Iraqi Bulletin of Geology and Mining *Vol.16, No.2, 2020* *p 33 – 50*

SIGNIFICANCE OF FORAMINIFERA DURING THE PALEOCENE – EOCENE THERMAL MAXIMUM (PETM) IN THE AALIJI AND KOLOSH FORMATIONS, NORTH AND NORTHEAST IRAQ

Ahmed N. Al-Fattah[1], Ali I. Al-Juboury[1] and Imad M. Ghafor[2]

Received: 28/ 03/ 2020, Accepted: 14/ 07/ 2020
Key words: PETM; Biostratigraphy; Paleocene/ Eocene (P/E) boundary; Northern and Northeastern Iraq

ABSTRACT

Paleontological study is used to determine Paleocene/ Eocene boundary as principal step to investigate the Paleocene Eocene Thermal Maximum (PETM) characteristics, and to extrapolate the global warming event in three separate sections of Paleogene marine sedimentary rocks in the Sinjar, Dhouk and the Shaqlawa area, in Sinjar, Dohuk and Shaqlawa areas, North and Northeastern Iraq. Shape, size, decline and abundance of the foraminiferal species and generic diversity of photoautotrophic (oligotrophic conditions) in the Aaliji and Kolosh formations respond to the PETM environmental conditions, as well as to the extinction events in deep marine sections with general decrease in larger foraminifera, followed by abundance stage in shallow marine sections. The paleontological and sedimentological, characteristics within the Aaliji and Kolosh formations represent records of PETM- associated events which is obviously distinguished in shallow marine environments exactly at the Dohuk section compared to deep marine environment at the Shaqlawa section.

أهمية الفورامينفيرا للحد الحراري الأقصى لفترة الباليوسين – الأيوسين (تكويني عليجي و كولوش) في شمال وشمال شرق العراق

احمد نذير الفتاح، علي اسماعيل الجبوري و عماد محمود غفور

المستخلص

تبين هذه الدراسة أهمية متحجرات الفورامنفيرا عبر فترة التطرف الحراري الأقصى للباليوسين – الإيوسين كخطوة رئيسية لاستقراء حدث الاحترار العالمي في ثلاثة مقاطع تمثل الصخور الرسوبية البحرية من عصر الباليوجين في مناطق سنجار، ودهوك، وشقلاوة شمال وشمال شرق العراق. اعتمدت الدراسة على عينات صخور من تكويني عليجي وكولوش وتبين منها أن شكل وحجم وقلة شيوع أنواع من الفورامنفيرا في هذين التكوينين هي استجابة للظروف البيئية لفترة التطرف الحراري الأقصى للباليوسين – الإيوسين فضلا عن الانقراض في المناطق العميقة وانخفاض الحشود للانواع الكبيرة الحجم من الفورامنفيرا في المناطق الضحلة. إن ربط الشواهد الرسوبية والباليونتولوجية في تكويني عليجي وكولوش هي سجل لحدث التطرف الحراري الأقصى والذي ميز بشكل أفضل في البيئات الضحلة (مقطع دهوك) قياسا الى البيئات البحرية العميقة (مقطع شقلاوة).

[1] Department of Geology, College of Sciences, University of Mosul, Mosul, Iraq, e-mail: anf1277@uomosul.edu.iq ; alialjubory@uomosul.edu.iq
[2] Department of Geology, College of Science University of Sulaimani, Sulaimaniya, Iraq, e-mail: imad.gafor@univsul.edu.iq

INTRODUCTION

The Paleocene Eocene Thermal Maximum (PETM) was the most severe global change in the Cenozoic era (Lee and Kodama, 2009), A number of exceptional events, are collectively known as the (PETM), characterize the transition from the Paleocene to the Eocene. It is the most notable short term warming trend within long term early Paleogene warming trend, The PETM is discovered by (Kennett and Stott, 1991) when they noted an abrupt shift in measured oxygen and carbon isotopes ratio for specific species of foraminifera, which is approximately, marked as the Paleocene – Eocene boundary. Bowen *et al*. (2006) considered that rapid and extreme changes in earth system may be triggered by natural carbon cycle perturbation even in times of globally warm climate and in an ice-free world and the PETM phenomena was the obvious indicator to that perturbation.

There are many studies on the RETM such as:
(Bolle *et al*. 2000a, b, and c) in northern (Kazakhstan and Uzbekistan), southern Egypt, and Palestine, Speijer and Wagner (2002) in southern Tethyan margin, Egypt and Palestine, Gavrilov *et al*. (2003) in northeastern peri Tethys (black sea Tadjikstan), Scheibner *et al*. (2005) in west of the Gulf of Suez, Egypt., Ernst *et al*. (2006) in southern Tethys (Egypt), Giusberti *et al*. (2007) in NE Italy, Guasti and Speijer (2007) in Egypt and Jordan across a middle neritic to upper bathyal transect of the Tethyan continental margin, Giusberti *et al*. (2009) in, Italy, Alegret *et al*. (2010) in Spain, Soliman *et al*. (2011) in Upper Egypt during PETM, Handley *et al*. (2012) in tropical East Africa, Stassen *et al*. (2012) in Tunisia and Khozyem *et al*. (2013) in the Wadi Nukhul, Sinai, Egypt. Most of the performed sedimentological studies on the Paleocene – Eocene successions in Iraq were focused mainly on lithofacies, microfacies analysis, petrography, paleoenvironmental reconstructions and sequence stratigraphy approaches such as (Lawa, 2004; Al-Sakry, 2006; and Malak, 2010) as well as other studies dealing with biostratigraphy, geochemistry, and tectonic evolution (Al-Nakib, 1989; Al-Qayim, 1993; and Al-Juboury, 2011).

Three sections are selected for the present study from Northern and Northeastern of Iraq; between latitudes (36 – 37º) N. (Fig.1), which are: **A)** Sinjar (northern limb of Sinjar anticline near Zerwa Village) (36° 24' 58.53'' N, 41° 59' 9.09'' E), **B)** Dohuk (southern limb of Bakhir anticline near Germ Ava Lake) (36° 55' 52.22'' N, 42° 57' 56.45'' E), and **C)** Shaqlawa (northern limb of Sephin anticline near Shaqlawa Town) (36° 24' 25.07'' N, 44° 19' 44.57'' E). During the Paleocene – Eocene times these areas were part of the Tethys marine environments realm between paleolatitude (25 – 30º) N, (Scheibner and Speijer, 2008). Tectonically and according to (Jassim and Buday, 2006), Dohuk and Shaqlawa areas are located in the High Folded Zone whereas Sinjar area lies in the Foot Hill Zone (Hemrin – Makhul Subzone). The main objective of this paper is to study changes in litho- and biostratigraphic characteristics during the (PETM) in the Aaliji and Kolosh formations.

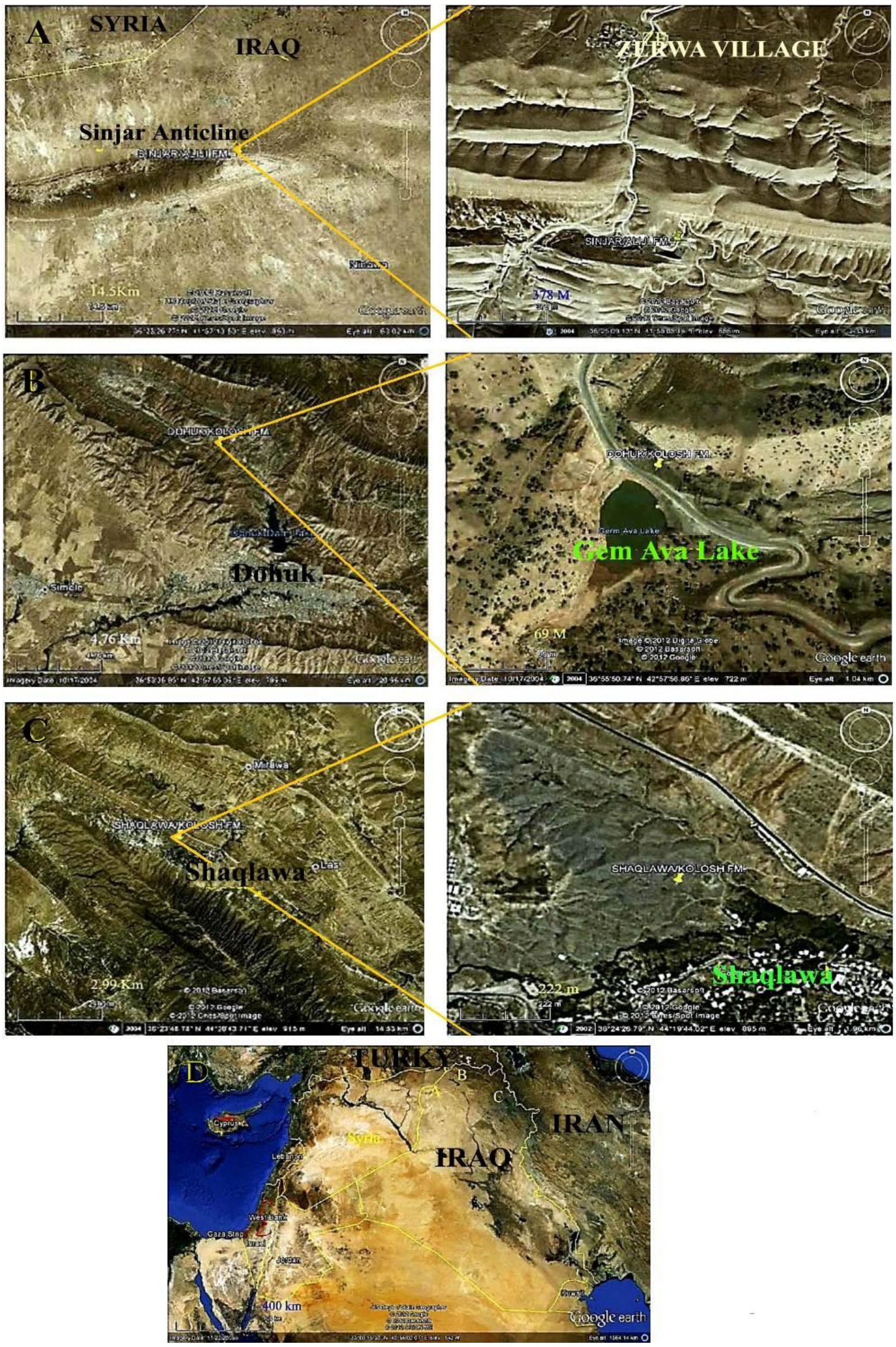

Fig.1: Google Earth Image showing the studied locations:
A) Sinjar section (Aaliji Formation). **B)** Dohuk section (Kolosh Formation). **C)** Shaqlawa section (Kolosh Formation) and **D)** Regional location map of Iraq

METHODOLOGY

Fieldwork and sampling is achieved accurately in three outcrop sections in the Aaliji and Kolosh formations, twenty four samples are measured and described lithologically according to rock type, bed or sequence thickness, rock color, grain size, and available sedimentary structures. All samples were processed according to standard micropaleontological procedures. The fraction >125 μm was used for all foraminiferal studies. Analysis of foraminifera has been carried out firstly on three – five test samples located on long intervals space within Paleocene /Eocene expected position for each section. The first results enable us to limitation of the upper Paleocene/lower Eocene spanning samples approximately About 50 – 100 gm of rock samples was crushed into fragments of about 1 to 10 mm in diameter; each of the studied samples was dried at 60 °C for 24 h. Then, the samples were soaked in a 0.5 M Na2CO3 solution for a couple of days until the rock is saturated then strained through a filter paper. After disintegration, the samples were washed over a 63- μm sieve and dried at 60 °C again. For some samples, the soaking treatment was repeated because the sediments remained aggregated. After drying, the residues were sieved with mesh-sizes of 125 and 63 μm. The samples became ready for picking using a picking tray, which is flat and black surface divided into numbered squares about 5 x 5 mm, and easy to clean to reduce the risk of contamination. Finally, genera and species were identified using scanning electron microscope (SEM). The SEM work was carried out at the Department of Earth Science of the University College London (UCL) to study morphology of the foraminifera using a high resolution JEOL JSM-6480LV Scanning Electron Microscope, after gold coating of samples and a magnification between 75X and 400X. The identification of the planktonic and benthonic species of foraminifera is based on the study of Brassier (1980); Lirer (2000) and Silva *et al*. (2003).

RESULTS AND DISCUSSION

- **Lithostratigraphic Signatures of the PETM**

Despite of detailed lithological description of the three studied sections in the Aaliji and Kolosh formations, the explanation of the lithological PETM lithesome signs in these sections is required because they are adopted principally in selecting sampling intervals in the field and in samples selection for biostratigraphical analysis to investigate the PETM position along litho-sections.

In the Aaliji Formation at the Sinjar anticline, the studied succession is composed mostly of marly limestone, marlstone, and calcareous shale. The Paleocene interval is mostly made up of thinning upward marly limestone beds associated with thickening upward marlstone and calcareous/ marly shale. At the upper Paleocene – Lower Eocene lithesome, the intercalation of thin-bedded calciturbidites marly limestone (4 – 10 cm thick) becomes interestingly more frequently accompanied with color change from greenish gray dominated facies to yellowish and/ or brownish gray dominated facies (Figs.2 A and B).

The Kolosh Formation in Dohuk and Shaqlawa sections exhibit other field physical properties, which are considered as a clue to PETM lithesome. In Dohuk section, an abrupt transition from clastic turbidite Bouma sequence mode deposits to calcarenitic tempestite sequence mode deposits (eventstone) which excites the attention that there is an abnormal event particularly when the main sequence color change from green to yellowish white and presence of shells (tempestite beds) (Fig.2C).

On the other hand, yellowish marl and reddish brown bands as well as high organic matter, rich black shale, are distinguished in the PETM lithesome at Shaqlawa section (deep marine facies of the Kolosh Formation) (Fig.2D). The field features mentioned above are related to the Paleocene – Eocene lithosomes in the studied formations.

Detailed lithological description of the three studied sections (Aaliji and Kolosh Formations) is illustrated in (Fig.3). Generally, the anomalies in lithology, color change observed in the Paleocene an Eocene formations mentioned above: are considered as indications to the PETM event (Speijer *et al*., 2011) and may refer to semi-arid conditions when considered together with other hints and indications.

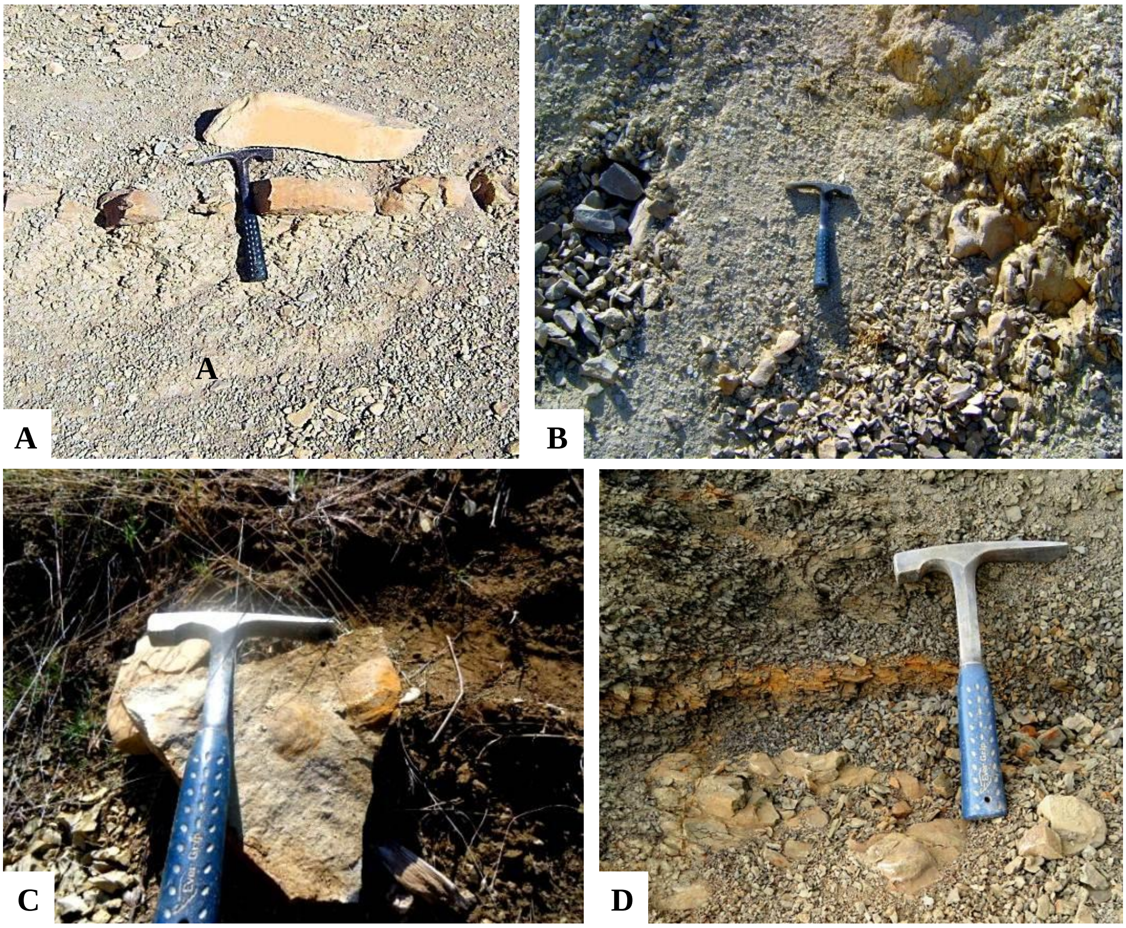

Fig.2: **A)** Calciturbidite thin beds of marly limestone. **B)** Color defference at the Paleocene Eocene transition facies of the Aaliji Formation at the Sinjar anticline. **C)** Yellowish white calcarenitic limestone (Tempestite) in the Dohuk section. **D)** Yellowish marl and reddish brown band in black shale of the Shaqlawa section

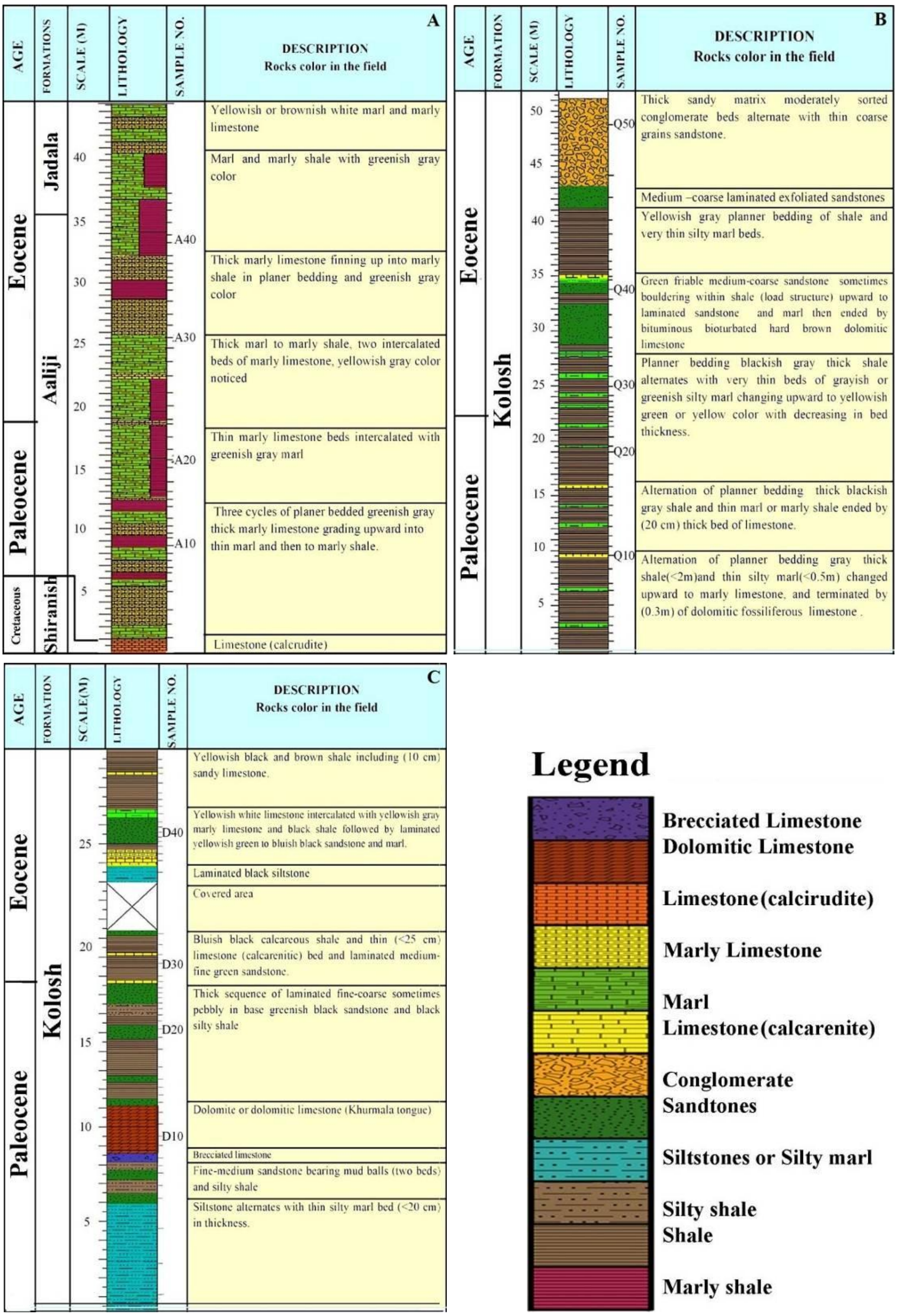

Fig.3: Litostratigraphy and age assignment of
A) Sinjar section (Aaliji Formation), **B)** Dohuk section (Kolosh Formation), and
C) Shaqlawa section (Kolosh Formation)

- **Biostratigraphic Analysis**

Planktonic and benthonic foraminifera are used for the PETM characterization at the studied sections. (Figs.4, and 5 – 7).

- **Planktonic Foraminifera**

Analysis of planktonic foraminifera is carried out in the present work for the Aaliji Formation at the Sinjar section (samples A10-A30) covering approximately (20 m) thickness, which includes the Paleocen – Eocene expected lithesome. Biostratigraphy of the planktonic foraminifera is based on Berggren and Pearson, (2005). Preservation of tests is generally good, and most morphological features are easily identifiable, although tests are commonly recrystallized. The genera and species are identified using Rea *et al*. (1990); El-Eissa and Mohammad (1997); Olsson *et al.* (1999); Silva *et al*. (2003); Pearson *et al.* (2006); Luciani *et al.* (2007); Guasti and Speijer (2007); and Stassen *et al.* (2009).

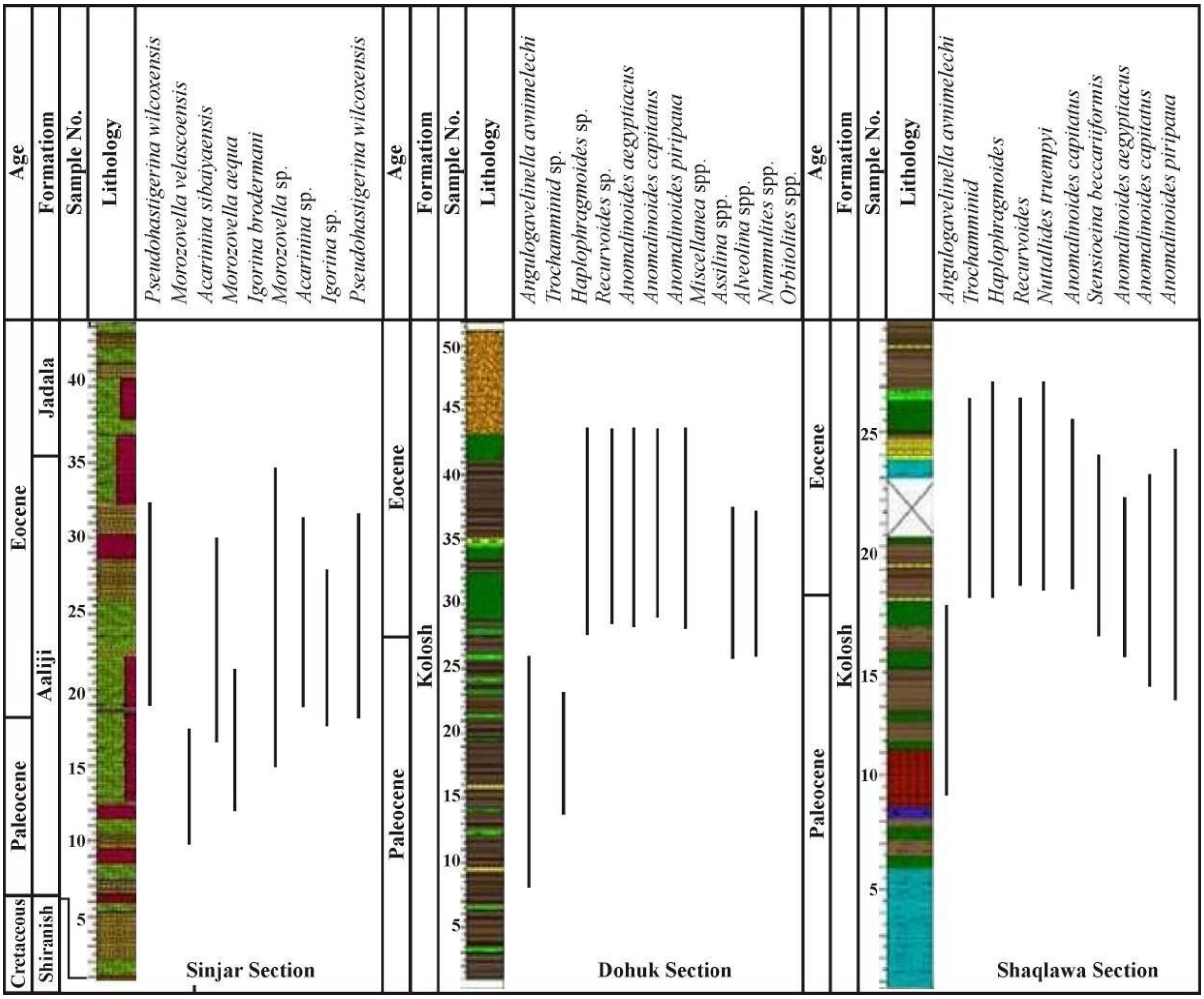

Fig.4: Foraminiferal distribution in the Sinjar, Dohuk, and Shaqlawa sections

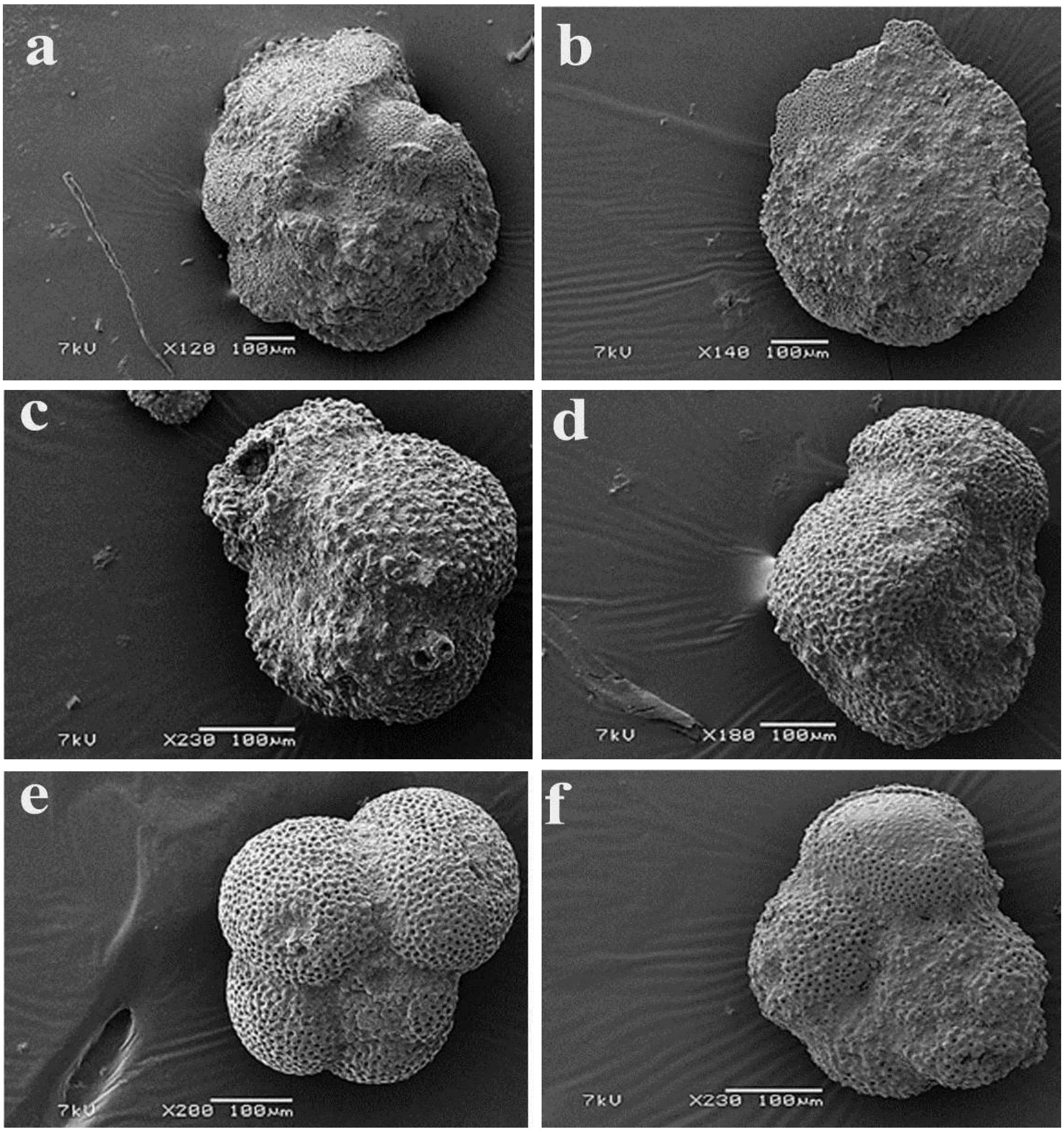

Fig.5: SEM images of diagnostic microfossils in the Sinjar section/ Aaliji Formation (Late Paleocene/ Early Eocene)

a) *Morozovella velascoensis* (Cushman, 1925), Ventral view, Late Paleocene (P5) Biozone, (sample A23); **b)** *Morozovella velascoensis* (Cushman, 1925), Dorsal view, Late Paleocene (P5) Biozone (sample A23); **c)** *Morozovella aequa* (Cushman and Renz, 1942),Ventral view, Late Paleocene (P5) Biozone, (sample A23); **d)** *Morozovella aequa* (Cushman and Renz, 1942), Dorsal view, Late Paleocene (P5) Biozone, (sample A23); **e)** *Acarinina sibaiyaensis* (Jenkins, 1971), Dorsal view, Early Eocene, (E1) Biozone (sample A24); and **f)** *Acarinina sibaiyaensis* (Jenkins, 1971), Ventral view, Early Eocene, (E1) Biozone (sample A24)

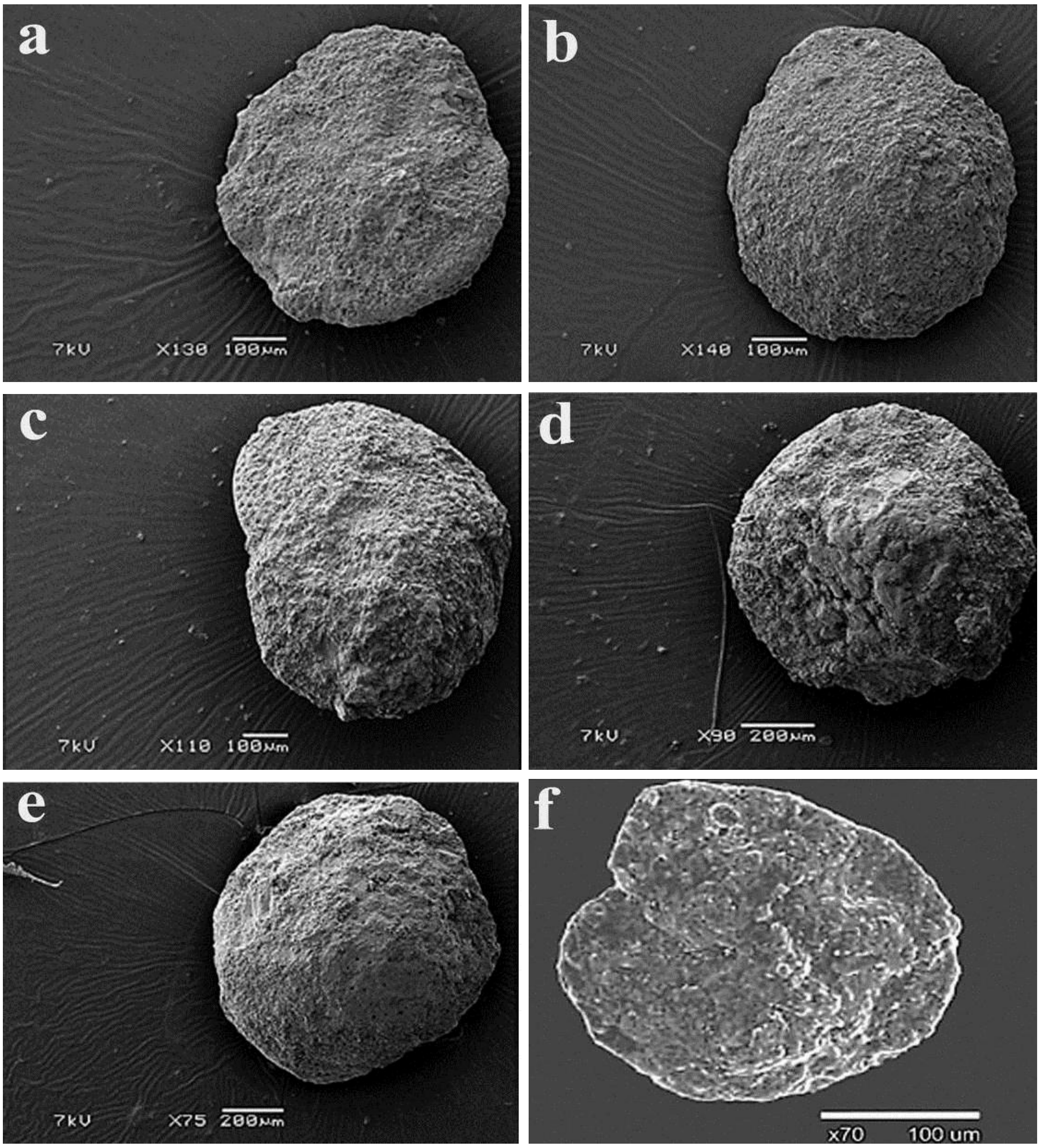

Fig.6: SEM images of diagnostic microfossils in the Dohuk section/ Kolosh Formation (Late Paleocene/ Early Eocene)

a) *Anomalinoides aegyptiacus* (LeRoy, 1953), Ventral view, (sample D28), Late Paleocene; **b)** *Anomalinoides aegyptiacus* (LeRoy, 1953), Dorsal view, (sample D26), Late Paleocene; **c)** *Angulogavelinella avnimelechi* (Reiss, 1952), Dorsal view (sample D28), Late Paleocene; **d)** *Oridorsalis plummerae* (Cushmann, 1926), Ventral view, (sample D 28), Late Paleocene; **e)** *Trochamminid* sp. Dorsal view, (sample D31), Early Eocene; and **f)** *Haplophragmoides* sp. Dorsalview, (sample D31), Early Eocene

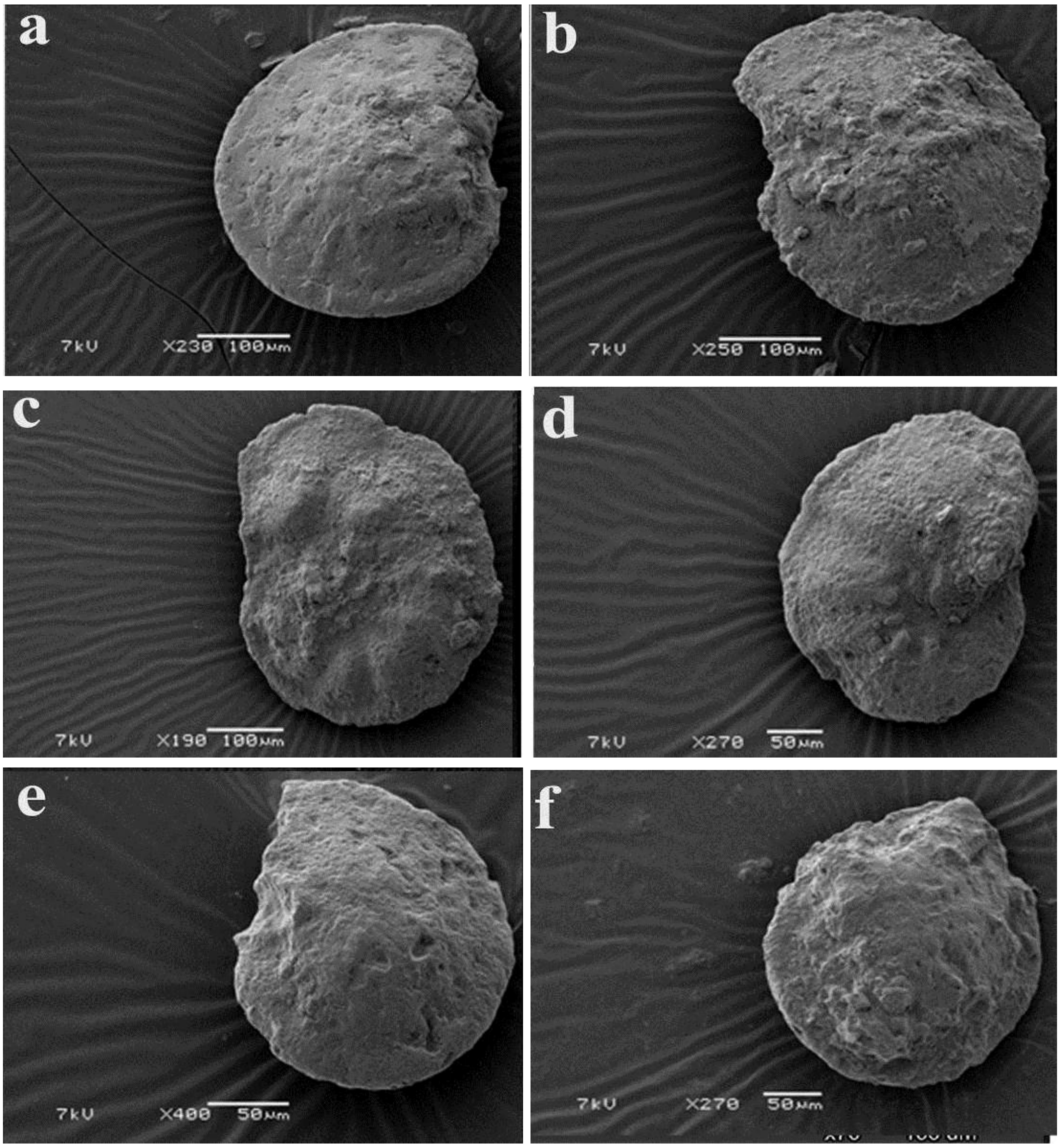

Fig.7: SEM images of diagnostic microfossils in the Shaqlawa section/ Kolosh Formation (Late Paleocene/ Early Eocene)

a) *Anomalinoides piripaua* (Finlay, 1939), Dorsal view, (sample Q24), Late Paleocene; **b)** *Anomalinoides piripaua* (Finlay, 1939), Dorsal view, (sample Q24), Late Paleocene; **c)** *Anomalinoides capitatus* (Gümbel, 1870), Ventral view, (sample Q25), Early Eocene; **d)** *Anomalinoides capitatus* (Gümbel, 1870), Dorsal view, (sample Q25), Early Eocene; **e)** *Nuttallides truempyi* (Nuttall, 1930), Ventral view, (sample Q25), Early Eocene; and **f)** *Nuttallides truempyi* (Nuttall, 1930), Dorsal view, (sample Q25), Early Eocene

The main marker species used to define the standard biozones of the Paleocene – Eocene (Aaliji Formation) transition are recognized within two biozones which are:

a- ***Morozovella velascoensis*** **Zone** (P5)**:** This zone is based on the partial range of the nominate zone taxon (Berggren and Pearson, 2005). It corresponds to the interval between highest occurrence or Last Appearance Datum (LAD) of *Morozovella velascoensis* and lowest occurrence or First Appearance Datum (FAD) of *Acarinina sibaiyaensis* (Molina *et al*., 1999; Pardo *et al*., 1999). Late Paleocene is assigned as age of this biozone.

b- ***Acarinina sibaiyaensis*** **Zone** (E1)**:** The base of this Interval Range Zone is defined by the First Appearance Datum (FAD) of *Acarinina sibaiyaensis.* The First Appearance Datum (FAD) of *Pseudohastigerina wilcoxensis* marks the end of this zone (Molina *et al*., 1999; Pardo *et al*., 1999). Early Eocene is the adequate age for this biozone.

As mentioned above, the Paleocene Eocene biostratigraphic boundary is delimited at the Last Appearance Datum (LAD) of *Morozovella velascoensis* (sample A23) and First Appearance Datum (FAD) of *Acarinina sibaiyaensis* (sample A24). Both species are recognized in the Aaliji Formation within biozones (P5 then E1) as well as other important species in (P5) biozone assemblages such as *Morozovella aequa* and *Igorina brodermani* in (E1) biozone, Figs. (5 – 7). Regardless of the lower (P5) biozone contact and upper (E1) biozone contact, the occurrence of (P5) and (E1) biozones alternately refer biostratigraphically to continuous sedimentation or condensed section for the Aaliji Formation and delimited the Paleocene- Eocene boundary. The E1 Zone is documented to contain the stratigraphic record of isotopic shifts (CIE) related to the PETM (Zili and Zaghbib-Turki, 2010). For comparison with Dababiya section of Egypt (global stratotype section of P – E boundary), the base of this zone coincides with the onset of a (CIE) (Alegret *et al*., 2005; Berggren and Pearson, 2005; Aubry *et al*., 2007; Alegret and Ortiz, 2007) and indicates the Paleocene – Eocene boundary.

An observed decline of the genus *Morozovella* coupled with insignificant modifications in *Acarinina* relative abundance is marked as key character in latest Paleocene. Whereas, the key character of the Paleocene-basal Eocene is the relative increase in Acarininids. Finally The so-called excursion taxa (e.g., *A. sibaiyaensis*) increased progressively after Early Eocene. This result considerably coincides with major changes in planktonic foraminiferal assemblages phases recorded across the PETM by Pardo *et al*. (1999); Luciani *et al*. (2007) and Alegret *et al*. (2010).

Planktonic foraminifera are often considered to have been relatively unaffected by global climatic and oceanographic change. This is largely because during the global warming peak (over toleration); tropical and subtropical taxa (Acarinids, Morozovellids) temporarily invaded high latitudes (most moderation by then) and displaced cooler water taxa. This generally resulted in the replacement of one fauna by another (Canudo *et al*., 1995); there was no net loss in species diversity and conversely, no mass extinction (Lu and Keller, 1993 in Canudo *et al*., 1995). This indirectly suggests that absence of planktonic foraminifera in sediments should not be necessarily attributed to missing age, but may be attributed to severe migration with continuous sedimentation as a result of exceptional events (such as PETM). Since eutrophication preferentially affect planktonic foraminiferal species cosmopolitan, variations of planktonic foraminiferal palaoebiographical indices should be considered as climatically forced only when there is evidence that trophic resources did not change (Payros *et al*., 2006) (Fig.4).

- **Benthonic Foraminifera of the Kolosh Formation**

The analysis of benthonic Foraminifera has been carried out in the Kolosh Formation at both Dohuk and Shaqlawa sections. Absence or very rare distribution of planktonic foraminifera in these sections may be attributed to either as a result of decrease in the Planktonic – Benthonic foraminiferal ratio P/B (shallowing mode) or may be further attributed to discontinuous distribution and changes in relative abundance of species. These specifications characterize the global planktonic foraminiferal turnover event at Paleocene/ Eocene boundary interval (El-Nady, 2005).

Generally, the benthonic assemblages are moderately well preserved and highly diverse, they mostly occurring as broken (thick-shelled) tests and made up of 30 – 50 % of non-calcareous agglutinated foraminiferal tests. The semi-complete absence of planktonic foraminifera and the occasional abundance of agglutinated foraminifera in the Kolosh Formation samples may provide evidence of severe dissolution (CCD shallowing) of the primary assemblages.

Selected samples within the Paleocene – Eocene expected lithesome are taken from the Dohuk section {samples D20-D35 (9 m thick)} and from Shaqlawa section {samples Q15-Q30 (10 m thick)}. The Benthonic foraminfera biostratigraphy is based on Berggren (1974), Kaiho and others (1993), Ortiz (1995), Alegret and Ortiz (2007) and Alegret and others (2009a and b). Benhonic foraminifera are subdivided into small and large.

- **Benthonic Foraminifera and the P/E Boundary**

Small and Large benthonic foraminifera are recognized in the studied sections, the small benthic foraminifera is a key tool in identifying the position of the P/E boundary in open marine sequences (Scheibner and Speijer, 2009). According to Berggren and Miller (1989) in Scheibner and Speijer (2009) bathyal benthonic foraminiferal Zone BB1, which spans the entire Paleocene and is characterized by Velasco type taxa, is distinguished from BB2 (Lower Eocene) through the extinction of *Angulogavelinella avnimelechi* and other species. Characteristic BB2 taxa are *Nuttallides truempyi* among other diagnostic species.

Benthonic foraminifera can be used as accurate paleobathymetric markers because their distribution in the oceans is controlled by a series of depth-related parameters. The mixed calcareous-agglutinated assemblages indicate deposition above the CCD for the studied section (neritic and bathyal environments). Nevertheless, the CCD shallowing may have relatively affected the biodiversity in the Shaqlawa section, especially when taking into account the extremely low P/B ratio which may be due to severe dissolution. The diverse benthonic foraminiferal assemblages recognized consist mainly of non-calcareous agglutinated foraminifera. The `Paleocene –Early Eocene benthonic foraminiferal faunas of the Kolosh Formation in both sections are composed typically of mixed Midway type/ Velasco-type taxa and some of the Tethyan carbonate taxa (at Dohuk section exclusively).

As mentioned above, the Paleocene/ Eocene boundary can be easily delineated by the sudden extinction of *Angulogavelinella avnimelechi*, which is the most common marker taxon in the Middle East and Tethys basin outer neritic deposits (Scheibner and Speijer, 2009). Therefore, the last recorded occurrence of *Angulogavelinella avnimelechi*, in sample (D28) and sample (Q24) at Dohuk and Shaqlawa sections respectively, represents good indication of deposition close to the boundary between middle and upper bathyal or slope environments (800 – 200 m depth) and that this environment closed the uppermost Paleocene time in Dohuk and Shaqlawa areas. In addition, the extinction of *Angulogavelinella avnimelechi* has been proven to be a useful marker for delineating the Benthic Foraminifral Extinction Event (BFEE), (Alegret and Ortiz, 2007; Alegret *et al*., 2009b).

The neritic to upper bathyal environmental wide range (100 – 500 m depth) of *Angulogavelinella avnimelechi* species or taxa and the exclusive rare contribution of *Stensioeina beccariiformis* at Shaqlawa area suggests, (based on Ortiz, 1995; Speijer and Wagner, 2002), that the sequence at the Shaqlawa area was deposited in a relatively deeper environment (middle-upper bathyal) than that in the Dohuk area (mid-outer neritic) during Late Paleocene.

The early Eocene time is characterized by deep-water agglutinated foraminifera (DWAF) such as *Trochamminid* sp., *Haplophragmoides* sp., *Recurvoides* sp. and some calcareous foraminifera as *Nuttallides truempyi*, *Anomalinoides capitatus* among others (Berggren and Miller, 1989; Speijer and Wagner, 2002). *Trochamminid* sp., *Haplophragmoides* sp. are recognized in both sections (in sample D31, Q25), whereas *Nuttallides truempyi*, *Anomalinoides capitatus* are recorded only at the Shaqlawa section (in sample Q25).These assemblages are typical of the low to mid-latitude continental slope or middle-upper bathyal Velasco-type fauna (Alegret *et al*., 2009b).

The occurrence of the benthonic microfouna *Anomalinoides aegyptiacus* assemblage (*A.aegyptiacus*, *A. capitatus*, *A.pirpaua*) at the uppermost Paleocene – lowermost Eocene samples in Dohuk and Shaqlawa sections, refer to continuous sedimentation and onset of PETM turbulence events that have dominated the environment of this assemblages (Dupuis *et al*., 2003; Ernst *et al*., 2006).

All the species of Large Benthic Foraminifera (LBF) recognized in the Dohuk section provide another clue to relative shallow environmental position of the Dohuk section compared to the Shaqlawa section. Depending on (Scheibner and Speijer, 2008; and 2009; Wan *et al*., 2010) the shallow benthonic zones boundary (SBZ4/SBZ5) demonstrates an unambiguous correlation with Paleocene/ Eocene boundary. SBZ4 (Late Paleocene) is characterized here at and prior to sample D28 by *Miscellanea* spp. and *Assilina* spp. while SBZ5 (Early Eocene) is characterized in the samples after (D28) by the presence of *Alveolina* spp., *Nummulites* spp., *Orbitolites* sp., and the absence of *Miscellanea* spp. The lowermost Eocene in the studied sections are characterized by the dominant presence of Alveolinids and Nummulitids (SBZ5), planktonic foraminifera assemblages of Zone E1 and smaller benthonic foraminifera typical of BB2 Zone (Fig.4).

- **Tethyan Foraminiferial Impression During PETM**

During the earliest Eocene, the planktonic foraminifera are characterized by a marked increase of *Acarinina* and the concomitant decline of *Morozovella*, with some differences in the species composition and relative abundance. This response is similar to what has been recorded at several other Tethyan sites as well as high latitude environments. The size of planktonic foraminifera are extremely sensitive to the chemical and physical parameter (specially temperatures) of the ambient sea water, the changing in test size is a morphological adaptive response to less than favorable environmental conditions associated with PETM (Kaiho *et al*., 2006; Wade and Olsson, 2009; Alegret *et al*., 2010).

The Paleocene – Eocene oceanographic changes that triggered the Benthic Foraminiferal Extinction Event, exhibited its first manifestation in the Tethys region (Ortiz, 1995). During PETM interval, the southern Tethyan margin experienced the (BFEE) and a dramatic decrease in species richness, diversity and heterogeneity, with assemblages dominated by opportunistic fauna (survivors) that indicate transient eutrophic and/or low oxygen conditions at the seafloor (Speijer and Wagner 2002; Alegret *et al*., 2005).

After the (BFEE) extinction event, which is proved above by *Angulogavelinella avnimelechi* extinction, the occurrence of small finely agglutinated *(Haplophrugmoides)* at Dohuk section and thin-walled epifaunal taxa (*Nuttallides truempyi*) at Shaqlawa section indicates sluggish circulation, bottom waters undersaturated in calcium carbonate and dysaerobic conditions (Ortiz, 1995). In shallower setting of southern Tethys, such as that in the Dohuk section , *Anomalinoides aegyptiacus* is abundant in the P/E boundary and it has been considered an opportunist taxon indicative of stressful conditions with low-oxygen levels and high productivity (e.g., Speijer *et al*., 1997; Speijer and Wagner, 2002; Ernst *et al*., 2006) (Fig.4).

PETM environmental conditions on the shelves, hampered the growth of aragonitic corals, while calcitic larger foraminifera flourished and dominanted carbonate platform inhabitant, as the widespread *Miscellanea miscella* in the Tethys which is restricted to the Paleocene. This indicates a stepwise Tethyan platform stage evolution around the Paleocene/ Eocene boundary; from platform stage II (characterized by larger foraminifera) to platform stage III (dominated by larger foraminifera) according to (Scheibner and Speijer, 2008) as observed in the Dohuk section.

CONCLUSIONS

- PETM occurrence in the three sections selected carefully to represent northern Iraq region ensure that this area is affected by PETM climatic disaster event during Paleocene – Early Eocene Period.
- The direct and indirect paleontological (foraminiferal), and sedimentological, indicators and the integration relationship among them suggest that both Aaliji and Kolosh Formations are included at least in principle the lithological or sedimentary records of PETM- associated events.
- Planktonic foraminiferal analysis results and occurrence of *Anomalinoides aegyptiacus* assemblage in the Aaliji and Kolosh formations, suggest continuous sedimentation or condensed section for both formations around the Paleocene/ Eocene boundary in the studied sections.
- The Aaliji Formation planktonic foraminifera assemblages response to PETM environmental conditions is represented by species reorganization (decline/ abundance) and morphological optimal adaptation (shape and size). While their response in the Kolosh Formation is represented by benthic extinction event (BFEE) (in deep environment areas) with general decrease in generic diversity of photoautotrophic (oligotrophic conditions) larger foraminifera followed by abundance stage (in shallow environment areas). The PETM- is distinguished more obviously in shallow marine environments (Dohuk section) compared to deep marine environments (Aaliji Formation).

REFERENCES

Alegret, L., Ortiz, S., Arenillas, I. and Molina, E., 2005. Paleonvironmental turnover across the Paleocene/ Eocene boundary at the Stratotype section in Dababiya (Egypt) based on benthic foraminfiera. Terra Nova, Vol.17, p. 526 – 536.

Alegret, L. and Ortiz, S., 2007. Global extinction event in benthonic foraminifera across the Paleocene/ Eocene boundary at the Dababiya Startotype section, J. of Micropaleontology, Vol.52, No.5, p. 433 – 447.

Alegret, L., Ortiz, S. and Molina, E., 2009a. Extinction and recovery of benthic foraminifera across the Paleocene – Eocene Thermal Maximum at the Alamedilla section (Southern Spain): Palaeogeography, Palaeoclimatology, Palaeoecology, Vol.279, p. 186 – 200.

Alegret, L., Ortiz, S., Orue-Etxebarria, X., Bernaola, G., Baceta, J.I., Monechi, S., Apellaniz, E. and Pujalte, V., 2009b. The Paleocene – Eocene Thermal Maximum: new data from the microfossil turnover at Zumaia section. Palaios Vol.24, p. 318 – 328.

Alegret, L., Ortiz, S., Arenillas, I. and Molina, E., 2010. What happens when the ocean is overheated? The foraminiferal response across the Paleocene – Eocene Thermal Maximum at the Alamedilla section (Spain). Geol. Soc. Am. Bull. Vol.122, p. 1616 – 1624.

Al-Juboury, F.N.H.A., 2011. Planktonic Foraminifral Biostratigraphy, Depositional Environment and Sequence Stratigraphy of Upper Cretaceous – Middle Eocene Sequences at selected Wells in Khabbaz Oil Field Northestern Iraq. Ph.D. Thesis in geology (In Arabic), Unpublished, University of Mosul, 215pp.

Al-Nakib, M.A., 1989. Geochemical study of Kolosh Formation in North Iraq. Unpublished M. Sc. thesis. Mosul University, 138pp.

Al-Sakry, S.I., 2006. Sequence Stratigraphy of the Paleocene – Lower Eocene Succession, Northeastern Iraq, Unpublished PH. D Thesis, University of Baghdad, 240pp.

Al-Qayim, B., 1993. Petrofacies analysis and tectonic evolution of Zagroside flysch suites from northeastern Iraq. In: Kumon and Ku (Eds.), Petrology of sandstones in relation to tectonics, V.S.P, Netherlands, p. 33 – 34.

Aubry, M.P., Ouda, K., Dupuis, C., Berggren, W.A. and Van Couvering, J.A., 2007. Members of the Working Group on the Paleocene – Eocene Boundary the Global Standard Stratotype-Section and Point (GSSP) for the base of the Eocene Series in the Dababiya section (Egypt). Episodes Vol.30, p. 271 – 286.

Berggren, W.A., 1974. Late Paleocene – Early Eocene benthonic foraminiferal biostratigraphy and paleoecology of Rockall Bank. Micropaleontology, Vol.20, p. 426 – 448.

Berggren, W.A., Miller, K.G., 1989. Cenozoic bathyal and abyssal calcareous benthic foraminiferal zonation. Micropaleontology, Vol.35, p. 308 – 320.

Berggren, W.A. and Pearson, P.N., 2005. A revised tropical to subtropical planktonic foraminiferal zonation of the Eocene and Oligocene: Journal of foraminiferal Research, Vol.35, p. 279 – 298.

Bolle, M.P., Pardo, A., Adatte, T., von Salis, K. and Burns, S., 2000a.Climatic evolution on the southeastern margin of the Tethys (Negev, Israel) from the Palaeocene to the early Eocene: focus on the late Palaeocene Thermal Maximum. Journal of the Geological Society, London, Vol.157, p. 929 – 941.

Bolle, M.P., Pardo, A., Hinrichs, K. U., Adatte, T., von Salis, K., Burns, S., Keller, G. and Muzylev, N., 2000b. The Paleocene – Eocene transition in the marginal northeastern Tethys (Kazakhstan and Uzbekistan). International Journal of Earth Sciences, Vol.89, p. 390 – 414.

Bolle, M.P., Tantawy, A. A., Pardo, A., Adatte, T., Burns, S. and Kassab, A., 2000c. Climatic and environmental changes documented in the upper Paleocene to lower Eocene of Egypt. Eclogae Geologicae Helvetiae, Vol.93, p. 33 – 51.

Bowen, G.J., Bralower, T.J., Delaney, M.L., Dickens, G.R., Kelly, D.C., Koch, P.L., Kump, L.R., Meng, J., Sloan, L.C., Thomas, E., Wing, S.L. and Zachos, J.C., 2006. Eocene Hyperthermal Event Offers Insight Into Greenhouse Warming, EOS, Transactions of the American Geophysical Union, Vol.87, No.17, p. 165 – 169.

Brassier, M.D., 1980. Microfossils. George Allen and Unwin Ltd., London, 193pp.

Canudo, J.I., Keller, G., Molina, E. and Ortiz, N., 1995. Planktic foraminiferal turnover and $\delta13C$ isotopes across the Paleocene – Eocene transition at Caravaca and Zumaya, Spain. Palaeogeography, Palaeoclimatology, Palaeoecology Vol.114, p. 75 – 100.

Dupuis, C., Aubry, M.P., Steurbaut, E., Berggren, W., Ouda, K., Magioncalda, R., Cramer, B., Kent, D., Speijer, R. and Heilmann-Clausen, C., 2003. The Dababiya Quarry section: lithostratigraphy, clay mineralogy, geochemistry, and paleontology. Micropaleontology, Vol.49 (Suppl. 1), p. 41 – 59.

El-Eissa, M.I. and Mohammad, S.H., 1997. The topographic development of the Paleocene- Eocene depositional basin in the Northern and central of Iraq, Iraqi geological journal, Vol.30, p. 1 – 8.

El-Nady, H., 2005. The impact of Paleocene/ Eocene (P/E) boundary events in northern Sinai, Egypt: Planktonic foraminiferal biostratigraphy and faunal turnovers, Revue de Paléobiologie, Genève, Vol.24, No.1, p. 1 – 16.

Ernst, S.R., Guasti, E., Dupuis, CH. and Speijer, R.P., 2006. Environmental perturbation in the southern Tethys across the Paleocene/ Eocene boundary (Dababiya, Egypt): Foraminiferal and clay mineral records. Marine Micropaleontology, Vol.60, p. 89 – 111.

Ernst, S.R., Guasti, E., Dupuis, CH. and Speijer, R. P. 2006.Environmental perturbation in the southern Tethys across the Paleocene/ Eocene boundary (Dababiya, Egypt): Foraminiferal and clay mineral records. Marine Micropaleontology, Vol.60, p. 89 – 111.

Gavrilov, Y.O., Shcherbinina, E.A. and Oberhänsli, H., 2003. Paleocene – Eocene boundary events in the northeastern Peri-Tethys. Geological Society of America Special Paper, Vol.369, p.147 – 168.

Giusberti, L., Rio, D., Agnini, C., Backman, J., Fornaciari, E., Tateo, F., and Oddone, M., 2007. Mode and tempo of the Paleocene – Eocene Thermal Maximum in an expanded section from the Venetian pre-Alps. Geological Society of America Bulletinm Vol.119, p.391 – 412.

Guasti, E. and Speijer, R.P., 2007. The Paleocene – Eocene Thermal Maximum in Egypt and Jordan: an overview of the planktic foraminiferal record. Geol. Soc. Am. Spec. Pap., Vol.424. Tulsa, p. 53 – 67.

Giusberti, L., Coccioni, R., Sprovieri, M., Tateo, F., 2009. Perturbation at the sea floor during the Paleocene – Eocene Thermal Maximum: evidence from benthic foraminifera at Contessa Road, Italy. Marine Micropaleontology, Vol.70, No. 3 – 4, p. 102 – 119.

Handley, L., Halloran, A.O., Pearson, P.N., Hawkins, E., Nicholas, C.J., Schouten, S., McMillan, I.K. and Pancost, R.D., 2012. Changes in the hydrological cycle in tropical East Africa during the Paleocene – Eocene Thermal Maximum, Palaeogeography, Palaeoclimatology, Palaeoecology, 329 – 330, p. 10 – 21.

Jassim, S.Z. and Buday, T., 2006. Middle Paleocene – Eocene Megasequence (AP 10). In: Jassim, S.Z., and Goff, J.C. (Eds) Geology of Iraq. Dolin, Prague and Moravian Museum, Brno, Czech Republic. p.155 – 167.

Kaiho K., Morgans H.E.D. and Okada, H., 1993. Faunal turnover of intermediate-water benthic foraminifera during the Paleogene in New Zealand, J. of Marine Micropaleontology, Vol.23, p. 51 – 86.

Kaiho, K., Takeda, K., Petrizzo, M.R. and Zachos, J.C., 2006. Anomalous shifts in tropical Pacific planktonic and benthic foraminiferal test size during the Paleocene – Eocene thermal maximum, Palaeogeography, Palaeoclimatology, Palaeoecology Vol.237, p. 456 – 464.

Kennett, J.P. and Stott, L.D., 1991. Abrupt Deep-Sea Warming, Palaeoceanographic Changes and Benthic Extinctions at the end of the Palaeocene. Nature 353, p. 225 – 229.

Khozyem, H., Adatte, T., Spangenberg, J. E., Tantawy, A. A. and Keller, G., 2013. Palaeoenvironmental and climatic changes during the Palaeocene – Eocene Thermal Maximum (PETM) at the Wadi Nukhul Section, Sinai, Egypt, Journal of the Geological Society, London, Vol.170, p. 341 – 352.

Lawa, F.A.A., 2004. Sequence stratigraphic analysis of the Middle Paleocene – Middle Eocene in the Sulaimani District (Kurdistan Region) Doctorate of Philosophy in geology, Unpublished, University of Sulaimani, 258pp.

Lee, Y.S. and Kodama, K., 2009. A possible link between the Geomagnetic Field and Catastrophic Climate at the Paleocene – Eocene Thermal Maximum, Geology, Vol.37, No.11, p. 1047 – 1050.

Lirer, F., 2000. A new technique for retrieving calcareous microfossils from lithified limedeposits. Micropaleontology, Vol.46, p. 365 – 369.

Luciani, V., Giusberti, L., Agnini, C., Backman, J., Fornaciari, E. and Rio, D., 2007. The Paleocene – Eocene Thermal Maximum as recorded by Tethyan planktonic foraminifera in the Forada section (northern Italy). Marine Micropaleontology, Vol.64, p. 189 – 214.

Malak, Z. A., 2010. Sedimentological and Stratigraphical Study of the Paleocene – Eocene Successions from Selected Areas-North Iraq, Ph.D. Thesis in geology (In Arabic), Unpublished, University of Mosul, 215pp.

Molina, E., Arenillas, I. and Pardo, E., 1999. High resolution planktic foraminiferal biostratigraphy and correlation across the Paleocene/ Eocene boundary in the Tethys. Bulletin de la Société géologique de France 174, p. 521 – 530.

Olsson, R.K., Berggren, W.A., Hemleben, C. and Huber, B.T., 1999. Atlas of Paleocene Planktonic Foraminiferal, Smithsonian Institution Press, Washington, D.C., Vol.85, p. 1 – 252.

Ortiz, N., 1995. Differential patterns of benthic foraminiferal extinctions near the Paleocene/ Eocene boundary in the North Atlantic and the western Tethys. Marine Micropaleontology, Vol.26, p. 341 – 359.

Pardo, A., Keller, G. and Oberhansli, H., 1999. Paleocologic and paleo-oceanographic evolution of the tethyan realm during the Paleocene – Eocene transition. Journal of Foraminiferal Research, Vol.29, p. 37 – 57.

Payros, A., Orue-Etxebarria, X. and Pujalte, V., 2006. Covarying sedimentary and biotic fluctuations in Lower – Middle Eocene Pyrenean deep-sea deposits: Palaeoenvironmental implications. Palaeogeography, Palaeoclimatology, Palaeoecology, Vol.234, p. 258 – 276.

Pearson, P.N., Olsson, R.K., Huber, B.T., Hemleben, C.H. and Berggren, W.A., 2006. Atlas of Eocene planktonic foraminifera, Cushman Foundation special publication, Vol.41, 513pp.

Rea, D.K., Zachos, J.C., Owen, R.M. and Gingerich, D., 1990. Global change at the Paleocene – Eocene boundary: climatic and evolutionary consequences of tectonic events. Palaeogeography, Palaeoclimatology, Palaeoecology, Vol.79, p. 117 – 128.

Scheibner, C. and Speijer, R.P., 2008. Late Paleocene – early Eocene Tethyan carbonate platform evolution -a response to long- and short-term paleoclimatic change. Earth-Science Reviews, Vol.90, p. 71 – 102.

Scheibner, C. and Speijer, R.P., 2009. Recalibration of the Tethyan shallow-benthic zonation across the Paleocene – Eocene boundary: the Egyptian record. Geologica Acta, Vol.7, No. 1 – 2, p. 195 – 214.

Scheibner, C., Speijer, R.P., Marzouk, A.M., 2005. Larger foraminiferal turnover during the Paleocene/ Eocene thermal maximum and paleoclimatic control on the evolution of platform ecosystems. Geology, Vol.33, p. 493 – 496.

Silva, I.P., Pettori, R. and Verga, D., 2003. Practical Manual of Paleocene and Eocene Planktonic Foraminifera, Dipartimento di Scienze della Terra, University of Perugia (Italy), Internationa; School on Planktonic Foraminifera, Perugia. 152 Pages.

Soliman, M.F., Aubry, M.P., Schmitz, B., Sherrell, R.M., 2011. Enhanced coastal paleoproductivity and nutrient supply in Upper Egypt during the Paleocene/Eocene Thermal Maximum (PETM): Mineralogical and geochemical evidence, Palaeogeography, Palaeoclimatology, Palaeoecology, Vol.310, p. 365 – 377.

Speijer, R.P., Schmitz, B. and van der Zwaan, G.J., 1997. Benthic foraminiferal extinction and repopulation in response to latest Paleocene Tethyan anoxia. Geology, Vol.25, p. 683 – 686.

Speijer, R. and Wagner, T., 2002. Sea-level changes and black shales associated with the late Paleocene thermal maximum: Organic-geochemical and micropaleontologic evidence from the southern Tethyan margin (Egypt – Israel). Boulder: Geological Society of America, Special Paper, Vol.356, p. 533 – 549.

Speijer, R.P., Bornemann, A., Kouwenhoven, T.J., Pirkenseer, C., Schulte, P., Stassen, P. and Steurbaut, E., 2011. Identification and characterization of early Eocene hyperthermals in shallow marine sequences, (Abstract), Berichte Geol. B.-A., 85 (ISSN 1017-8880) – CBEP, Salzburg, June 5^{th} – 8^{th}.

Stassen, P., Dupuis, C., Morsi, A.M.M., Steurbaut, E. and Speijer, R.P., 2009. Reconstruction of a latest Paleocene shallow-marine eutrophic paleoenvironment at Sidi Nasseur (Central Tunisia) based on foraminifera, ostracoda, calcareous nannofossils and stable isotopes (δ13C, δ18O). Geologica Acta, Vol.7, p. 93 – 112.

Stassen, P., Dupuis, C., Steurbaut, E., Yans, J. and Speijer, R.P., 2012. Perturbation of a Tethyan coastal environment during the Paleocene – Eocene thermal maximum in Tunisia (Sidi Nasseur and Wadi Mezaz). Palaeogeography, Palaeoclimatology, Palaeoecology, 317 – 318, p. 66 – 92.

Wade, B.S. and Olsson, R.K., 2009. Investigation of pre-extinction dwarfing in Cenozoic planktonic foraminifera. Palaeogeography, Palaeoclimatology, Palaeoecology, p. 1 – 8.

Wan, X.Q., Wang, X. and Jansa, L.F., 2010. Biostratigraphy of a Paleocene Eocene Foreland Basin boundary in southern Tibet, Geoscience Frontiers, Vol.1, p. 69 – 79.

Zili, L. and Zaghbib-Turki, D., 2010. Foraminiferal Biostratigraphy and Palaeoenvironmental Reconstruction of the Paleocene – Eocene Transition at the Kharrouba Section, Tunisia (Southern Tethys Margin), Turkish Journal of Earth Sciences, Vol.19, p. 385 – 408.

About the authors

Ahmed Natheer Thanoon Al-Fattah, born in Mosul 1977 and obtained his B.Sc. in Earth Sciences in 1999 from the University of Mosul; M.Sc. (Sedimentology) in 2002 and Ph.D. (Sedimentology) in 2014 from the same university. From 2002 till now he is a member of the teaching staff at the University of Mosul and Member of the Iraqi Geologists Union.

e-mail: anf1277@uomosul.edu.iq
Mailing address: University of Mosul, Mosul, Iraq

Ali I. Al-Juboury, Professor at the Geology Department, University of Mosul, Iraq. He obtained his B.Sc. in Geology and M.Sc. in Sedimentology in 1980 and 1983, respectively, and his Ph.D. from Comenius University, Slovakia, in 1992. He has published 100 papers in local and peer-reviewed journals in the fields of mineralogy, petroleum geology, sedimentology and geochemistry. He is a member of numerous international societies and serves in the editorial board of several journals inside and outside Iraq. He also received several awards among which are, Distinguished Scholars Award from the Arab Fund for Economic and Social Development, Kuwait, in 2009 and the Science and Technology (Geology) Award from the Islamic States in 2014.

e-mail: alialjubory@uomosul.edu.iq
Mailing address: University of Mosul, Mosul, Iraq

Imad M. Ghafor, Professor in Micropaleontology and Biostratigraphy at the Geology Department of the Sulaimani University, Kurdistan Region, Iraq. He graduated from the Sulaimani University in June 1981 and got his M.Sc. degree from Salahaddin University (Erbil) in December 1988. He obtained his Ph.D. degree from Sulaimani University in July 2004. Professor Ghafor participated in more than 16 international conferences and has more than 34 published papers in local and international peer referred journals in the field of Paleontology, Micropaleontology, Stratigraphy, Biostratigraphy and Paleoecology. He supervised 8 Master and Doctorate studies. Professor Ghafor has been teaching Paleontology, Micropaleontology, Stratigraphy, Biostratigraphy, Palynology and Paleoecology for undergraduate geology students for more than 30 years, and teaching postgraduate students Advanced Paleontology, Advanced Micropaleontology, Applied Biostratigraphy, Advanced Biostratigraphy and Tertiary Biostratigraphy.

e-mail: imad.gafor@univsul.edu.iq
Mailing address: University of Sulaimani, Sulaimaniya, Iraq