
BIOSTRATIGRAPHY, MICROFACIES ANALYSIS AND SEQUENCE STRATIGRAPHY OF THE MIOCENE SUCCESSIONS IN CAIRO-SUEZ DISTRICT, EGYPT

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ABSTRACT

Two Miocene sections in Cairo-Suez district at Tall Zamzam and Wadi Hommath are detailed examined for their foraminiferal, nannofossil contents and microfacies types. Wadi Hommath section is named as the Sadat Formation, while Tall Zamzam section is named as the Genefe Formation. 21 species of planktonic, 20 species of benthic, 19 species of nannofossils are identified. Two zones of planktonic foraminifera and one zone of nannofossil attributed the Sadat Formation to *Globigerinoides bisphericus* (M4) Zone, *Praeorbulina sicana* (M5a) Zone and Genefe Formation to *Praeorbulina glomerosa* (M5b) Zone, while *Helicosphaera ampliamperta* Zone (NN4) of (Burdigalian-Langhian) age is recorded in the two studied sections. The identified benthic foraminifera was used to recognize three biofacies types: Nonion biofacies of inner-shelf environment, *Cibicides* biofacies of middle-shelf environment and *Uvigerina* biofacies of outer-shelf environment. Six microfacies types are identified. These successions are subdivided into three depositional sequences of which 2 fourth order and one third order sequences.

Keywords: Foraminifera, nannoplankton, sequence stratigraphy, Miocene, Cairo-Suez district, Egypt.

1. INTRODUCTION

The exposed rock units in Cairo-Suez district fall within a span of time beginning with the Late Early Eocene in the east followed westward by other different rock units of Eocene, Oligocene and Miocene time units. 36 representative rock samples were collected from these sections as follows: 13 rock samples from Wadi Hommath, 23 rock samples from Tall-Zamzam (Fig. 1). The Paleocene sediments are totally missing or not exposed in the study area. These encountered rock units were greatly influenced by the events which prevailed over the Red Sea and Gulf of Suez regions during the late stage of the Eocene and continued to the Late Miocene (Patton et al.1994). The most common event was the Gulf of Suez rifting, which resulted in the displacement of many blocks relatively to each other giving rise to a complex stratigraphic setting on both sides of the Gulf (Steckler et al. 1988; Issawi 2002, 2005; Osman 2003; Issawi et al. 2009).

2. MATERIALS, METHODS AND DEPOSITORY

Two stratigraphic Miocene sections along Cairo-Suez district were measured at Wadi

Hommath towards east, and Tall Zamzam towards west. To describe the sedimentary structures and microfacies types of the studied succession, 13 petrographic thin sections from the calcareous units were examined (e.g. sandy limestones; Fig. 2). A standard petrographic microscope equipped with a digital camera was used to qualitatively identify the microfossils in the thin sections. Microfacies analysis was carried out using the standard models of Wilson (1975) and Flugel (2010). The texture of the carbonate rocks was described based on Dunham's classification scheme (1962), as refined by Embry and Klovan (1971). The mixed siliciclastic-carbonate rocks were characterized using the principles proposed in the classification of Mount (1985). Microfacies classification was carried out by the combined analysis of the mineralogical components, macro- and microfossil assemblages, and textures of the samples observed in the thin sections. The sequence stratigraphic interpretation is based upon bounding surface characteristics, vertical cycle stacking patterns and variations in the depositional facies and their interpreted environments. The identified foraminifera as well as nannofossils are deposited in the collection of Prof. Abd el Galil Hewaidy, Azhar University, Faculty of Science.

3. LITHOSTRATGRAPHY

The Neogene sediments are exposed in Cairo-Suez district at Tall Zamzam, Wadi Ghoweiba, Wadi Hagul, and to the north at Gebel Iweibed, Gebel Homeiyra, and Gebel Gharra. The central part of the Cairo–Suez district consists of a nearly parallel, high mountain ridges trending in an E–W and NW–SE directions with lowlands in-between. The Middle Eocene and Miocene rocks mainly build the mountains and high scarps overlooking both sides of the Qattamiya–Ain Sukhna road, while both the Upper Eocene and Oligocene sediments fill the low topographic areas. The Miocene sequence in the studied stratigraphic sections is characterized by considerable lateral facies changes from east to west of the Cairo–Suez district. These rock units belong to the Early and Middle Miocene and represented by Sadat, Gharra (Early Miocene), Hommath and Genefe (Middle Miocene).

Sadat Formation

The Sadat Formation named by Abdallah and Abdelhady (1966) at Wadi El Ramiya, Sadat Quarry, Suez-Sukhna district and assigned it an early Miocene (Burdigalian) age. the Sadat Formation measures 98 m in thickness and overlies unconformably the Eocene strata and underlies the Middle Miocene Hommath Formation. According to Cherif and Yehia (1977), it can be subdivided into the Taratir member at base and Quarry member at top. The Sadat Formation, as a lower subdivision of the Miocene succession, exclusively occupies the northeastern reach of the studied area. The formation also crops out in the upper reach of Wadi Hagul. It transgressively overlaps either the Middle or Upper Eocene rocks and is downlapped westward by the younger Miocene rocks.

In the studied area, the Sadat Formation has been measured and described at Wadi Hommath area. It attains about 13m thick and consists of white to pale yellow limestone intercalated by yellowish brown, fine to coarse calcareous sandstone (Fig.2). These sandstones

are intercalated by shale at the base, and shell bed of sandy fossiliferous limestone at the top. The shell beds are commonly formed of large, thick-shelled oysters including *Ostrea* sp

Genefe Formation

The name Genefe Member was first used by Ghorab and Marzook (1965) to describe the uppermost limestone beds (ca \approx 68.5m thick) of the Genefe Formation at Gebel Genefe, west of the Suez Canal. Said (1990) raised this unit to formational rank and assigned it to the middle Miocene (Langhian) age. The Genefe Formation in the present study is measured and described at Tall Zamzam section (Fig. 3). It is made up of yellowish white to snow white algal limestone (about 23m thick) that is unconformably overlain by the upper Miocene non-marine sediments. The lower part of the Genefe Formation at Tall Zamzam section is measured and described along several trenches. It is composed of yellow, massive, argillaceous limestone rests on yellowish brown, planner cross-bedded, fine to coarse grained sandstone, medium grained calcareous sandstone with mudstone intercalations at the base (Fig. 3,4). These deposits overlie unconformably the Oligocene weathered basalt and reddish brown, gravely sandstones.

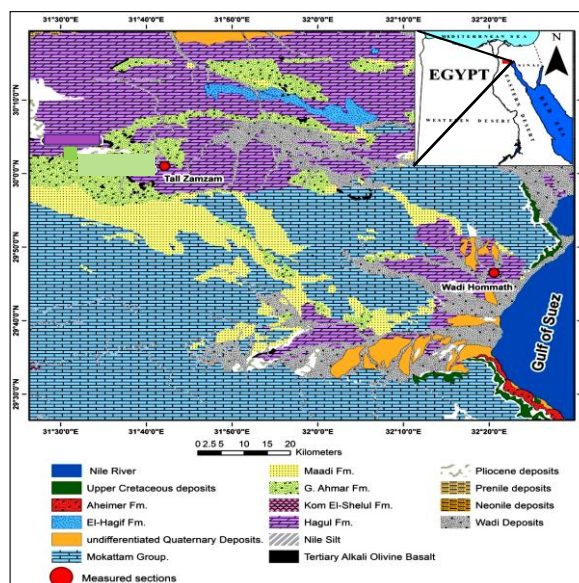


Figure 1: Geological map of Cairo-Suez district, showing the location of the measured sections (modified after Conoco, 1987).

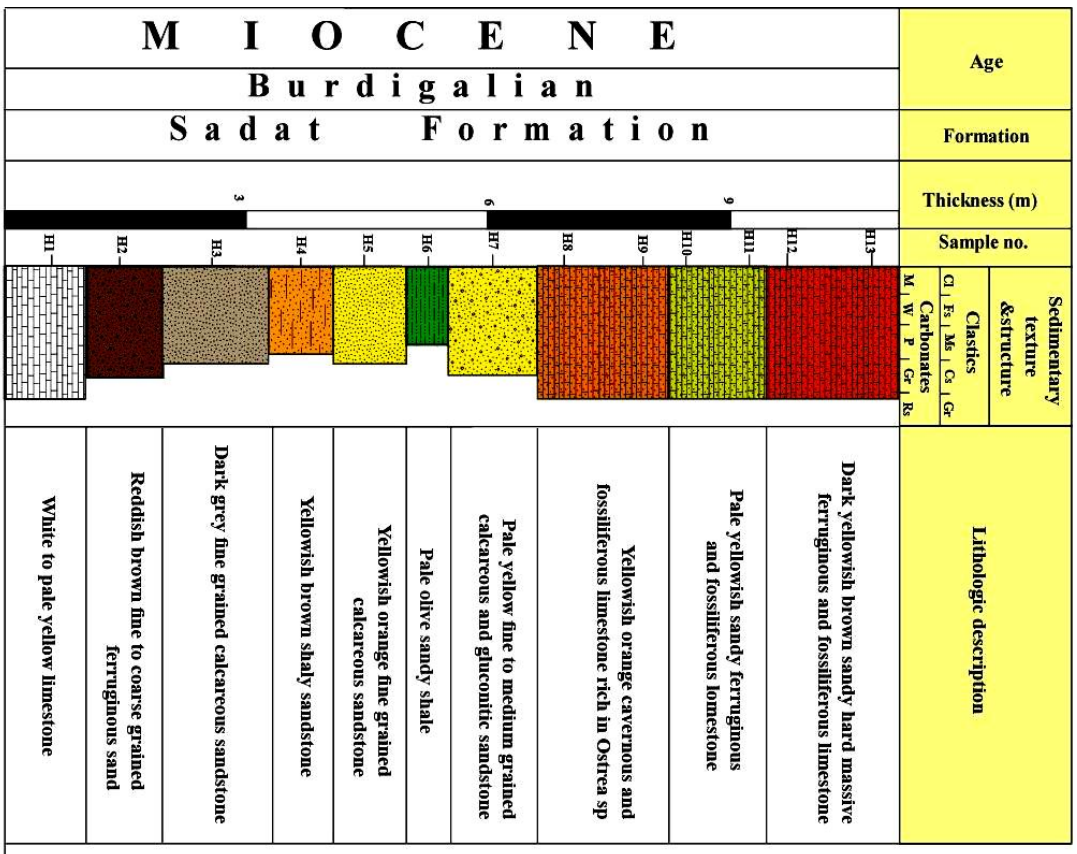


Figure 2: Lithostratigraphic succession of the Sadate Formation at Wadi Homnath

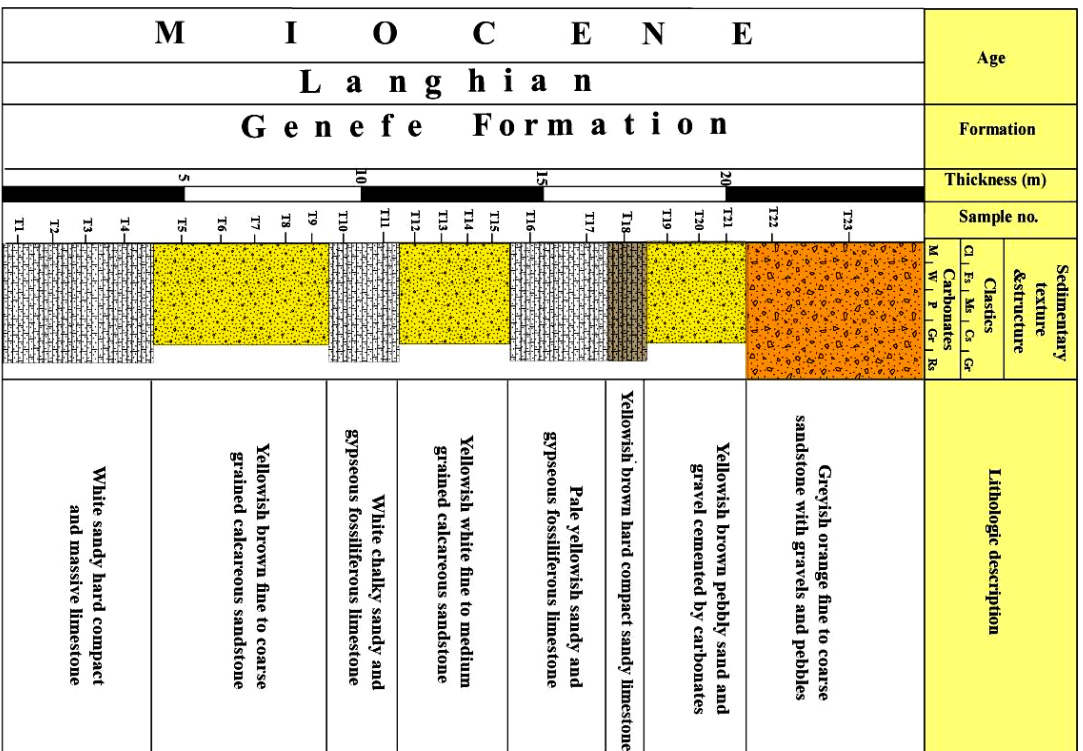


Figure 3: Lithostratigraphic succession of the Genefe Formation at Tal Zamzam section.

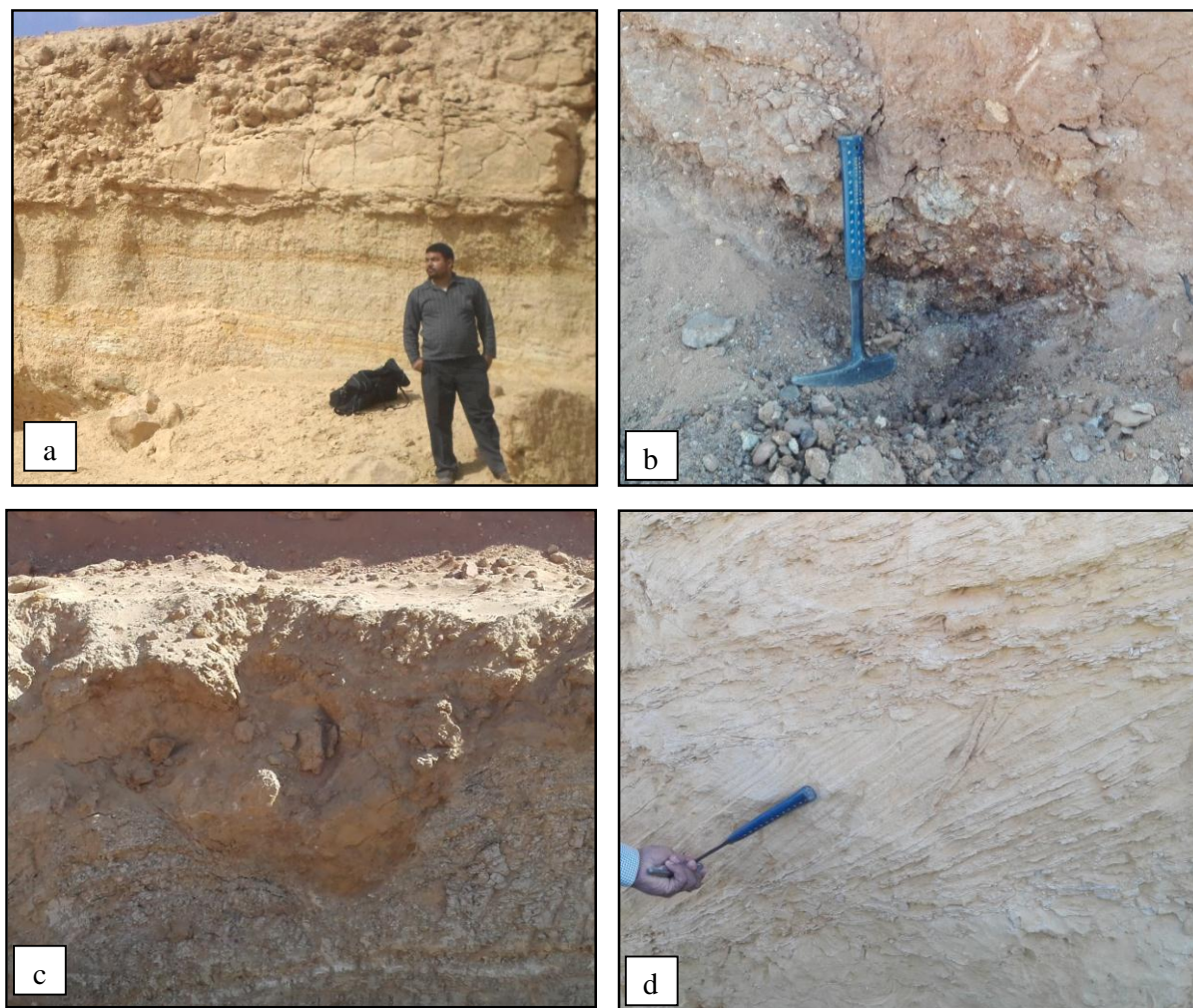


Figure 4: Field photographs showing lithological characteristics of the studied Miocene successions: a) sandstones alternating with shales and limestones of the Sadat Formation at Wadi Hommath section; b) contact between the Oligocene weathered basalt and overlying Miocene deposits at Tall Zamzam area; c) sandstone intercalated by mudstone of Genefe Formation at Tall Zamzam section; d) planar cross-bedded sandstone with ichno sedimentary structures in the lower part of the Genefe Formation at Tall Zamzamy section.

4. RESULTS AND INTERPRETATION

4.1. Microfacies analysis

The Miocene successions in Cairo – Suez district display a cyclic sedimentation and relatively rapid lateral facies change. This change may be related to deposition on an irregular shelf with submerged structural highs and lows. Consequently, the aim of the microfacies analysis is to integrate sedimentological and paleontological results to appraise the depositional history of the Lower and Middle Miocene sections in the study area.

13 thin sections are prepared and six microfacies types have been determined from

the studied sections by using field observation, mineralogical components, macrofossil and microfossil assemblages, and texture of the examined samples. These microfacies types are represented by three carbonate microfacies and three siliciclastic facies types. The identified carbonate microfacies are: 1. Sandy dolostone; 2. Sandy algal bioclastic packstone/grainstone; and 3. Sandy wackestone. Furthermore, the siliciclastic facies types are represented by calcareous quartz arenite, quartz arenite and mudstone. In the following paragraphs, the description and interpretation of the different microfacies types are deciphered, with an emphasis on their depositional environments.

i. Sandy dolostone

This microfacies type is recorded in the upper part the Genefe Formation at Tall Zamzam and the middle parts of the Sadat Formation at Hommath section (samples No. T18, T22 and 5H respectively). It is made up of yellowish orange, very hard, highly fossiliferous, sandy dolostone. Microscopically it is characterized by fine subangular to subrounded, moderately sorted quartz grains forming about 30-35% of the rock (Fig.5A). These quartz grains are scattered in a diagenetic dolomite groundmass with relics of micrite matrix. Dolomite crystals range from euhedral (idiotopic) to subhedral (hypedotopic), polymodal, rhombic textures and originated from recrystallization of calcite matrix. The predominance of fine quartz grains and micrite matrix reflect slightly quite, shallow neritic depositional environment of this microfacies.

ii. Sandy algal bioclastic packstone/grainstone

This microfacies is recorded in several intervals of the Genefe Formation at Tall Zamzam section and made up of white to pale yellow, semi-hard to hard, less compact to compact, fossiliferous, sandy limestone. Allochems form $\approx 70-80\%$ of this microfacies type and composed mainly of algae (*Lithothamnium* sp.) with few echinoid shell fragments. Although these algal fossils are made up of cryptocrystalline calcite, some algal parts are recrystallized and formed of microsparite. The non-carbonate particles (about 15% of the rock) are represented by fine to medium, subrounded to subangular, ill sorted quartz grains (Fig. 5B). Shell fragments are increased in size upwardly, carbonate matrix and glauconite content can be noted in the studied Tall Zamzam section. Different grains are scattered in fine cryptocrystalline micrite matrix that partially recrystallized and neomorphosed to sparry calcite. Enrichment of red algal shell fragments and fine carbonate matrix and depletion of siliciclastic input denote quite inner neritic depositional environment of this studied microfacies.

iii. Sandy wackestone

This microfacies type is recorded in the lower part of the Genefe Formation in Tall Zamzam section (sample -3/2, 1/2,3/2). This microfacies type consists of grayish white, massive, semi-hard, sandy limestone. Allochems of this microfacies are represented by coarse to medium, moderately sorted, quartz grains (up to 15%) and algal bioclastic fragments (about 5%) scattered in cryptocrystalline calcite matrix (up to 85% of the rock) (Fig.5C). This microfacies type is characterized by small fenestral cavities or birdseyes microstructure. These cavities are filled with sparry calcite cement. Predominance of calcite matrix with birdseyes microstructure and the paucity of quartz and algal grains reflect a restricted intertidal-supratidal depositional environment.

iv. Calcareous quartz arenite

This sandstone facies type is recorded in the lower part of both Genefe and Sadat formations at Tall Zamzam and Wadi Hommath sections respectively (samples No. 3T, 4T and 4H respectively) and made up of moderately hard, grayish yellow to yellow, fine to coarse grained sandstones. It is characterized by subrounded to subangular, occasionally rounded, moderately to poorly sorted quartz grains that form $\approx 65\%$ of the rock. Green, rounded glauconitic pellets are well developed in this sandstone type at the Sadat Formation forming about 7-10 % of the rock (Fig.5D). Few (<5%) feldspar grains (plagioclase and microcline) can be observed. All of these grains are cemented by microcrystalline calcite (microsparite) and/or iron oxides. The dominance of moderately sorted quartz grains, glauconitic pellets and microcrystalline calcite cement reflects an intertidal to shallow inner neritic depositional environments.

v. Quartz arenite

This microfacies type is recorded in the lower part of the Genefe Formation at Tall Zamzam section (sample -1/1, 3/1, 6/1). It is composed of pale yellow, medium to fine,

semi-hard and planar cross-bedded sandstone intercalated with mudstone thin lenses. At the Genefe Formation this sandstone type of facies overlies weathered basalt and red sandstone of Oligocene age. Microscopically, this sandstone type of facies is made up of medium to fine sand (main size is 0.6 mm), moderately sorted, monocrystalline, occasionally polycrystalline, sub-angular, elongated to spherical quartz grains occupying > 95% of the sample in an open backing texture (Fig.5E). Few (<5%) rock fragments and feldspar grains can be observed in this facies type (Fig.5F). The dominance of moderately sorted quartz grains and planar cross-bedding of this facies type reflect an intertidal depositional environment.

vi.. Mudstone

This microfacies type is recorded in several stratigraphic intervals of the Genefe Formation at Tall Zamzam section (Fig. 4C). It is composed of variegated dark yellow, pale-olive, grey and ferruginous mudstone with gypsum venticles. Laboratory analysis revealed absence of fossil content in this facies type. This microfacies can be deposited in a quiet, restricted, shallow, inner neritic platform environment with low-energy conditions. The paucity of fauna reflects the deposition under low-oxygen water conditions and/or high argillaceous input during the deposition.

4.2. Biostratigraphy

4.2.1. Biostratigraphy and age model

Rare planktonic diagnostic microfossils are recorded in the Miocene units in Cairo-Suez area. No previous works touched this topic. The high-resolution biostratigraphy based on planktonic foraminifera and nannofossils in the Sadat Formation of Wadi Hommath section and the Genefe Formation of Tall Zamzam section. Quantitative analyses of selected calcareous nannofossil and planktonic foraminiferal species were used to determine the placement of the biozonal boundaries in the studied successions.

Both planktonic foraminifera and calcareous nannoplankton are useful tools for

high-resolution biostratigraphy which are used in the present study. However, these assemblages of study area provide a comprehensive biostratigraphic framework for the early-middle Miocene succession. Consequently, they are suitable for chronostratigraphic correlation in this region. Moreover, planktonic foraminifera and calcareous nannofossils are the most extensively used biotic taxa for long-distance biostratigraphic correlation of marine strata. The results of biostratigraphic analysis from treated samples of the study area led to the identification of 21 species belonging to 9 genera of planktonic foraminifera and 19 species belonging to 10 genera of calcareous nannoplankton. The distribution charts of these species were shown on figures 6 and 7.

The Early-Middle Miocene standard and widely used biostratigraphic zonal schemes are adopted here for planktonic foraminifera (e.g. Bolli, 1957; Blow, 1979; Berggren *et al.*, 1995; Berggren and Pearson, 2005; Wade *et al.*, 2011) and for calcareous nannoplankton (e.g. Martini, 1971; Okada and Bukry, 1980; Agnini *et al.*, 2014). The presented biostratigraphy of the measured sections is based on the ranges and assemblages of calcareous nannoplankton and planktonic foraminiferal datum events.

a.Planktonic foraminiferal biozones

The Miocene planktonic foraminiferal biozones at the study area are arranged from base to top as follows: Zone M4 (*Globigerinoides bisphericus* Partial Range Zone) , Zone M5a (*Praeorbulina sicana* Lowest-Occurrence Subzone) and Zone M5b (*Praeorbulina glomerosa* Lowest-Occurrence Subzone).

i- The *Globigerinoides bisphericus* Partial-Range Zone (M4)

This subzone was defined by Berggren and Pearson (2005) as the partial (range of the nominate taxon between the HO of *Catapsydrax dissimilis* (Cushman and Bermudez) and the LO of *Praeorbulina sicana* (Di Stefani). This interpretation is based

on the HO of *Catapsydrax dissimilis* (Cushman and Bermudez) and co-occurrence of *Globigerinoides bisphericus* (Todd). This zone corresponds to Zone N7 of Blow (1969, 1979) in extent, if not intent, and to the lowerpart of the *Globigerinatella insueta*

Interval Range Zone of Cushman and Stainforth 1945; as emended by Bolli, 1957b. appearance of *Globigerinoides bisphericus* (Todd) (Berggen et al.,1995). This Zone (M4) is defined as the interval between the Lowest Occurrence (LO) of *Globorotalia semivera*

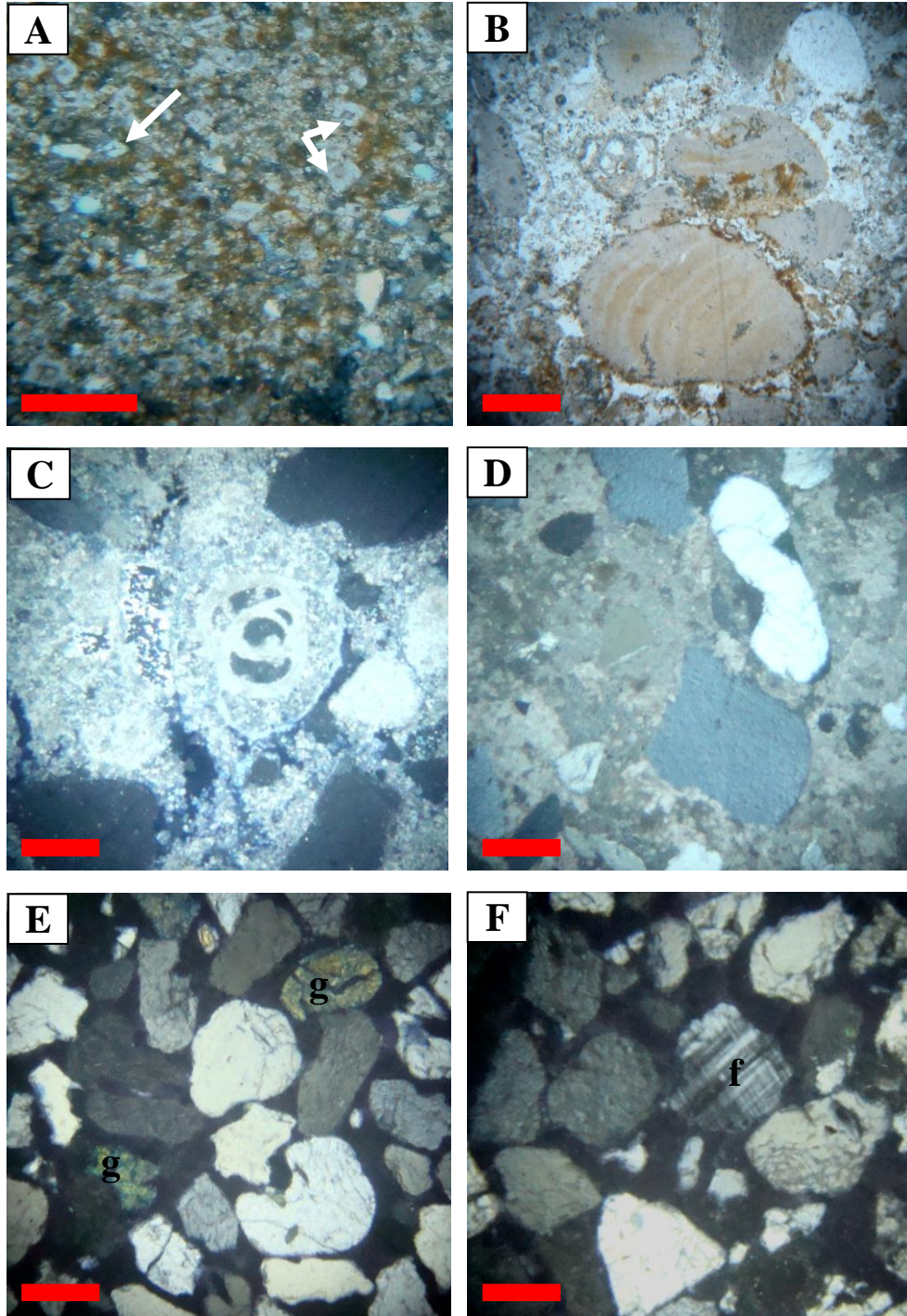


Figure 5: Photomicrographs show microfacies types of the studied Miocene deposits: A) sandy dolostone microfacies with euhedral dolomite crystals (arrows) with traces of micrite matrix; B) sandy algal bioclastic packstone/grainstone; C) sandy wackestone; D) calcareous quartz arenite; E,F) quartz arenite facies type with traces of glauconitic (g) and feldspar (f) grains. Bar scale =0.5mm.

(Hornibrook) and the Lowest Occurrence (LO) of *Globigerinoides trilobus* (Reuss) and the first common occurrence of *Globigerinoides bisphericus* (Todd). Additional events are employed to support the zonal assignment of the lower part of the Sadat Formation to M4 Zone. These are: the co-occurrence of *Globigerinoides bisphericus* with *Globigerinoides trilobus*. In Egypt, this zone is equivalent to the *C. dissimilis/Praeorbulina sicana* (M4) Zone recorded by Hewaidy *et al.* (2013) and to the *G. trilobus* Zone which was recorded by many authors (Haggag *et al.*, 1990; Phillip *et al.*, 1997; Mandur 2004).

ii- The *Praeorbulina sicana* Lowest-Occurrence Subzone (M5a)

This subzone was defined by Berggren and Pearson (2005). Wade *et al.* 2011 defined this subzone as the biostratigraphic interval between the LO of *Praeorbulina sicana* and the LO of *Praeorbulina glomerosa*. In the present study, the *Praeorbulina sicana* Subzone is represented by the upper part of the Sadat Formation, (samples No.H9 to H13) (Fig.4.4.). Additional events are employed to support the zonal assignment of the upper part of the Sadat Formation to M5a Zone. These are: the co-occurrence of *Praeorbulina sicana* and *Praeorbulina curva*.

iii- The *Praeorbulina glomerosa* Lowest-Occurrence Subzone (M5b)

The *Praeorbulina glomerosa* Lowest-Occurrence Subzone (M5a) was defined by Berggren and Pearson (2005); Wade *et al.*, 2011 defined this subzone as the biostratigraphic interval between the LO of *Praeorbulina glomerosa* and the LO of *Orbulina suturalis*. In the present study, the *Praeorbulina glomerosa* Subzone is represented by the middle part of the Genefe Formation at Tall Zamzam section, (samples No. T11 and T18) (Fig. 6b). The assignment of the Genefe Formation to *P.glomerosa* Zone (M5b) is based on the FO of *Praeorbulina circularis*, *Orbulina bilobata* and disappearing *Orbulina suturalis*.

b. Calcareous nannoplankton biozones

Helicosphaera ampliaperta Zone (NN4) is recorded in the two studied sections. It covers the early (Burdigalian) and Middle (Langhian) Miocene in the studied sections ((Ogg *et al.*, 2016)). *Helicosphaera ampliaperta* zone (NN4) (Bramlette & Wilcoxon, 1967, emend.Martini, 1971). The calcareous nannofossil content of the studied succession attributed the Sadat Formation to the Early Miocene and Genefe Formation to the Middle Miocene parts of *H. ampliaperta* Zone NN4. The recognition of *H. ampliaperta* Zone NN4 in the study area was recorded in the Sadat Formation at Wadi Hommath section and the Genefe Formation at Tall Zamzam section (Fig.7). The LO of *H. ampliaperta* is considered a more reliable marker event for the *H. ampliaperta* Zone in the Sadat and Genefe formations of the Miocene sections. In Egypt, this zone is equivalent to the *H. ampliaperta* Zone of El- Heiny and Martini (1981), Marzouk (2009), Sadek (2001), Mandur (2009), Faris *et al.* (2007, 2009), and Soliman *et al.* (2012).

4.2. Benthic foraminiferal biofacies

The distribution of benthic foraminifera was restrained by the environmental conditions (e.g., substrate, salinity, temperature, wave energy, oxygenation, and nutrients) and these conditions are usually depth dependent (Bandy, 1953; Walton, 1964). Thus, it is possible to build a model relating water depth to benthic biofacies (Nyong and Olsson, 1984; Olsson, 1991). This model is a unique tool to interpret environmental changes, for instance deepening and shallowing trends in the studied succession. Moreover, Q-mode cluster analysis on the relative abundance data with a Pearson correlation coefficient using OriginLab Software (<http://www.originlab.com/2017>) version 2017 is performed (Fig. 4). Consequently, by using Q-mode cluster analysis it was conceivable to classify the samples into biofacies and then recognize which taxa were associated with each biofacies. Accordingly, three biofacies based on the distribution of the benthic foraminifera are recognized in the present study (Fig. 5). These biofacies provided assemblages dominated by

species that populated inner, middle, to outer neritic environments (Fig. 5).

i. *Nonion* biofacies

The *Nonion* biofacies is represented by 47% of the benthic faunal variation (Fig. 8). This biofacies has greater percentages of shallow water indicator taxa such as *Nonion* (17%) and *Elphidium* (12%; Fig. 5). This faunal assemblage indicates that the environment is very shallow, not deeper than a few to a dozen of meters (Murray, 1991; Poag, 1981; Hayward and Brook, 1994; Gonera, 2012; Chan et al., 2017). In the study area, the *Nonion* biofacies is recorded in samples No. (H9, H10) of the Sadat Formation and samples No. (T17 and T18) of the Genefe Formation (Fig. 8). It is associated with beds containing the highest percentage of siliciclastic sediments (e.g. silty shale, shaly sandstone, and sandy marl; Fig. 8). Otherwise, the average percentage of planktonic foraminifers for samples belonging to this biofacies is 25%. Therefore, this biofacies is the shallowest biofacies (~50 m water depth) of the studied succession, based on the lowest percent of planktonic foraminifera (25%) and the coarsest and raised abundances of siliciclastic sediments.

ii. *Cibicides* biofacies

The *Cibicides* is the dominating genus in this biofacies, and is represented by 40% of the studied forams (Fig. 8). Modern *Cibicides* is typical of middle neritic environments generally <100 m (Hayward and Brook, 1994; Miller et al., 2008). *Miliolina* (2%), *Lenticulina* (2%) and *Quinqueloculina* (6%) are minor constituents of this biofacies that are typically observed in shallow mid-shelf deposits 0-70 m (Murray, 1973; Murray and Wright, 1974; Boltovskoy and Wright, 1976; Gonera, 2012). This biofacies is represented by 40% of the benthic faunal variation (Fig. 8b). It is associated with sediments consists of sandy limestone and observed in samples No. H4 and H9 of the middle-upper part of the Sadat Formation (Fig. 8b). The *Cibicides* biofacies denotes deeper water than the *Nonion* biofacies

based on lithologic and faunal criteria (32% planktonic foraminifera).

iii. *Uvigerina* biofacies

This biofacies is characterized by the rare occurrence of *Uvigerina* biofacies. It is represented by 8 % of the benthic faunal variation. Furthermore, the *Uvigerina* biofacies comprises 43% planktonic foraminifera and has suggested water depth of ~125 m. Moreover, it includes a minor constituent of the benthic faunal assemblages such as *Anomalinoidea* (2%) and *Gyroidinoidea* (2%) that are typically found in modern outer neritic deeper environments (van Morkhoven et al., 1986). This biofacies is restricted to the middle part of the Genefe Formation and associated with sediments containing a high percentage of carbonates (e.g. sample No.T10; Fig.). Normally, the *Uvigerina* is abundant on the outer shelf and the uppermost continental slope (Murray, 1973; Boltovskoy et al., 1980). Consequently, the *Uvigerina* biofacies is the deepest biofacies represented in the study area >100 m water depth (Miller and Lohman, 1982).

4.2.2. Biostratigraphic integration

The planktonic foraminifera and nannofossil zonation are integrated to reach to high resolution biostratigraphic scheme from the Miocene stratigraphy. A correlation and age model from analysis of studied calcareous nannofossil and planktonic foraminiferal assemblages for the studied successions.

a. Late Burdigalian Stage

The Late Burdigalian Stage is defined by two planktonic foraminiferal zones (M4, M5a) which coincide with the calcareous nannofossil zone NN4 (Fig.4.2, 4.4.). It is represented by (9 m thick.) at the middle part of the Sadat Formation at Wadi Hommath section and it was deposited between (17.26 Ma and 16.97 Ma) at a rate of (290 m/Ma).

b. Burdigalian/Langhian stage boundary

The Burdigalian/Langhian stage boundary is placed at the first appearance of

Paraeorbulina glomerosa Blow (Iaccarino, 1985; Rögl, 1985; Haggag et al., 1990; Hewaidy et al., 2013). Blow (1969, 1979), Banner and Blow (1965), Ayyad (1983), and Kennett and Srinivasan (1983) placed the Burdigalian/Langhian boundary at the first appearance of *Orbulina suturalis* Brönnimann 1951. On the basis of calcareous nannofossils, the Burdigalian/Langhian boundary coincides with the *Helicosphaera ampliaperta* (NN4)/*Sphenolithus heteromorphus* (NN5) zonal boundary (Fornaciari et al. 1996; Mandur 2009; Sadek 2001; El Deeb et al. 2004; Gradstein et al. 2012). Marzouk (1998) placed the Burdigalian/Langhian boundary at the top of the *H. ampliaperta* (NN4) Zone. This boundary should be placed at the base of the *S. heteromorphus* (NN5) Zone (El-Heiny and Martini 1981). Faris et al. (2007) cited the Burdigalian/Langhian boundary at the base of the *Globorotalia fohsi peripheroronda* Zone by planktonic foraminifera and within the *H. ampliaperta* Zone (NN4) by calcareous nannofossils. Faris et al. (2009) placed the boundary at the base of the *O. suturalis* Zone. In the present study, the Burdigalian/Langhian boundary is defined by the FO *Praeorbulina circularis* Blow 1956 at the middle part of the Genefe Formation at Tall Zamzam section.

c. Early Langhian Stage

The Early Langhian Stage is defined by the planktonic foraminiferal zone (M5b), which coincides with the calcareous nannofossil zone NN4 (Figs.4.3, 4.5.). It is represented by (12 m thick.) of the middle part of the Genefe Formation at Tall Zamzam section. It was deposited between (16.97 Ma and 15.97 Ma) at a rate of (1 m/Ma).

4.3. Sequence stratigraphy

The integrated high-resolution biostratigraphic studies carried out on the Lower-Middle Miocene sediments in Cairo-Suez, Egypt provides a framework for sequence stratigraphic interpretation of these sediments. These successions are subdivided into three depositional sequences. The following is the detailed description of these depositional sequences and their sequence boundaries.

Sequence boundary (SB1): it is recorded at the change from the Oligocene sequence to the Lower Miocene Zone M4 of the Sadat Formation at Wadi Hommath section at the first occurrence of *Globorotalia semivera* Hornibrook, 1961. This boundary most probably corresponds to worldwide, short-lived sea-level fall during the Early Miocene at the base of the *Globigerinoides bisphericus* Zone (Hardenbol et al. 1998; Ogg et al., 2016). It is a continental erosional surface indicating a break in sedimentation linked with a relative sea-level fall at the top of the the Early Miocene. This sequence boundary is indicated by transition between tectonically stable conditions to rapid subsidence and deep water and may be synchronous with the world short term-sea level fall which took place at base of M4 Zone (Hardenbol et al. 1998; Miller et al. 2005).

a. Sequence 1: Early Burdigalian Sequence (M1): this depositional sequence includes a single transgressive–regressive depositional sequence at the Lower Burdigalian in the Sadat Formation at Wadi Hommath section (Fig. 9). It is estimated to span CA 0.29 Myr. from ~17.26 Ma at the first occurrence (FO) of *Globigerinoides trilobus* Reuss, 1850 to ~16.97 Ma (Fig.11). (the sequence boundary at which lithologic features change from coarse sandstone to finer sandy limestone at the first occurrence (FO) of *Praeorbulina sicana* then transgression took place at basal part of the *Praeorbulina sicana* Zone M5a (Fig. 9).

Transgressive systems tract (TST): it consists of middle to inner shelf brownish red sandy limestone with oysters. The transgressive systems tracts of the studied sequence is assigned to the planktonic foraminiferal zone M4 and the lower part of calcareous nannoplankton zone NN4. It consists of carbonate-clastics alternation package covers the lower Miocene interval from sample No. H1 to sample No. H3. The lower part of this package (sample interval H1-H2) is found barren of any foraminiferal content (Fig. 9). Section upwards, in the middle part of the Sadat Formation (sample interval H3-H9), planktonic assemblages are generally rare, the tests are often moderately preserved and the

most abundant species is *Globigerina woodi connecta* Jenkins 1964 (Fig. 9). On the other hand, benthic foraminifers occur more frequently, and part of the benthic foraminiferal assemblages are relatively diverse (Fisher's α diversity 6.36 to 8.75; Individuals 16 to 22; Species No. 3 to 14, the values of Shannon index (H) in this sample interval declined which indicates an increase of the water depth (Buzas and Gibson, 1969). Furthermore, these sediments are prevailed by *Cibicides* biofacies (11-19.5 %), that typically observed in shallow mid-shelf deposits 0-70 m (Murray, 1973; Murray and Wright, 1974; Boltovskoy and Wright, 1976; Gonera, 2012) (Fig. 9). Otherwise, the relative abundances of P/B ratio (79%) from the lower middle part of the Sadat Formation (sample No. H3), indicates an outer neritic environment with a water depth of >100 m (Fig.9), whereas the *Uvigerina* biofacies that a characteristic feature of the outer neritic environment is absent. Therefore, these support the hypothesis that a deepening upward trend occurred within this segment of the section and it probably reflects a Burdigalian transgression during deposition the Sadat Formation.

Maximum flooding surface (MFS): the MFS of this sequence coincides with the top of the fine-grained sand where a bathymetrically deepest interval is recorded. It includes a maximum frequency of planktonic foraminifera (Fig. 9). It is tentatively located at sample No. H3 in the lower part of the Sadat Formation, where the P/B ratio reaches maximum, and expresses the change from inner neritic to outer neritic environments (Fig. 9). It is also synchronous with the MFS recorded in Bur4 sequence of Hardenbol et al., (1998). Furthermore, a tentative age estimate for this MFS is ~17.05Ma where its placed at the FO of *Gds. trilobus* (Ogg et al., 2016) (Fig. 11).

Highstand systems tract (HST): it superimposes the MFS and shallowing upward to the overlying sequence boundary (Posamentier et al., 1988). Otherwise, in the present study, the highstand deposits consist of clastics-shale parasequences stacked in a progradational pattern. They make up the

middle part of the Sadat Formation (Fig. 9). This part of the sequence is assigned to the planktonic foraminiferal zone M4 and the top part of the calcareous nannoplankton zone NN4 (Fig. 9). The P/B ratio reduces gradually upwards (from 66 to 36), indicating a period of gradual shallowing and progressively decreasing water depth upward. The microfacies types recorded in this package indicate that the sea level retreated upwards from restricted marine platform to shallow inner neritic environment (Fig. 9). Therefore, the upward decreasing in the abundance of the P/B ratio and the microfacies types observed in this package provide an additional argument in favor of a shallowing-upward process. As a result, a progradational parasequence set was deposited during a rapid eustatic sea-level rise (Fig. 9).

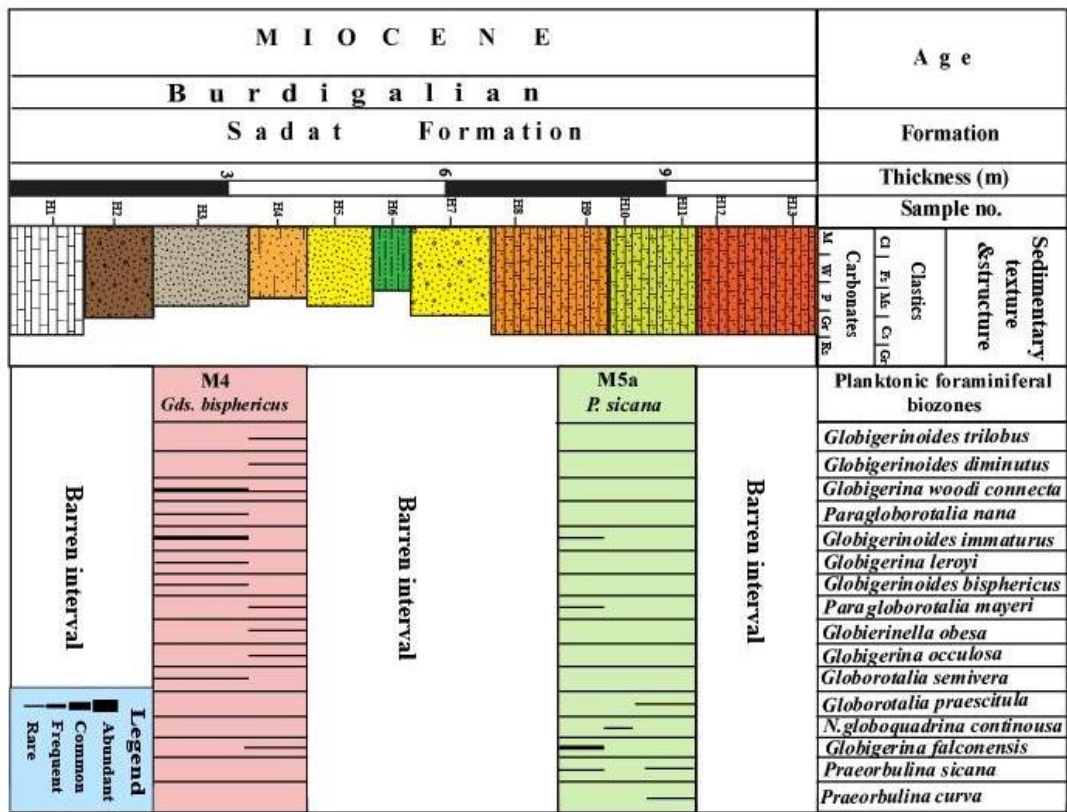
Sequence boundary (SB2): it occurs between Lower Miocene zones M4 and M5a at the Sadat Formation at the first occurrence of *P.sicana* Di Stefani,. This boundary most probably corresponds to worldwide, short-lived sea-level fall during the Early Miocene at the top of the *Globigerinoides bisphericus* Zone (M4) (Hardenbol et al., 1998; Ogg et al., 2016) (Fig. 11).

b. Sequence2: Middle-Late Burdigalian Sequence (M2): it is recorded in the Sadat Formation at Wadi Hommath section and represented by the Middle-Upper Burdigalian Sadat Formation (Fig. 9). It is bounded at the base by the sequence boundary (SB2). It includes a transgressive systems tract (TST).

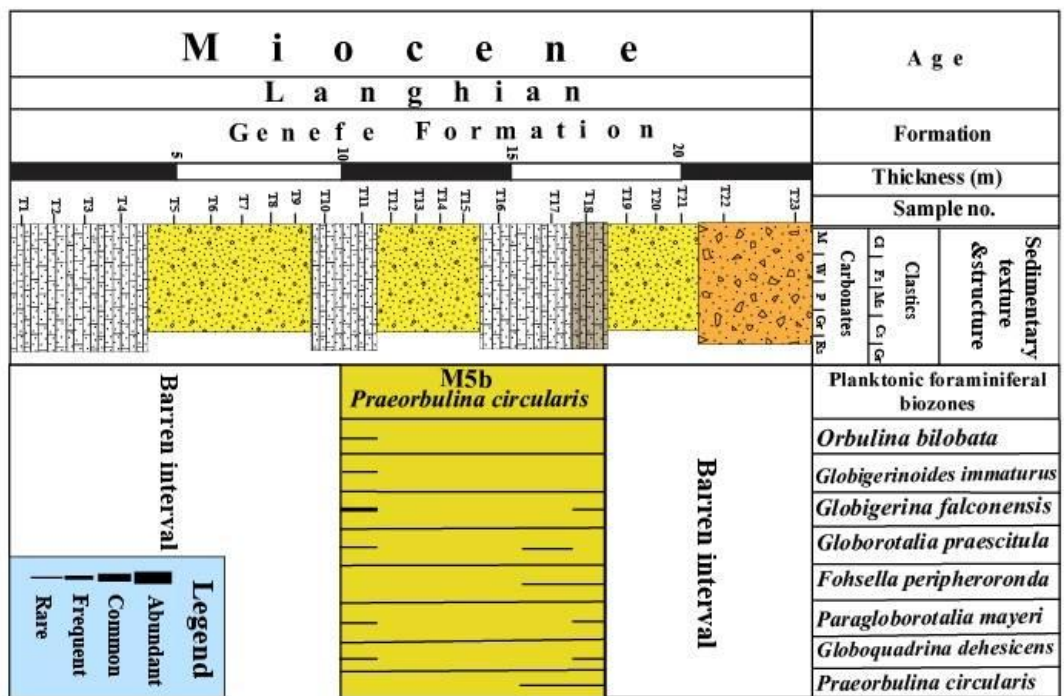
Transgressive surface: the transgressive surface coincides with the sequence boundary due to rapid relative sea level rise and missing of the lowstand systems tract.

Transgressive systems tract (TST): it falls within the interval of the *Praeorbulina sicana* (M5a) Zone at the Sadat Formation at Wadi Hommath section (Fig. 9). It is composed of brown to dark brown, hard, argillaceous, fossiliferous and dolomitic limestone. It is characterized by a moderate planktonic/benthic

ratio (28-36%), low diversity, and high dominance of the *Nonion and Cibicides* Biofacies that suggest an inner-middle neritic environments (Fig. 9).



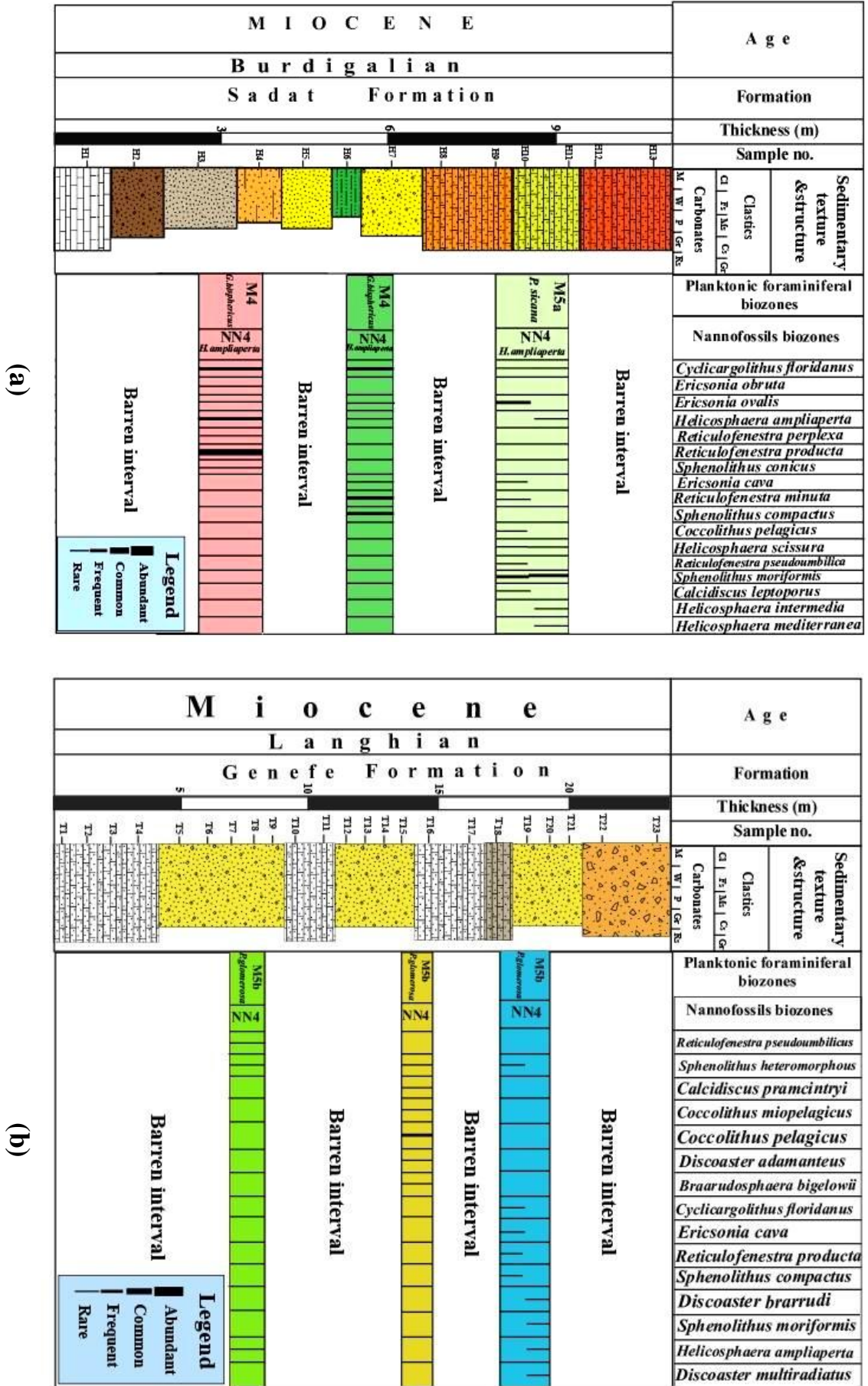
(a)

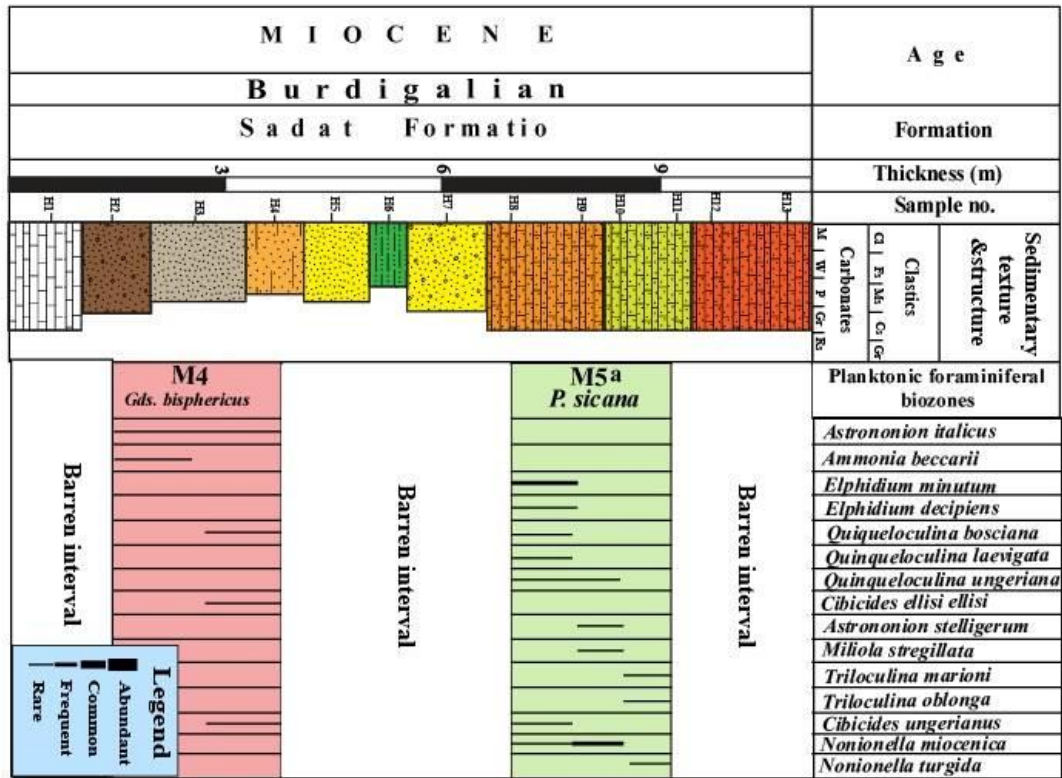


(b)

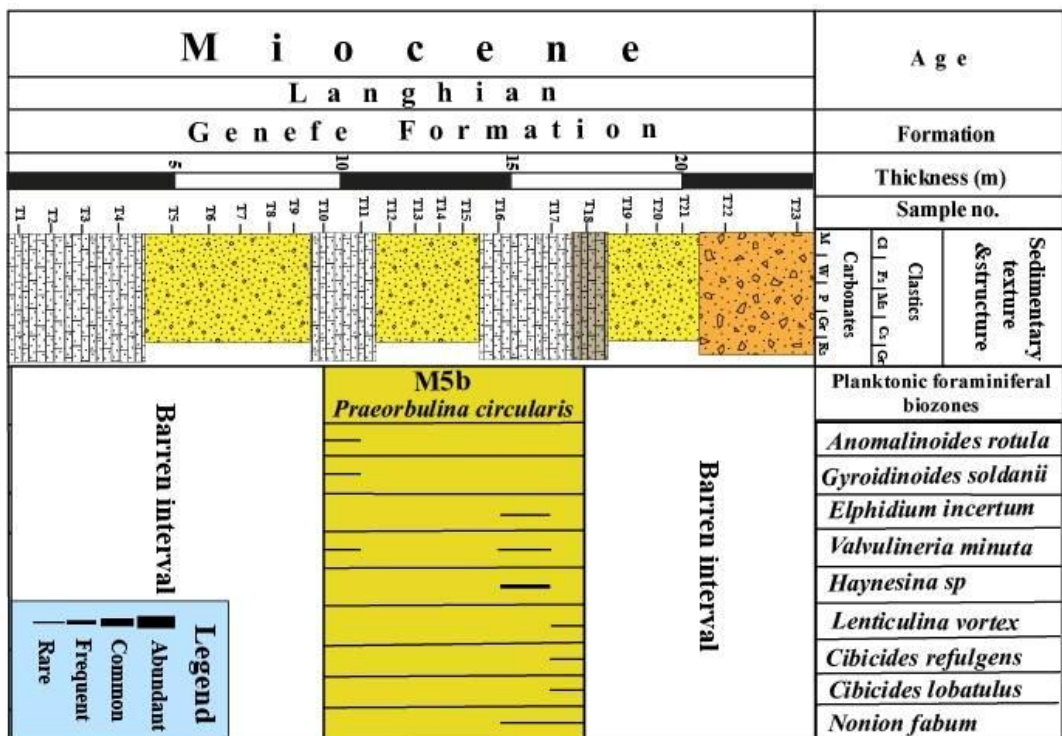
Figure 6. Distribution chart of the planktonic foraminiferal species recorded in (a) the Sadat Formation and (b) the Genefe Formation.

Figure 7. Distribution chart of calcareous nanofossil species recorded in (a) the Sadat Formation and (b) the Genefe Formation.





(a)



(b)

Figure 8. Distribution chart of the benthic foraminiferal species, recorded in (a) the Sadat Formation and (b) the Genefe Formation.

c. Sequence 3: Early Langhian sequence (M3): the third depositional sequence in the Genefe Formation at Tall Zamzam section is attributed to the Early Langhian portion of the Genefe Formation (Fig. 10). This sequence spans CA 0.42 Myr. from ~15.97 Ma at the first occurrence (FO) of *Praeorbulina circularis* Blow to ~15.55 Ma at the first occurrence (FO) of *Reticulofenestra pseudoumbilica* Gartner, 1967.

Transgressive systems tract (TST): this tract of this sequence are assigned to planktonic foraminiferal Zone M5b and the lower part of calcareous nannoplankton Zone NN4 (Fig. 10). It consists of carbonate-clastics alternation package covers the early Miocene interval from sample No. T1 to sample No. T11 (Fig. 10). The lower part of this package (sample interval T1-T10) is found barren of any foraminiferal content. Section upwards, in the middle part of the Genefe Formation (sample interval T11-T18), planktonic assemblages are generally rare, the tests often moderately preserved and the most abundant species is *Globigerina falconensis* (Fig.10).

Benthic foraminifera occur more frequently, and part of the benthic foraminiferal assemblages are relatively diverse (Fisher's α diversity 6.18 to 13.19; Species No. 4 to 6; Fig. 10). The values of Shannon index (H) in this sample interval declined which indicates an increase of the water depth (Buzas and Gibson, 1969). Furthermore, these sediments are prevailed by *Cibicides* biofacies (5.5-27.7 %), that typically observed in shallow mid-shelf deposits 0-70 m (Murray, 1973; Murray and Wright, 1974; Boltovskoy and Wright, 1976; Gonera, 2012). Otherwise, the relative abundances of P/B ratio (77%) from the lower middle part of the Genefe Formation (sample No. T11), are indicative of an outer neritic environment with a water depth of >100 m (Fig. 10). whereas the *Uvigerina* biofacies that a characteristic of the outer neritic environment is 11%. Therefore, these support the hypothesis that a deepening upward trend occurred within this segment of the section and it probably reflects the Burdigalian transgression of the Genefe Formation.

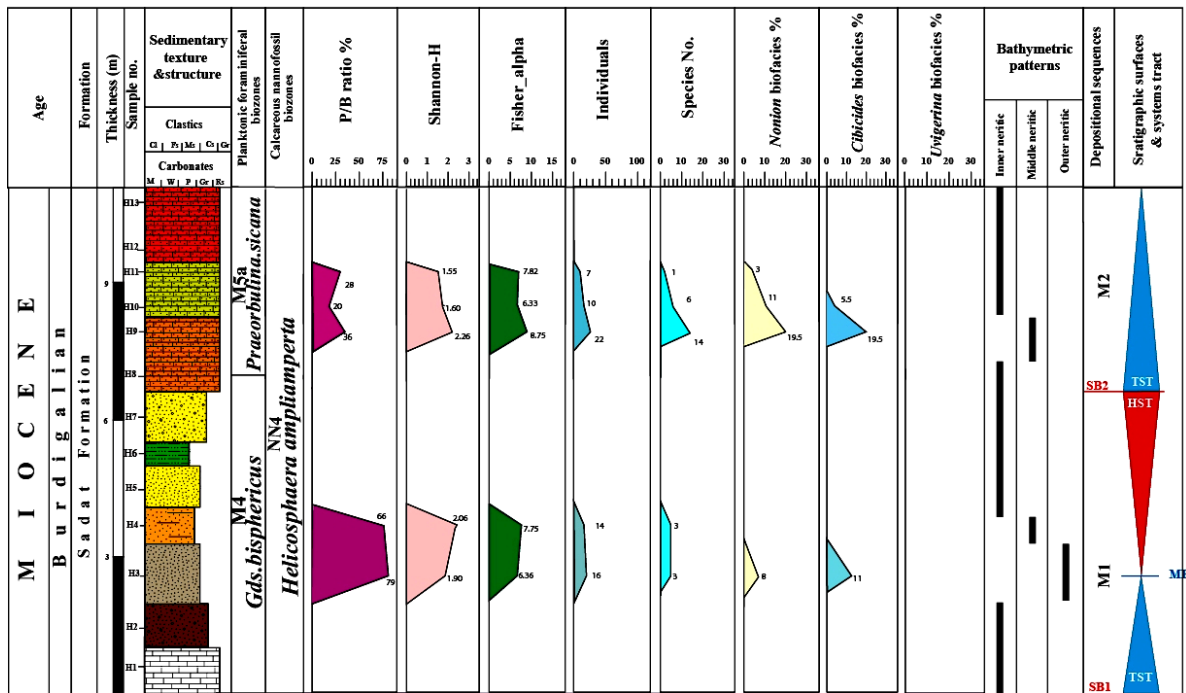


Figure 9. Stratigraphic succession of the Sadat Formation at Wadi Hommath section shows their sequence stratigraphy and eustatic sea level changes.

Maximum flooding surface (MFS): the MFS of the studied sequence coincides with the top of the fine-grained sandy limestone where the bathymetrically deepest interval and including the maximum frequency of planktonic foraminifera (Fig. 9). It is tentatively located at sample No. T11 in the lower part of the Genefe Formation, where the P/B ratio reaches a maximum, and expresses the change from inner neritic to the outer neritic environments. It is also synchronous with the MFS recorded in Bur5 sequence of Hardenbol et al. 1998. Furthermore, a tentative age estimate for this MFS is ~15.55 Ma where placed at the FO of *Reticulofenestra pseudumbilica* Gartner, 1967 (Ogg et al., 2016) (Fig. 11).

Highstand systems tract (HST): it spans the systems tract above MFS and shallows upward to the overlying sequence boundary (Posamentier et al., 1988). Otherwise, in the

present study, the highstand deposits consist of clastics-carbonate parasequences stacked in the progradational pattern; they make up the upper part of the Genefe Formation (Fig. 10). This part of the sequence is assigned to planktonic foraminiferal Zone M5b and the top calcareous nannoplankton Zone NN4 (Fig. 10). The P/B ratio reduces gradually upwards (from 77 to 30), indicating a period of gradual shallowing and progressively decreasing water depth (Fig. 10). The microfacies types that observed in this package indicate that the sea level retreats upwards from restricted marine platform to shallow inner neritic environments (Fig. 10). Therefore, the upward decreasing in the abundance of the P/B ratio and the microfacies types observed in this package provide an additional argument in favor of a shallowing-upward process. As a result, a progradational parasequence set was deposited during a rapid eustatic sea-level rise (Fig. 10).

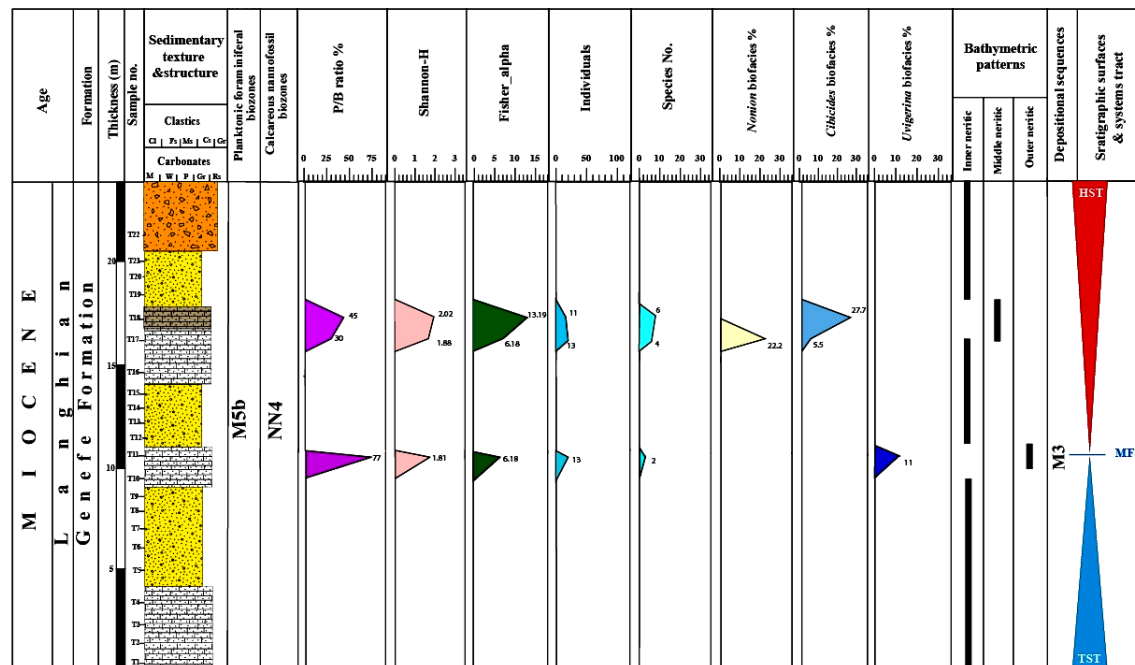


Figure 10. Stratigraphic succession of the Genefe Formation in Tall Zamzam shows their sequence stratigraphy and eustatic sea level changes.

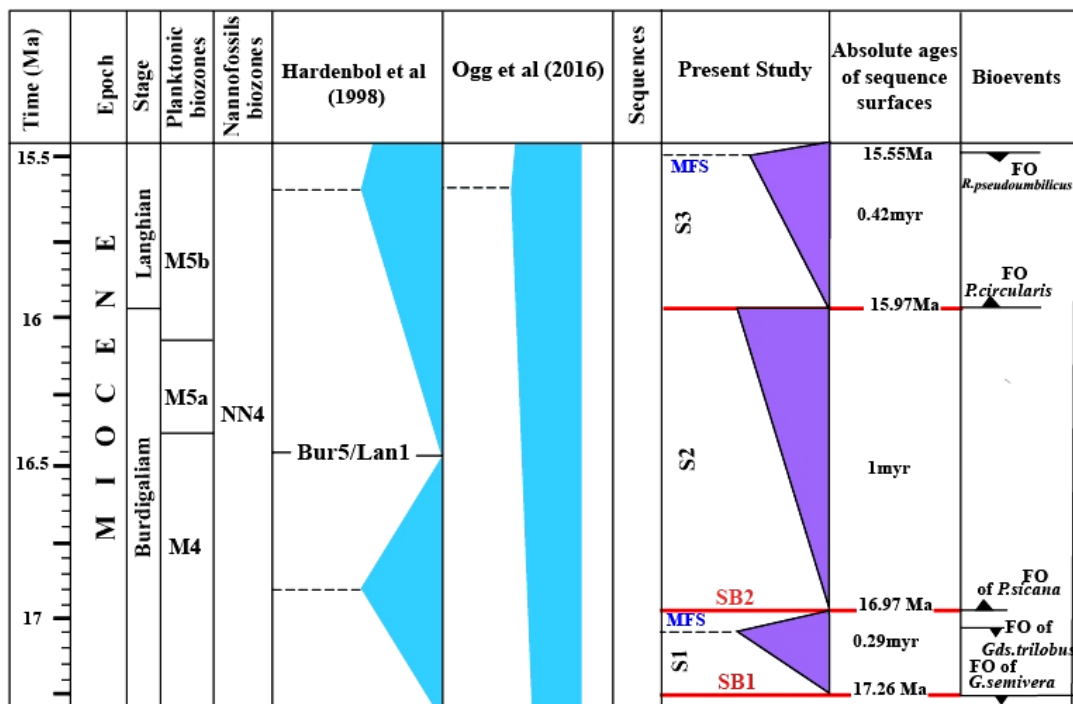


Figure 11. Correlation of the studied Miocene sequence surfaces of the Sadat Formation at Wadi Hommath section and the Genefe Formation at Tall Zamzam section with those of regional studies.

5. Conclusions

The Miocene successions in Cairo – Suez district display cyclic sedimentation and relatively rapid lateral facies changes that may be related to deposition on an irregular shelf with submerged structural highs and lows. The microfacies analysis of the studied lower and middle Miocene sections revealed presence of six microfacies types that represented by three carbonate microfacies and three siliciclastic facies types. The identified carbonate microfacies are: 1. sandy dolostone; 2. sandy algal bioclastic packstone/grainstone; and 3. sandy wackestone. Furthermore, the siliciclastic facies types are represented by calcareous quartz arenite, quartz arenite and mudstone reported in the lower part of the Genefe Formation at Tall Zamzam section.

21 species belonging to 9 genera of planktonic foraminifera and 19 species belonging to 10 genera of calcareous

nannoplankton are identified. Three planktonic foraminifera are identified. These are: i) *Globigerinoides bisphericus* Partial-Range Zone (M4); ii) *Praeorbulina sicana* Lowest-Occurrence Subzone (M5a); and iii) *Praeorbulina glomerosa* Lowest-Occurrence Subzone (M5b). The nannofossil biozone *Helicosphaera ampliamperta* zone (NN4) is also represented in the studied succession. Benthic foraminiferal biofacies are represented by: i) *Nonion* biofacies; ii) *Cibicides* biofacies; and iii) *Uvigerina* biofacies. These benthic foraminiferal biofacies provided assemblages dominated by species that populated inner, middle, or outer neritic environments.

Three depositional sequences corresponding to early - middle Miocene (late Burdigalian- early Langhian) are distinguished. These sequences are: i) Early Burdigalian Sequence (S1) includes a single transgressive–regressive depositional sequence throughout the Burdigalian in the Sadat Formation at Wadi Hommath. ii) Middle-Late Burdigalian

Sequence (S2 at the Sadat Formation in Wadi Hommath section and includes a transgressive systems tract (TST). iii) Early Langhian sequence (S3) is represented by the Genefe Formation at Tall Zamzam section.

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الملخص الغربي

يوجد قطاعين من الميوسين علي طريق القاهرة السويس، مصر تمت عليهم الدراسة وهما تل زمزم ووادي حومص ، حيث سجل متكون السادات في قطاع وادي حومص وسجل متكون جينيفه في قطاع تل زمزم سته وثلاثون عينه جمعت وحلت لمعرفة محتواها الحفري من الفورامينيفرا والنانو بلانكتون حيث أمكن التعرف على تسعة عشره نوعا من النانو بلانكتون و واحد وعشرون نوعا من الفورامينيفرا القاعيه و تسعة عشره نوعا من الفورامينيفرا الطافيه .

أتاحت دراسة المحتوي الحفري تقسيم تتابع الميوسين السفلي والاوسط بطريق القاهرة- السويس الي ثلاثه نطاقات من الفورامينيفرا القاعيه و نطاق واحد من النانوبلانكتون. هي من الاقدم الي الاحدث كالتالي: Zone (M4) ، *Globigerinoides bisphericus* عمره الميوسين السفلي (Burdigalian) ، *Praeorbulina* (Zone (M5a) *sicana* الميوسين السفلي (Burdigalian) ، *Praeorbulina glomerosa* Zone (M5b) عمره الميوسين الاوسط (Langhian) ، يكافئها نطاق حيوي واحد خاص بحفريات النانو بلانكتون وهو Zone (NN4) (*Helicosphaera ampliaperta*) عمره الميوسين السفلي (Burdigalian) الي الميوسين الاوسط (Langhian).

دراسة محتوي الفورامينيفرا الطافيه حقق الحصول على ثلاثه تجمعات بيئيه ، للحفريات تبعا لبيئته الترسيب وهي (*Nonion* biofacies) التي تترسب في بيئة جنوب شاطئيه حتى عمق متر ٥٠، (*Cibicides* biofacies) التي تترسب في بيئته متوسطه العمق و (*Uvigerina* biofacies) التي تترسب في بيئته عميقه يزيد عمقها عن ٢٥0 متر.

وقد تم تعريف سته قطاعات من القطاعات الرقيقة لهذه الصخور ادت الي ان هذه المتكونات ترسبت في ما بين بيئة بحرية ضحلة وبيئة بحرية عميقة.

كما امكنا تقسيم هذا التتابعات الطبقيه للقطاعا التتابع المدروس الي ثلاثه انواع من التتابعات الطبقيه الترسيبيه (three depositional sequences) احدهم من النوع الثالث (3rd order) والإثنين الاخرين من النوع الرابع (4th order) ، يفصل بين هذه التتابعات الطبقيه اسطح تمثل فواصل بين هذه التتابعات Sequence boundaries .