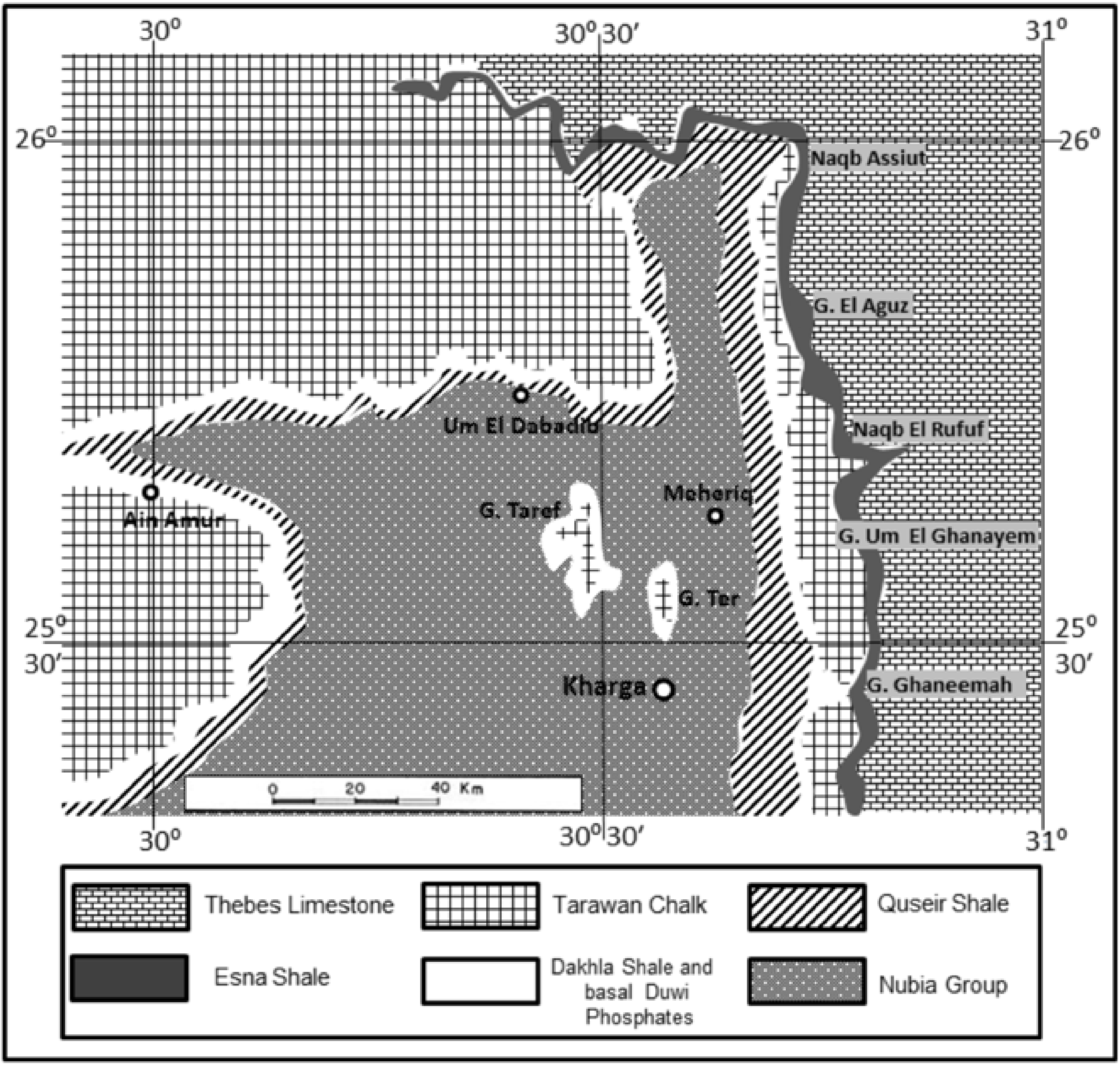


Fig. 2: Simple geological map of northern Kharga Oasis (Redrawn after Ball, 1900 and Beadnell, 1909 in Said, 1960).

(both lithologically and biostratigraphically) to the contact between the Dababiya Quarry Member and the overlying El Mahmiya Member at Dababiya in the southern Nile Valley (Aubry *et al.,* 2007; Ouda *et al.*, 2013).

The El Mahmiya Member (Aubry *et al.,* 2007) which constitutes the greater middle part of the Esna Shale) attains 55 m thick and followed upward by the Abu Had Member (upper part of the Esna Shale, Abdel Razik, 1972) with a thickness of ~33.5 m. The top levels of the eastern escarpment of G. El Aguz are made up of massive nummulitic limestone belonging to the Thebes Formation (Said, 1960). The contrast in lithology and color between the hard white to cream colored carbonates of Thebes Formation and the underlying soft dark grey to green shale of Esna Formation makes distinction between both rock units easy (Fig. 3).

2. MATERIALS AND METHODS

297 samples were collected and paleontologically studied from 7 Upper Paleocene-Lower Eocene sections in G. El Aguz (Fig. 4a). Of these samples 32 samples from section NK2, (3.2 m thick, Lat. 25° 50′ 10.8″ N, Long. 30° 43′ 2.4″ E, Fig. 4b) including the topmost part of the

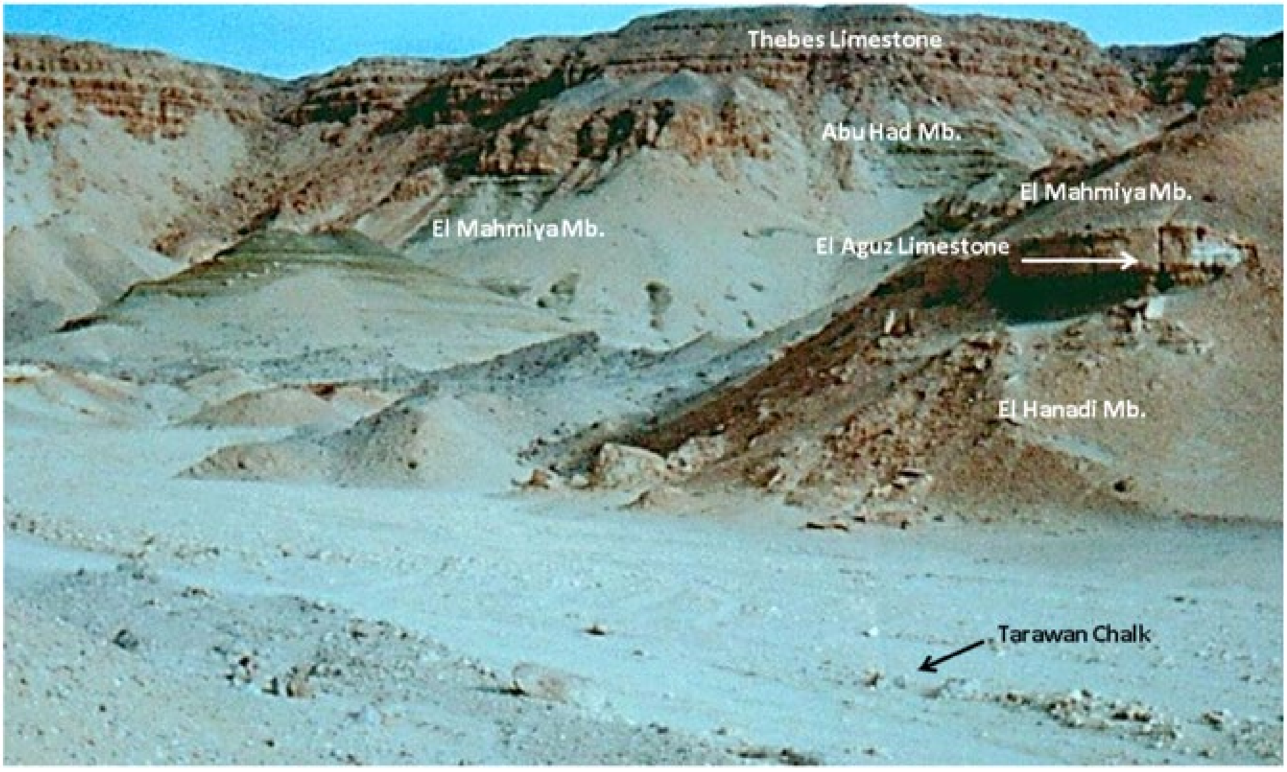
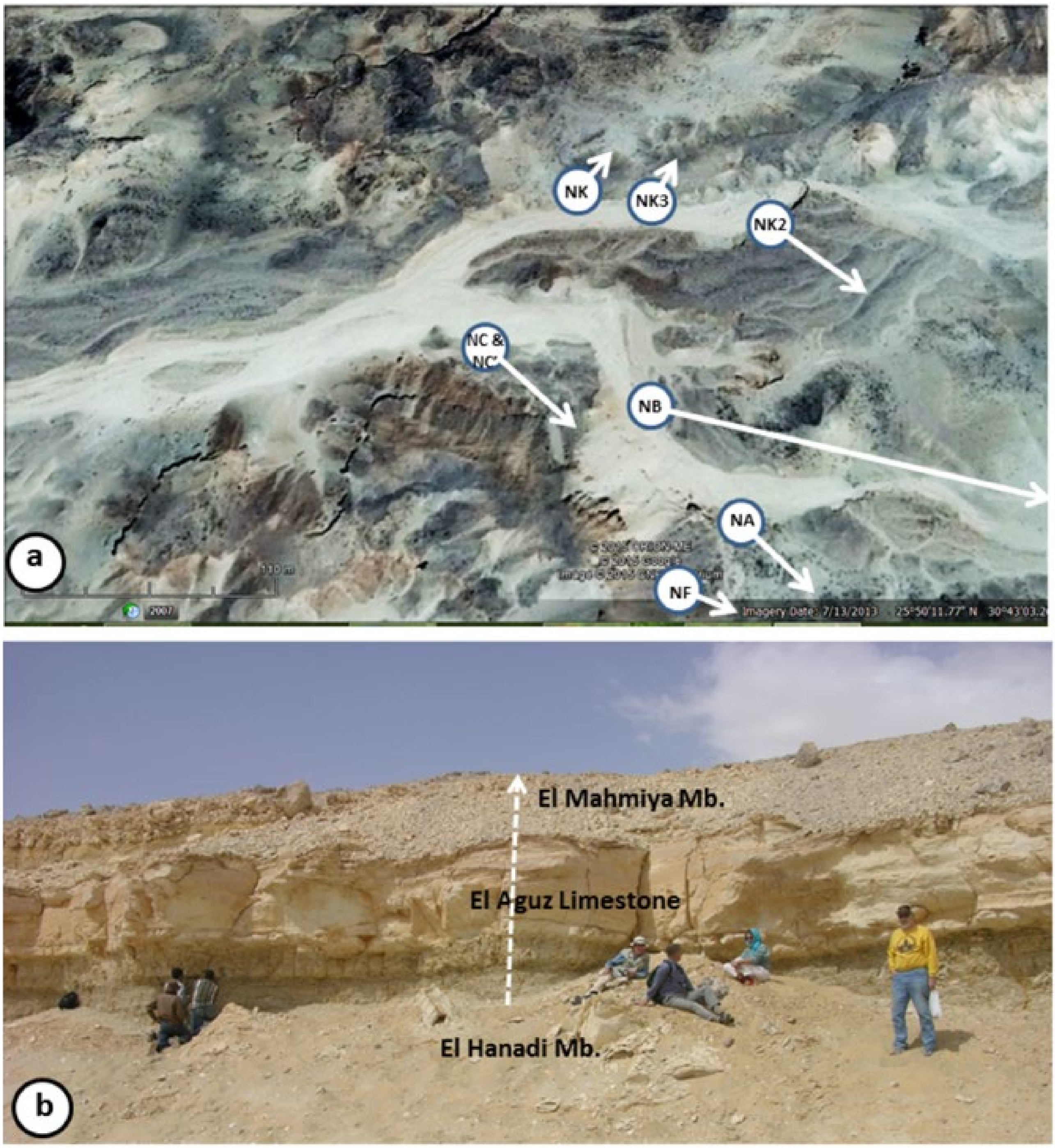


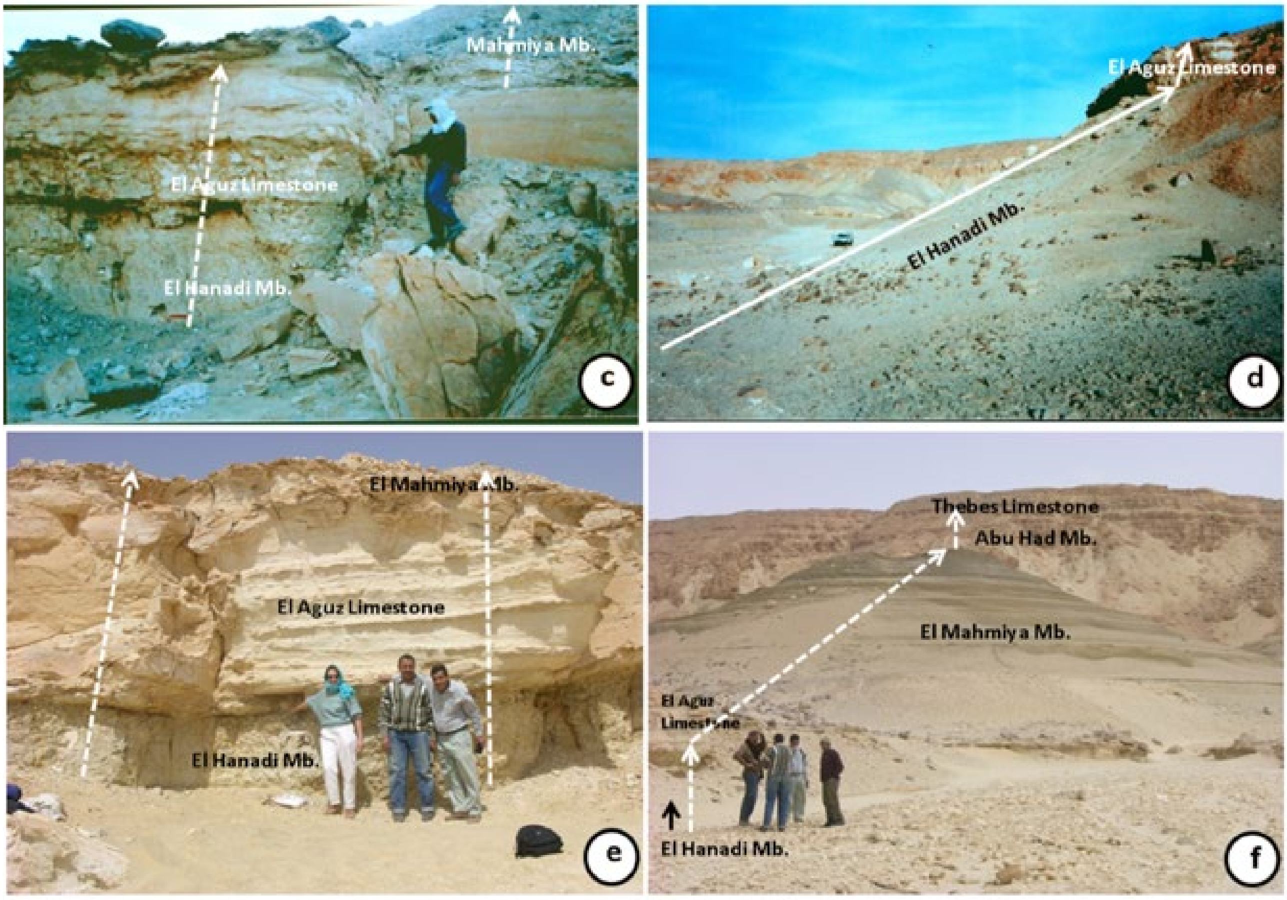
Fig. 3: Panorama of G. El Aguz, northeast Kharga Oasis showing the Esna Shale members (El Hanadi Mb, El Aguz Limestone, El Mahmiya Mb. and Abu Had Mb.) overlying the Tarawan Chalk and underlying the Thebes Limestone.

El Hanadi Member and the overlying El Aguz Limestone with a sampling interval of 10 cm apart; 71 samples from section NA (13.0 m thick, Lat. 25° 50′ 8.82″ N, Long. 30° 43′ 3.48″ E, Fig. 4c) including the topmost part of the El Hanadi Member, the El Aguz Limestone and the lower part of the overlying El Mahmiya Member with sampling intervals varying from 10 cm to 25 cm; 54 samples from section NC (14.6 m thick, Lat. 25° 50′ 9.92″ N, Long. 30° 43′ 0.4″ E, Fig. 4d) including the topmost part of the Tarawan Formation, the El Hanadi Member and the lower exposed part of the overlying El Aguz Limestone, with sampling intervals varying from 10 cm to 100 cm; 28 samples from two adjacent sections NK (3.2 m thick,) and NK3 (4.2 m thick, Lat. 25° 50′ 11.8″ N, Long. 30° 43′ 2.4″ E, Fig. 4e) including the topmost part of the El Hanadi Member and the overlying El Aguz Limestone, with sampling intervals varying from 10 cm to 20 cm; 96 samples from section NB (110 thick, Lat. 25° 50′ 9.82″ N, Long. 30° 43′ 2.5″ E, Fig. 4f), including the topmost part of the El Aguz Limestone, the El Mahmiya Member, the Abu Had Member and the basal part of the Thebes Limestone with sampling intervals varying from 25 cm to 3.0 m; 16 samples from section NF (3.2 m thick, Lat. 25° 50′ 7.4″ N, Long. 30° 43′ 1.5″ E) including the topmost part of the El Hanadi Member and the overlying El Aguz Limestone, with sampling intervals varying from 10 cm to 20 cm.

Two hundred grams of each sample were dried at 80°C, and weighed. The dry samples were soaked in a 0.5 molar Na_2CO_3 solution. Most shale, marl and calcarenite samples are disintegrated readily and washed carefully over a 63 µm screen until the clay fractions washed completely, then dried and sieved over 125, 250 and 500 µm screens. Samples of the hard limestone were treated in a different manner. They were crushed into small fragments and heated at about 100°C, then immediately soaked in kerosene for 24 hours until disaggregated. The fractions were weighed and preserved in glass vials. The foraminiferal faunas were concentrated in the size fractions of 125 and 250 µm from which the fossils were picked and then preserved on cardboard slides. Microphotographs of the index planktonic foraminiferal taxa of the Paleocene/Eocene boundary (Plates I-V) are taken by Scanning Electron Microscope (JEOL-JSM-5400LV) at Assiut University in Egypt. The planktonic foraminiferal zonal scheme applied here is the tropical to subtropical Paleogene zonation of Berggren & Pearson (2005).



Figs 4a-b: Studied sections of G. El Aguz. (a) Google Earth satellite image showing the location of the studied sections at G. El Aguz, NE Kharga Oasis, Western Desert, Egypt; (b) Field photograph of section NK2 (Lat. 25° 50′ 10.8″ N, Long. 30° 43′ 2.4″ E). Arrows point to direction of sampling.



Figs 4c-f: Field photographs of the studied sections in G. El Aguz. © Section NA (Lat. 25° 50′ 8.82″ N, Long. 30° 43′ 3.48″ E); (d) Sections NC and NC' (Lat. 25° 50′ 9.92″ N, Long. 30° 43′ 0.4″ E); (e) Sections NK (left) and NK3 (right)(Lat. 25° 50′ 11.8″ N, Long. 30° 43′ 2.4″ E); (f) Section NB (Lat. 25° 50′ 9.82″ N, Long. 30° 43′ 2.5″ E). Arrows point to direction of sampling.

3. LITHO- AND BIOSTRATIGRAPHY

3.1. The El Hanadi Member (corresponding to Subbiozone P4c and Biozone P5 of Berggren & Pearson, 2005):

Section NC (from sample NC 0.0 at base to sample NC11.3 at top) (Fig. 5)
Section NC'(from sample NC' 1.3 at top to sample NC' 5.2 at base) (Fig. 5)
Section NK3 (from sample 0.0 m at base to sample 2.0 m at top) (Fig. 6)
Section NA (from sample 0.0 m at base to sample 1.5 m at top) (Fig. 7)
Section NF (from sample 0.0 m at base to sample 2.3 m at top) (Fig. 8)
Section NK2 (from sample 0.0 m at base to sample 2.1 m at top) (Fig. 9)
Section NK (from sample -1.0 m at base to sample 0.1 m at top) (Fig. 10)

This lower member of the Esna Formation consists of bioturbated gray shale intercalated in its upper part with grayish marly shale and weathered whitish marl. Its base is only exposed in section NC where it overlies the Tarawan Chalk and attains a total thickness of 11.3 m. In all other sections the base of the El Hanadi Member is not exposed and the member varies in thickness from 1.0 m to ~2.5 m. A distinct erosional contact marks the top of this member and the shale below this contact does not appear to be uniformly correlative in all sections. The most complementary section is NC which extends uniformly with a gentle dip from the Tarawan Chalk at base to El Aguz Limestone at top.

The contact between the Tarawan Chalk and the El Hanadi Member lies a short stratigraphic interval above the base of Subbiozone P4c as recorded by the simultaneous Lowest Occurrences (LOs) of *Acarinina soldadoensis, Ac. primitiva, Ac. coalingensis* and *Morozovella aequa* in the uppermost part of the Tarawan Chalk (1.0 m below the base of the El Hanadi Member). These synchronous bioevents occur also within the uppermost marly levels of the Tarawan Formation at G. Owaina (Ouda *et al.*, 2003) and Dababiya (Berggren & Ouda, 2003a), 2 m and 1.5 m respectively below the base of the Esna Shale.

The El Hanadi Member spans the uppermost part of the

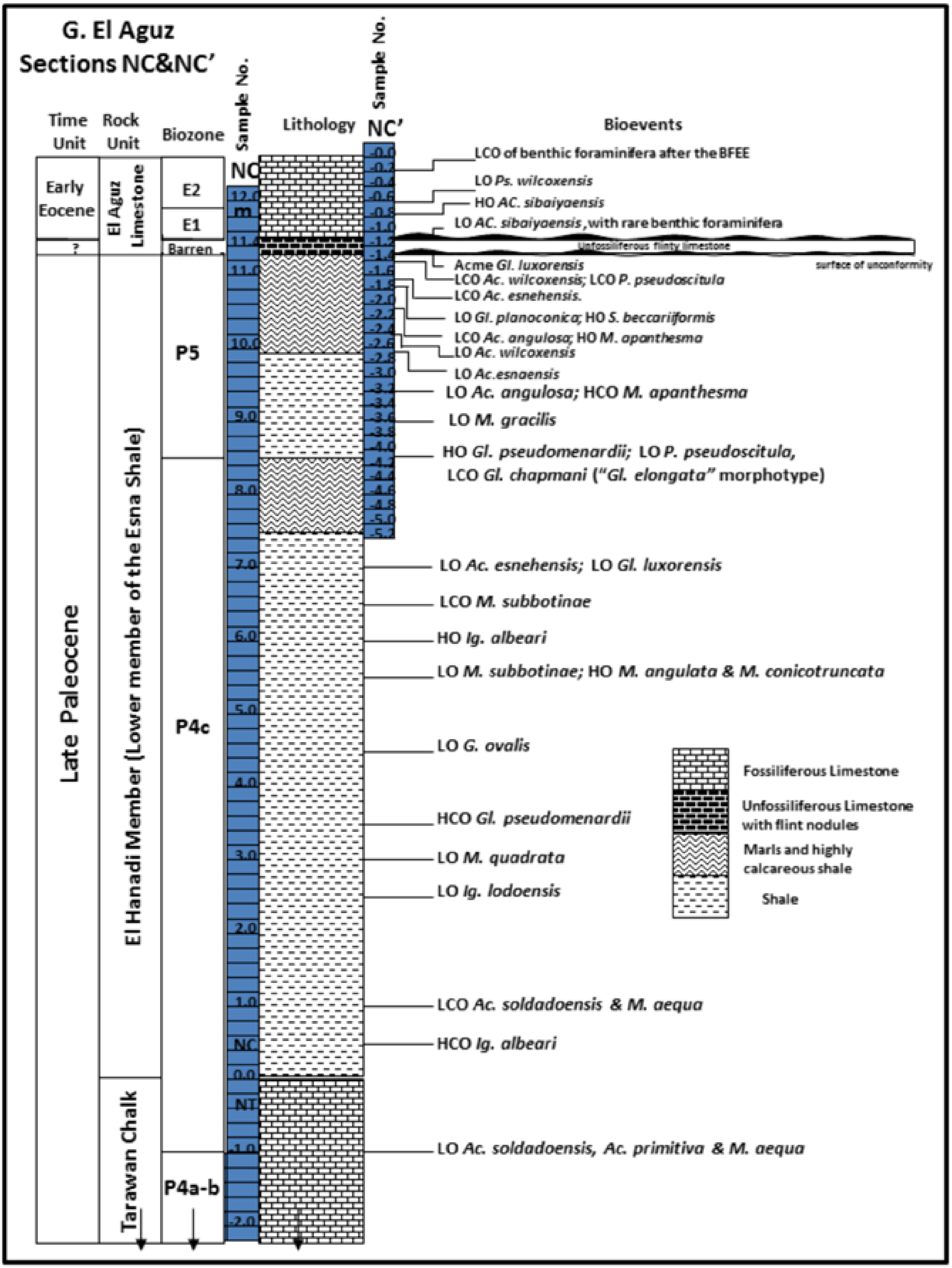


Fig. 5: Lithology, biozones and characteristic bioevents of the upper Paleocene-lower Eocene succession of G. El Aguz (Section NC - NC') northeastern Kharga Oasis, Western Desert.

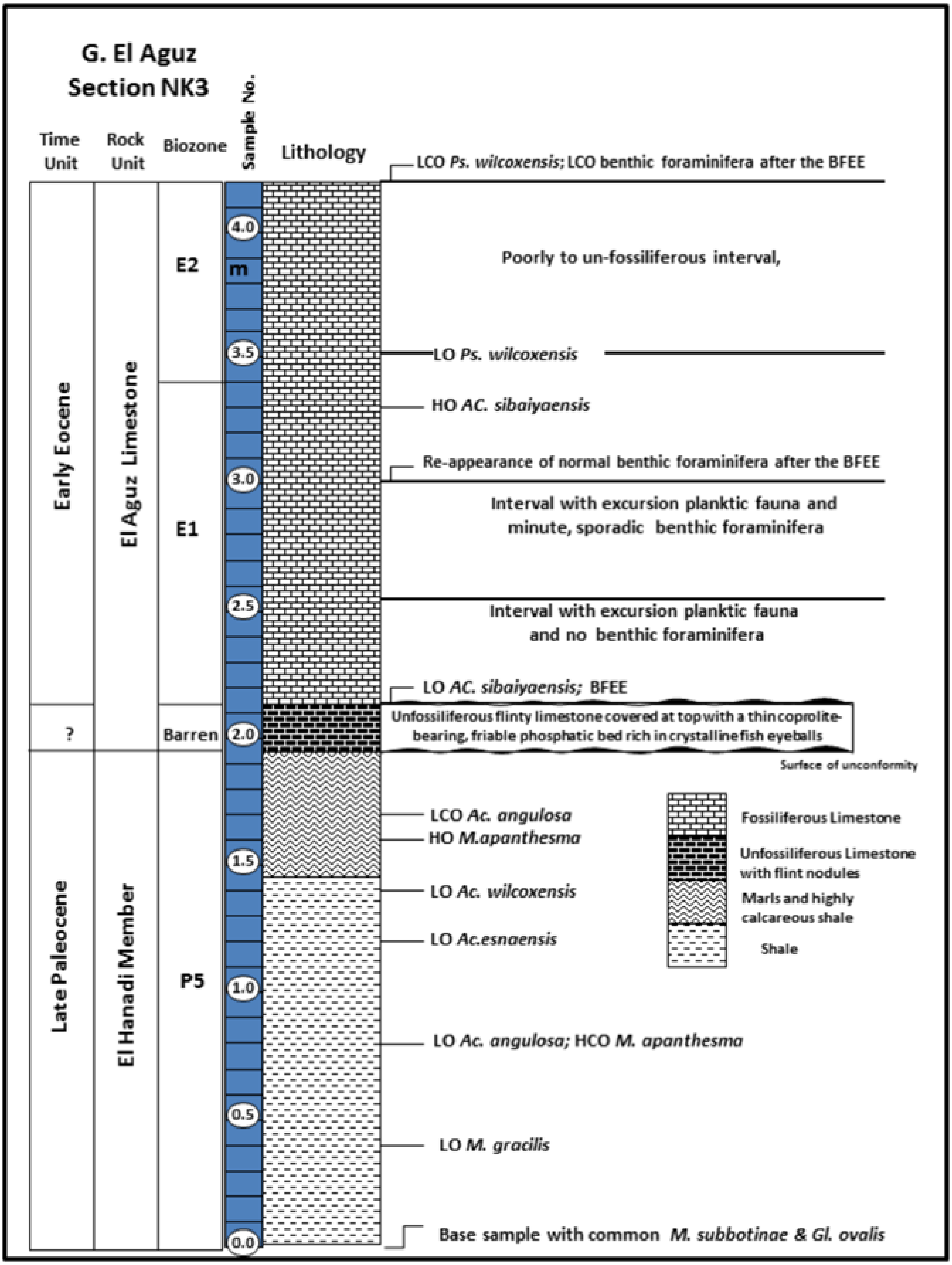


Fig. 6: Lithology, biozones and characteristic bioevents of the upper Paleocene-lower Eocene succession of G. El Aguz (Section NK3), northeastern Kharga Oasis, Western Desert.

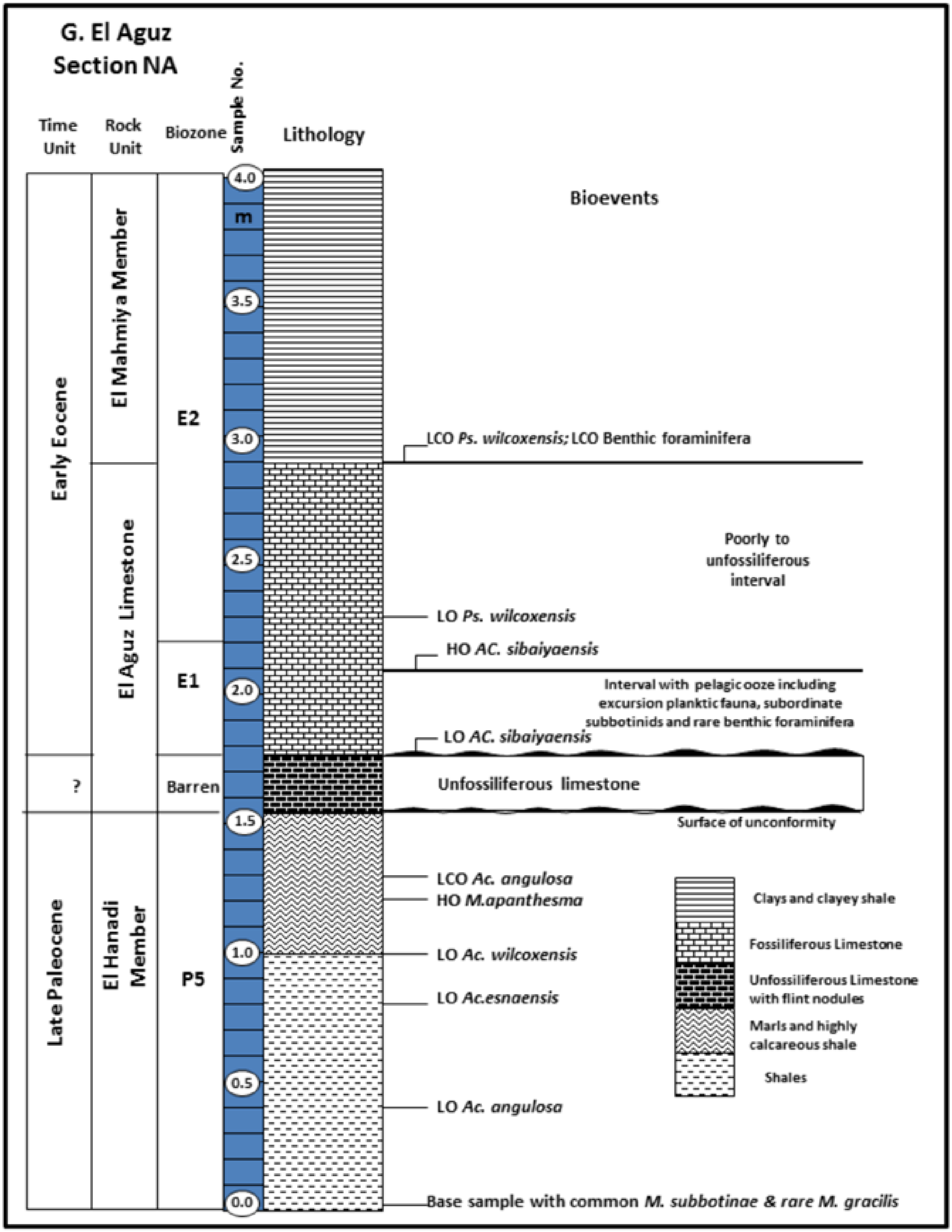


Fig.7 : Lithology, biozones and characteristic bioevents of the upper Paleocene-lower Eocene succession of G. El Aguz (Section NA), northeastern Kharga Oasis, Western Desert.

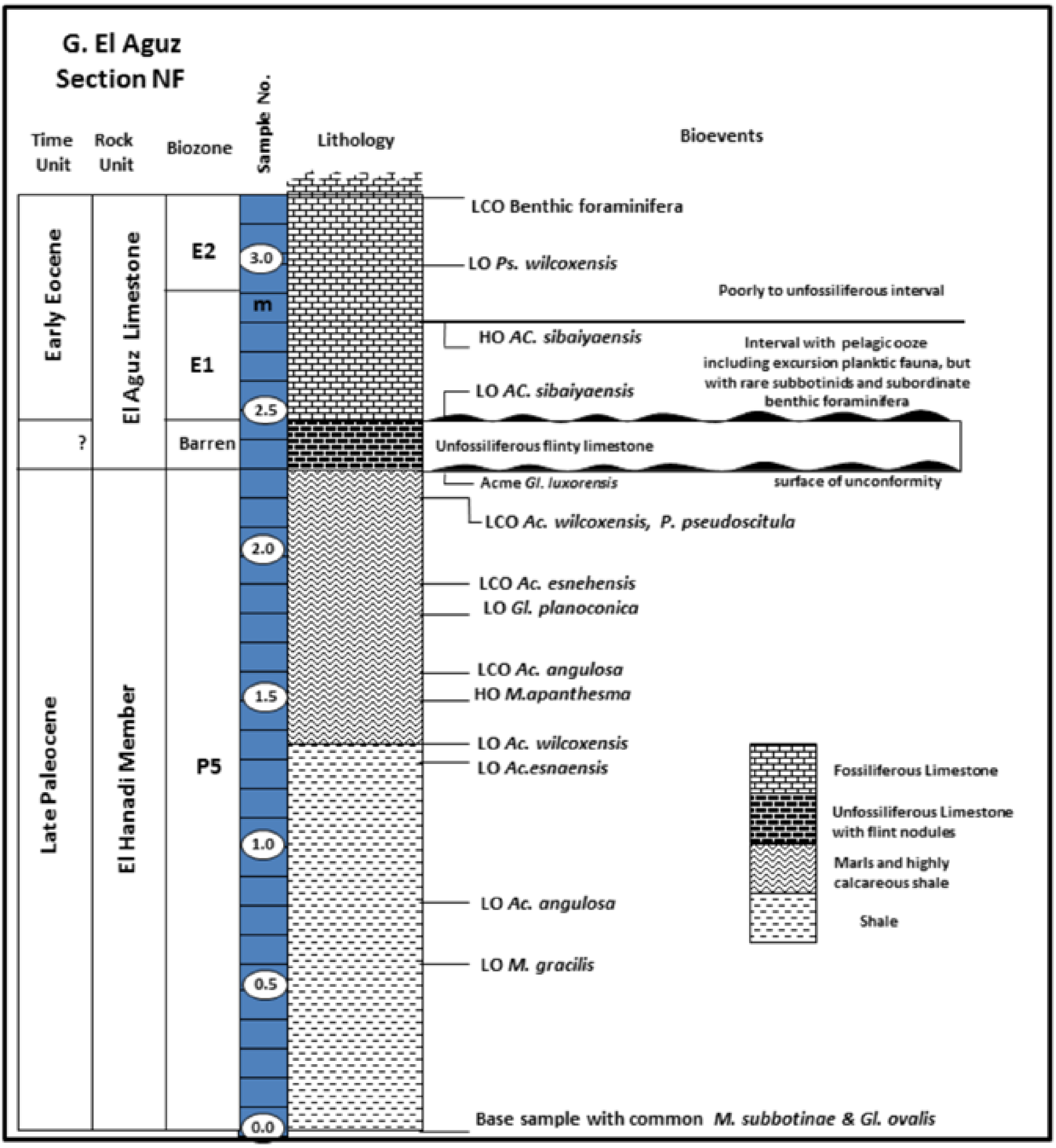


Fig. 8: Lithology, biozones and characteristic bioevents of the upper Paleocene-lower Eocene succession of G. El Aguz (Section NF), northeastern Kharga Oasis, Western Desert.

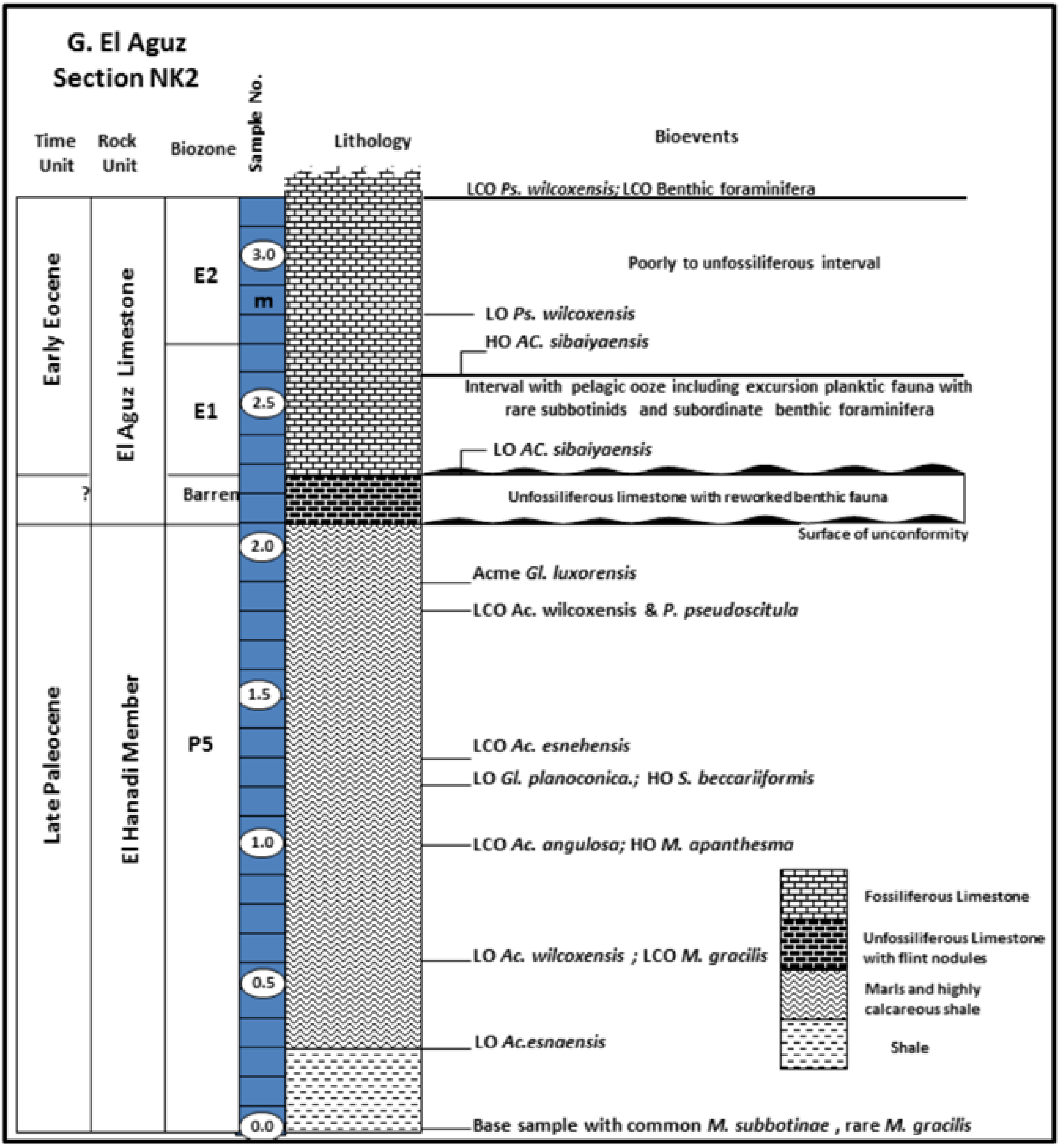


Fig. 9: Lithology, biozones and characteristic bioevents of the upper Paleocene-lower Eocene succession of G. El Aguz (Section NK2), northeastern Kharga Oasis, Western Desert.

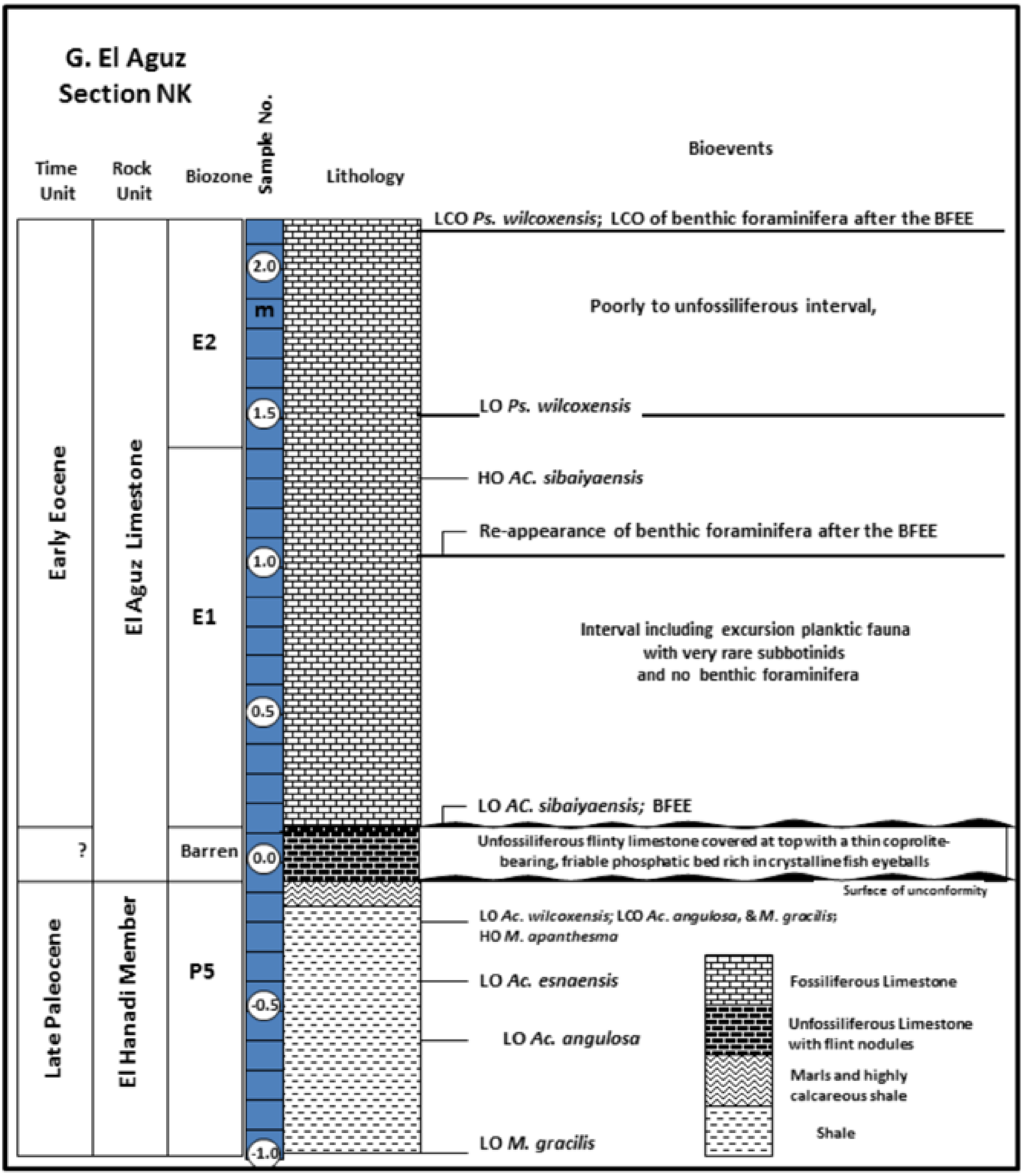


Fig. 10: Lithology, biozones and characteristic bioevents of the upper Paleocene-lower Eocene succession of G. El Aguz (Section NK), northeastern Kharga Oasis, Western Desert.

Paleocene Series and belongs to Subbiozone P4c and Biozone P5. The most significant bioevents encountered in this Member (Fig. 11) are arranged from older to younger as follow:

1. The Highest Common Occurrence (HCO) of *Igorina albeari* is recorded at a level which is 50 cm (NC 0.5) above the base of the El Hanadi Member, then followed by the LCO of *Ac. soldadoensis* in sample NC 1.0 m. In the southern Nile Valley the HCO of *Ig. albeari* is synchronous with the LOs of *Ac. soldadoensis* and *Ac. coalingensis* (Ouda & Berggren, 2003). Thus, it seems that no beds are missing at the base of the El Hanadi Member at G. El Aguz and the Tarawan/Esna boundary is essentially conformable. Above in the El Hanadi Member *Ig. albeari* occurs only rarely and sporadically until becoming extinct below the base of Subbiozone P5.
2. The HCO of *Globanomalina pseudomenardii* is recorded in sample NC 3.5 m above the base of El Hanadi Member, while the HO of this taxon which marks the P4/P5 zonal boundary is recorded at sample NC 8.5 m (= sample NC' -4.1 m, Figs 5 and 11). The abundance of this form in the El Hanadi Member at G. El Aguz differs from its abundance in the Nile Valley where it is a function of the intensity of carbonate dissolution in the uppermost Tarawan and lowermost Esna Formation (e.g. Dababiya: Berggren & Ouda, 2003a; Ouda *et al.,* 2013; Qreiya: Berggren & Ouda, 2003b; Owaina and Kilabiya: Ouda *et al.,* 2003). However, in places where carbonate deposition continued beyond deposition of the Tarawan Formation (Garra Formation at Wadi Abu Ghurra, Berggren *et al.,* 2003) *Gl. pseudomenardii* occurs commonly up to the P4/P5 biochronozonal boundary. In section NC at G. El Aguz, where the Tarawan/Esna formational boundary is well exposed and the El Hanadi Member is represented by its most complete section, the biochronozonal P4/P5 boundary could be delineated in the higher marly part of the section based on the HO of *Gl. pseudomenardii*, ~2.7 m below the base of El Aguz Limestone.
3. The evolution of the geographically broadly distributed morozovellids of the *M. quadrata* - *M. subbotinae* - *M. gracilis* lineage in the El Hanadi Member in samples NC 3 m, NC 5.5 m and NC 9.4 m (=NC' -3.2 m) respectively (Fig. 11). This lineage evolved from *M. aequa* which has its LO slightly below the base of the EL Hanadi Member (= base of the Esna Shale). The members of this lineage have also successive LOs in a short stratigraphic interval that straddles the P4/P5 zonal boundary in the Nile Valley (Ouda & Berggren, 2003). *M. subbotinae* the ancestral form of *M. gracilis* has its LO in both the Nile Valley and Kharga Oasis below the HO of *Gl. pseudomenardii,* whereas *M. gracilis* has its LO immediately above the HO of *Gl. pseudomenardii.*
   The LO of *M. subbotinae* is synchronous with the HO of *M. angulata* and *M. conicotruncata* (Fig. 11). The interval of overlap of *M. subbotinae* and *Gl. pseudomenardii* is about 3 meters in G. El Aguz, and yields three interesting bioevents: a) the extinction of *Ig. albeari* b) The evolution of *Globanomalina luxorensis*, c) the evolution of *Planorotalites pseudoscitula.* Similar bioevents have been recorded by Ouda & Berggren (2003) within the stratigraphic interval of overlap between the LO of *M. subbotinae* and HO of *Gl. pseudomenardii* in the lower part of the Esna Shale in the southern Nile Valley (Esna 1 of Dupuis *et al.*, 2003 corresponding to El Hanadi Member of Aubry *et al.,* 2007).
   Thus, these bioevents can serve well as indicators for the delineation of the P4/P5 zonal boundary in the lower part of the Esna Shale (El Hanadi Member) in the southern Nile Valley where *Gl. pseudomenardii* is rare, difficult to characterize, or absent due to carbonate dissolution.
4. The acme appearance of *Gl. chapmani* (the non-keeled morphotype of *Gl. pseudomenardii*) including specimens referable to the *Gl. troelseni* morphotype and *Gl. elongata auct* morphotype at the same level as the LO of *M. gracilis,* 1 m above the P4/P5 zonal boundary (i.e. above the HO of *Gl. pseudomenardii*).
5. The radiation of acarininids within a short stratigraphic interval in the upper part of the El Hanadi Member (= upper part of Biozone P5), shortly before/below the onset of the PETM interval which marks the overlying El Aguz Limestone, a case which is similarly encountered in the southern Nile Valley (Berggren & Ouda, 2003a, b; Ouda *et al.,* 2003; Berggren *et al.,* 2003; Ouda & Berggren, 2003; Ouda *et al.,* 2013). This includes the sequential LOs of *Ac. angulosa, Ac. esnaensis* and *Ac. wilcoxensis s.s* (Figs 5-11) at successive levels of Biozone P5 in all sections, e.g. samples NC 9.4 m (=NC' -3.2 m) NC 9.9 m (=NC' -2.7 m) NC 10.2 m (=NC' -2.4 m) respectively. However, these three acarinids do not occur frequently before the higher levels of Biozone P5, e.g. from sample NC 10.5 m (=NC' -2.1 m) to sample NC11 (= NC' -1.5 m), 80-20 cm below the base of the PETM calcarenite. The same sequence of bioevents was previously found in the upper levels of Zone P5 in all sections studied in the Nile Valley, either in clastic (Esna Formation, Ouda & Berggren, 2003) or calcareous facies (Garra Formation, Berggren *et al.,* 2003). This implies that it can reliably be used to approximate the P5/E1 zonal boundary and to predict the location of the stratigraphic interval that records the PETM.
6. The LO of *Gl. planoconica* at sample NC' -1.8 m, at a horizon which is coincident with the datum of HO of *S. beccariiformis*, ~50 cm below the base of the PETM calcarenitic interval of the El Aguz Limestone. This diagnostic planktonic species can also be used to approximate the P5/E1 zonal boundary.

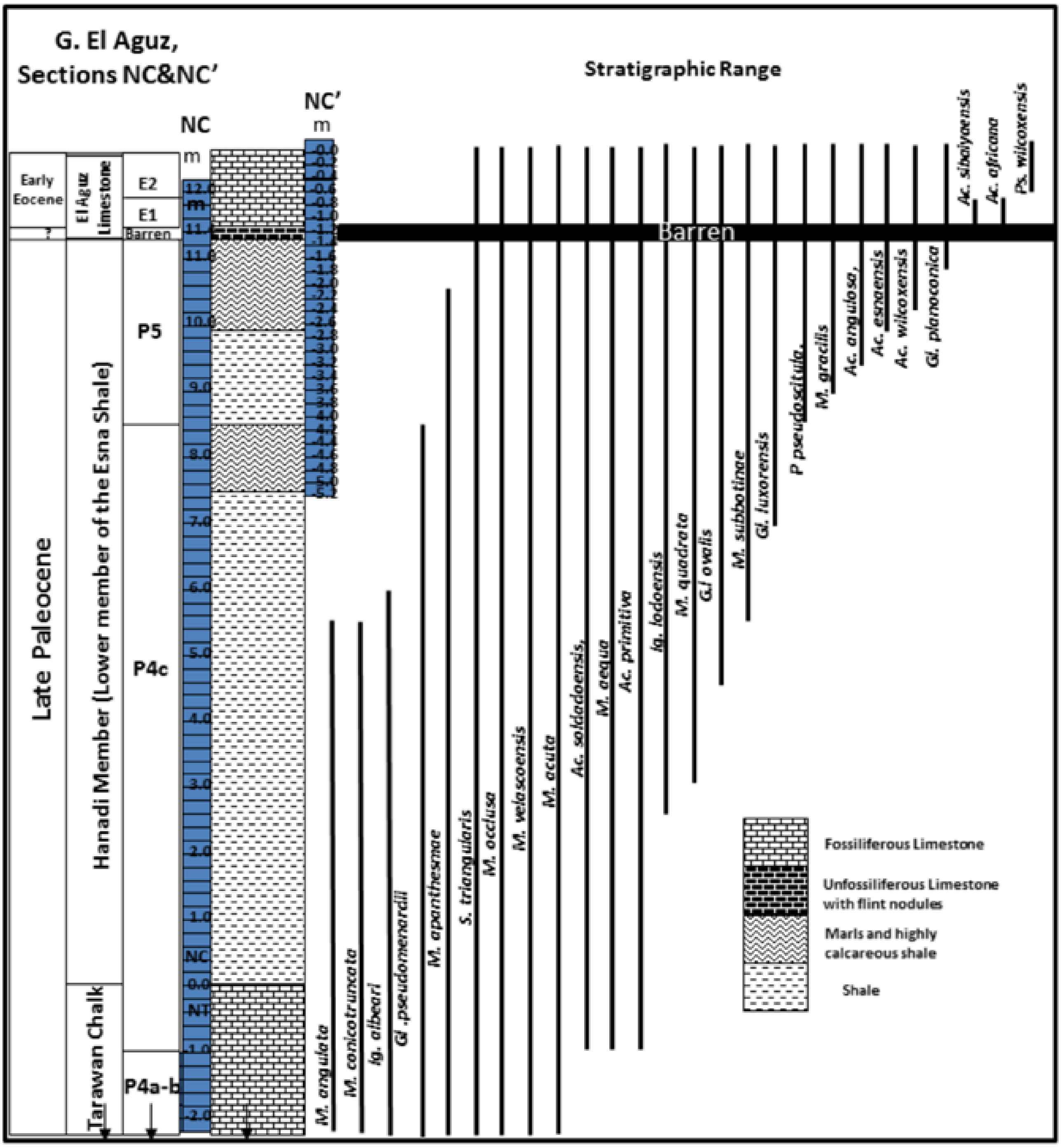


Fig. 11: Stratigraphic distribution of biostratigraphically important planktonic foraminifera in the upper Paleocene-lower Eocene succession of G. El Aguz (Section NC - NC'), northeastern Kharga Oasis, Western Desert.

7. The benthic foraminifera in the El Hanadi Member at G. El Aguz (Subbiozone P4c and Biozone P5) are characterized by mixed elements of the so-called "Midway" fauna, typical of neritic water depths (down to 200 m) and "Velasco" fauna, typical of deep (upper bathyal) water depths (Berggren & Aubert, 1975). In section NC - NC', both types of benthic faunas alternate with each other. The Velasco fauna is almost restricted to the marl and marly shale beds which alternate with the shale beds of the El Hanadi Member in the uppermost part of Subbiozone P4c (from sample NC' -5.1 m to sample NC' -3.4 m) and Biozone P5 (from sample NC' -2.1 m to sample NC' -1.6 m). *Anomalinoides danica, Angulogavelinella avnimelechi, Stensioina beccarriformis, Tritaxia midwayensis, Neoflabellina jarvisi* and *Gyroidinoides*

giraradana are the most common Velasco faunal elements in the El Hanadi Member. *S. beccarriformis* accompanies *A. danica* in the uppermost part of the El Hanadi Member until disappearing together with several benthic foraminifera in sample NC' -1.6 m, ~30 cm below the erosional surface of the overlying El Aguz Limestone.

Other distinctive benthic foraminifera of the "Midway" type fauna that are common in the El Hanadi member include: *Anomalinoides midwayensis, An. umboniferous, Bulimina midwayensis, B. reussi, Cibicidoides alleni, Eponides lotus, E. plummerae, Frondicularia phosphatica, Gyroidinoides subangulata, Lenticulina midwayensis, Marginulinopsis tuberculata, Osangularia plummerae, Valvulineria scrobiculata,* and *Stilostomella stephensoni*.

8. The topmost sample of the El Hanadi Member (Samples NC' from -1.4 m to -1.3 m) contains a subbotinid-rich planktonic foraminiferal association among which globanomalinids (*Gl. chapmani, Gl. planoconica*) are common while morozovellids are subordinate and mainly represented by *M. acuta*.

3.2. The El Aguz Limestone: (Spanning the E1/E2 zonal boundary of Berggren & Pearson, 2005)

- Section NC-NC' (NC', from sample 0.0 m at top to sample 1.3 m at base and NC, from sample 11.3 at base to sample 12.0 at top) (Fig. 5)
- Section NK3 (from sample 2.0 m at base to sample 4.2 m at top) (Fig. 6)
- Section NA (from sample 1.6 m at base to sample 2.9 m at top) (Fig. 7)
- Section NF (from sample 2.3 m at base to sample 3.2 m at top). (Fig. 8)
- Section NK2 (from sample 2.1 m at base to sample 3.2 m at top) (Fig. 9)
- Section NK from sample 0.0 m at base to sample 2.2 m at top) (Fig. 10)

This calcareous unit varies in thickness from 90 cm to 2.2 m and can be divided into three subunits, namely from older to younger as follow:

3.2.1. A lower, Flinty Limestone Subunit

This subunit unconformably separates the underlying El Hanadi Member from the overlying calcarenitic limestone bed at G. El Aguz. It is ~20 cm thick and composed of an indurated limestone enclosing flint nodules, containing dispersed specimens of reworked Paleocene foraminifera of Biozone P5 and is penetrated by bioturbations filled with the overlying calcarenite. Well preserved specimens of *Gl. luxorensis and Gl. chapmani* of different sizes are recorded immediately below the base of this limestone (upper limit of the El Hanadi Member). In some sections (section NC' sample 1.2 m and section NK2, samples 2.0 m-2.2 m) few sporadic specimens of these species are encountered throughout this bed. The limestone is capped in some localities (e.g. section NK3) by a thin tongue, reaching up to 10 cm thick of coprolites-bearing, friable phosphatic bed rich in fish eyeballs separating this limestone bed from the overlying calcarenite. The age of limestone cannot be defined precisely because of its almost barren nature, but its stratigraphic position between the higher levels of Biozone P5 and the higher levels of Biozone E1 of Berggren & Pearson (2005) would suggest its assignment as a surface of disconformity or unconformity at the base of the Eocene.

3.2.2. A middle Calcarenite Subunit containing Planktonic Foraminiferal Excursion Fauna (PFEF), corresponding to Biozone E1 of Berggren & Pearson (2005)

This calcarenite subunit is unconformably overlying the unfossiliferous flinty limestone and begins with a pelagic ooze made up exclusively of planktonic foraminifera, while benthic foraminifera are very rare or entirely absent. It spans a reduced thickness of 30 cm in sections NC', NA and NK2 (Figs 5, 7 and 9). However the thickness of this subunit reaches up to 1.1 m in sections NK3 and NK (Figs 6 and 10). The foraminiferal association of this subunit belongs to the younger part of Biozone E1, corresponding to those of the lower (PETM) part of Bed 5 (Berggren & Ouda, 2003a, re-defined as Bed 5a by Ouda *et al.,* 2013) of the Dababiya Quarry Member in the Nile Valley. In sections NK and NK3, this calcarenite subunit attains a considerable thickness and contains foraminiferal fauna comparable to those of Beds 4 and 5a of the Dababiya Quarry Member in the southern Nile Valley. In general, this calcarenite bed is characterized by the following bioevents:

a. The common appearance of PFEF of which *Ac. sibaiyaensis* is predominant.
b. The general impoverishment or even the complete absence of subbotinids.
c. The predominance of the (sub)tropical morozovellids with common *M. velascoensis* and *M. acuta*.
d. The very rare or absence of benthic foraminifera. When present, they are mainly represented by small nodosariids, lenticulinids and siphogenerinids.

In section NK2 (Fig. 9) the PFEF occurs commonly during the interval from sample 2.3 m to sample 2.6 m where a pelagic ooze with well preserved faunas marks this interval. The fauna is primarily represented by *Ac. sibaiyaensis*, whereas *Ac. africana* and *M. allisonensis* occur rarely, and the subbotinids never exceed 1% of the total planktonic foraminifera throughout this calcarenite, a case which mirrors the PETM part of the calcarenite bed at Dababiya (lower part of Bed 5 in the DBH, Berggren & Ouda, 2003a). Benthic foraminifera increase in diversity upward, but still very rare as regards to number of individuals.

In section NC' the calcarenite spans the interval from NC' 1.1 m to NC' 0.8 m (Fig. 5). *Ac. sibaiyaensis*-bearing planktonic foraminiferal association is well represented where it includes very rare subbotinids, few benthic foraminifera and *M. acuta* as the main morozovellid.

In section NA, the calcarenite is interrupted by a thin, poorly unfossiliferous limestone horizon (samples NA 1.9 m and 2.0 m, Fig. 7). In this section *Ac. sibaiyaensis* occurs in a pelagic ooze containing rare benthic foraminifera and no subbotinids in samples 1.8 m and 2.1 m.

All these bioevents show the same foraminiferal pattern of both planktonic and benthic foraminifera in the PETM calcarenite bed (lower part of Bed 5 of the Dababiya quarry Member) in the Nile Valley (e.g. Dababiya: Berggren & Ouda, 2003a, Ouda *et al.,* 2013; Qreiya: Berggren & Ouda, 2003b). However, in section NK where the calcarenite attains its maximum thickness (~110 cm), the lower 30 cm of which (from sample NK 0.2 m to sample NK 0.5 m) contains few well developed *Ac. sibaiyaensis* together with *M. acuta* as the sole morozovellid. No subbotinids are ever recorded whereas benthic foraminifera are entirely absent, an association which characterizes Bed 4 of the Dababiya Quarry Member in the Nile Valley. The calcarenite bed becomes flooded by planktonic foraminifera in samples NK 0.5 m to NK 1.0 m and contains well developed specimens of *Ac. sibaiyaensis* together with rare *Ac. africana* in a subbotinid-poor pelagic ooze rich in (sub)tropical morozovellids, and with rare benthic foraminifera. Benthic foraminifera show a noticeable increase in number of species and individuals in sample NK 1.0 m, whereas *Ac. sibaiyaensis* continues sporadically upwards until sample NK 1.2 m. Thus, it appears reasonable to correlate the calcarenite interval from NK 0.5 m to NK1.2 m with Bed 5a of the Dababiya Quarry Member of the Nile Valley.

Section NK3 mirrors section NK with regard to the calcarenite bed. However, the El Hanadi Member in both sections appears to have subjected to significant erosion of different rates before the deposition of the El Aguz Limestone leading to the absence of the upper (marly) part of Biozone P5 as compared to section NC (Figs 6 and 10).

3.2.3. An upper Limestone Subunit (corresponding to Biozone E2 of Berggren & Pearson, 2005)

The PFEF calcarenite subunit of the El Aguz Limestone is directly overlain (with no apparent stratigraphic break) by a limestone bed varying in fossil content from completely barren to commonly fossiliferous and ranging in thickness from 40 cm to 90 cm. In section NA this limestone spans the stratigraphic interval between samples NA 2.1 m and NA 2.9 m (Fig. 7). The lower 30 cm of this interval is unfossiliferous, then followed by 10 cm of commonly fossiliferous limestone (sample NA 2.5 m) with no PFEF, but with rare sporadic specimens of *Ps. wilcoxensis* together with abundant *Gl. luxorensis* and *Gl. chapmani* among an acarininids-rich, subbotinid-poor foraminiferal association, with rare sporadic benthic foraminifera. This is followed by 20 cm thick of unfossiliferous limestone, then 20 cm thick (samples NA 2.8 m and 2.9 m) highly fossiliferous limestone rich in subbotinids, acarininids and morozovellids in approximately equal ratios, but with very rare benthic foraminifera. The LCO of *Ps. wilcoxensis* is recorded at sample NA 2.9 m just below the base of the El Mahmiya Member where a pelagic ooze rich in subbotinids marks the change of the unfossiliferous limestone into shale. The alternation of fossiliferous horizons with unfossiliferous horizons within this limestone bed probably reflects alternating preservational basis due to post-depositional sea floor corrosion. The E1/E2 zonal boundary in this section lies somewhere between sample NA 2.1 m (HO of *Ac. sibaiyaensis*) and sample NA 2.3 m (LO of *Ps. wilcoxensis).* Correlation with other sections would suggest the placement of this boundary at sample NA 2.2 m.

In section NK3 and NK the post-PFEF limestone subunit which directly follows the calcarenite bed is 90 cm thick between samples 3.3 m-4.2 m in section NK3 (Fig. 6) and samples 1.3 m-2.2 m in section NK (Fig. 10). The lower 20 cm is devoid of fossils whereas the upper 70 cm are poorly fossiliferous. The LO of *Ps. wilcoxensis*, the distinctive zonal marker of Biozone E2, is recorded at samples NK3 3.5 m and NK 1.5 m. Subbotinids also retain their Paleocene abundance in the latter samples together with the lowest common occurrence of benthic forms.

In section NK2, The post-PFEF limestone spans the interval between sample 2.6 m and 3.2 m (Fig. 9). The lower 20 cm are commonly fossiliferous whereas the upper 40 cm are made up of alternations of poorly fossiliferous and unfossiliferous limestone beds (see above). The LO of *Ps. wilcoxensis* occurs at sample 2.8 m in association with a rich assemblage of *Gl. luxorensis* and *Gl. chapmani*, whereas its LCO is recorded at sample 3.2 m. The E1/E2 zonal boundary is consequently placed at sample 2.7 m between the HO of *Ac. sibaiyaensis* (sample 2.6 m) and the LO of *Ps. wilcoxensis* (sample 2.8).

In section NC' the post-PFEF limestone is also made up of alternation of poorly to unfossiliferous beds and highly fossiliferous pelagic ooze. It is composed of ~20 cm poorly fossiliferous limestone occupying the stratigraphic interval between samples -0.8 m and -0.6 m, then highly fossiliferous limestone between samples -0.6 m to NC' -0.4 m containing rare *Ps. wilcoxensis* with no PFEF (Fig. 5). This is followed upward by unfossiliferous limestone (between samples -0.4 m and 0.2 m), then a pelagic ooze from sample -0.2 m to top of section (sample 0.0) containing a normal association of subbotinids-acarininids-morozovellids, accompanied by rich *Gl. luxorensis*, rare *Ps. wilcoxensis* and common benthic foraminifera. The E1/E2 zonal boundary in this section is placed between the HO of *Ac. sibaiyaensis*

(sample NC' -0.8 m) and the LO of *Ps. wilcoxensis* (sample NC' -0.6 m).
In section NF the post PFEF limestone is poorly fossiliferous, with no PFEF. The LO of *Ps. wilcoxensis* occurs at sample 3.0 m and attains its LCO at its top (sample 3.2 m). *Ac sibaiyaensis,* on the other hand, has its HO at sample 2.8 m. Thus, the E1/E2 zonal boundary is placed at sample NF 2.9 m.

The sequential bioevents in the middle calcarenite and upper limestone subunits of the El Aguz Limestone

The sequential bioevents exhibited by the included foraminifera faunas in the calcarenite - limestone subunits of the El Aguz carbonate unit strongly supports its correlation with the higher levels of the Dababiya Quarry Member along the southern Nile Valley. The lower part of the calcarenite bed in sections NK and NK3 yields a subbotinid-poor planktonic foraminiferal assemblage with common PFEF (predominantly *Ac. sibaiyaensis*) whereas benthic foraminifera are almost entirely absent, thus being correlatable with the foraminiferal content of the lower calcareous phase (Bed 4) of the Dababiya Quarry Member at Dababiya, Nile Valley (Ouda & Berggren, 2003; Ouda *et al.,* 2013). The upper part of the calcarenite bed contains a pelagic ooze containing PFEF, and including the LO of benthic foraminifera, whereas subbotinids remain rare, thus being correlatable with the lower (PETM) part of Bed 5 (Bed 5a) of the Dababiya Quarry Member at Dababiya. The top of the calcarenite subunit is more or less coincident with the HO of *Ac. sibaiyaensis* and other planktonic foraminifera excursion fauna (e.g., *Ac. africana, M. allisonensis*). *Pseudohastigerina wilcoxensis*, on the other hand, makes its LO a short stratigraphic interval (~20 cm) above the HO of *Ac. sibaiyaensis.* Thus, the top of the calcarenite subunit appears more or less coincident with the top of the PETM interval in the DBH section (The GSSP of the P/E boundary, Berggren & Ouda, 2003a) at Dababiya and the E1/E2 zonal boundary should consequently be placed within the 20 cm interval between the calcarenite and the overlying limestone subunit in G. El Aguz.
The overlying limestone subunit is also marked by a significant increase in the content of subbotinids accompanied by a marked drop in the abundance of the morozovellids, thus being correlatable with the upper post-PETM part of Bed 5 of the Dababiya Quarry Member at Dababiya (=Bed 5b of Ouda *et al.,* 2013). The benthic foraminifera are generally low in both number of species and individuals throughout the calcarenite and the overlying limestone subunits. They do not resume their pre-PFEF frequency before the top of the El Aguz limestone where their LCOs are recorded at the base of the El Mahmiya Member, but remain impoverished as regards to diversity with respect to Paleocene faunas. The compositional pattern of planktonic foraminifera also regains its pre-PFEF relative generic ratios at the base of the El Mahmiya Member, but differs in being more enriched in *M. gracilis, Ac. angulosa, Ac. wilcoxensis, Ac. pseudotoplensis* and *Ig. broedermanni*.

The El Mahmiya Member (corresponding to Biozones E2 and E3 of Berggren & Pearson, 2005)

Section NA (from sample 2.9 m at base to sample 12.5 m at top) (Fig. 7)
Section NB (from sample 1.5 m at base to sample 56.5 m at top) (Fig. 12)
The El Aguz Limestone is directly overlain by ~55 m thick of the El Mahmiya Shale (Aubry *et al.,* 2007= Esna 2 of Dupuis *et al.,* 2003) which represents the middle part of the Esna Shale. The member is made up of a thick highly fossiliferous succession of shale, with numerous thin intercalations of calcarenite, particularly in the lower part. The basal part of this member at section NA (from sample 2.9 m to sample 3.4 m), is marked by the reappearance of two horizons of calcarenite (samples NA 2.9 m and 3.2-3.3 m) full of foraminifera (pelagic ooze) and separated from each other by poorly fossiliferous shales (NA 3.0 m and 3.1 m). The foraminiferal assemblage of the pelagic ooze reflects a normal intermediate condition, being enriched in subbotinids, acarininids and intermediate-subtropical morozovellids (both *M. subbotinae* and *M. velascoensis* Groups). The faunas include common *Ps. wilcoxensis* as well as common benthic foraminifera of which *Gaudryina laevigata* (acme appearance) and *Gavelinella rubignosa* are the most common forms. The composition of this pelagic ooze is similar to that recorded from marker beds Pk1 and Pk2 at the basal part of the El Mahmiya Member at Dababiya (Berggren & Ouda, 2003a).
The El Mahmiya Member continues upward in section NA (up to sample NA 12.5 m) as a highly fossiliferous shale very rich in acarininds (*Ac. wilcoxensis, Ac. soldadoensis, Ac. esnaensis, Ac. pseudotopilensis* and *Ac. angulosa)*, subbotinids *(S. velascoensis)* and morozovellids *(M. subbotina, M. velascoensis, M. gracilis, M. acuta, M. occlusa, M. aequa, M. apanthesma)* together with *Ig. broedermanni, Ps. wilcoxensis*. Immediately above sample NA 12.5 m an unconformity exists where the Thebes Limestone overlaps the Esna Shale, suggestive of intense tectonism at the mid part of Biozone E2 as exemplified in section NA. Thus, the section was completed at outcrop/section NB which lies slightly eastwards across the site of section NA and contains a continuous succession of the Esna Shale above the EL Aguz Limestone (Figs 3, 4f and 12).
The E2/E3 zonal boundary of Berggren & Pearson (2005 corresponding to the biochronozonal P5/P6a boundary of Berggren *et al.,* 1995) is placed at the level of the HO of *M. velascoensis* which lies in sample NB 22, 19.5-20 m above the base of Biozone E2 (Fig. 12). Biozone E3 is 35 m thick and marked by the LOs of *M. quetra* and *M. edgari,* the common occurrence of *M. gracilis* and *M. marginodentata,* the absence of several morozovellid

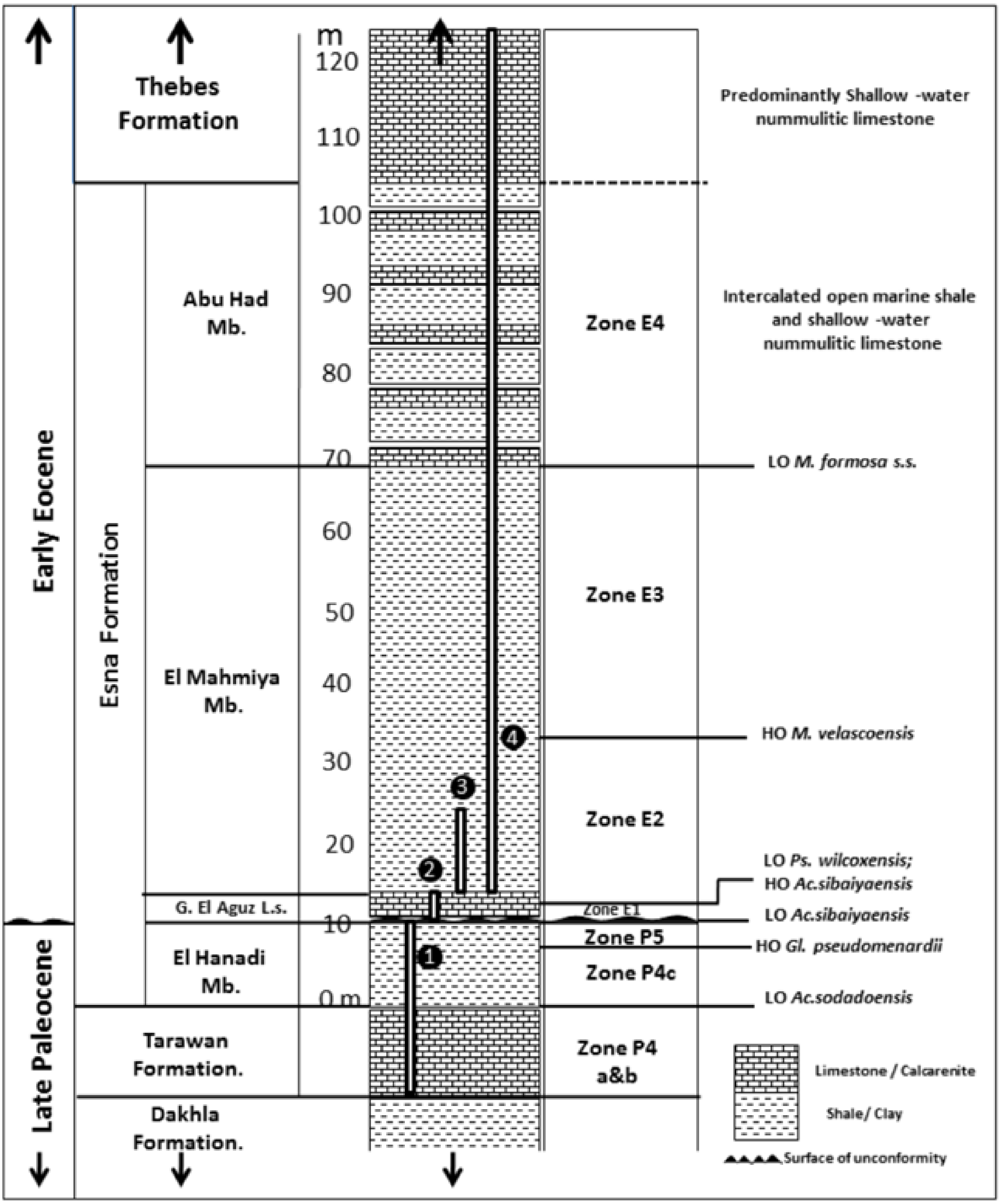


Fig. 12: Litho- and biostratigraphy of the upper Paleocene-lower Eocene succession of G. El Aguz, northeastern Kharga Oasis, Western Desert. Composite from sections NC (1), NK (2), NA (3) and NB (4). Total thickness of the El Mahmiya and Abu Had members of the Esna Shale is well represented in section NB. The Mahmiya Mb. starts in section NB at 1.5 m above the base of the El Aguz Limestone and ends at sample 56.5 m, while the Abu Had Mb. extends from sample 56.5 m up to sample 90 m (the base of the Thebes Formation).

species such as members of the *velascoensis* group (*M. acuta, M. occlusa, M. velascoensis)* and the common to abundant occurrence of *Ac. pseudotopilensis* and *Ac. wilcoxensis*. *Acarinina interposita* begins their LOs in sample NB 46 m.

The Abu Had Member (corresponding to Biozone E4 of Berggren & Pearson, 2005)

Section NB (from sample 56.5 m at base to sample 90.0 m at top) (Fig. 12)

The El Mahmiya shale begins to alternate with a thin horizon of limestone rich in *Nummulites* sp. and *Discocyclina* sp. (sample level NB 56.5 m), then exhibits a shallowing in facies, poorly fossiliferous (with benthic foraminifera only) and alternating with bands rich in *Nummulites* sp. and *Discocyclina* sp. from sample NB 58 m to sample NB 90 m with the exception of samples NB 57 m and NB 65 m which are pelagic oozes. On the basis of the divisions of the Esna Shale made up by Aubry *et al.* (2007), the lithologic boundary between the El Mahmiya and Abu Had members should be placed at sample NB 56.5 m where the first nummulitic limestone bed begins to intercalate the shale of the El Mahmiya Member. Thus, the total thickness of the Abu Had Member does not exceed 33.5 m.

Typical *M. formosa s.s* with 5.5 to 6.0 chambers in the last whorl among a rich *M. gracilis*-bearing planktonic association is encountered in sample NB 57 m just overlying the first nummulitic limestone bed, thus providing a good criterion to assign the Abu Had Member to Biozone E4 of Berggren & Pearson (2005) (= Subbiozone P6b of Berggren *et al.,* 1995). The greatest part of this member is poorly fossiliferous and contains only benthic foraminifera, both smaller and larger. The uppermost 10 m of this member (from sample NB 80 m to sample NB 90 m) is made up exclusively of unfossiliferous, shallow water clays.

The Abu Had Member (upper member of the Esna Shale) is overlain by a thick and massive limestone of predominantly shallow water facies, referred to as the Thebes Formation (Said, 1960). The Thebes Formation forms the top of the eastern escarpment where it varies considerably in thickness, from 35 m at Naqb Assiut in the north to 150 m at G. Ghaneemah in the south. It should be noted that the location of the lower boundary of this formation in southern Egypt is not clear partly because of the obvious disparity that exists in the opinion of authors with regards to its position, and partly because of the lateral facies changes. Consequently a number of formal and informal units have been used in recent years to describe different litho- and biofacies of the same rock unit. These names refer to equivalents of the Thebes Formation or to its subdivisions. The study of the Thebes Formation is beyond the scope of this work and until additional data become available we will retain the formational name of Thebes Formation as originally introduced by Said (1960) at the type locality of G. Gurnah (Luxor), despite the fact that this name has been elevated to group level by the authors of the geological map of Egypt to include all the facies variants in the Nile Valley, Quseir district, Gulf of Suez and Sinai.

4. SUMMARY AND CONCLUSION

297 samples representing seven Upper Paleocene-Lower Eocene sections at G. El Aguz, midway between Naqb Assist and G. Ghanayim along the eastern escarpment of Kharga oasis, have been critically investigated for their foraminiferal content. The P-E succession at this locality covers the stratigraphic interval from Biozone P4a+b to Biozone E4 of Berggren & Pearson (2005) and is lithologically represented by 5 rock units arranged from base to top: the upper part of the Tarawan Formation, the El Hanadi Member (lower part of the Esna Shale), the El Aguz Limestone Bed (here proposed), the El Mahmiya Member (middle part of the Esna shale) and the Abu Had Member (the upper part of the Esna Shale) (Fig. 12).

The upper part of the Tarawan Formation is belonging to Biozone P4. The P4a+b/P4c subzonal boundary cuts through the topmost part of the Tarawan, one meter below the base of the El Hanadi Member. The latter Member spans the greater most part of the stratigraphic interval of Subbiozone P4c and the entire Biozone P5 of Berggren & Pearson (2005). It is characterized by the evolution of the geographically broadly distributed morozovellids of the *M. quadrata - M. subbotinae - M. gracilis* lineage, the acme appearance of *Gl. chapmani* (the non-keeled morphotype of *Gl. pseudomenardii*), the radiation of acarininids including the sequential LOs of *Ac. angulosa*, *Ac. esnaensis* and *Ac. wilcoxensis s.s.* within a short stratigraphic interval in the upper part of Biozone P5, before/below the onset of the PETM, and the LO of *G. planoconica* at the uppermost levels of the same biozone, a case which is similarly encountered in the southern Nile Valley. It is also marked by the occurrence of mixed benthic foraminiferal elements of the so-called “Midway” fauna, typical of neritic type (down to 200 m) and “Velasco” fauna, typical of deep (upper bathyal) water depths. In some sections both types of benthic faunas alternate with each other, thus suggestive of fluctuation of water depth and/or facies changes around the neritic/bathyal interface. Correlation of characteristic planktonic foraminiferal datum planes between different sections of the El Hanadi Member are given in Fig. 13.

The Dababiya Quarry Member which conformably overlies the El Hanadi Member at Dababiya, southern Nile Valley and which yields a detail record of the geochemical and biotic changes induced by the PETM (Ouda & Aubry, 2003; Aubry *et al.,* 2007; Ouda *et al.*, 2013) is not completely represented in the oldest Eocene succession at G. El Aguz. The earliest Eocene clayey and phosphatic phases which characterize the stratigraphic interval of maximum negative shift of the CIE values

Fig. 13: Litho- and biostratigraphic correlation of the Paleocene-Eocene boundary interval in different sections of Gebel Aguz, Kharga Oasis. Not scaled horizontally. Datum plane is the Highest Occurrence (HO) of *Ac. sibaiyaensis* and the Lowest Occurrence (LO) of *Ps. wilcoxensis*.

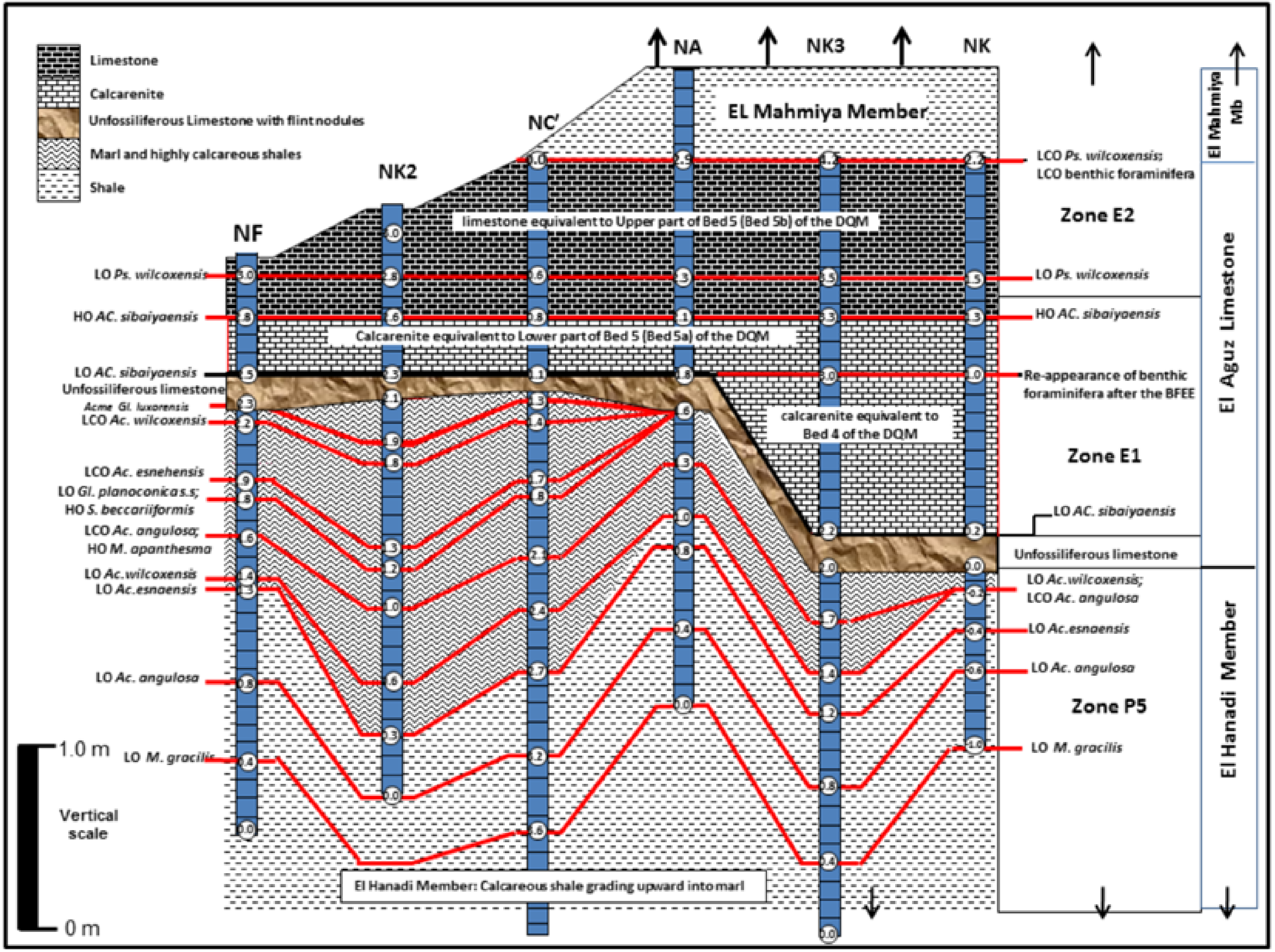
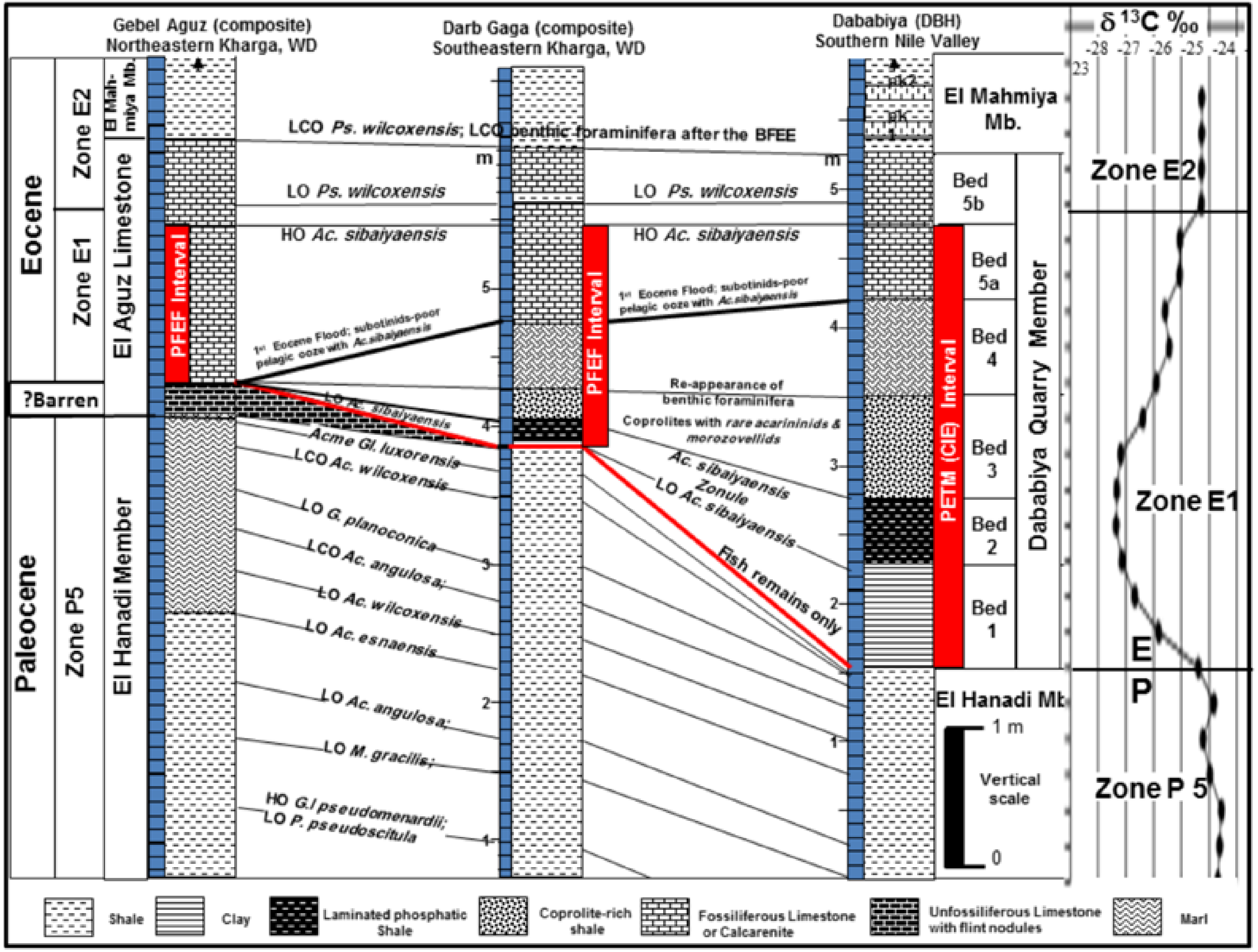


Fig. 14: Biostratigraphic correlation of the Upper Paleocene-Lower Eocene succession in Gebel El Aguz, northeastern Kharga Oasis, Darb Gaga, southeastern Kharga Oasis (Ouda *et al.*, 2016) and Dababiya (GSSP of the P/E boundary), southern Nile Valley (Dupuis *et al.*, 2003; Berggren & Ouda, 2003a; Aubry *et al.*, 2007; Ouda *et al.*, 2013). Not scaled horizontally.



(lower Biozone E1), corresponding to Beds 1, 2 and 3 of the Dababiya Quarry Member at Dababiya are missing at G. El Aguz. On the other hand, the younger calcareous phase which characterizes the interval of progressive increase in the CIE values (upper Biozone E1 and lower Biozone E2), corresponding to Beds 4 and 5 of the Dababiya Quarry Member could easily be distinguished at G. El Aguz as well as along the escarpment between Naqb Assiut and G. El Aguz as the earliest phase of the Eocene Tethyan flood during the younger phase of the PETM.

The earliest Eocene calcareous phase is represented at G. El Aguz by a prominent carbonate unit (defined here as El Aguz Limestone) covering unconformably the Upper Paleocene El Hanadi Member with a distinct erosional contact. The limestone reflects a vertical variation as regards to its depositional environment and faunal content. It starts with a hard, flinty, almost unfossiliferous limestone bed, 20 cm thick, representing a surface of unconformity or disconformity at the base of the Eocene. This is directly overlain by a detrital limestone of calcarenitic nature (with pelagic oozes including PFEF) varying in thickness from 0.3 m to 1.1 m.

The included planktonic foraminiferal association in the calcarenite is entirely belonging to Biozone E1. It is marked by the common appearance of well preserved specimens of *Ac. sibaiyaensis,* the general impoverishment or even absence of deep-dwelling fauna (subbotinids) and bottom-dwelling fauna (benthic foraminifera), the predominance of the (sub)tropical morozovellids, of which *M. velascoensis* and *M. acuta* are the most dominant. This foraminiferal pattern suggests warm conditions with a very low content in dissolved oxygen in the "intermediate" and deep waters. The association strongly supports its correlation with those of the calcareous transgressive phase of the Dababiya Quarry Member, corresponding to the lower (PETM) part of Bed 5 (Bed 5a as re-defined by Ouda *et al.,* 2013) at Dababiya. In some places the calcarenite subunit is exceptionally thick, (sections NK and NK3) and the frequency of fauna increases upward into unprecedental flood of planktonic foraminifera, thus being correlatable with those of Bed 4 and Bed 5a of the Dababiya Quarry Member of the Nile Valley (Fig. 13).

The calcarenitic limestone passes conformably upward into a poorly to unfossiliferous limestone (40-90 cm thick) which is devoid of glauconite or PFEF and marked by a significant increase in the content of subbotinids accompanied by a drop in the abundance of the morozovellids. The LO of *Ps. wilcoxensis* is recorded in this limestone, thus being comparable with the upper (post-PETM) part of Bed 5 (re-defined as Bed 5b by Ouda *et al.,* 2013) of the Dababiya Quarry Member at Dababiya, corresponding to the lower part of Biozone E2 (Fig. 14). The Eocene benthic foraminifera as well as *Ps. wilcoxensis* become not common before the upper limit of the El Aguz limestone (the lower limit of the overlying El Mahmiya Member), thus mirroring the Dababiya Quarry/Mahmiya formational boundary at Dababiya (Ouda & Berggren, 2003; Ouda *et al.,* 2013).

It is, thus, apparent that the calcarenite subunit of El Aguz Limestone represents the successive floods of Tethyan

Plate I

(In all figures scale bar = 100 µm)

Figs 1-4: *Globanomalina chapmani* (Parr, 1938).
1. Umbilical view, sample 0.5 m, section NC, G. El Aguz.
2. Dorsal view, sample 0.5 m, section NC, G. El Aguz.
3. Dorsal view, sample 4.0 m, section NC, G. El Aguz.
4. Umbilical view, sample 4.0 m, section NC, G. El Aguz.

Figs 5-6: *Globanomalina chapmani* (Parr, 1938) = *Globanomalina troelseni* (Loeblich & Tappan, 1957)
5. Umbilical view, sample 11.2 m, section NC, G. El Aguz.
6. Dorsal view, sample 11.2 m, section NC, G. El Aguz.

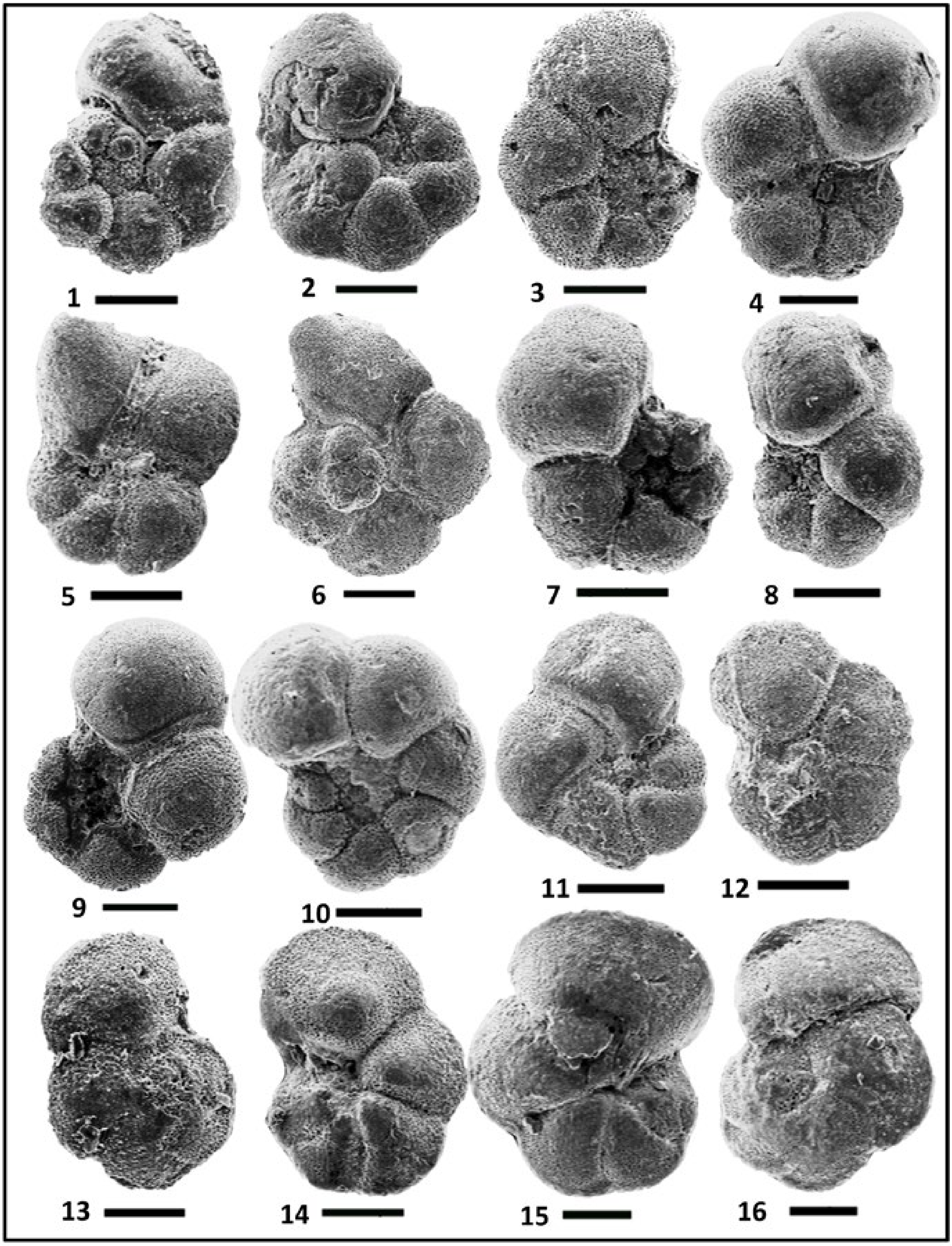
Figs 7-9: *Globanomalina luxorensis* (Nakkady, 1950).
7. Dorsal view sample 2.5 m, section NC, G. El Aguz.
8. Umbilical view, sample 2.5 m, section NC, G. El Aguz.
9. Umbilical view, sample 4.0 m, section NC, G. El Aguz.

Fig. 10: *Pseudohastigerina wilcoxensis* (Cushman & Ponron, 1932).
Side view, sample 2.9 m, section NA, G. El Aguz

Figs 11-12: *Globanomalina planoconica* (Subbotina, 1953).
11. Umbilical view, sample 11.2 m, section NC, G. El Aguz.
12. Dorsal view, sample 11.2 m, section NC, G. El Aguz.

Figs 13-16: *Globanomalina pseudomenardii* (Bolli, 1957).
13. Dorsal view, sample 0.5 m, section NC, G. El Aguz.
14. Umbilical view, sample 0.5 m, section NC, G. El Aguz.
15. Umbilical view, sample 2.5 m, section NC, G. El Aguz.
16. Dorsal view, sample 3.0 m, section NC, G. El Aguz.

Plate I



waters of different intensities which have transgressed the southern Tethys platform during the younger phase of the PETM (Dupuis *et al.,* 2003; Aubry *et al.,* 2007). This has led to the deposition of widespread bioclastic carbonate sediments of continuously increased faunal densities in Egypt (corresponding to Bed 4 and/or Bed 5 of the Dababiya Quarry Member at Dababiya, southern Nile Valley (Berggren & Ouda, 2003a). This transgression which followed the maximum warming during the subsequent decrease in temperature was accompanied by a regional subsidence in basinal areas, thus leading to the deposition of calcarenite either conformably or unconformably over older rocks (El Hanadi Member or older beds of the Dababiya Quarry Member). Similar erosive contacts at the base of the Eocene (corresponding to Bed 5 of the Dababiya Quarry Member) have been recorded in the Red Sea Coast (Speijer *et al.,* 2000; Bolle *et al.,* 2000) and the western central Sinai (Speijer *et al.,* 1997; Bolle *et al.,* 2000).

The El Aguz Limestone is directly overlain by 55 m thick of the El Mahmiya Shale which is made up of a thick highly fossiliferous succession of shale, with thin intercalations of calcarenites, particularly in the lower part. The lithological boundary between the El Aguz Limestone and the overlying Mahmiya Member is synchronous with the Dababiya Quarry/Mahmiya formational boundary at Dababiya as deduced from both lithology and faunal content. The planktonic foraminifera of the El Mahmiya Shale provide the recognition of Zones E2 and E3. The lithological boundary between the El Mahmiya and the overlying Abu Had members is placed at where the first nummulitic limestone bed begins to intercalate the shale of the El Mahmiya Member. Thus, the total thickness of the Abu Had Member does not exceed 33.5 m thick. The E3/E4 zonal boundary is placed just above the first nummulitic limestone bed, thus providing a good criterion to assign the Abu Had Member to Biozone E4 of Berggren & Pearson (2005). The greater upper part of this member is poorly fossiliferous and containing only benthic foraminifera, both smaller and larger (particularly *Nummulites* and *Discocyclina)*, thus exhibiting a shallow warm water environment. The uppermost 10 m of this member is made up exclusively of unfossiliferous, shallow water clays.

Litho- and biostratigraphic correlation of the Paleocene-Eocene boundary interval at G. El Aguz (composite section) with those of the DBH section at Dababiya, Nile Valley (the GSSP of the P/E boundary, Dupuis *et al.,* 2003; Berggren & Ouda, 2003a; Aubry *et al.,* 2007) and the Darb Gaga (composite) section, southeastern Kharga Oasis (Ouda *et al.,* 2016) has revealed that the P/E boundary changes from conformable relationship in the southern Nile Valley and southern Kharga Oasis to unconformable relationship in the northern Kharga Oasis (Fig. 14). This would suggest that the eastern escarpment of the Kharga Oasis was progressively upraised from south to north during the maximum warming of the PETM (corresponding to the lower part of Biozone E1) before it became subsided and transgressed by the Tethyan water masses of progressively decreasing temperature and gradual increasing in content of dissolved oxygen from the water surface downward (corresponding to the upper part of Biozone E1). This has led to the partial erosion of the topmost part of the Paleocene sequence of G. El Aguz at different rates (uppermost part of the El Hanadi Member corresponding to the upper part of Biozone P5) and the non-deposition/erosion of the lowermost part of the Eocene sequence (lower part of the Dababiya Quarry Member including at least Beds 1, 2 and 3 (corresponding to the lower part of Biozone E1).

Plate II

(In all figures scale bar = 100 μm)

Figs 1-2: *Morozovella angulata (*White, 1928).
1. Umbilical view, sample 0.5 m, section NC, G. El Aguz.
2. Dorsal view, sample 0.5 m, section NC, G. El Aguz.

Figs 3, 6: *Morozovella occlusa* (Loeblich & Tappan, 1957).
3. Dorsal view, sample 2.5 m, section NC, G. El Aguz.
6. Umbilical view, sample 2.5 m, section NC, G. El Aguz.

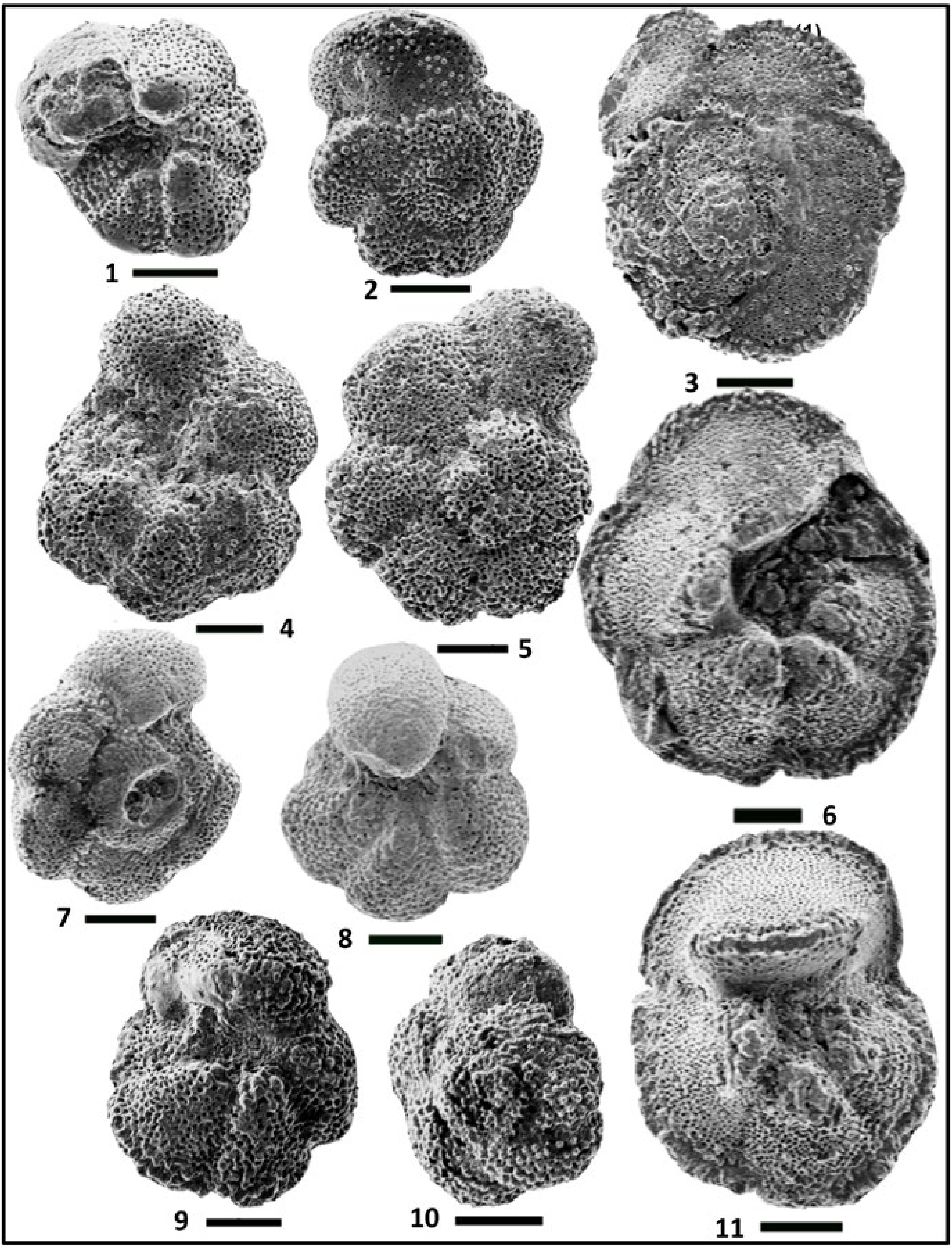
Figs 4-5: *Morozovella apanthesma* (Loeblich & Tappan, 1957).
5. Umbilical view, sample 4.0 m, section NC, G. El Aguz.
6. Dorsal view, sample 4.0 m, section NC, G. El Aguz.

Figs 7-8: *Morozovella conicotruncata* (Subbotina, 1947).
7. Dorsal view, sample 2.5 m, section NC, G. El Aguz.
8. Umbilical view, sample 2.5 m, section NC, G. El Aguz.

Figs 9-10: *Morozovella gracilis* (Bolli, 1957).
9. Umbilical view, sample 4.0 m, section NC, G. El Aguz.
10. Dorsal view, sample 4.0 m, section NC, G. El Aguz

Fig. 11: *Morzovella acuta* (Toulmin, 1941).
Umbilical view, sample 0.5 m, section NC, G. El Aguz.

Plate II



Opposite to G. El Aguz, at Um Dabadib along the western escarpment of Kharga Oasis and westward towards Dakhla Oasis (Fig. 2), the Upper Paleocene El Hanadi Member becomes entirely missing together with the overlying Lower Eocene El Aguz Limestone, El Mahmiya Member, Abu Had Member, and Thebes Formation, thus indicating a much longer (both stratigraphically and geographically) uplift during the upper Paleocene-Lower Eocene west of the Kharga Oasis.

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Plate III

(In all figures scale bar = 100 µm)

Figs 1-2: *Morozovella velascoensis* (Cushman, 1925).
1. Umbilical view, sample 2.5 m, section NC, G. El Aguz.
2. Dorsal view, sample 2.5 m, section NC, G. El Aguz.

Figs 3-4: *Morozovella parva* (Rey, 1955).
3. Dorsal view, sample 3.0 m, section NC, G. El Aguz.
4. Umbilical view, sample 3.0 m, section NC, G. El Aguz.

Figs 5: *Morozovella pasionensis* (Bermudez, 1961).
Dorsal view, sample 0.5 m, section NC, G. El Aguz.

Figs 6, 9: *Morozovella aequa* (Cushman & Renz, 1942).
6. Umbilical view, sample 2.5 m, section NC, G. El Aguz.
9. Dorsal view, sample 2.5 m, section NC, G. El Aguz.

Figs 7-8: *Morozovella subbotinae* (Morozova, 1939).
7. Umbilical view, sample 4.0 m section NC, G. El Aguz.
8. Dorsal view, sample 4.0 m, section NC, G. El Aguz.

Plate III

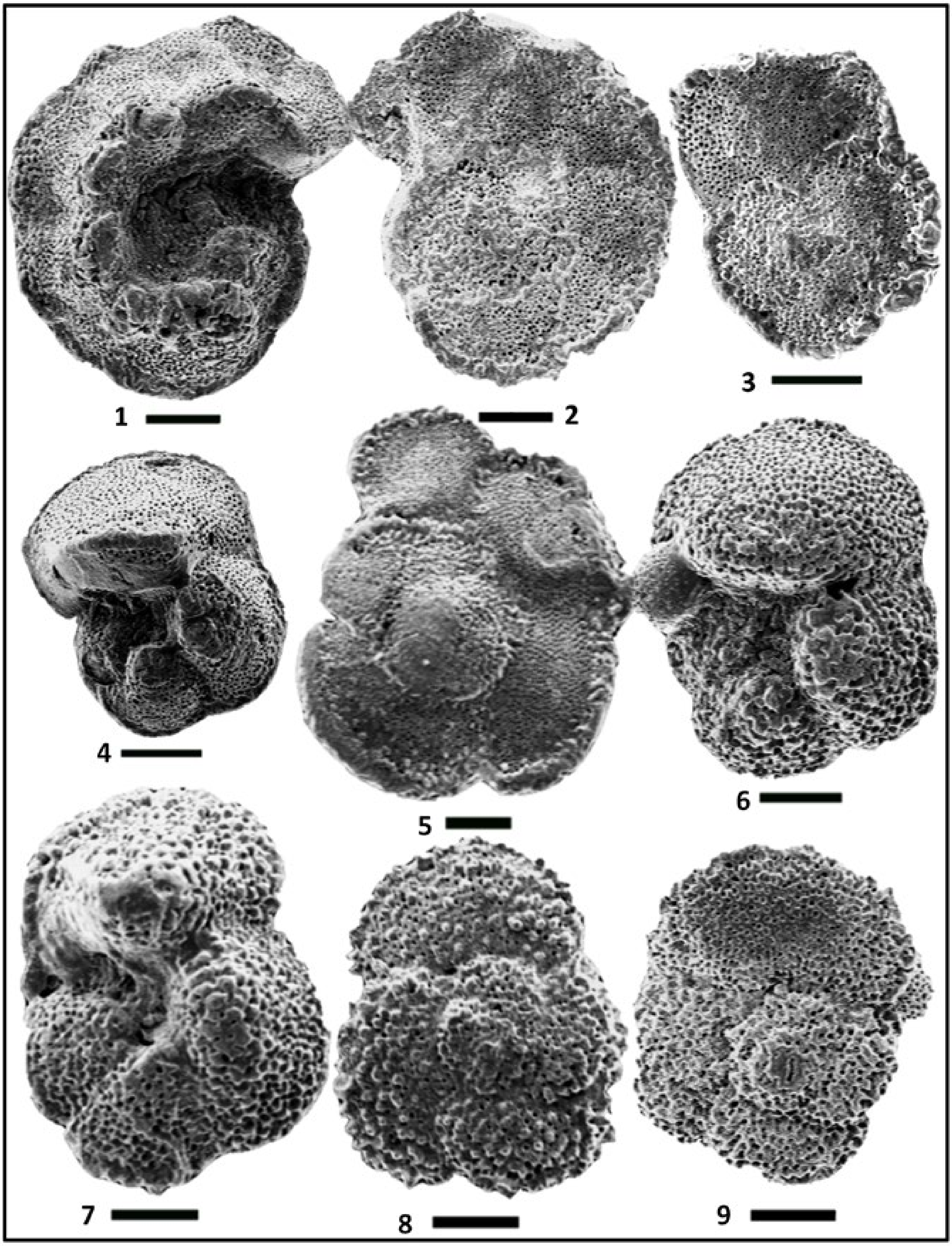

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Plate IV

(In all figures scale bar = 100 µm)

Figs 1-2: *Acarinina soldadoensis* (Brönnimann, 1952).
1. Dorsal view, sample 0.5 m, section NC, G. El Aguz.
2. Umbilical view, sample 0.5 m, section NC, G. El Aguz.

Fig. 3: *Acarinina esnaensis* (Le Roy, 1953).
Umbilical view, sample 0.5 m, section NC, G. El Aguz.

Figs 4-5: *Acarinina mckanni* (White, 1928).
4. Umbilical view, sample 0.5 m, section NC, G. El Aguz.
5. Dorsal view, sample 0.5 m, section NC, G. El Aguz.

6-7: *Subbotina triloculinoides* (Plummer, 1926).
6. Umbilical view, sample 3.0 m, section NC, G. El Aguz.
7. Dorsal view, sample 3.0 m, section NC, G. El Aguz.

Figs 8-9: *Subbotina triangularis* (White, 1928).
8. Dorsal view, sample 2.5 m, section NC, G. El Aguz.
9. Umbilical view, sample 2.5 m, section NC, G. El Aguz

Plate IV

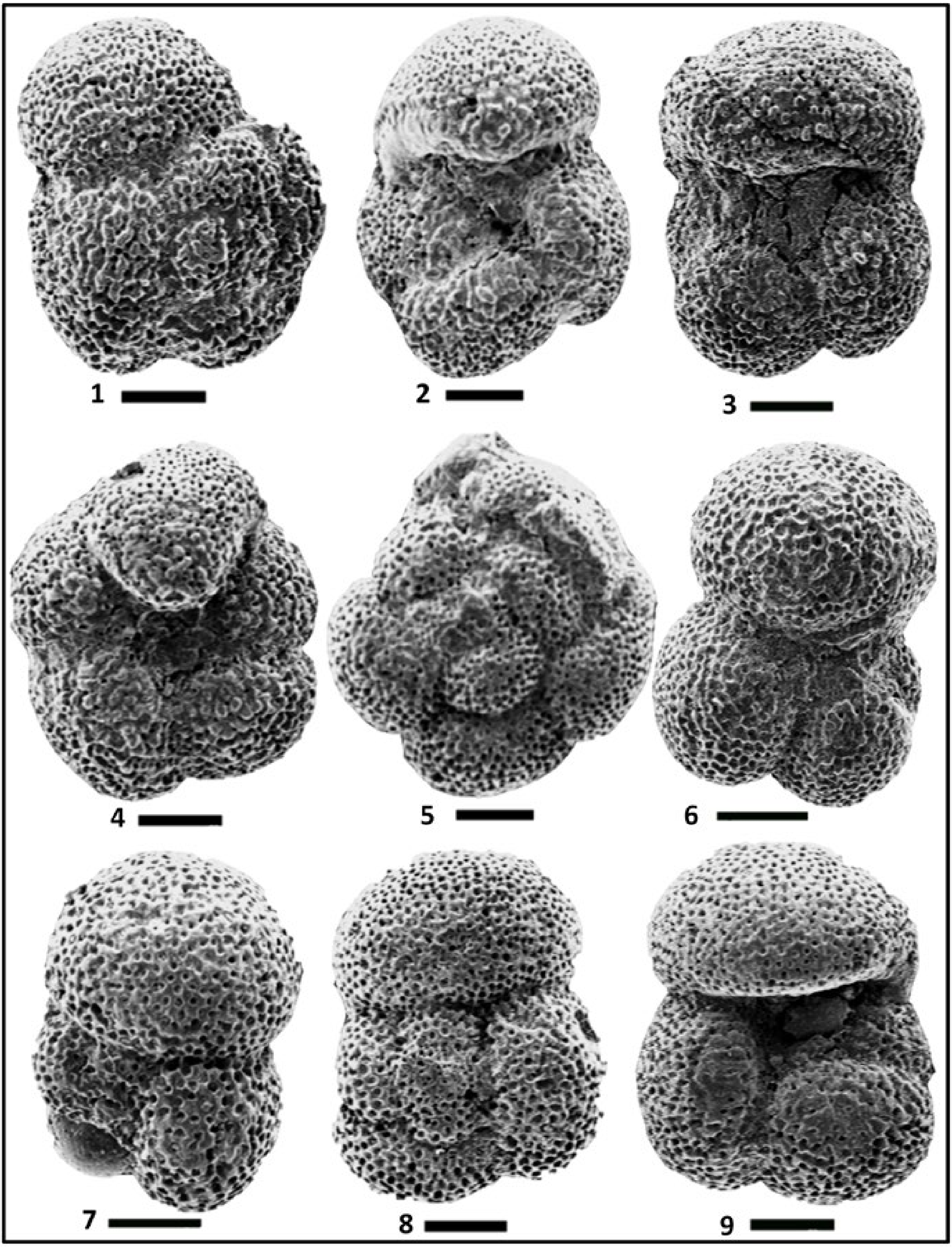

Plate V

(In all figures scale bar = 100 µm)

Figs 1-2: *Subbotina velascoensis* (Cushman, 1926).
1. Umbilical view, sample 3.0 m, section NC, G. El Aguz.
2. Dorsal view, sample 3.0 m, section NC, G. El Aguz

Figs 3-9: *Acarinina sibaiyaensis* (El Naggar, 1966).
3. Umbilical view, sample 1.8 m, section NA , G. El Aguz.
4. Umbilical view, sample 11.5 m, section NC, G. El Aguz.
5. Dorsal view, sample 11.5 m, section NC, G. El Aguz
6. Dorsal view, sample 11.5 m, section NC, G. El Aguz
7. Umbilical view, sample 1.8 m, section NA, G. El Aguz
8. Side view, sample 1.8 m, section NA, G. El Aguz
9. Dorsal view, sample 1.8 m, section NA, G. El Aguz

Plate V