Planktonic Foraminiferal Biostratigraphy of the Campanian-Maastrichtian Sudr Formation at Esh El-Mellaha Area, North Eastern Desert, Egypt

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Abstract: Three upper Campanian-upper Maastrichtian exposures on the western flank of Esh El-Mellaha range, north Eastern Desert, Egypt from north to south: Wadi Dib, Wadi Abu Had, and Bir Mellaha sections are studied. This interval is represented by the Sudr Formation which is classified into Markha and Abu Zeneima members from base to top. This rock unit is found very rich in planktonic foraminiferal assemblages. Fifty seven planktonic foraminiferal species belonging to seventeen genera, six subfamilies, five families, four superfamilies and one suborder are recorded and most of them are belonging to family "Globotruncanidae” where it includes eleven genera and thirty eight species. So, the phylogenetic development of the recorded species and genera from this important family is discussed. Eleven planktonic foraminiferal biozones are distinguished in the studied sequence; one of late early Campanian to late Campanian age (Globotruncanenta ventricosa Zone); two of late Campanian age (Globotruncanella havanensis (=CF9) and Globotruncanca aegyptica (CF8a) zones); four of early Maastrichtian age (Rugoglobigerina hexacamerata (CF8b), Gansserina gansseri (CF7), Contusotruncanca contusa (CF6), Pseudotextularia intermedia (CF5) zones); and for the first time four of late Maastrichtian age (Racemiguembelina fructicosa (CF4), Pseudoguembelina hariaensis (CF3), Pseudoguembelina palpebera (CF2), and Plummerita hantkeninoides (CF1) zones). The Campanian/Maastrichtian boundary is located within the lower part of the Abu Zeneima Member between (CF8a) and (CF8b) zones, while the early /late Maastrichtian boundary is located within the upper part of the Abu Zeneima Member between (CF5) and (CF4) zones. Two unconformity surfaces are recorded within the Sudr Formation. The first one is recorded at the three studied sections and it lies between the Markha and Abu Zeneima Members due to absence of the late Campanian Globotruncanca calcarea Zone; while the second unconformity surface is recorded at both Wadi Abu Had and Wadi Dib sections only and it lies within the uppermost part of Abu Zeneima Member due to absence of the last two latest Maastrichtian CF2 and CF1 zones.


Key words: planktonic foraminifera, Sudr Formation, systematic, phylogeny, biostratigraphy, upper Campanian, upper Maastrichtian, Esh El-Mellaha.

1. Introduction

Esh El-Mellaha range is located at the southwestern part of the Gulf of Suez, between latitudes 27°24’ N and 27°49’ N and longitudes 33°11’ E and 33°40’ E., north Eastern Desert, Egypt (Fig.1.A). Esh El-Mellaha range is composed of igneous and metamorphic rocks covered by Miocene rock patches on its eastern flank, while, it is covered by Upper Cretaceous-Eocene rocks on its western flank. In this area, the Sudr Formation was measured in three sections. These are from north to south: Wadi Dib (latitude 27° 48’ 40’ N and longitude 33° 13’ 05’ E), Wadi Abu Had (latitude 27° 39’ 37’ N and longitude 33° 21’ 45’ E), and Bir Mellaha (latitude 27° 34’ 51’ N and longitude 33° 25’ 56’ E.), (Fig.1B).

Few previous studies dealing with the Upper Cretaceous planktonic foraminiferal paleontology and biostratigraphic classification at Esh El-Mellaha area were carried out. The most important of these are Abdallah et al., 1984, Prat et al., 1986, Aref et al., 1988, Aref and Ramadan, 1990, and Cherif and Ismail, 1991. The upper Campanian—upper Maastrichtian interval in the present study area is represented by the Sudr Formation which primarily has been introduced as Sudr Chalk by Ghorab, 1961 to describe a sequence exposed at Wadi Sudr, west central Sinai. It consists of 100-130m thick of snow white chalk, partly changing to marl or argillaceous limestones containing sometimes chert bands or nodules. The name Sudr Chalk was emended by Tewfik and Ebeid, 1972 to Sudr Formation. Ghorab, 1961 subdivided this formation into a lower Markha Member of Campanian age and an upper Abu Zeneima Member of Maastrichtian age. The Sudr Formation in the study area is subdivided into two members; Markha Member at base and Abu Zeneima at top.
The Markha Member is composed of argillaceous and fossiliferous limestone intercalated with banks of the large oyster *Pycnodonte vesicularis* (Lamarck). It attains about 12 m thick at Wadi Dib section, about 11.5 m thick at Wadi Abu Had section, and about 17 m thick at Bir Mellaha section. The Markha Member directly overlies the Duwi Formation and underlies the Abu Zeneima Member. It is assigned to the upper part of lower Campanian to upper Campanian ages.

The Abu Zeneima Member is composed of yellowish-white to pale grey soft argillaceous limestone and chalky limestone containing *Pecten farafrensis* (Zittel) in the lower part intercalated with thin fossiliferous shale band. It attains about 38 m thick a Wadi Dib section, about 22.5 m thick at Wadi Abu Had section, and about 49 m thick at Bir Mellaha.
section. It overlies the Markha Member with disconformity surface and also underlies with disconformity surface the Esna Formation at the three studied sections. It is assigned to the upper Campanian to uppermost Maastrichtian ages.

The main targets of the present work on the Upper Campanian-Upper Maastrichtian Sudr Formation at Esh El Mellaha area are: 1. Phylogenetic analysis of the recorded species and genera of the Family “Globotruncanidae”; 2. High resolution planktonic foraminiferal biostratigraphic classification of the studied interval; 3. Campanian/Maastrichtian and early/late Maastrichtian stage boundary analysis.

**Systematic and Phylogenetic Development**

Fifty seven planktonic foraminiferal species belonging to seventeen genera, six subfamilies, five families, four superfamilies and one suborder have been identified from the three studied sections. These identified planktonic foraminiferal species are photographed by Scanning Electron Microscope (SEM) in the laboratories of the Egyptian Mineral Resources Authority and are shown on Plates 1-4 and their vertical distribution is shown on Figs. 6-8.

Out of the identified fifty seven planktonic foraminiferal species, thirty eight species are belonging to the Family Globotruncanidae. Most of the zonal marker species of the studied interval are members of that family. So, the phylogenetic development of theses genera and species is discussed here (Figs. 2-4). The recorded genera are Hedbergella, Contusotruncanana, Gansserina, Globotruncanana, Globotruncananita, Globotruncanella, Abathomphalus, Archaeoglobigerina, Rugotruncanana, Rugoglobigerina, and Plummerita. The following is the description of the evolutionary lineages of these genera and their included species at the present study:

1- **Genus Hedbergella Bronnimann and Brown 1958**

- 1826 Globigerina d’Orbigny, p. 277; Masters, 1977, p. 446.
- 1955 Hedbergina Bronnimann and Brown, p. 529.
- 1958 Hedbergella Bronnimann and Brown: p. 16, pl. 495, figs. 7-15; 1984 Robaszynski et al., p. 260; 1985 Caron, p. 57.
- 1959 Praeglobotruncanana (Hedbergella) Banner and Blow: p. 18.

**Type species**: Anomalina lorneiana d’Orbigny, var. trochoidea Gandolfi, 1942, p. 98.

This Cretaceous genus is marked by its trochospiral biconvex test with open umbilicus, lobate rounded periphery and lack of keel or pore less margin. A detailed synonymy of this genus is discussed by Masters, 1977.

The genus Hedbergella was considered as the ancestor of all genera of the Family Globotruncanidae (Caron, 1985), where, it is the oldest and most primitive genus of this family (Figs. 2-4). In the present study, genus Hedbergella is represented only by Hedbergella holmdelensis Olsson, 1964 which is marked by its more robust, larger test size, compact arrangement of its sub-globular chambers and exceptionally sparse and small perforations.

2- **Genus Contusotruncanana Korchagin, 1982**

- 1927c Globotruncan Cushman, p. 81. 1941.

**Type species**: Pulvinulina arca var. contusa Cushman, p. 23.

- 1984 Rosita Robaszynski, Caron, Gonzales-Donoso and Wonders, p. 244, pl. 35; 1985 Caron, p. 67. **Type species**: Rosita fornicata (Plummer, 1931).

The genus Contusotruncanana is marked by its moderate to high spiral side of the test, last chambers have a characteristic undulating surface and narrow double keels.

This genus was initiated from Marginotruncanana sinuosa Porthault, 1970 by giving Contusotruncanana fornicata (Plummer, 1931) in the Santonian time (Robaszynski et al., 1984) through gradual increase in the spire height, size of chambers and placation of chamber surfaces. In the present study, this genus is represented by four species representing an evolutionary line including Contusotruncanana fornicata (Plummer, 1931), C. patelliformis (Gandolfi, 1955), C. contusa (Cushman, 1926), and C. plicata (White, 1928) (Fig. 4).

**Contusotruncanana fornicata** (Plummer, 1931) is marked by low trochospiral test with slightly undulating surface of the last chamber and strong double keels.

**Contusotruncanana patelliformis** (Gandolfi, 1955) is marked by moderately to fairly high trochospire intermediate between Contusotruncanana fornicata (Plummer, 1931) and Contusotruncanana contusa (Cushman, 1926) leading to an asymmetrical profile with a flat to concave umbilical side.

**Contusotruncanana contusa** (Cushman, 1926) is marked by its highly trochospiral test, two narrow keels, and deep umbilicus.

**Contusotruncanana plicata** (White, 1928) is marked by its larger test with less globular chambers and depressed sutures without well-developed sutureal ridges on the spiral side.

3- **Genus Gansserina Caron, Gonzales Donoso, Robaszynski and Wonders, 1984**

- 1927c Globotruncan Cushman, p. 81.
1984 *Gansserina* Caron, Gonzales Donoso, Robaszynski and Wonders, p. 292, pl. 51, figs. 1-7; 1985 Caron, p. 45.

**Type species:** *Globotruncana gansseri* Bolli, 1951, p. 196.

The genus *Gansserina* is marked by its flat spiral side, convex umbilical side, a distinct peripheral keel running along the edge of the spiral side and rugosities on the umbilical keel.

This genus was derived from genus *Archaeoglobigerina* Pessagno, 1967 through the development of a single keel and coarse rugosities (Robaszynski et al., 1984, and Caron, 1985). The evolution in this genus shows the transition from forms with two keels to single keeled forms. In the present study, this genus is represented by two species: *Gansserina wiedenmayeri* (Gandolfi, 1955) and *Gansserina gansseri* (Bolli, 1951) (Fig. 2).

*Gansserina wiedenmayeri* (Gandolfi, 1955) is marked by a flatter chamber surface on the spiral side, a more pustules surface on the umbilical side, and lacking an umbilical ridges and it is considered an intermediate form between single and double keeled forms where it has two keels at least on the first chamber of the last whorl.

*Gansserina gansseri* (Bolli, 1951) is marked by having a plano-convex test with single keel, strongly convex on the umbilical side, chambers hemispherical in shape in the lateral view.

4- Genus *Globotruncana* Cushman, 1927

1927 *Globotruncana* Cushman: p. 81, pl. 504, figs. 1-10 & pl. 505, figs. 1-5; 1984 Robaszynski et al., p. 176, pl. 1; 1985 Caron, p. 50.


1982 Truncomarginata Korchagin: p. 117.


**Type species:** *Pulvinulina arca* Cushman, 1926, p. 23.

The genus *Globotruncana* is marked by trochospiral test; chambers profile often truncated, with two keels separated by imperforate peripheral band; and periphery subcircular to strongly lobate.

This genus was derived from genus *Marginotruncana* Hofker, 1956 by changing the primary aperture from extraumbilical protected by portici to become umbilical protected by tegilla (Robaszynski et al., 1984). In the present study, it is represented by ten species: *Globotruncana linneiana* (d’ Orbigny, 1839), *G. bulloides* Voglar, 1941, *G. ventricosa* White, 1928, *G. rosetta* (Carsey, 1926), *G. aegyptiaca* Nakkady, 1950, *G. arca* (Cushman, 1926), *G. rugosa* (Marie, 1941), *G. orientalis* El Naggar, 1966, *G. falsostuarti* Sigal, 1952, and *G. esnehensis* Nakkady, 1950 (Fig. 3).

*Globotruncana linneiana* (d’ Orbigny, 1839) is marked by its box-like test shape with two well raised and widely spaced keels on all chambers. it is considered the central form of this genus and derived from *Marginotruncana pseudolineiana* Pessagno, 1967 by migration of the extra umbilical primary aperture towards umbilical position and replacement of the portici by tegilla.

*Globotruncana bulloides* Voglar, 1941 is marked by its pronounced inflation of chambers on both the spiral and umbilical sides. It is evolved from *Globotruncana linneiana* (d’ Orbigny, 1839) by changing the shape of chambers from the subtrapezoidal flat to slightly convex to become trapezoidal and inflated.

*Globotruncana ventricosa* White, 1928 is marked by its trapezoidal chambers in the last whorl; very low trochospiral; two keels, equally developed and parallel. It is evolved from *Globotruncana mariei* Banner and Blow, 1960 by acquiring a symmetrical profile with the umbilical side more convex than the spiral side, reduction of two keels to one keel in the last chambers, and an increase in size.

*Globotruncana aegyptiaca* Nakkady, 1950 is marked by its plano-convex, low trochospiral test; rectangular chambers in last whorl and truncated by two closely spaced keels. It is evolved from *Globotruncana mariei* Banner and Blow, 1960 by developing more globular chambers, a more asymmetrical profile, and a more rapid increase in chamber size.

*Globotruncana arca* (Cushman, 1926) is marked by its large biconvex test, truncate periphery with two widely spaced keels. It is derived from *Globotruncana linneiana* (d’ Orbigny, 1839) by a change in profile from rectangular to biconvex, and a change in position of the keel band to become oblique.

*Globotruncana rugosa* (Marie, 1941), is marked by its convex chamber surface with pustules on the chambers on both sides, and pronounced keels. It is evolved from *Globotruncana arca* (Cushman, 1926) by changing the chamber surface to become convex, the presence of pustules on the chambers to become on both sides of the initial whorls, and the two keels on all chambers to become pronounced keels.

*Globotruncana orientalis* El Naggar, 1966 is marked by its two keels at least on the first chambers of the last whorls. It is also evolved from *Globotruncana arca* (Cushman, 1926) by changing the two keels to become closer to each other but remaining parallel.
Fig. 4: Phylogeny and biostratigraphic range of the recorded species of Globotruncaninae, and Controtruncaninae genera at Fa. El-Melah area.
Globotruncana falsostuarti Sigal, 1952 is marked by presence of two keels on the earlier chambers and presence of tegilla covering the umbilical area. It is also evolved from Globotruncana arca (Cushman, 1926) by changing the two keels to become converging at the middle of chamber.

Globotruncana esnehensis Nakkady, 1950 is marked by its rectangular chambers in the last whorl, one peripheral keel on all chambers, and more curved sutures on the dorsal side. It is also evolved from Globotruncana arca (Cushman, 1926) by changing the umbilical keel on the last formed chambers to become reduced to absent.

5- Genus Globotruncana Reiss, 1957

1927c Globotruncana Cushman, p. 81.

1957 Globotruncana Reiss: p. 3, pl. 505, figs. 6-9; 1984 Robaszynski et al., p. 218, pl. 22.; 1985 Caron, p. 51.

Type species: Rosalina stuarti de Lapparent, 1918, p. 11.

The genus Globotruncana is marked by its trochospiral test, umbilical primary aperture protected by portici, and single keeled.

This genus was derived from Marginotruncana sigali Reichel, 1950, where the primary aperture became umbilical in its position, then the two keels in the first chambers of the last whorl soon disappeared resulting in atypical single keeled Globotruncana (Robaszynski et al., 1984). In the present study, this genus is represented by five species: Globotruncana stuartiformis (Dalbiez, 1955), Globotruncana stuarti (De Lapparent, 1918), Globotruncana subspinosa (Pessagno, 1960), Globotruncana conica (White, 1928), Globotruncana pettersi (Gandolfi, 1955) (Fig. 4).

Globotruncana stuartiformis (Dalbiez, 1955) is considered the central form of this genus and it is marked by its biconvex test, and having subtriangular chambers.

Globotruncana stuarti (De Lapparent, 1918) is marked by its biconvex test and regular trapezoidal shaped chambers. It is evolved from Globotruncana stuartiformis (Dalbiez, 1955) by changing the form of the chambers on the spiral side from subtriangular to trapezoidal to sub rectangular chambers.

Globotruncana subspinosa (Pessagno, 1960) is marked by its crescent-shaped chambers with posterior lobes on each chamber, and irregular outline of the umbilico-convex test. It is evolved from Globotruncana stuartiformis (Dalbiez, 1955) by changing its profile to has posterior lobes on each chamber and umbilico-convex test.

Globotruncana conica (White, 1928) is marked by its symmetrical spiro-convex test with a high spiral side and a more flat umbilical side. It is evolved from Globotruncana stuartiformis (Dalbiez, 1955) by changing the form of the chambers on the spiral side from subtriangular to trapezoidal to sub rectangular chambers.

Globotruncana pettersi (Gandolfi, 1955) is marked by its fewer chambers in the last whorl, absence of a central cone on the spiral side, and presence of ad umbilical ridges. It is evolved from Globotruncana stuartiformis (Dalbiez, 1955) by changing its profile to become has very low trochospiral test with trapezoidal chambers.

6- Genus: Globotruncanella Reiss, 1957

1927c Globotruncanella Cushman, p. 81.

1957 Globotruncanella Reiss: p. 136, pl. 508, figs. 8-10; 1984 Robaszynski et al., p. 264; 1985 Caron, p. 51.


The genus Globotruncanella is marked by its trochospiral test with flattened chambers and imperforate, angular periphery or passing gradually to one keel; exumbilical primary aperture protected by portici.

This genus was derived from genus Hedbergella Bronnmann and Brown 1958 by changing the primary aperture from extraumbilical –nearly peripheral protected by lips to become extraumbilical protected by portici with an imperforate peripheral band or even pustulose keel.

In the present study area this genus is represented by three species: Globotruncanella havanensis (Voorwijk, 1937), Globotruncanella petaloidae (Gandolfi, 1955), and Globotruncanella citae Bolli, 1951.

Globotruncanella havanensis (Voorwijk, 1937) is characterized by an imperforate margin instead of a true keel, and primary aperture protected by triangular porticus. It is evolved from Hedbergella holmdelensis Olsson, 1964 by its having umbilical system composed of portici with imperforate peripheral band.

Globotruncanella petaloidae (Gandolfi, 1955) is marked by the presence of 4 chambers in the last whorl which gives it petaloid aspect in equatorial view.. It is evolved from Hedbergella holmdelensis Olsson, 1964 by changing its profile to has umbilical system composed of portici with four petaloid chambers in the last whorl.

Globotruncanella citae Bolli, 1951 is marked by its compressed test in edge view with rudimentary peripheral keel. It is evolved from Globotruncanella havanensis (Voorwijk, 1937) by changing the rounded periphery to become angular provided with a row of pustules forming a single keel.

7- Genus: Abathomphalus Bolli, Loeblich and Tappan, 1957

1927c Abathomphalus Bolli, Caron, p. 51.
1957 Abathomphalus Bolli, Loeblich and Tappan: p. 43, pl. 509, figs. 1-9; 1984 Robaszynski et al., p. 270, pl. 45; 1985 Caron, p. 42.

Type species: Globotruncana mayaroensis, Bolli, 1951, p. 198.

The genus Abathomphalus is marked by its trochospiral test, umbilical –extraumbilical primary aperture protected by tegilla, periphery with two keels, and radial umbilical sutures.

This genus was evolved from genus Globotruncanella Reiss, 1957 by changing the rounded periphery or even pustulose keel to become double keel (Robaszynski et al., 1984 and Caron, 1985). In the present study, this genus is represented only by Abathomphalus mayaroensis (Bolli, 1951) which it is considered one of the more distinctive species among the Family Globotruncanidae and it is characterized by its double keel present on all chambers of the last whorl and they are composed of short, and radially oriented costellae. It is evolved from Globotruncanella citae Bolli, 1951 by a change angular periphery provided with a row of pustules forming a single keel to become a double keels.

8- Genus Archaeoglobigerina Pessagno, 1967

1927c Globotruncanella Cushman, p. 81.
1967 Archaeoglobigerina Pessagno: p. 315, pl. 510, figs. 1-10; 1984 Robaszynski et al., p. 275; 1985 Caron, p. 43.
1984 Kassabella El-Nakhal: p. 140.

Type species: Archaeoglobigerina blowi Pessagno, 1967.

The genus Archaeoglobigerina is marked by its trochospiral test, umbilical primary aperture protected by tegilla, presence of a wide imperforate peripheral band bordered by two faint keels on the globular early chambers of the last whorl.

This genus was derived from genus Whiteinella Pessagno, 1967 by changing the primary aperture from extraumbilical protected by portici to become umbilical protected by tegilla (Robaszynski et al., 1984, and Caron, 1985).

In the present study, this genus is represented only by Archaeoglobigerina blowi Pessagno, 1967 which is characterized by its lobulate outline, imperforate band which occurs mainly on the first one or two chambers of the last whorl and more rapidly increasing chambers in the last whorl (Fig. 2).

9- Genus Rugoglobigerina Bronnimann, 1952a

1955a Globotruncanella (Rugoglobigerina) Bronnimann- Gandolfi, p. 15.
1956 Kuglerina Bronnimann and Brown, p. 557.

Type species: Globigerina rugosa Plummer, 1927, p. 38.

The genus Rugoglobigerina is marked by its trochospiral test, umbilical primary aperture protected by tegilla, periphery with inflated rugose chambers, umbilical sutures depressed, radial with costellae arranged in meridional pattern, globulose periphery.

This genus was evolved from genus Archaeoglobigerina Pessagno, 1967 by accentuation of the ornamentation of the chamber surface leading to the costellae type arranged in ameridional pattern (Fig. 2). In the present study, it is represented by eight species: Rugoglobigerina rugosa (Plummer, 1926), Rugoglobigerina macrocephala Bronnimann, 1952, Rugoglobigerina hexacamerata Bronnimann, 1952, Rugoglobigerina scotti Bronnimann, 1952, Rugoglobigerina reicheli Bronnimann, 1952, Rugoglobigerina milamensis Smith and Pessagno, 1973, Rugoglobigerina pennyi Bronnimann, 1952, and Rugoglobigerina rotundata Bronnimann, 1952. The distinction between them is based on the number of chambers in the last whorl, the rate of increase of chamber size, the hight of the trochospire, and the diameter of the umbilicus.

Rugoglobigerina rugosa (Plummer, 1926) is characterized by the almost flat trochospire, the rapid increase in chamber size, 4-5 chambers in the last whorl, and the absence of spine.

Rugoglobigerina macrocephala Bronnimann, 1952 is marked by its 3-31/2, exceptionally 4 globular chambers in the last whorl which more rapid increase in their size and the last one forms about half the volume of the test with a surface covered by thick rugosities and costellae.

Rugoglobigerina hexacamerata Bronnimann, 1952 is characterized by its typical six chambers in the last whorl, a slow increase in chamber size, a low to flat trochospire and a low height/diameter ratio.

Rugoglobigerina scotti Bronnimann, 1952 is marked by its compressed profile of the last chamber.

Rugoglobigerina reicheli Bronnimann, 1952 is characterized by the presence of strong spines on the peripheral margin of the first chamber of the last whorl.

Rugoglobigerina milamensis Smith and Pessagno, 1973 is marked by high trochospiral test covered by thick closely-spaced costellae arranged in a meridional pattern.

Rugoglobigerina pennyi Bronnimann, 1952 is characterized by 5-6 chambers increasing slowly in their size and large umbilicus.

Rugoglobigerina rotundata Bronnimann, 1952 is marked by 41/2 – 6 globular chambers with a surface covered by pustules and rugosities.
10- Genus Plummerita Bronnimann, 1952b
1952a Rugoglobigerina (Plummerita) Bronnimann: p. 37, pl. 511, figs. 4-6.
1952b Rugoglobigerina (Plummerella) Bronnimann: p. 146.
Type species: Rugoglobigerina (Plummerella) hantkeninoides hantkeninoides Bronnimann, 1952.
The genus Plummerita is marked by having radially elongated chambers terminating in tubule spines in the last whorl.
This genus was derived from genus Rugoglobigerina Bronnimann, 1952a by changing the globular chambers to become radially elongated chambers terminating in tubule spines in the last whorl (Fig. 2).
In the present study, this genus is represented only by Plummerita hantkeninoides (Bonnimann, 1952) which is characterized by (5-6) inflated, triangular chambers; radial, depressed sutures, the chamber periphery rounded to compressed, some or all chambers bearing tubule spines.
11- Genus Rugotruncana Bronnimann and Brown, 1956
1927c Globotruncana Cushman, p. 81.
1956 Rugotruncana Bronnimann and Brown: p. 546, pl. 506, figs. 8-10; 1985 Caron, p. 76.
1959 Globotruncana (Rugotruncana) Banner and Blow: p. 11.
Type species: Rugotruncana tilevi Bronnimann and Brown, 1956.
The genus Rugotruncana is marked by its trochospiral test, globigeriniform early chambers, imperforate peripheral band and well developed double keel.
This genus was evolved from genus Rugoglobigerina Bronnimann, 1952a by flattening of its chambers and by development of a true double keel (Fig. 2). In the present study, this genus is represented by Rugotruncana subcircumnodifer (Gandolfi, 1955), and Rugotruncana subpennyi (Gandolfi, 1955).
Rugotruncana subcircumnodifer (Gandolfi, 1955) is characterized by its 4-5 chambers in the last whorl. Two keels on all chambers of the last whorl; and its surface covered by rugosity.
Rugotruncana subpennyi (Gandolfi, 1955) is characterized by its 6 chambers forming the last whorl, a flat spiral side and two more closely spaced keels, and often absent in the two final chambers.
Biostratigraphy
Many planktonic foraminiferal zonations schemes for the Campanian-Maastrichtian interval were established. For more accurate biostratigraphic resolution, the identified planktonic foraminiferal species in the three studied sections at Esh El-Mellaha area are used to distinguish eleven biozones based on zonal schemes of Caron, 1985, Li and Keller, 1998a, b and Li et al., 1999. The vertical ranges of these species are shown on Figs. 5-7. A comparison between the biozones established here and those proposed by different authors is shown on Table. 2. The following is a detailed description for these recorded planktonic foraminiferal biozones arranged from older to younger.
1. Globotruncana ventricosa Zone (Partial range zone) (late early Campanian to late Campanian)
This planktonic foraminiferal biozone was originally proposed by Dalbiez, 1955 from Tunisia. It is considered the oldest recorded zone in the present study. According to Caron, 1985, it is defined as a biostratigraphic interval extended from the first appearance of Globotruncana ventricosa White at the base to the first appearance of Globotruncanita calcarata (Cushman) at the top. In the study area, due to absence of Globotruncanita calcarata (Cushman), this zone is defined as a biostratigraphic interval extended from the first appearance of Globotruncana ventricosa White at base and followed by a sedimentary hiatus (Hiatus-1) where the Globotruncana ventricosa Zone is directly overlain by Globotruncanella havanensis Zone at the three studied sections. This zone attains about 9.5 m thick at Wadi Dib section, 12 m thick at Wadi Abu Had section, and about 14 m thick at Bir Mellaha section. It is assigned to the upper part of the early Campanian to the late Campanian. It is characterized by the presence of banks of large oyster Pycnodonte vesicularis (Lamarck). It is equivalent to the Globotruncana ventricosa Zone of Robaszynski et al., 1984 and Caron, 1985. In Egypt, this Zone may be equivalent to the Globotruncana ventricosa Zone of Khalil and Meshaly, 2004. The most important recorded planktonic foraminiferal species within this Zone at the three studied sections are shown on Figs. 5-7.
2. Globotruncanella havanensis Zone (=CF9) (Partial range zone) (Late Campanian)
This zone was originally proposed by Caron, 1978. In the present study, it is defined as a biostratigraphic interval extended from the first appearance of Globotruncanella havanensis (Voorwijk) at the base to the first appearance of Globotruncana aegyptiaca Nakady at the top. It attains about 5m thick at both Wadi Dib and Bir Mellaha sections, and about 2.5 m thick at Wadi Abu Had section. It is considered of late Campanian age (74.00- 72.48 Ma). as it is may be equivalent to Globotruncanella subcrinatus (CF9) Zone of Li and Keller, 1998a, b and Li et al., 1999. The base of this
biozone was used by some authors to mark the beginning of the Maastrichtian (e.g. Robaszynski et al., 1984 and Caron, 1985); while at the study, this biozone is belonged to the Late Campanian according to Li et al., 1999. It is equivalent to the G. lapparenti tricarinata Zone of Bolli, 1966; the G. havanensis Zone of Caron, 1985; the lower part of G. falsostuwarti Zone of Robaszynski et al., 1984, Al Mogi-Labin et al., 1986; the lower part of G. stuartiformis Zone of Postuma, 1971; the lower part G. tricarinata Zone of Boersma, 1984a, Barr, 1972, the lower part of G. havanensis Zone of Huber, 1990; the G. suberinatus Zone (CF9) of Li and Keller, 1998a, b and Li et al., 1999. In Egypt, this Zone may be equivalent to the lower part of G. havanensis Zone of El-Nady, 1995; Shahin & El Nady, 2001; the lower part of G. lapparenti tricarinata Zone of Beckmann et al., 1969; the lower part of G. falsostuwarti Zone of Hewaidy, 1987, Hewaidy et al., 1991; the G. tricarinata Zone of Shahin, 1988; Ayyad et al., 1996; the lower part of G. aegyptiaca Zone of Shahin, 1992; and the lower part of G. aegyptiaca-G. stuartiformis Zone of El-Dawy et al., 1992. The most important recorded planktonic foraminifer species within this Zone at the three studied sections are shown on Figs. 5-7.

3. Globotruncanana aegyptiaca Zone (CF8a) (Partial range zone) (Late Campanian)

The Globotruncanana aegyptiaca Zone was originally proposed by Caron, 1985, as interval extended from the first appearance of Globotruncanana aegyptiaca Nakkady at the base to the first appearance of Gansserina gansseri (Bolli) at the top. In the present study, the definition of Li et al., 1999 is followed to include a biostratigraphic interval extended from the first appearance of Globotruncanana aegyptiaca Nakkady at the base to the first appearance of Rugoglobigerina hexacamerata Bronnimann at the top. It attains about 4 m thick at Wadi Dib section, 2 m thick at Wadi Abu Had section, and about 3 m thick at Bir Mellaha section. It is assigned to the uppermost part of late Campanian age (72.48- 71.00 Ma according to Li et al., 1999). The base of this biozone was used by some authors to mark the beginning of the Maastrichtian (e.g. Robaszynski et al., 1984 and Caron, 1985); while at the present study, this biozone is attributed to the latest Campanian according to Li et al., 1999. and the Campanian/Maastrichtian boundary is placed on the top of this biozone. It is equivalent to the middle part of G. tricarinata Zone of Boersma, 1984; the middle part of G. havanensis Zone of Huber, 1990; the lower part of G. aegyptiaca Zone of Caron, 1985; to the lower part of G. aegyptiaca Zone (CF8) of Li and Keller, 1998a, b; to the upper part of G. falsostuwarti Zone of Robaszynski et al., 1984, Almogi-Labin et al., 1986. Also, it is equivalent to the G. aegyptiaca Subzone (CF8a) of Li et al., 1999. In Egypt, this biozone may be correlated with the middle part of G. lapparenti tricarinata Zone of Beckmann et al., 1969; the lower part of G. aegyptiaca Zone of Shahin, 1992, El-Nady, 1995, Shahin & El Nady, 2001, Ayyad et al., 1996; the middle part of G. falsostuwarti Zone of Hewaidy, 1987; the middle part of G. tricarinata Zone of Shahin, 1988; the middle part of G. aegyptiaca-G. stuartiformis Zone of El-Dawy et al., 1992. The most important recorded planktonic foraminifer species within this Zone at the three studied sections are shown on Figs. 5-7.

4. Rugoglobigerina hexacamerata Zone (CF8b) (Partial range zone) (early Maastrichtian)

This zone was proposed by Li et al., 1999. In the present study, it is defined as a biostratigraphic interval extended from the first appearance of Rugoglobigerina hexacamerata Bronnimann at the base to the first appearance of Gansserina gansseri (Bolli) at the top. It attains about 1.5 m thick at Wadi Dib section and about 2 m thick at both Wadi Abu Had, and Bir Mellaha sections. It is assigned to Early Maastrichtian age (71.00- 70.39 Ma according to Li et al., 1999). In the present study area, the base of this biozone is used to mark the Campanian-Maastrichtian boundary. It is equivalent to the upper part of G. lapparenti tricarinata Zone of Bolli, 1966; the upper part of G. tricarinata Zone of Boersma, 1984; the upper part of G. tricarinata Zone of Barr, 1972; the upper part of G. stuartiformis Zone of Postuma, 1971; the upper part of G. falsostuwarti Zone of Robaszynski et al., 1984, Almogi-Labin et al., 1986; the upper part of G. havanensis Zone of Huber, 1990; the upper part of G. aegyptiaca Zone of Robaszynski et al., 1984; and Caron, 1985; the upper part of G. aegyptiaca Zone (CF8) of Li and Keller, 1998a, b. Also, it is equivalent to the Rugoglobigerina hexacamerata Subzone (CF8b) of Li et al., 1999. In Egypt, this biozone may be correlated with the upper part of G. lapparenti tricarinata Zone of Beckmann et al., 1969; the upper part of G. aegyptiaca Zone of Beckmann et al., 1969; the lower part of G. aegyptiaca Zone of Shahin, 1992, El-Nady, 1995, Shahin & El Nady, 2001, Ayyad et al., 1996; the upper part of G. falsostuwarti Zone of Hewaidy, 1987, Hewaidy et al., 1991; the upper part of G. stuartiformis Zone of El-Dawy et al., 1992. The most important recorded planktonic foraminifer species within this Zone at the three studied sections are shown on Figs. 5-7.

5. Gansserina gansseri Zone (CF7) (Partial range zone) (early Maastrichtian)

The Gansserina gansseri zone was originally introduced for the first time from the late Maastrichtian of Trinidad by Bronnimann, 1952 as Globotruncanana gansseri Zone to include a biostratigraphic interval from the first appearance of Globotruncanana gansseri Bolli at the base to the first
appearance of *Abathomphalus mayaroensis* (Bolli). Robaszyński *et al.*, 1984, and Caron, 1985 used the same biozone of Bronnimann, 1952 with its same boundaries and they named it *Gansserina gansseri* Zone. Li *et al.*, 1999 considered this biozone of early Maastrichtian age and shorten its range to cover a biostratigraphic interval from the first appearance of nominate taxon at the base to the first appearance of *Contusotruncana contusa* (Cushman). In the present study, the definition of Li *et al.*, 1999 is used to include a biostratigraphic interval extended from the first appearance of *Gansserina gansseri* (Bolli) at the base to the first appearance of *Contusotruncana contusa* (Cushman) at the top. It attains about 5.5 m thick at Wadi Dib section, about 4 m thick at Wadi Abu Had section, and about 7 m thick at Bir Mellaha section. It is assigned to early Maastrichtian age (70.39-69.56 Ma according to Li *et al.*, 1999). In most zonal schemes, the base of this biozone informally marks the Lower-Upper Maastrichtian boundary (Robaszyński *et al.*, 1984, Caron, 1985, 1991 and Li and Keller, 1998a, b). In the study area, it is equivalent to the lower part of *G. gansseri* Zone of Bolli, 1957a; the lower part of *Gansserina gansseri* Zone of Robaszyński *et al.*, 1984, and Caron, 1985; the lower part of *A. mayaroensis* Zone of Boersma, 1984a, and Huber, 1990; and the *G. gansseri* Zone of Wonders, 1980; and also the *G. gansseri* Zone (CF7) of Li and Keller, 1998a, b, and Li *et al.*, 1999. In Egypt, this biozone may be correlated with the lower part of *G. gansseri* of El-Naggar, 1966; Ansary and Tewfik, 1966; Beckmann *et al.*, 1969; Abdel-Kireem, 1986; Cherif and Hewaidy, 1987; Shahin, 1988, 1992; Cherif *et al.*, 1989; Luning *et al.*, 1998; the lower part of *G. gansseri* Zone of Luger, 1985; Cherif and Ismail, 1991; Anan, 1992; Hewaidy and Soliman, 1993; Hewaidy, 1994; Abdel-Kireem and Samir, 1995 and with the *G. gansseri* (CF7) of Tantawy *et al.*, 2001 and Samir, 2002. The most important recorded planktonic foraminiferal species within this Zone at the three studied sections are shown on Figs. 5-7.

6. **Contusotruncana contusa** Zone (CF6) (Partial range zone) (early Maastrichtian)

This zone was originally proposed by Dalbiez, 1955 as *Globotruncana contusa* Zone for the upper Maastrichtian of Tunisia. In the present study, the definition of Li and Keller, 1998a, b is applied to include a biostratigraphic interval extended from the first appearance of *Contusotruncana contusa* (Cushman) at the base to the last appearance of *Globotruncana linneiana* (d’Orbigny) at the top. It attains about 3.5 m thick at Wadi Dib section, about 2.5 m thick at Wadi Abu Had section, and about 4 m thick at Bir Mellaha section. It is assigned to Early Maastrichtian age (69.56-69.06 Ma according to Li *et al.*, 1999). It is equivalent to the lower part of *Rosita contusa* Zone of Premoli-Silva & Bolli, 1973; Wonders, 1980; the lower middle part of *Gansserina gansseri* Zone of Robaszyński *et al.*, 1984, and Caron 1985; D’Hondt & Keller, 1991; and it also equivalent to the *Rosita contusa* Zone (CF6) of Li and Keller, 1998a, b and Li *et al.*, 1999. In Egypt, this biozone is equivalent to the lower part of *Rosita contusa* Zone of Abdel-Kireem *et al.*, 1994; the lower middle part of *Gansserina gansseri* Zone of El-Naggar, 1966; Luger, 1985; Abdel-Kireem and Samir, 1995. It is also equivalent to the *Rosita contusa* Zone (CF6) of Tantawy *et al.*, 2001. The most important recorded planktonic foraminiferal species within this Zone at the three studied sections are shown on Figs. 5-7.

7. **Pseudotextularia intermedia** Zone (CF5) (Partial range zone) (late Maastrichtian)

The *Pseudotextularia intermedia* zone was originally introduced by Nederbragt, 1990 as the interval from the first appearance of *Planoglobulina acervulinoideis* at the base to the first appearance of *Racemiguembelina fructicosa* at the top. In the present study area, the definition of Li & Keller, 1998a, b is used to include a biostratigraphic interval extended from the last appearance of *Globotruncana linneiana* (d’Orbigny) at the base to the first appearance of *Racemiguembelina fructicosa* (Egger) at the top. It attains about 4 m thick at both Wadi Dib and Bir Mellaha sections, and about 2.5 m thick at Wadi Abu Had section. It is assigned to the early Maastrichtian age (69.06-68.33 Ma according to Li *et al.*, 1999). Li *et al.*, 1999 used the top of this biozone to place the early/late Maastrichtian boundary based on biostratigraphic correlation with the geometric time scale at DSDP site 525A, Tunisia. In the present study, this zone is probably equivalent to the upper middle part of *Gansserina gansseri* Zone of Robaszyński *et al.*, 1984; Caron, 1985; Keller, 1988; D’Hondt & Keller, 1991; the *Ps. intermedia* Zone (CF5) of Li and Keller, 1998a, b and Li *et al.*, 1999. In Egypt, this biozone is equivalent to the upper middle part of *Gansserina gansseri* Zone of El-Naggar, 1966; Beckmann *et al.*, 1969; Cherif & Hewaidy, 1987; Shahin, 1988, 1992; Anan, 1992; Omran, 1997; Luger, 1985; Abdel-Kireem and Samir, 1995 and Luning *et al.*, 1998. The most important recorded planktonic foraminiferal species within this Zone at the three studied sections are shown on Figs. 5-7.
PLATE – 1

1 & 2- Heterohelix globulosa (Ehrenberg, 1840), sample 103, Sudr Formation, Bir Mellaha section, Early Maastrichtian.
3- Heterohelix reussi (Cushman, 1938a), sample 87, Sudr Formation, Bir Mellaha section, Late Campanian.
4 & 5- Heterohelix aegytiaca Ansary and Tewfik, 1966, 4: sample 93, 5: sample 107, Sudr Formation, Bir Mellaha section, Late Campanian-Maastrichtian.
6 & 7- Heterohelix striata (Ehrenberg, 1840), 6: sample 104, 7: sample 84, Sudr Formation, Bir Mellaha section, Late Campanian-Maastrichtian.
8 & 9- Heterohelix navarroensis Loeblich, 1951, 8: sample 117, 9: sample 93, Sudr Formation, Bir Mellaha section, Early Late Maastrichtian.
10- Heterohelix planata (Cushman, 1938), sample 113, Sudr Formation, Bir Mellaha section, Early-Late Maastrichtian.
11- Planoglobulina carseyae (Plummer, 1931), sample 108, Sudr Formation, Bir Mellaha section, Late Maastrichtian.
12- Planoglobulina glabrata (Cushman, 1938), sample 114, Sudr Formation, Bir Mellaha section, Late Maastrichtian.
13 & 14- Pseudotextularia elegans (Rzehak, 1891), 13: sample 114, 14: sample 107, Sudr Formation, Bir Mellaha section, Late Maastrichtian.
15-17- Pseudotextularia deformis (Kikoine, 1948), 15: sample 108, 16: sample 107, 17: sample 116, Sudr Formation, Bir Mellaha section, Late Maastrichtian.
8. Racemiguembelina fructicosa Zone (CF4) (Partial range zone) (late Maastrichtian)

Smith & Pessagno, 1973 was originally proposed this zone as the upper subzone of the *Gansserina gansseri* Zone. They defined this zone as a biostratigraphic interval between the first appearance of *Racemiguembelina fructicosa* (Egger) at the base and *Abathomphalus mayaroensis* (Bolli) at the top. In the present study, the definition Li and Keller, 1998a, b and Li et al., 1999 is used to include a biostratigraphic interval extended from the first appearance of *Racemiguembelina fructicosa* (Egger) at the base to the first appearance of *Pseudoguembelina hariaensis* Nederbragt at the top. It attains about 4 m thick at both Wadi Dib, about 2.5 m thick at Wadi Abu Had section, and about 5 m thick at Bir Mellaha section. It is assigned to the Late Maastrichtian age (68.33- 66.83 Ma according to Li et al., 1999). It is equivalent to the combined topmost part of *G. gansseri* Zone and the lower most part of *A. mayaroensis* Zone of Robaszynski et al., 1984; Caron, 1985; D’Hondt & Keller, 1991; the middle part of *A. mayaroensis* Zone of Boersma, 1984a, and Huber, 1990; the lower part of *R. fructicosa* Zone of Nederbragt, 1991; and also it is equivalent to *R. fructicosa* Zone (CF4) of Li and Keller, 1998a, b and Li et al., 1999.

In Egypt, this biozone is equivalent to the combined topmost part of *G. gansseri* Zone and *G. esnehensis* Zone recorded by El- Naggar, 1966; the combined topmost part of *G. gansseri* Zone and the lower most part of *A. mayaroensis* Zone of Beckmann et al., 1969; Ayyad et al., 1996; Hewaidy, 1987, Hewaidy et al., 1991; Shahin, 1988, 1992; Anan, 1992; El-Nady, 1995; Omran, 1997; Lunning et al., 1998; and Shahin & El-Nady, 2001. It is also equivalent to *R. fructicosa* Zone (CF4) of Tantawy et al., 2001; and Samir, 2002. The most important recorded planktonic foraminiferal species within this Zone at the three studied sections are shown on Figs. 5-7.

9. Pseudoguembelina hariaensis Zone (CF3) (Partial range zone) (late Maastrichtian)

This zone was firstly introduced by Nederbragt, 1990 as the total range of the zonal marker. In the present study, the definition of Li & Keller, 1998a, b and Li et al., 1999 is used to include a biostratigraphic interval extended from the first appearance of *Pseudoguembelina hariaensis* Nederbragt at the base to the last appearance of *Gansserina gansseri* (Bolli) at the top. It attains about 4.5 m thick at both Wadi Dib, about 5 m thick at Wadi Abu Had section, and about 6 m thick at Bir Mellaha section. It is assigned to the Late Maastrichtian age (66.83- 65.45 Ma according to Li and Keller, 1998a, b). It is equivalent to the middle part of the *A. mayaroensis* Zone of Caron 1985; the lower upper part of *A. mayaroensis* Zone of Boersma, 1984a, and Huber, 1990. Also, it is equivalent to the *P. hariaensis* (CF3) of Li and Keller, 1998a, b and Li et al., 1999. In Egypt, this biozone may be correlated with the lower part of *A. mayaroensis* Zone recorded by Hewaidy, 1987; the *G. esnehensis* Zone of El Naggar, 1966, and the *Ps. hariaensis* Zone (CF3) of Tantawy et al., 2001; Samir, 2002; El Sabbagh, 2007; Al-Wosabi and Abu Shama, 2007. The most important recorded planktonic foraminiferal species within this Zone at the three studied sections are shown on Figs. 5-7.

10. Pseudoguembelina palpebra Zone (CF2) (Partial range zone) (late Maastrichtian)
1- *Contusotruncana plicata* (White, 1928), 1a: ventral view, 1b: side view, 1c: dorsal view, sample 104, Sudr Formation, Bir Mellaha section, Early Maastrichtian.

2- *Gansserina wiedenmayeri* (Gandolfi, 1955), 2a: ventral view, 2b: side view, 2c: dorsal view, sample 110, Sudr Formation, Bir Mellaha section, Late Maastrichtian.

3- *Gansserina gansseri* (Bolli, 1951), 3a: ventral view, 3b: side view, 3c: dorsal view, sample 112, Sudr Formation, Bir Mellaha section, Late Maastrichtian.

4- *Globotruncana aegyptiaca* Naklady, 1950, 4a: ventral view, 4b: side view, 4c: dorsal view, 4a & 4b: sample 94, 4c: sample 109, Sudr Formation, Bir Mellaha section, Early-Late Maastrichtian.

5- *Globotruncana falsostuarti* Sigal, 1952, 5a: ventral view, 5b: side view, 5c: dorsal view, sample 103, Sudr Formation, Bir Mellaha section, Early Maastrichtian.

6- *Globotruncana ventricosa* White, 1928, 6a: ventral view, 6b: side view, 6c: dorsal view, 6a & 6c: sample 105, 6b: sample 107, Sudr Formation, Bir Mellaha section, Late Campanian – Late Maastrichtian.


8- *Globotruncana arca* (Cushman, 1926), 8a: ventral view, 8b: side view, 8c: dorsal view, sample 85, Sudr Formation, Bir Mellaha section, Late Campanian.


10 & 11- *Globotruncana linneiana* (d’Orbigny, 1839), 10a & 11a: ventral view, 10b & 11b: side view, 10c & 11c: dorsal view, 10 & 11b: sample 107, 11a & 11c: sample 80, Sudr Formation, Bir Mellaha section, Late Campanian-Late Maastrichtian.

12- *Globotruncana rosseta* (Carsey, 1926), 12a: ventral view, 12b: side view, 12c: dorsal view, sample 105, Sudr Formation, Bir Mellaha section, Early Maastrichtian.
PLATE - 3

1. *Globotruncanita rugosa* (Marie, 1941), 1a: ventral view, 1b: side view, 1c: dorsal view, sample 86, Sudr Formation, Bir Mellaha section, Late Campanian.
2. *Globotruncanita eschenensis* Nakkady, 1950, 2a: ventral view, 2b: side view, 2c: dorsal view, sample 114, Sudr Formation, Bir Mellaha section, Late Maastrichtian.
5. *Globotruncanita stuarti* (De Lapparent, 1918), 5a: ventral view, 5b: side view, 5c: dorsal view, 5a: sample 116, 5b & 5c: sample 104, Sudr Formation, Bir Mellaha section, Early-Late Maastrichtian.
8. *Globotruncanella petaloidea* (Gandolfi, 1955), 8a: ventral view, 8b: side view, 8c: dorsal view, 8a & 8b: sample 104, 8b: sample 106, Sudr Formation, Bir Mellaha section, Early-Late Maastrichtian.
10. *Globotruncanella citae* Bolli, 1951, 10a: ventral view, 10b: side view, 10c: dorsal view, sample 84, Sudr Formation, Bir Mellaha section, Late Campanian.
This zone was introduced by Li & Keller, 1998a, b from DSDP Site 525A and Tunisia respectively. In the present study, it is defined as a biostratigraphic interval extended from the last appearance of *Gansserina gansseri* (Bolli) at the base to the first appearance of *Plummerita hantkeninoides* (Bonnimann) at the top. It is recorded only at Bir Mellaha section and attains about 3m thick. It is assigned to the Latest Maastrichtian age (65.45- 65.30 Ma according to Li and Keller, 1998a). It is equivalent to the upper part of *A. mayaroensis* Zone of Premoli Silva & Bolli, 1973; Robaszynski et al., 1984; Caron, 1985; Boersma, 1984a; Huber, 1990; D’Hondt & Keller, 1991; Molina et al., 1996; and it is also equated to Ps. *Palpebra* Zone (CF2) of Li and Keller, 1998a, b, and Li et al., 1999. In Egypt, it is equivalent to the upper part of *A. mayaroensis* Zone of Beckmann et al., 1969; Ayyad et al., 1996; Hewaidy, 1987, Hewaidy et al., 1990; Shahin, 1988, 1992; El-Nady, 1995; El-Dawy et al., 1992; Marzouk and Luning, 1998; Abdel-Kireem & Abdou, 1979; Lunning et al., 1998; and also it is equated to the *Ps. Palpebra* Zone (CF2) of Samir, 2002. The most important recorded planktonic foraminiferal species within this Zone at the three studied sections are shown on Figs. 5-7.

11. *Plummerita hantkeninoides* Zone (CF1) (Total range zone) (latest Maastrichtian)

Pardo et al., 1996 was originally introduced this planktonic foraminiferal biozone for the latest Maastrichtian of Spain. In the present study, the definition of Li et al., 1999 is used to include a biostratigraphic interval of the total range of *Plummerita hantkeninoides* (Bonnimann). It is considered as the youngest Late Maastrichtian zone (Masters, 1984; Ion, 1993; Pardo et al., 1996; Keller, 2002; El-Sabbagh et al., 2004, El-Sabbagh, 2007). In the present study, it occupies the topmost part of Abu Zeneima Member at Bir Mellaha section and attains about 3m thick indicating the completeness of the uppermost part of the Maastrichtian age at this section. It is assigned to the latest part of the late Maastrichtian age (65.30 – 65.00 Ma according to Li et al., 1999). The upper boundary of this biozone is used to place the Cretaceous /Paleogene (K/P3) boundary in the study area. It is equivalent to the topmost part of the *A. mayaroensis* Zone of Boersma, 1984a; Robaszynski et al., 1984; Caron, 1985, and Huber, 1990. It is also equivalent to *Pl. hantkeninoides* (CF1) of Arz, 1996; Li & Keller, 1998b; Li et al., 1999; the upper part of Zone (CF1-2) of Li & Keller, 1998a&b. In Egypt, this biozone is equivalent to the *Kassabiana falsocalarata* Zone of Luger, 1998; the upper part of *Pl. reicheli* Subzone of Shahin, 1992; El-Nady, 1995; Omran, 1997; the *Pl. hantkeninoides* (CF1) of Samir, 2002, El- Sabbagh, 2007. The most important recorded planktonic foraminiferal species within this Zone at the three studied sections are shown on Figs. 5-7.

The two latest Maastrichtian *Pseudoguembelina palpebra* (CF2) and *Plummerita hantkeninoides* (CF1) zones which recorded at Bir Mellaha section are missing at both Wadi Abu Had and Wadi Dib sections indicating presence of second unconformity surface (Hiatus-2) within the uppermost part Abu Zeneima Member at these two sections.

A correlation between the distinguished eleven planktonic foraminiferal biozones at the three studied sections is shown on Fig. 8.

Stage Boundaries In The Study Area

1. The Campanian/ Maastrichtian boundary

There is general agreement on placing the Campanian/ Maastrichtian boundary at the top of the *Globotruncanita calcarata* Zone (e.g. Robaszynski et al., 1984; Caron, 1985; Brauger et al., 1995, Li and Keller, 1998a, b, and Cherif and Ismail, 1991).

Li et al., 1999 followed Gradstein et al., 1995 in placement of the Campanian/ Maastrichtian boundary and they informally used the planktonic foraminiferal datum of *Rugoglobigerina hexacamerata* Bronnimann at 71 Ma for this boundary based on biostratigraphic correlation with the geomagnetic time scale at DSDP site 525A. Tunisia. This datum event is within the range of Gradstein et al., s estimate of (71.60 ± 0.7 Ma) for this boundary.

Odin, 2001 in the Tercis section (France) placed this boundary at the first occurrence (FO) of *Contusotruncana contusa* (Cushman) and the FO of *Rugoglobigerina scotti* Bronnimann at 72 Ma. Recently, Gradstein et al., 2012 placed this boundary within the upper part of *Gansserina gansseri* Zone at 72 Ma.

In the present study, the Campanian/ Maastrichtian boundary is located within the lower part of the Abu Zeneima Member followed Li et al., 1999 in the placement of this boundary on the top of *Globotruncanita aegyptiaca* Zone (CF8a) and at the first appearance of *Rugoglobigerina hexacamerata* Bronnimann Figs. 5-7 and Tab. 1.
1- Rugotruncana subcircumnodifer (Gandolfi, 1955), 1a: ventral view, 2b: side view, 1c: dorsal view, sample 86, Sudr Formation, Bir Mellaha section, Late Campanian.
2- Rugotruncana subpennyi (Gandolfi, 1955), 2a: ventral view, 2b: side view, 2c: dorsal view, 2a & 2c: sample 84, 2b: sample 116, Sudr Formation, Bir Mellaha section, Late Campanian-Maastrichtian.
3 & 4- Rugoglobigerina macrocephala Bronnimann, 1952, 3a & 4a: ventral view, 3b & 4b: side view, 3c & 4c: dorsal view, 3a & 4: sample 104, 3b: sample 114, 3c: sample 106, Sudr Formation, Bir Mellaha section, Early to Late Maastrichtian.
5- Rugoglobigerina rugosa (Plummer, 1926), 5a: ventral view, 5b: side view, 5c: dorsal view, sample 106, Sudr Formation, Bir Mellaha section, Late Maastrichtian.
6- Rugoglobigerina hexacamerata Bronnimann, 1952, 6a: ventral view, 6b: side view, 6c: dorsal view, 6a: sample 110, 6b & 6c: sample 108, Sudr Formation, Bir Mellaha section, Late Maastrichtian.
8- Rugoglobigerina scotti Bronnimann, 1952, 8a: ventral view, 8b: side view, 8c: dorsal view, sample 92, Sudr Formation, Bir Mellaha section, Early Maastrichtian.
10- Rugoglobigerina pennyi Bronnimann, 1952, 10a: ventral view, 10b: side view, 10c: dorsal view, sample 104, Sudr Formation, Bir Mellaha section, Early Maastrichtian.
12 & 13- Plummerita hankeninoides (Bronnimann, 1952), ventral views, sample 118, Sudr Formation, Bir Mellaha section, Latest Maastrichtian.
Fig. 5: Distribution chart of the identified late Campanian to late Maastrichtian planktonic foraminiferal species at Bir Mellaha section.
### Geologic Time

<table>
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<th>Paleogene</th>
<th>Paleocene</th>
<th>Eocene</th>
<th>Oligocene</th>
<th>Miocene</th>
<th>Pliocene</th>
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<td>Late Campian</td>
<td>Early Senonian</td>
<td>Late Senonian</td>
<td>Early Cenomanian</td>
<td>Late Cenomanian</td>
<td>Early Turonian</td>
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### Rock units

- Cretaceous
- Senonian
- Early Cretaceous
- Late Cretaceous

### Planktonic foraminiferal zones

<table>
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<th>Thick. (m)</th>
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</table>

### Lithology

1. *Heterohelix globulosa*
2. *Heterohelix russi*
3. *Heterohelix strata*
4. *Heterohelix navarrensis*
5. *Heterohelix planata*
6. *Plectolobatina carveyae*
7. *Plectolobatina giubata*
8. *Pseudotextularia elegans*
9. *Pseudotextularia deformis*
10. *Pseudotextularia interna*
11. *Racemiguumella fractiosa*
12. *Racemiguumella pesseli*
13. *Pseudogumella kuriensis*
14. *Pseudogumella colutula*
15. *Pseudogumella exfolia*
16. *Globigerinelloides praevinitens*
17. *Globigerinelloides ultramicro*
18. *Hedbergella holmdelensis*
19. *Concavatruncana fornicata*
20. *Concavatruncana contusa*
21. *Gazusserina gansseri*
22. *Gazusserina agyptica*
23. *Gazusserina fulvovarii*
24. *Gazusserina orientalis*
25. *Gazusserina ventricosa*
26. *Gazusserina arca*
27. *Gazusserina lineata*
28. *Gazusserina bollida*
29. *Gazusserina rosetta*
30. *Gazusserina rugosa*
31. *Gazusserina emekensis*
32. *Gazusserina elica*
33. *Gazusserina stuartiformis*
34. *Gazusserina stuartiformis*
35. *Gazusserina subplanina*
36. *Gazusserina petaloidea*
37. *Gazusserina huxleyensis*
38. *Gazusserina citata*
39. *Rugotruncana subcircummodifera*
40. *Archeosphigerina bowi*
41. *Rugotruncana subpennyi*
42. *Rugogladastrina macrolepida*
43. *Rugogladastrina rugosa*
44. *Rugogladastrina huxleyensis*
45. *Rugogladastrina recheli*
46. *Rugogladastrina scotti*
47. *Rugogladastrina rotundata*
48. *Rugogladastrina pesseli*
49. *Rugogladastrina milanensis*
Fig. 8: Biostratigraphic correlation chart between the three studied sections.
Tab. 1: Summary of the used planktonic foraminiferal zonal schemes for the late Campanian-Maastrichtian, age estimated and their equivalents at the Esh El-Mellaha area. The estimated ages and datum events are based on Li and Keller, 1998a, b & Li et al., 1999, and Correlation with Caron, 1985.

<table>
<thead>
<tr>
<th>Time (Ma)</th>
<th>Stage</th>
<th>Planktonic Foraminiferal datum events</th>
<th>Li et al.,1999</th>
<th>Li&amp; Keller (1998a, b)</th>
<th>Caron (1985)</th>
<th>Present study</th>
<th>Stage</th>
<th>Cherif &amp; Ismail (1991)</th>
<th>South-west Gulf of Suez</th>
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<td>68.0</td>
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2. The Early/ Late Maastrichtian boundary
Planktonic foraminiferal authors have generally placed the early- late Maastrichtian boundary at the first appearance of *Gansserina gansseri* (Bolli) (e.g. Robaszynski et al., 1984, Caron, 1985, and Li and Keller, 1998a, b) or at the first appearance of *Abathomphalus mayaroensis* (Bolli) (e.g. Boersma, 1984a, and Huber, 1990) or at the first appearance of *Racemiguembelina fructicosa* (Egger) (e.g. Nederbragt, 1991, and Li et al., 1999). In present study, we are not used the first appearance of *Abathomphalus mayaroensis* (Bolli) to place the early/ late Maastrichtian boundary because of many studies have been shown that this taxon is poor biostratigraphic marker and not a reliable zonal index species because both first appearance and last appearance of this species are diachronous (Keller, 1989, Huber, 1990, Pardo et al., 1996); appear much earlier in high latitudes and is rare or absent in neritic environment and also, this taxon is rarely present in continental shelf areas due to it is deeper dwelling habitat (e.g. Masters, 1984, 1993; Hultberg and Malmgren, 1987; Keller, 1988, 1989, 1993; Huber, 1992, Nederbragt, 1991, and Keller et al., 1996). Li and Keller, 1998a, b noted that *Abathomphalus mayaroensis* (Bolli) first appears about 4m below the *Gansserina gansseri* (Bolli) at site 525A, Tunisia. However, in low latitudes the first appearance of *Abathomphalus mayaroensis* (Bolli) is generally appears much later at approximately the first appearance of *Racemiguembelina fructicosa* (Egger) (e.g. Robaszynski et al., 1984, and Caron, 1985). Gradstein et al., 1995 proposed that the early/ late Maastrichtian boundary be placed at 69.50 Ma within the upper part of C31R. This interval corresponds to the first appearance of *Contusotruncana contusa* (Cushman) which marks the base of Zone (CF6) of Li and Keller, 1998a, b and Li et al., 1999. In contrast,
Bralower et al., 1995, proposed that this boundary be placed at the base of C30N at about 67.60 Ma, which corresponds to within the middle of Racemiguembelina fructicosa Zone (CF4) of Li and Keller, 1998a, b and Li et al., 1999. Li et al., 1999 were informally used the first appearance of Racemiguembelina fructicosa (Egger) to approximate the early/late Maastrichtian boundary at 68.30 Ma based on biostratigraphic correlation with the geometric time scale at DSDP site 525A, Tunisia. At the three studied sections, the early/late Maastrichtian boundary is located within the upper part of Abu Zeneima Member and we are followed Li et al., 1999 in placement it at the first appearance of Racemiguembelina fructicosa (Egger) Figs. 5-7 and Tab.1.

Summary And Conclusions

- This work can be summarized in the following items:

1. The present study deals with the high resolution planktonic foraminiferal biostratigraphy of the Upper Campanian to Upper Maastrichtian Sudr Formation and its stage boundaries for three exposures on the western flank of the Esh El-Mellah area, North Eastern Desert, Egypt from north to south are Wadi Dib, Wadi Abu Had, and Bir Mellaha sections.

2. Lithostratigraphically, this interval is represented by the Sudr Formation which classified into Markha and Abu Zeneima members from base to top and this rock unit is found very rich with planktonic foraminiferal assemblages.

3. Fifty seven planktonic foraminiferal species belonging to seventeen genera, six superfamilies, five families, four superfamilies and one suborder are recorded most them are belonged to family "Globotruncanidae" where it includes 11 genera and 38 species. So, the phylogenetic development of the recorded species and genera belonged to this important family is described.

4. The genus Hedbergella Bronnimann and Brown 1958 was considered as the ancestor of all genera of the family Globotruncanidae, where, it is the oldest and most primitive genus of this family. The genus Contusotruncana Korchagin, 1982 was initiated from Marginotruncana sinuosa Porthault, 1970 through gradual increase in the spire height, size of chambers and plaction of chamber surfaces. The genus Gansserina Caron, Gonzales Donoso, Robaszynski and Wonders, 1984 was derived from genus Archaeoglobigerina Pessagno, 1967 through the development of a single keel and coarse rugosities. The genus Globotruncanca was derived from genus Marginotruncana Hofker, 1956 by migration of the extra umbilical primary aperture towards umbilical position and replacement of the portici by tegilla. The genus Globotruncanita Reiss, 1957 was derived from Marginotruncanca sigali Reichel, 1950, where the primary aperture became umbilical in its position and the two keels in the first chambers of the last whorl disappeared. The genus Globotruncanella Reiss, 1957 was derived from genus Hedbergella Bronnimann and Brown 1958 by changing the primary aperture from extraumbilical –nearly peripheral protected by lips to become extraumbilical protected by portici with an imperforate peripheral band or even pustulose keel. The genus Abathomphalus was evolved from genus Globotruncanella Reiss, 1957 by changing the rounded periphery to became double keel. The genus Archaeoglobigerina Pessagno, 1967 was derived from genus Globotruncanella Pessagno, 1967 by accentuation of the ornamentation of the chamber surface leading to the costellae type arranged in amergional pattern. The genus Plummerita Bronnimann, 1952b was derived from genus Rugoglobigerina Bronnimann, 1952a by changing the globular chambers to become radially elongated chambers terminating in tubulospines in the last whorl. Finally the genus Rugotruncanca Bronnimann and Brown, 1956 was evolved from genus Rugoglobigerina Bronnimann, 1952a by flattening of its chambers and by development of a true double keel.

5. Depending on the stratigraphic distribution of all recorded species within the Sudr Formation at these three studied sections, the upper Campanian- upper Maastrichtian interval biostratigraphically is classified into eleven planktonic foraminiferal biozones for the first time in the present study area: one of upper part of early Campanian to late Campanian age (Globotruncanca ventricosa Zone); two of late Campanian age (Globotruncanella havanensis (=CF9) and Globotruncanca aegyptiaca (CF8a) zones); four of early Maastrichtian age (Rugoglobigerina hexacamerata (CF8b), Gansserina gansseri (CF7), Contusotruncanca contusa (CF6), Pseudotextularia intermedia (CF5) zones); and four of late Maastrichtian age (Racemiguembelina fructicosa (CF4), Pseudoguembelina hariensis (CF3), Pseudoguembelina palpebera (CF2), and Plummerita hankeninoides (CF1) zones). In contrast with our results, the late Maastrichtian age was not recorded previously in the study area.

6. The Campanian / Maastrichtian boundary in the present study area, is located within the lower part of the Abu Zeneima Member between Globotruncanca aegyptiaca (CF8a) and Rugoglobigerina hexacamerata (CF8b) zones.
7. The early / late Maastrichtian boundary in the present study area, is located within the upper part of the Abu Zeneima Member between *Pseudotextularia intermedia* (CF5) and *Racemiguembelina fructicosa* (CF4) zones.

8. Two unconformity surfaces are recorded within the Sudr Formation in the present study area:

- The first one is recorded at the three studied sections and it lies between the Markha and Abu Zeneima Members due to absence of the late Campanian *Globotruncanita calcarata* (CF10) Zone, where the *Globotruncanana ventricosa* Zone directly overlain by *Globotruncanella havanensis* (=CF9) Zone.

- On the other hand, the second unconformity surface lies in the topmost part Abu Zeneima Member and it is recorded at both Wadi Abu Had and Wadi Dib only where the two latest Maastrichtian *Pseudoguembelina palpebra* (CF2) and *Plummerita hantkeninoides* (CF1) zones which recorded at Bir Mellaha section are missing at these two studied sections.

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