Nukhul Formation in Wadi Baba, southwest Sinai Peninsula, Egypt

Abdel Galil A. Hewaidy, Sherif Farouk and Haitham M. Ayyad

ABSTRACT

The Nukhul Formation is the oldest syn-rift rock unit in the Gulf of Suez rift system in Egypt. The age of the formation is inadequately resolved by biostratigraphy and it is generally assigned to the Lower Miocene by stratigraphic position. For this study a surface section was measured and sampled at Wadi Baba, located in the southwestern Sinai Peninsula. It yielded 17 planktonic foraminiferal species and 17 foraminiferal benthonic species. The planktonic foraminiferal assemblage was used to divide the formation into two planktonic foraminiferal zones: (1) \textit{Globigerina ciperoensis} Zone (O6) of Late Oligocene Chattian age; and (2) \textit{Globigerinoides primordius} Zone (M1) of Early Miocene Aquitanian age. The two zones coincide with depositional sequences: (1) Chattian Lower Nukhul Sequence, with its upper boundary coinciding with the Chattian/Aquitanian (Oligocene/Miocene) boundary; and (2) Aquitanian Upper Nukhul Sequence, with its upper sequence boundary coinciding with the Aquitanian/Burdigalian boundary.

INTRODUCTION

The Nukhul Formation is an important exploration target and oil-producing reservoir in the Gulf of Suez of Egypt (Figure 1). It is the oldest syn-rift formation in the Gulf and has been the subject of many geological studies that have generally assigned it an Early Miocene age (e.g. Said, 1962; Egyptian General Petroleum Corporation - EGPC, 1964; Souaya, 1965, 1966; Said and El Heiny, 1967; National Stratigraphic Sub-committee, 1974; Garfunkel and Bartov, 1977; Andrawis and Abdel Malik, 1981; El-Heiny and Martini, 1981; El-Heiny and Morsi, 1992; Haggag et al., 1990; El-Azabi, 1996, 2004; Evans, 1988; Phillip et al., 1997; Amundsen et al., 1998; Shahin, 1998, 2000; Abul-Nasr and Salama, 1999; El-Deeb et al., 2004; El-Barkooky et al., 2006).

Contrary to these papers this study indicates the Nukhul Formation is Late Oligocene–Early Miocene implying the Suez Rift System started in the Oligocene. Our conclusion is based on the results of a biostratigraphic study of the Nukhul Formation at Wadi Baba (Figure 1, 28°57'16''N; 33°16'08''E). For the study 26 samples were collected and prepared for foraminiferal studies. The planktonic and benthonic foraminiferal contents were separated, identified and photographed by scanning microscope and are shown in Plates 1 and 2 for the planktonic species, and Plate 3 for benthonic ones. The systematic classification of the identified planktonic and benthonic foraminiferal species follows Loeblich and Tappan (1988) and are listed in the appendixes.

LITHOLOGY OF THE NUKHUL FORMATION, WADI BABA

At Wadi Baba the Nukhul Formation unconformably overlies the Middle Eocene Darat Formation (Figure 2a). The underlying units below this boundary are recognized by different names in the Gulf of Suez and related to the early riftling tectonic event (e.g. Garfunkel and Bartov, 1977; Evans, 1988; El-Azabi 2004; Bosworth et al., 2005). The Nukhul Formation unconformably underlies the Rudeis Formation, which consists of calcareous shale and marl, rich in microfaunal content (Figures 2b and 3). The formation has a thickness of about 94 m at Wadi Baba, and can be divided into the following lithologic units; from base to top:

\textbf{Unit 1} is composed of poorly sorted, unstratified polymictic conglomerates, 4 m thick, followed by 9.5 m of cross-bedded, conglomeratic sandstones (Figure 2c). The clasts are composed of reworked nummulitic limestone derived from the underlying Eocene rocks with very limited transportation, in addition to basalt fragments and subrounded chert.
Unit 2 comprises pale yellow to light green marl, 18.5 m thick, containing mixed reworked and syn-sedimentary foraminiferal assemblages.

Unit 3 consists of grayish limestone, 15 m thick, with Ostrea carolinensis Conrad, Pecten ziziniae Blanckenhorn and Chlamys gloriamaris Dubois. The upper part is ca. 25 m thick and consists of planar cross-bedded and fossiliferous argillaceous sandstone with chert fragments (Figure 2d).

Unit 4 is ca. 22 m thick and composed of soft yellow marl and shale, succeeded by burrowed calcareous sandstone (Figure 3).

**BIOSTRATIGRAPHY OF THE NUKHUL FORMATION, WADI BABA**

The Nukhul Formation at Wadi Baba yielded rich planktonic and benthonic foraminiferal assemblages associated with some reworked Eocene foraminifera. The syn-sedimentary foraminiferal fauna includes 17 planktonic and 17 benthonic species. The syn-sedimentary planktonic foraminiferal assemblage was used to divide the Nukhul Formation into two foraminiferal zones separated by barren intervals. The distribution of the identified planktonic and small benthonic foraminiferal species is shown in Figure 4. The following is the discussion for the identified biozones from older to younger.
**Globigerina ciperoensis Zone**

**Definition:** Originally this zone was defined as the interval with zonal marker from the last occurrence (LO) of *Globigerina opima opima* to the first occurrence (FO) of *Globorotalia kugleri* (Cushman and Stainforth, 1945, and emended by Bolli, 1957a). In the studied section the two markers characterizing the lower and upper boundaries are missing. Some authors (e.g. Haggag et al., 1990; Ouda, 1998 and Kučenjak et al., 2006) noted the absence of *Globorotalia kugleri* (Blow) in the Gulf of Suez area. Thus, the zone is identified as the interval with the nominate taxon to the FO of *Globigerinoides* spp.

**Age:** Late Oligocene (Chattian).

**Thickness:** This zone attains a total thickness of 71 m and spans units 1 to 3 in the lower part of the Nukhul Formation at Wadi Baba, including the nearly barren Unit 1 (Figure 4).

**Assemblage:** This zone is marked by high diversity with moderately preserved planktonic and benthonic foraminiferal assemblages. The assemblage includes *Globigerina ciperoensis* Bolli, *Streptohilus pristinum* Brönnimann & Resig, *Paragloborotalia opima nana* (Bolli), *Tenuitellinata angustiumbilicata* (Bolli), *Paragloborotalia mayeri* (Cushman & Ellisor), *Globorotaloides sutera* Bolli, *Paragloborotalia pseudokugleri* (Blow) (at the upper part of the zone), *Globigerina praebulloides* Blow, *Globoturborotalita gnaucki* (Blow & Banner) and *Globoturborotalita ouachitaensis* (Howe & Wallace). For the complete assemblage of this zone refer to Figure 4. Some of the reworked elements recorded in this zone are *Pseudohastigerina micra* (Cole), *Chiloguembelina cf. cubensis* (Palmer), *Turborotalia increbescens* (Bandy) and *Truncorotaloides* spp.

The important benthonic elements of this zone are *Ammonia beccarii* (Linné), *Nonion scapha* (Fichtel and Moll), *Bolivia dilatata* Reuss, *B. oligocaenica* Spandel, *B. shukrii shukrii* Souaya, *Lenticulina submamiliger* (Cushman) and *Planularia helena* (Karrer).

**Remarks:** The presence of the *Globigerina ciperoensis* group and other small-sized planktonic forams recorded in the lower part of the Nukhul Formation, in addition to the absence of any *Globigerinoides* spp., indicate a Late Oligocene age. The *Globigerina ciperoensis* group (*G. ciperoensis* and *Tenuitellinata angustiumbilicata*) was best-adapted in the Late Oligocene (e.g. Bolli, 1957a; Postuma, 1971; Bolli and Saunders, 1985; Kučenjak et al., 2006). Kennett and Srinivasan (1983) noted that it is a valuable index for the Late Oligocene but is rare in the Early Miocene.

The presence of a few poorly preserved *Paragloborotalia pseudokugleri* (Blow) in Sample Number 57 at the top part of the *Globigerina ciperoensis* Zone may indicate a younger stratigraphic level in the Late Oligocene. This may be the *Paragloborotalia pseudokugleri* (O7) Zone. According to Wade et al. (2010), this zone represents the upper part of Zone (O6) (*Globigerina ciperoensis* Partial-range Zone) of Berggren and Pearson (2005).

The great ratio of reworked fossils at the lower levels of the Nukhul Formation leads to great controversy about the age of that unit in southwestern Sinai Peninsula. The detailed study of these reworked fauna was neglected in previous studies. Some previous studies concluded that the lower part of the Nukhul Formation is barren of planktonic foraminifera and assigned it to the Lower Miocene (Aquitanian) by stratigraphic position (e.g. Evans, 1988; Haggag et al., 1990; Ouda and Masoud 1993; Philip et al., 1997; El-Deeb et al., 2004; El-Azabi, 2004 and El-Barkooky, 2006). On the other hand, a marine Upper Oligocene planktonic foraminifera was recorded in surface (Shahin, 1998, 2000) and subsurface (Ouda and Masoud, 1993) areas of the Gulf of Suez (Figure 5).

The samples of this part of Wadi Baba section was checked for nannofossils by Prof. Abdel Aziz Tantawy and yielded a Late Oligocene (NP24) fauna (*Helicosphaera recta, H. euphratis, H. bramlettei, H. compacta, Sphenolithus ciperoensis, S. pseudoradians, S. capricornutus, Dictyococcites scrippsae, Cyclicargolithus floridanus, Pontosphaera enorris, Chiasmolithus altus, Zygospholithus bijugatus, Discouer deflandre*).
**Globigerinoides primordius Zone**

**Definition:** Total range of the nominate taxon (Blow, 1969).

**Thickness:** This interval is ca. 22 m thick in the upper Unit 4 of the Nukhul Formation (Figure 4).

**Assemblage:** The most important planktonic elements recorded in this zone are: *Globigerinoides primordius* Blow and Banner, *Gg. immaturus* Le Roy, *Gg. subquadratus* Brönnimann, *Gg. trilobus* (Reuss), *Globigerina venezuelana* Hedberg, *Catapsydrax dissimilis* Cushman and Bermudez and *Cassigerinella chipolensis* Cushman & Ponton. In addition to a larger size and well-preserved *G. ciperoensis* recorded in the lower part of this zone. The most important benthonic elements recorded in this zone are *Bulimina elongata* elongate (d’Orbigny), *B. striata* d’Orbigny, *Lenticulina submamiliger* (Cushman), *Elphidium fichtelianum praeforme* Papp and *Nonion scapha* (Fichtel and Moll).

**Remarks:** A marked change in the size, preservation and diversity of the foraminiferal fauna from Chattian to Aquitanian are noted. A change from small-sized and limited diversity to large-sized and high diversity represented the transition from Chattian to Aquitanian.
The FO of *Globigerinoides* has widely been accepted as the datum for the Oligocene/Miocene boundary (Banner and Blow, 1965; Bolli, 1966; Cita, 1976; Bolli and Premoli Silva, 1973; Blow, 1969, 1979; Bolli and Saunders, 1985; Haggag et al., 1990; Philip et al., 1997; El-Deep et al., 2004). On the other hand, the FO of small-sized *Globigerinoides primordius* was observed in *Globigerina ciperoensis* Zone by some authors (e.g. Ouda and Masoud, 1993; Mancin et al., 2003; Kućenjak et al., 2006). In the present study, the FO of genus *Globigerinoides* including FO of *Globigerinoides primordius* and *Globigerinoides trilobus* together is the main character of the basal Miocene.

Haggag et al., (1990) studied the planktonic content of the Nukhul Formation using ditch samples taken from some offshore wells drilled in the northern part of the Gulf of Suez. The lower part of the Nukhul Formation in these wells was found barren of foraminifera, while its upper part includes a planktonic assemblage composed of *Globigerina ciperoensis* group associated with some elements of *Globigerinoides primordius* assemblage and attributed this interval to the Aquitanian age. They stated that the *Globigerinoides primordius* Zone is the oldest Miocene planktonic foraminiferal zone in the Gulf of Suez.
Figure 3: Stratigraphic interpretations and relative sea-level curve with sequence-stratigraphic interpretation of the Chattian–Aquitanian succession exposed at Wadi Baba, southwest Sinai (See Figure 1 for location).

SEQUENCE STRATIGRAPHY OF THE NUKHUL FORMATION, WADI BABA

The Nukhul Formation in Wadi Baba is interpreted as two third-order depositional sequences corresponding to the Chattian Nukhul Sequence A and Aquitanian Nukhul Sequence B.

Nukhul Sequence A

Nukhul Sequence A is ca. 71 m thick and is represented by units 1 to 3 of the Nukhul Formation and the Globigerina ciperoensis Zone. It is bounded at the base by a major unconformity (SB1) separating the syn–rift basal Oligocene clastics of the Nukhul Formation from the underlying pre-rift sediments of the Middle Eocene Darat Formation. This boundary (SB1) may be correlated to a
Figure 4: Biostratigraphic distribution chart of the planktonic and benthonic foraminiferal species recorded in the Wadi Baba section. (for symbols and hachuring see Figure 3).
Figure 5: Comparison of results of the present study with some previous studies.

global short-term, sea-level fall (Haq et al., 1987; Hardenbol et al. 1998; Miller et al., 2005). Nukhul Sequence A includes the following systems tracts.

The lowstand systems tract (LST) corresponds to Unit 1, which was deposited in a fan-delta system. The transgressive systems tract (TST) consists of Unit 2. The syn-sedimentary foraminiferal assemblage recorded in this unit denotes a Chattian age and a neritic affinity. It is characterized by a low abundance of planktonic foraminifers (< 15–20%) and reworked Eocene foraminiferal fauna. The main benthonic genera recorded in Unit 2 are Ammonia, Bolivina, Nonion, Bulimenella, Bulimina, and Astrononion with a few smooth ostracods. This assemblage denotes an inner-shelf environment. Ammonia beccarii inhabits sheltered inner-shelf and estuarine environments, being tolerant of brackish water condition. It is the dominant living species in shallow-marine settings (< 10 m), and is a common component of many modern New Zealand lagoonal foraminiferal assemblages (Naish and Kamp, 1997).

The maximum flooding surface (MFS) is represented by the top part of Unit 2 and includes the maximum occurrence of the benthonic and planktonic fauna in this interval. The highstand systems tract (HST) corresponds to Unit 3 and comprises argillaceous limestone characterized by the presence of a few oysters and pectens, followed by planar cross-bedded calcareous sandstone and topped by argillaceous sandstone with chert fragments (Figures 2d and 3). This succession was deposited in a coastal environment with moderate energy conditions and tidal processes.

The FO of Globigerinoides primordius and Globigerinoides trilobus together with abundant reworking and agitation processes at the top of this systems tract indicate a minor faunal break and characterizes the top part of the depositional sequence near the Oligocene/Miocene boundary. Nukhul Sequence A is terminated by sequence boundary SB2 separating the Chattian (Oligocene) from the Aquitanian (Miocene). This boundary apparently coincides with a major global eustatic sea-level drop (Haq et al., 1987). It also correlates well with Ch4/Aq1 sequence boundary of the European cyclic chart of Hardenbol et al. (1998) and with E6/Kw0 of Miller et al. (2005).

**Nukhul Sequence B**

Nukhul Sequence B falls within the Globigerinoides primordius Zone and corresponds to Unit 4. A lowstand systems tract is not recognized in this sequence. The oldest deposits show high planktic
ratios ranging from 60–80% with good preservation and a marked increase in genus *Globigerinoides*. The benthonic foraminifera are characterized by high diversity and abundant species of *Nonion* and *Bulimina*. A middle neritic environment is suggested for this interval. The MFS coincides with the maximum abundance of planktonic foraminifera and marks the change from deepening-upward to shallowing-upward biofacies deposits (Figure 3).

The overlying regressive deposits (HST), comprising the uppermost part of the Nukhul Formation, consist of sandy limestone rich in worm tubes. It exhibits: (1) a clear drop in planktonic/benthic (P/B) ratio, (2) a general decrease in faunal diversity, (3) an abundant occurrence of *Elphidium* biofacies, and (4) an absence of planktonic foraminiferal tests reflecting near shore paleoenvironments. The post-Nukhul event marks the transition between the tectonically stable conditions during the Nukhul deposition to the rapid subsidence and deep, open marine conditions, existed during deposition of the Rudeis Formation (Evans, 1988).

**CONCLUSIONS**

The present study attempts to throw light on the age of the Nukhul Formation, which is a controversial point in the stratigraphy of Egypt. The Nukhul Formation is marked by a rich reworked and syn-sedimentary foraminiferal assemblage. This reworked fauna reaches about 30% at the base of the Nukhul Formation at Wadi Baba section. This ratio decreased from base to top at this section. The detailed examination of the faunal contents of these reworked units was neglected in previous works.

The Upper Oligocene ( Chattian)–Lower Miocene (Aquitanian) Nukhul Formation in Wadi Baba contains rich planktonic and benthonic foraminifera: 17 planktonic and 17 benthonic species are identified. The formation is classified into *Globigerina ciperoensis* Zone (O6) of Late Oligocene (Chattian) age and *Globigerinoides primordius* Zone (M1) of Early Miocene (Aquitanian) age at top. This marine Upper Oligocene is correlated with a similar previous records in surface (Shahin 1998, 2000) and subsurface (Ouda and Masoud, 1993) areas of the Gulf of Suez. This may imply that the Clysmic rifting is older than the Chattian.

Based on sequence-stratigraphic analysis, two third-order depositional sequences, bounded by three major well-recognized unconformity surfaces, were recognized. These surfaces are coincident with the Middle Eocene/Late Oligocene (Chattian), Chattian/Aquitanian and Aquitanian/Burdigalian boundaries.

**ACKNOWLEDGEMENTS**

The authors are indebted to the three reviewers for their critical reading of the manuscript, and Moujahed Al-Husseini for helpful comments, support and encouragement. Deep thanks to Abdel Aziz Tantawy of Aswan Faculty of Science South Valley University, for checking the nannofossil content of the samples. We also thank GeoArabia Designer Arnold Egdane for designing the paper for press, and Kathy Breining for proof-reading it.

**REFERENCES**

Abul-Nasr, R.A. and G.R. Salama 1999. Paleoecology and depositional environments of the Miocene rocks in western Sinai, Egypt. Middle East Research Center Ain Shams University, Earth Science Series 13, p. 92-134.

Al-Husseini, M.I. 2008. Launch of the Middle East Geological Time Scale 2008. GeoArabia, v. 13, no. 4, p. 185-188.

Amundsen, H.E.F., T.A. Hellem, S.D. Prosser, M. Darwish, A.N. El-Barkkoy and N. Tewfik 1998. Dating and correlation within the Nukhul Formation, Gulf of Suez, using \(^{87}\text{Sr}/^{86}\text{Sr} \) stratigraphy. In “International structural and sequence stratigraphic analysis in Rift settings”. American Association of Petroleum Geologist, Hedberg Conference, Cairo, Egypt. Extended abstract.

Andrawis, S.F. and W.M. Abdel Malik 1981. Lower Miocene boundary in the Gulf of Suez region, Egypt. News Stratigraphy, v. 10, no. 3, p. 156-163.

Banner, F.T. and W.H. Blow 1965. Progress in the planktonic foraminiferal biostratigraphy of the Neogene. Nature, v. 208, p. 1164-1166.

Berggren, W.A. and P.N. Pearson 2005. A revised tropical and subtropical Paleogene planktonic foraminiferal zonation. Journal of Foraminiferal Research, v. 35, p. 279-298.
Blow, W.H. 1959. Age, correlation and biostratigraphy of the upper Tocuyo (San Lorenzo) and Pozón formations, eastern Falcon, Venezuela. Bulletin of the American Paleontology, v. 39, no. 178, p. 67-252.

Blow, W.H. 1969. Recent planktonic foraminiferal biostratigraphy. Proceedings of the First International Conference, Planktonic Microfossils, Leiden, E.J. Brill, v. I, p. 199-242.

Blow, W.H. 1979. The Cenozoic Globigerina. E.J. Brill, Leiden 3 volumes. 1413 p.

Blow, W.H. and F.T. Banner 1962. The Mid-Tertiary (Upper Eocene to Aquitanian) Globigerinaceae. In F.E. Eames, F.T. Banner, W.H. Blow and W.J. Clarke (Eds.), Fundamentals of Mid-Tertiary Stratigraphical Correlation, p. 61-151.

Bolli, H.M. 1954. Note on Globigerina concinna Reuss 1850 (Point-a-Pierre, Trinidad). Contributions from the Cushman Foundation for Foraminiferal Research, v. 5, no. 1, p. 1-3.

Bolli, H.M. 1957a. Planktonic foraminifera from the Oligocene-Miocene Cipero and Lengua formations of Trinidad, B.W.I. In A.R. Loeblich, H. Tappan, J.P. Beckmann, H.M. Bolli, E.M. Gallitelli and J.C. Troelsen (Eds.), Studies in Foraminifera. Bulletin of the United States National Museum, v. 215, p. 97-123.

Bolli, H.M. 1957b. Planktonic foraminifera from the Eocene Navet Formation and San Fernando formations of Trinidad, B.W.I. Bulletin of the United States National Museum, v. 215, p. 155-172.

Bolli, H.M. 1966. Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera. Boletin Informativo Asociacion Venezolana de Geologia, Mineria y Petroleo v. 9, p. 3-32.

Bolli, H.M. and I. Premoli Silva 1973. Oligocene to Recent Planktonic foraminiferal biostratigraphy and stratigraphy of the Leg 15 sites in the Caribbean Sea. Washington, D.C., Initial Reports of the Deep Sea Drilling Project, v. 15, p. 475-497.

Bolli, H.M. and J.B. Saunders 1985. Oligocene to Holocene low latitude planktic foraminifera. In H.M. Bolli, J.B. Saunders and K. Perch-Nielsen (Eds.), Plankton Stratigraphy. Cambridge University Press, Cambridge, p. 155-262.

Bolli, H.M., A.R. Loeblich and H. Tappan 1957. The Planktonic foraminiferal families Hantkeninidae, Orbulinidae, Globorotaliidae, and Globotruncanidae. Bulletin of the United States National Museum, v. 215, no. 1, p. 3-50.

Bosworth, W., P. Huchon and K. Mc Clay 2005. The Red Sea and Gulf of Aden Basins. Journal of African Earth Sciences, v. 43, p. 334-378.

Brönninger, P. 1953. Arenaceous foraminifera from the Oligo-Miocene of Trinidad. Cushman Foundation for Foraminiferal Research, Contributions, 4:87-100, pl. 15, text figures 1-15.

Brönninger, P. and J. Resig 1969. A Neogene Globigerinacea biochronologic time-scale of the southwestern Pacific. In Initial Reports of the Deep Sea Drilling Project, v. 7, p. 1235-1469.

Chaisson, W.P. and R.M. Leckie 1993. High-resolution planktonic foraminifer biostratigraphy of site 806, Ontong Java Plateau (Western Equatorial Pacific). In W.H. Berger, L.W. Kroenke, L.A. Mayer, et al. (Eds.), Proceedings of the Ocean Drilling Program, Scientific Results, v. 130 p. 157-178.

Cita, M.B. 1968. Planktonic foraminiferal biostratigraphy of the Mediterranean Neogene. Progress in Micropaleontology, Special Publication, Micropaleontology Press, the American Museum of Natural History, New York p. 47-68.

Cushan, J.A. and R.M. Stainforth 1945. The foraminifera of the Cipero Marl Formation of Trinidad, British West Indies. Washington, D.C., Cushman Laboratory For Foraminiferal Research, Special Publication no. 14, 75 p.

Egyptian General Petroleum Corporation “E.G.P.C”, 1964. Oligocene and Miocene rock-stratigraphy of the Gulf of Suez region. Unpublished report of the Stratigraphic Committee, 142 p.

El-Deeb, W.Z.M., A. Al Ashwah and M.M. Mandur 2004. Planktonic foraminifera and calcareous nannoplankton biostratigraphy of the lower and middle Miocene sequence in Wadi Gharandal, southwest Sinai, Egypt. Egyptian Journal of Petroleum, v. 13, no. 1, p. 105-122.

El Heiny, I. and S. Morsi 1981. Miocene foraminiferal and calcareous nanno-plankton assemblages from the Gulf of Suez region and correlation. Geology Mediterranean, v. 8, no. 2, p. 101-108.

El Heiny, I. and S. Morsi 1992. Stratigraphic correlation of Neogene sediments in the eastern Nile Delta and Gulf of Suez, Egypt. 11th Petroleum Exploration and Production Conference of the Egyptian General Petroleum Company “EGPC”, v.11, no.2, p. 166-193.

El-Azabi, M.H. 1996. A new suggested stratigraphic level for the Miocene Sarbût El-Gamal Formation in the Gulf of Suez, Egypt; A sedimentologic approach. 3rd International Conference on the Geology of the Arab World, Cairo University, p. 407-432.

El-Azabi, M.H. 2004. Facies characteristics, depositional styles and evolution of the syn-rift Miocene sequences in Nukhul-Feiran area, Sinai side of the Gulf of Suez rift basin, Egypt. Sedimentology of Egypt, v. 12, p. 69-103.

El-Barkooky, A.N., A. El-Araby and R. Gaupp 2006. Early syn-rift deposition of Alluvial-lacustrine facies in Wadi Nukhul, west central Sinai, Egypt. Egyptian Journal of Geology, v. 50, p. 141-169.

El-Deeb, W.Z.M., A. Al Ashwah and M.M. Mandur 2004. Planktonic foraminifera and calcareous nannoplankton biostratigraphy of the lower and middle Miocene sequence in Wadi Gharandal, southwest Sinai, Egypt. Egyptian Journal of Petroleum, v. 13, no. 1, p. 105-122.

El Heiny, I. and E. Martini 1981. Miocene foraminiferal and calcareous nanno-plankton assemblages from the Gulf of Suez region and correlation. Geology Mediterranean, v. 8, no. 2, p. 101-108.

Evans, A.L. 1988. Neogene tectonic and stratigraphic events in the Gulf of Suez rift area, Egypt. Tectonophysics, v. 153, p. 235-247.

Garfunkel, Z. and Y. Bartov 1977. The tectonics of the Suez rift. Geological Survey of Israel Bulletin, v. 71, p. 1-44.

Haggag, M.A., M.I. Youssef and G.R. Salama 1990. Stratigraphic and phylogenetic relationships of Miocene planktonic foraminifera from the Gulf of Suez, Egypt. Middle East Research Center, Ain Shams University, Earth Science Series, v. 4, p. 22-40.

Han, B.U., J. Hardenbol and P.R. Vail 1987. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. Society of Economic Paleontologists and Mineralogists, v. 42, p. 71-108.

Hardenbol, J., J. Thierry, T. Jacquin, P.-C. de Graciansky and P.R. Vail 1998. Mesozoic-Cenozoic sequence chronostratigraphic framework of European basins. In P.-C. de Graciansky, J. Hardenbol, T. Jacquin and P.R. Vail (Eds.), Sequence stratigraphy of European basins. SEPM Special Publication, v. 60, p. 3-14.

Hedberg, H.D. 1937. Foraminifers of the middle Tertiary Carapita Formation of northeastern Venezuela. Journal of Paleontology, v. 11 no. 8, p. 661-697.

Hooke, H.V. and W.E. Wallace 1932. Foraminifera of the Jackson Eocene at Danville Landing on the Ouachita, Catoahula Parish, Louisiana. Bulletin Louisiana, Department of Conservation Geology v. 2, p. 18-79.

Kendall, J.P. and M.S. Srinivasan 1983. Neogene planktonic foraminifera, A Phylogenetic Atlas. Hutchinson Ross, Stroudsburg, Pennsylvania, 265 p.

Kučenjak, M. H., V.P. Fuček, R. Slavković and I. Mesić 2006. Planktonic foraminiferal biostratigraphy of the late Eocene and Oligocene in the Palmyride area, Syria. Geologia Croatica, v. 59, no. 1, p. 19-39.

Le Roy, L.W. 1939. Some small foraminifers, ostracoda and ootoliths from the Neogene ("Miocene") of the Rokan-Tapanoeli area, Central Sumatra. Natuurk. Tijdschr. Ned. Indie, v. 99, no. 6, p. 215-296, plates 1-4.
APPENDIX A: PLANKTONIC FORAMINIFERA

Plate 1 (Figures 1–3):

**Order:** Foraminiferida Eichwald, 1830  
**Suborder:** Globigerinina Delage & Herouard, 1896  
**Superfamily:** Heterohelicacea Cushman, 1927  
**Family:** Chiloguembelinidae Reiss, 1963  
*Laterostomella pristinum* (Brönnimann & Resig, 1969)  
(Plate 1, Figures 1 and 2, sample 45)  
*Streptochilus pristinus* Brönnimann & Resig, 1969, p.1289 pl. 51, Fig. 4

**Remarks:** *Laterostomella* was originally placed in the Bolivinitidae but is a planktonic taxon. *Laterostomella* is the synonym of *Streptochilus* (Loeblich and Tappan, 1988).

**Superfamily:** Globorotaliacea Cushman, 1927

**Family:** Globorotaliidae Cushman, 1927  
*Paragloborotalia mayeri* (Cushman & Ellisor, 1939)  
(Plate 1, Figure 3, sample 45)  
*Globorotalia mayeri* Cushman & Ellisor, 1939, p.11 pl. 2, Figs 4a-c.  
*Paragloborotalia mayeri* (Cushman & Ellisor). Chaisson & Leckie 1993, p. 176, pl. 8; Figs. 16-20.

**Remarks:** This species is characterized by 5 to 6 chambers in the last whorl, slightly elongate equatorial periphery. The last chamber is sac-like resulting in a curved suture between the last two chambers.

Plate 1 (Figures 4–6):

*Paragloborotalia opima nana* (Bolli, 1957b)  
(Plate 1, Figures 4–6, sample 52)  
*Globorotalia opima nana* Bolli, 1957b, p. 118 pl. 28, Figs. 3a-c.  
*Paragloborotalia opima nana* (Bolli). Spezzaferri and Silva (1990), p.251 pl. XI; Figs. 4a-c.

**Remarks:** This species is distinguished from *Paragloborotalia opima opina* by its smaller size and four chambers in the last whorl compared to the larger size and more chambers (5 chambers) in the last whorl.

*Plate continued on next page.*
Plate 1 (Figures 7–11):

**Family:** Candeinidae Cushman, 1927
*Tenuitellinata angustiumbilicata* (Bolli, 1957b)
(Plate 1, Figures 7–10, sample 44)
*Globigerina ciperensis angustiumbilicata* Bolli, 1957b, p.109, pl. 22, Figs. 12a-13c.
*Tenuitellinata angustiumbilicata* (Bolli). Chaisson & Leckie, 1993, p. 169, pl. 1; Fig. 9.
**Remarks:** It differs from all Globigerina ciperensis subspecies in its narrow, almost closed umbilicus, 4–5 chambers in the last whorl.

**Family:** Catapsydracidae Bolli, Loeblich and Tappan (1957)
*Catapsydrax* sp.
(Plate 1, Figure 11, sample 45)
**Remarks:** The species is marked by four chambers in the last whorl and a well-developed bulla covering the umbilicus. Our specimen is marked by coarser textured bulla. It is close to *Catapsydrax dissimilis* (Cushman & Bermudez).

Plate 1 (Figures 12–17):

*Globorotaloides suteri* Bolli 1957
(Plate 1, Figures 12 and 13, sample 45)
*Globorotaloides suteri* Bolli, 1957b, p. 117 pl. 27, Figs. 9a-13b.
**Remarks:** This species is characterized by a final bulla like chamber, which is quite variable in size and shape. Bolli and Saunders, 1985 noted that “quite frequently this last bulla-like chamber may be absent”, the case which observed in our material.

**Family:** Cassigerinellidae Bolli, Loeblich and Tappan (1957)
*Cassigerinella chipolensis* Cushman & Ponton, 1932
(Plate 1, Figures 14–17, sample 52)
*Cassidulina chipolensis* Cushman & Ponton, 1932, p.98, pl. 15 Figs. 2a-c.
**Remarks:** The species is characterized by alternating chambers arrangement throughout the final whorl, inflated chambers resulting in a more rounded periphery.
*Plate continued on facing page.*
Superfamily: Globigerinaceaе Carpenter, Parker & Jones, 1862
Family: Globigerinidae Carpenter, Parker & Jones, 1862

Globigerina ciperoensis Bolli, 1954
(Plate 1, Figures 18–20, sample 45)
Globigerina ciperoensis Bolli, 1954, p. 1, Figs. 3-6.
Remarks: The species is characterized by a relatively small size of about 0.3 mm in diameter, a relatively low trochospiral test, and 5 chambers in the final whorl which gradually increase in size. The chambers of the earlier whors are distinct and well separated with 5 per whorl. The umbilicus is large, open, and pentagonal in shape, with a distinct umbilical aperture. The wall is non-cancellate spinose. Globigerina ciperoensis is consistent in size and morphology.

Globigerina praebulloides Blow, 1959
(Plate 1, Figures 21 and 22, sample 45)
Globigerina praebulloides Blow, 1959, p.180 pl. 8, Figs. 47a-47c.
Globigerina (Globigerina) praebulloides (Blow). Kennett and Srinivasan (1983), p. 36 pl. 6; Figs. 1-3.
Remarks: Globigerina praebulloides Blow is ancestral to Globigerina bulloides d’Orbigny, from which it differs in having elongate equatorial profile and smaller, less strongly arched aperture.

Globigerina praebulloides occlusa Blow & Banner, 1962
(Plate 1, Figures 23–25, sample 46)
Globigerina praebulloides occlusa Blow & Banner, 1962, p. 93, pl. 9, figs. U-W.
Remarks: Globigerina praebulloides occlusa is marked by its shallower umbilicus, smaller aperture and more coarsely perforate wall.

Globigerina venezuelana Hedberg, 1937
(Plate 1, Figures 26 and 27, sample 45)
Globigerina venezuelana Hedberg, 1937, p. 681 pl. 92, figs. 7a-b.
Remarks: This species is marked by 3.5–4 less inflated chambers, low trochospirally arranged in the last whorl.
Globigerinoides immaturus Le Roy, 1939
(Plate 2, Figures 1–2, sample 58)
Globigerinoides sacculifer Brady, var. immaturus Le Roy (1939), p.263, pl.3, Fig. 19-21.
Remarks: This subspecies is differentiated from the Globigerinoides trilobus by having smaller, less
inflated ultimate chamber which does not embrace the earlier chambers. Also it has low arched
primary aperture with one secondary aperture on spiral side. This taxon differs also from
Globigerinoides sacculifer in the absence of terminal sac-like chamber.

Globigerinoides primordius Blow and Banner, 1962
(Plate 2, Figures 3–4, sample 58)
Globigerinoides primordius Blow and Banner, 1962, p.15, pl- ix figs- Dd-Ff.
Remarks: This taxon is distinguished by its low trochospiral test, four chambers in last whorl,
low-arched primary aperture with single dorsal aperture on the ultimate chamber. This taxon
differs from Globigerina praebulloides or Globigerina woodi in having one dorsal aperture and is
differentiated from Globigerinoides altiaperturus by having low arched primary aperture. The
Globigerinoides quadrilobatus primordius is very rare, short-lived taxon in the early Miocene deposits
of the study area.

Globigerinoides subquadratus Brönnimann, 1953
(Plate 2, Figures 5–7, sample 58)
Globigerinoides subquadratus Brönnimann, 1953, p. 680, pl. 1, Figs. 8a–c.
Remarks: Subquadrate shape; three chambers in the last whorl, primary aperture with two
supplementary smaller apertures. This taxon differs from Globigerinoides ruber in being more
compressed test, subquadrate in outline and with high arched primary aperture.

Globigerinoides trilobus (Reuss), 1850
(Plate 2, Figures 8–10, sample 58)
Globigerina trioba Reuss, 1850, p. 374, pl. 447, Fig. 11a–c.
Remarks: Globigerinoides trilobus is distinguished by its relatively low arched, slit-like primary
aperture and supplementary apertures. The nominate taxon differs from Globigerinoides immaturus
in having more inflated final chamber which tends to embrace the earlier part of the test.

Globoturborotalita gnaucki (Blow & Banner), 1962
(Plate 2, Figures 11 and 12, sample 45)
Globigerina ouachitaensis gnaucki Blow & Banner, 1962, p.91, pl. IX, Figs. 1–n.
Globoturborotalita gnaucki (Blow & Banner). Pearson et al. (2006) p.124, pl. 6.4; Figs. 1–15.
Remarks: Wall cancellate, normal perforate, spinose. Test moderately low trochospiral, globular,
lobulate in outline, chambers globular; slightly embracing chambers in ultimate whorl, increasing
moderately in size, sutures depressed, straight; in umbilical side, aperture umbilical, a rounded
arch, bordered by a thin thickened rim.
Plate continued on facing page.
Plate 2 (Figures 13–15):

Globoturborotalita ouachitaensis (Howe & Wallace), 1932
(Plate 2, Figures 13–15, sample 45)
Globigerina ouachitaensis Howe & Wallace, 1932, p.74 pl. 10, Figs. 7a-b.
Globoturborotalita ouachitaensis (Howe & Wallace). Pearson et al., 2006, p.127, pl. 6.5; Figs. 1–16.
Remarks: This species is characterized by its small size, 4 globular, slightly embracing, chambers in the ultimate whorl, umbilical aperture, and cancellate, spinose wall texture.

Some identified reworked planktonic Eocene species

Plate 2 (Figures 16–26):

Chiloguembelina cf. cubensis (Palmer), 1934
(Plate 2, Figure 16, sample 45)
Turborotalia increbescens (Bandy), 1949
(Plate 2, Figures 17–18, sample 45)
Truncorotaloides spp.
(Plate 2, Figures 19–23, sample 45)
Pseudohastigerina micra (Cole), 1927
(Plate 2, Figures 24–26, sample 57)
Plate 3: See facing page for caption.
Plate 3 (Figures 1–32):

Suborder: Lagenina Delage and Herouard, 1896
Superfamily: Nodosariacea Ehrenberg, 1838
Family: Vaginulinae Reuss, 1860
Subfamily: Lenticulinae Chapman, Parr, and Collins, 1934
Lenticulina submamiliger (Cushman, 1917)
(Plate 3, Figures 1–3, sample 45)

Suborder: Rotaliina Delage and Herouard, 1896
Superfamily: Bolivinacea Glaessner, 1937
Family: Bolivinidae Glaessner, 1937
Bolivia shukrii shukrii (Cushman, 1951)
(Plate 3, Figure 4, sample 52).
Bolivia oligoconica Spandel, 1909
(Plate 3, Figure 5, sample 45)
Bolivia shukrii shukrii Souaya, 1965
(Plate 3, Figure 6, sample 52)

Superfamily: Cassidulinacea d’Orbigny, 1839
Family: Cassidulinidae d’Orbigny, 1839
Subfamily: Cassidulininae d’Orbigny, 1839
Cassidulina crucyi Marks, 1951
(Plate 3, Figures 7–9, sample 45)
Cassidulinoides bradyi Norman, 1881
(Plate 3, Figures 10 and 11, sample 45)

Superfamily: Buliminacea Jones, 1875
Family: Siphogenerinoididae Saidova, 1981
Subfamily: Tubulogenerininae Saidova, 1981
Rectuvigerina krachemensis Magne’ and Sigal, 1954
(Plate 3, Figure 12, sample 45)

Superfamily: Buliminacea Jones, 1875
Family: Buliminidae Jones, 1875
Bulimina elongata tenera Reuss 1947
(Plate 3, Figure 13, sample 45)
Bulimina striata d’Orbigny, 1837
(Plate 3, Figure 14, sample 45)
Buliminella cuvillieri Souaya, 1965
(Plate 3, Figure 15, sample 45)

Superfamily: Discorbacea Ehrenberg, 1838
Family: Bagginidae Cushman, 1927
Subfamily: Baggininae Cushman, 1927
Baggina regularis d’Orbigny, 1846
(Plate 3, Figure 16, sample 45)

Superfamily: Nonionacea Schultze, 1854
Family: Nonionidae Schultze, 1854
Subfamily: Nonioninae Schultze, 1854
Nonion bouanus d’Orbigny, 1846
(Plate 3, Figures 17–19, sample 45)
Nonion scapha Fichtel and Moll, 1798
(Plate 3, Figures 20–22, sample 45)

Subfamily: Astronomioninae Saidova, 1981
Astronomion italicus Cushman and Edwards, 1937
(Plate 3, Figures 23–26, sample 45)

Superfamily: Chilostomellacea Brady, 1881
Family: Alabaminidae Hofker, 1951
Alabamina perlata Andreea 1884
(Plate 3, Figures 27–28, sample 45)

Superfamily: Rotaliacea Ehrenberg, 1838
Family: Rotaliidae Ehrenberg, 1838
Subfamily: Ammoniinae Saidova, 1981
Ammonia beccarii (Linné), 1758
(Plate 3, Figures 29–30, sample 45)

Suborder: Rotaliina Delage and Herouard, 1896
Superfamily: Rotaliacea Ehrenberg, 1838
Family: Elphidiidae Galloway, 1933
Subfamily: Elphidiinae Galloway, 1933
Elphidium fichtelianum praforme Papp, 1963
(Plate 3, Figures 31–32, sample 45)

REFERENCES (continued)

Loeblich, A. Jr. and H. Tappan 1988. Foraminiferal genera and their classification. Von Nostrand Reinhold Co., New York, 970 p.
Mancin, N., C. Pirini, E. Bicchi, E. Ferrero and V. Gigliola 2003. Middle Eocene to middle Miocene planktonic foraminiferal biostratigraphy for internal basins (Monferrato and northern Appennines, Italy). Micropaleontology, v. 49, no. 4, p. 341-358.
Miller, K.G., M.A. Kominz, J.V. Browning, J.D. Wright, G.S. Mountain, M.E. Katz, P.J. Sugarman, B.S. Cramer, N. Christie-Blick and S.F. Pekar 2005. The Phanerozoic record of global sea-level change. Science, v. 310, p. 1293-1298.
Moustafa, A.R. 2004. Exploratory notes for the geologic maps of the eastern side of the Suez rift (western Sinai Peninsula), Egypt. American Association of Petroleum Geologists/Datapages, Incorporated, GIS Series (2004), 34 p.
Naish, T. and Kamp, P.J. 1997. Foraminiferal depth palaeoecology of Late Pliocene shelf sequences and systems tracts, Wanganui Basin, New Zealand. Sedimentary Geology, v. 110, p. 237-255.
National Stratigraphic Subcommittee “N.S.S.C” 1974. Miocene rock stratigraphy in the Gulf of Suez region, Egypt. Journal of Geology, v.18, p. 1-59.
Ouda, K. 1998. Biostratigraphy, paleoecology and paleogeography of the Middle and Late Tertiary deposits of the northern Western Desert, Egypt. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, v. 207, no. 3, p. 311-394.
Ouda, K. and M. Masoud 1993. Sedimentation history and geological evolution of the Gulf of Suez during the Late Oligocene-Miocene. Geological Society of Egypt, Special publication, v. 1, p. 47-88.
Pearson, P.N., R.K. Olsson, C. Hemleben, B.T. Huber and W.A. Berggren 2006. Atlas of Eocene Planktonic Foraminifera. Cushman Foundation Special Publication, V. 41, 513 p.

Phillip, G., M.M. Imam and G.I. Abdel Gawad 1997. Planktonic foraminiferal biostratigraphy of the Miocene sequence in the area between Wadi El-Tayiba and Wadi Sidri, west central Sinai, Egypt. Journal of African Earth Sciences, v. 25, no. 3, p. 435-451.

Postuma, J.A. 1971. Manual of Planktonic foraminifera. Elsevier Publishing Co., Amsterdam, 420 p.

Reuss, A.E. 1850. Neue foraminiferen aus den Schichten des Osterreichischen Tetiarbeeken. Koeniglich Akademie der Wissenschaften, Wien, Klasse, Denkschriften, v. 1, p. 365-390.

Said, R. 1962. The Geology of Egypt. Elsevier Publishing Co., Amsterdam, 377 p.

Said, R. and I. El Heiny 1967. Planktonic Foraminifera from the Miocene rocks of the Gulf of Suez region, Egypt. Cushman Foundation Foraminiferal Research, v. 18, p. 14-26.

Schlumberger, 1984. Well Evaluation Conference, Egypt. Geology of Egypt, p. 1-64.

Shahin, A. 1998. Tertiary planktonic foraminiferal biostratigraphy and paleobathymetry at Gebel Withir, southwestern Sinai, Egypt. Neues Jahrbuch Geologie Paläontologie, Abhandlungen, v. 209, no. 3, p. 323-348.

Shahin, A. 2000. Biostratigraphic significance, paleobiogeography and paleobathymetry of Tertiary Buliminacea and Bolivinacea in the western Sinai, Egypt. Neues Jahrbuch Geologie Paläontologie, Abhandlungen, v. 216, no. 2, p. 195-231.

Souaya, F.J. 1965. Miocene foraminifera of the Gulf of Suez region, U.A.R. Part I. Systematics (Astrorhizidea. - Buliminoidea). Micropaleontology, v. 11, p. 301-334.

Souaya, F.J. 1966. Miocene foraminifera of the Gulf of Suez region, U.A.R. Biostatigraphy. Micropaleontology, v. 12, no. 2, p. 183-202.

Spezzaferri, S. and I.S. Silva 1990. Oligocene planktonic foraminiferal biostratigraphy and paleoclimatic interpretation from Hole 538A, DSDP Leg 77, Gulf of Mexico. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 83, p. 217-263.

Wade, B.S., P.N. Pearson, W.A. Berggren and H. Pälike 2010. Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale. Earth Science Reviews, v. 104, p. 111-142. doi: 10.1016/j.earscirev.2010.09.003.

ABOUT THE AUTHORS

Abdel Galil A. Hewaidy was awarded a PhD in 1983 from Al-Azhar University, Cairo, Egypt. In 1989 he became an Assistant Professor and since 1995 he is a Professor of Micropaleontology and Stratigraphy in the same university. Abdel Galil worked from 1983 to 1987 as a consultant for micropaleontologic and stratigraphic studies in Suez Oil Company in Cairo. He served from 1987 to 1992 as a Lecturer and Assistant Professor of Micropaleontology and Stratigraphy in Qatar University. Abdel Galil became Chairman of the Geology Department at Al-Azhar University from 2005 to 2010. He is the Editor of the Egyptian Journal of Paleontology from 2001 to now and has published ten volumes of that journal. He is the member of the organizing committee of the Scientific Annual Meeting of the Paleontological Society of Egypt from 2001 to 2011. He has published numerous articles in many local and international journals.

ahewaidy50@yahoo.com

Sherif Farouk obtained a PhD in 2006 from Al-Azhar University, Egypt. He worked as a Field Geologist in the Geological Survey of Egypt from 1996 to 2007, and gained a wide field experience in most sedimentary provinces of Egypt. From 2007 until now he is a researcher at the Exploration Department of the Egyptian Petroleum Research Institute, Cairo.

geo.sherif@hotmail.com

Haitham M. Ayyad is currently working as an Assistant Lecturer in the Geology Department at Al-Azhar University, Egypt. He is a member of American Association of Petroleum Geologists (AAPG), Paleontological Society of Egypt (PSE) and the Geological Society of Egypt (GSE). Previously, he worked as a geologist in the General Petroleum Company of Egypt (GPC) in the development administration of the Western Desert fields. He received a BSc in Geology from Al-Azhar University in 2006 with honors.

goldenayyad@yahoo.com

Manuscript received March 13, 2011; Revised June 13, 2011; Accepted June 26, 2011