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# Biostratigraphy of the Cretaceous/Tertiary boundary in the Sirwan Valley (Sulaimani Region, Kurdistan, NE Iraq)

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**Abstract:** The Cretaceous/Tertiary (K/T) boundary sequence, which crops out in the studied area is located within the High Folded Zone, in the Sirwan Valley, northeastern Iraq. These units mainly consist of flysch and flysch-type successions of thick clastic beds of Tanjero/Kolosh Formations. A detailed lithostratigraphic study is achieved on the outcropping uppermost part of the Upper Cretaceous successions (upper part of Tanjero Formation) and the lowermost part of the Kolosh Formation. On the basis of the identified planktonic foraminiferal assemblages, five biozones are recorded from the uppermost part of Tanjero Formation and four biozones from the lower part of the Kolosh Formation (Lower Paleocene) in the Sirwan section. The biostratigraphic correlations based on planktonic foraminiferal zonations showed a comparison between the biostratigraphic zones established in this study and other equivalents of the commonly used planktonic zonal scheme around the Cretaceous/Tertiary boundary in and outside Iraq.

**Key words:** Cretaceous/Tertiary boundary, Iraq, Kurdistan region, Sulaimani, biostratigraphy.

## Introduction

The Tanjero, Kolosh and Red Bed Series basin, as a part of the Neotethys, was strongly deformed by the Alpine orogeny during its activity continuing from Jurassic to Miocene when a huge thickness of sediments was accumulated (Buday & Jassim 1987). The Jurassic to Miocene successions are generally well exposed in different localities and different types of stratigraphic units in Zagros mountain regions such as the Balambo, Qulqula, Qamchuqa, Aqra-Bekhme, Kometan, Shiranish and Tanjero Formations, in addition to the Kolosh, Gercus Formations and Red Bed Series. The basins of these units have a complicated history of development and tectonics, this history was demonstrated by different characteristics of these stratigraphic units.

This study deals with the biostratigraphy of Cretaceous/Tertiary boundary sequences in the Sulaimani, Kurdistan region, NE Iraq, depending on planktonic foraminifers through Late Maastrichtian and Early Paleocene. Lithologically it is concerned with the Tanjero and Kolosh Formations, in the studied area.

The studied area is located on the southern boundary (in front) of the Zagros Thrust Belt, which developed from the basin fill of the Neotethys and collision of the Iranian and Arabian plates (Buday 1980). Structurally the studied area is located within two different zones. The outcrops of the Sirwan Valley section (Halabja area) are located in the Imbricated Zone as divided by Buday & Jassim (1987), (Fig. 1).

**Tanjero Formation.** According to Dunnington (1952) in Bellen et al. (1959), the Tanjero Formation is first defined and described under this name from the selected type section in the Sirwan Valley, 2 km to the south of Kani Karweshkan village, near Halabja town (Fig. 1) and on the right bank of the Sirwan river (upstream of the Dialla river). The type section comprises two divisions; the lower division represents pelagic marl, and occasional beds of argillaceous limestone with siltstone beds in the upper part (Bellen et al. 1959), whereas, the upper division comprises silty marl, sandstone, conglomerate, and sandy or silty organic detrital limestone interfingering with the Aqra Limestone Formation. The sandstone is composed of chert and green igneous and metamorphic rocks. The conglomerates contain pebbles of Mesozoic limestones, dolomites, recrystallized limestones and radiolarian chert. The thickness of the formation is highly variable, with a maximum thickness of about 2000 meters between Rowandus and Chwarta (Jassim & Goff 2006).

The Tanjero Formation extends into Southeast Iran where it was referred to as the Maastrichtian flysch by Kent et al. (1952) in Jassim & Goff (2006), and is described as chert conglomerate by James & Wynd (1965). In Turkey, the Cretaceous parts of the Garmav Formation are equivalent to the Tanjero Formation (Buday 1980).

Abdel-Kireem (1986a) suggested removal of the word "clastic" from the name of the formation and to place its lower part within the Shiranish Formation, during their study of the formation within the stratigraphy of the Upper Cretaceous and Lower Tertiary of Sulaimani, Dokan region. Abdel-Kireem (1986b) subdivided the formation into three units according to the microfacies and lithofacies during their study of planktonic foraminifers and stratigraphy of Tanjero Formation.

Karim (2004, 2006) and Karim & Surdashy (2005a,b, 2006) investigated the basin analysis, paleocurrent, tectonic history and sequence stratigraphy of the Tanjero Formation. They indicated an unconformity in the lower part of Tanjero Formation which was represented by about 500 m of boulder

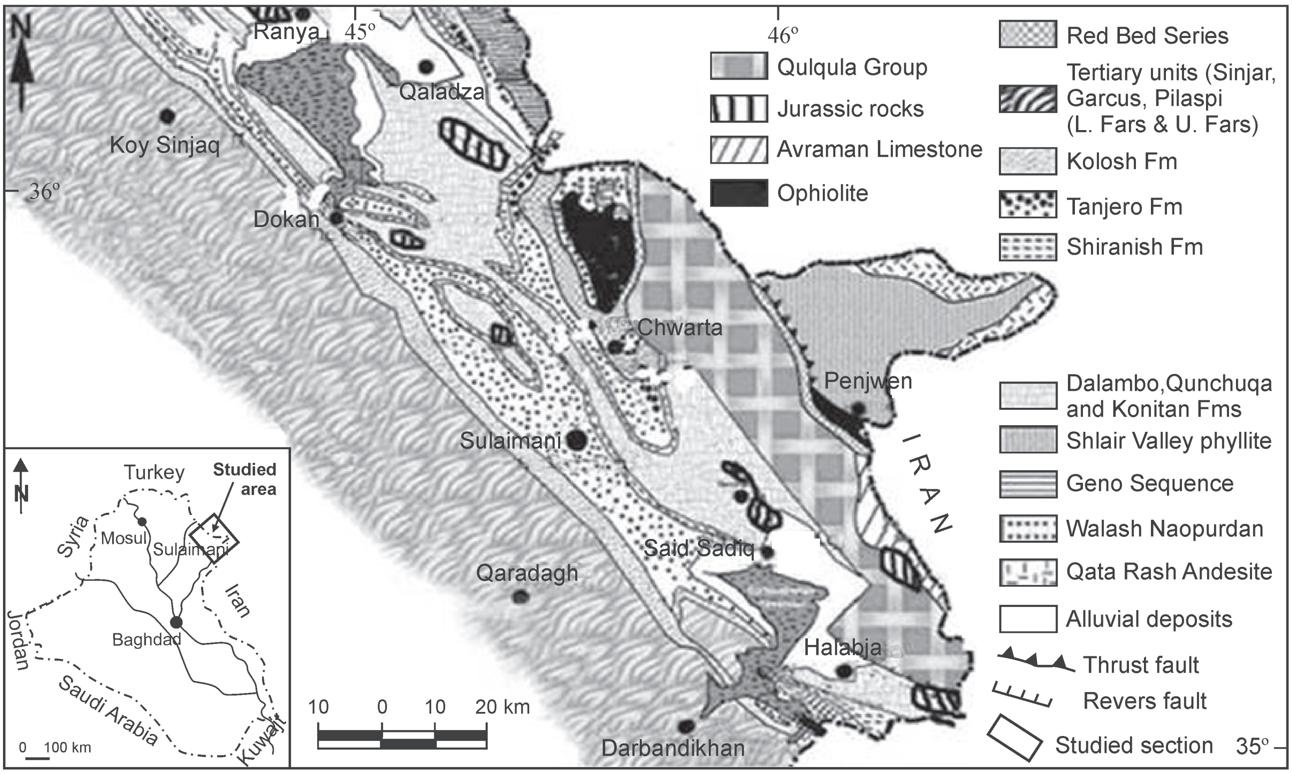


**Fig. 1.** Location map of the studied area (from Sissakian et al. 2000).

and gravel conglomerate. They mentioned that this conglomerate was deposited during sea-level fall (lowstand system tract). According to Sharbazheri (2007) the duration of this conglomerate unit in the Chwarta area were estimated to be 1.23 Myr.

**Kolosh Formation.** The formation was first described by Dunnington (1952, in Bellen et al. 1959) at Kolosh village, north of Koy Sinjaq in the High Folded Zone: Ditmar et al. (1971) also mentioned the occurrence of the upper part of the Sinjar Formation in the type locality. The formation consists of shale and sandstones composed of green rock, chert, and radiolarite.

Bellen et al. (1959) described the following units from the Kolosh type locality from the top to the base: 1–144 m of limestone and marl with *Miscellanea miscella*, ostracods and miliolids; 2–30 m of limestone with *Dictyokathina simplex* Smout, *Lokhartia* sp., valvulinids, miliolids, ostracods; 3–113.5 m of limestone and shales, red shales and sandstone with the same fossils but without *Dictyokathina simplex* Smout; 4–6 m of limestone with *Saudia labyrinthia*, miliolids and rotalids; 5–410 m of blue shale and green sand.

According to Ditmar et al. (1971), the following fossils were distinguished in the type locality: *Ammodiscus incertus*, *Globorotalia angulata*, *Globigerina bulloides*, *Gyroidina soldanii*, *Loxostoma applinae*, *Nodosaria zippei*, *Nuttalides truempyi*, *Pseudovalvulineria* sp., *Teredolites* sp., *Ovulites morelleti*, *O.* cf. *elongate*, *Trinocladus perplexus*, *Griphoporella arabica*, *Funcoporella diplopora*, *Cymoporella* sp.

Toward the west, the formation comprises mudstone, siltstone, and argillaceous limestone beds of distal lithological character in subsurface sections at the Chamchamal, Taq Taq and Mushorah region (Jassim & Goff 2006).

The biostratigraphy of the Kolosh Formation was studied by Kassab (1972, 1974, 1975b, 1976a,b, 1978) and Kassab et al. (1986) at the type locality and other locations in the north and northeast of Iraq. They recognized the planktonic foraminiferal zones of earliest Middle Paleocene, represented by *Globorotalia uncinata* Partial Range Zone.

## Review on the Upper Cretaceous–Lower Tertiary contact in Iraq

The Upper Cretaceous and Lower Tertiary sedimentary rocks in Iraq have been the subject of numerous stratigraphic and paleontological investigations. Such sediments are well developed in both surface and subsurface sections at northern and northeastern Iraq.

The Upper Cretaceous and Lower Tertiary boundary is marked by one of the most dramatic extinctions of different groups of organism; especially the planktonic foraminifers, the recognition of the major paleoclimatic change during the Late Maastrichtian has focused new attention on global climate changes and their effect on marine organisms.

In particular the last half million years of the Maastrichtian is increasingly recognized as a time of rapid and extreme climatic changes characterized by maximum cooling at about 65.5 Ma, followed by (3–4 °C) greenhouse warming and the major Deccan volcanic activity between 65.4 and 65.2 Ma (Li & Keller 1998a; Keller 2001).

Al-Shaibani et al. (1986) during their stratigraphic analysis of the Tertiary/Cretaceous contact in the Dokan area, (North Iraq), they placed the contact in Zone P3 (Middle Thanetian), based on overlapping of the range of *Globorotalia* (*T.*) *trinidadensis* Bolli (1957), and *Subbotina velascoensis* Cushman, 1925 and other species.

During their study of the biostratigraphy of the upper part of the Kolosh Formation from Sartaq-Bamo in northeastern Iraq, Ghafor & Karim (1999) recognized the *Globorotalia velascoensis* Zone of Late Paleocene age. Dunnington (1955, 1957) recorded the indication of a great gap in the stratigraphic column, in his biostratigraphic studies about the nature of the Cretaceous/Tertiary contact in Dohuk, Aqra and northern Iraq, indicated by the period of great regression of the ocean during the Late Maastrichtian and Early Paleocene time followed by uplifting of the area due to the tectonic orogeny, consequently this region underwent the process of erosion and a period of non deposition. This phenomenon is applied for almost the greater part of Iraq, exactly in the region of the northern and northeastern part. Al-Omari (1970) during his study on foraminifers of Mesozoic and Cenozoic at wells Butmah-9 and Ainzala-16, -17 from the northwestern part of Iraq, confirmed that the Aaliji Formation overlies the Shiranish Formation unconformably. Other biostratigraphic studies carried out in Iraq and especially in the studied area are summarized in (Fig. 2).

The Sirwan type section is located at the Sirwan Valley, on the right bank of the Sirwan river (upstream of Diyala river), 2 km to the south of Kani Karweshkan village, near Halabja town at latitude (35°07′26.7″) and longitude (45°52′34.7″). Most of the lower part of the type section for the Tanjero Formation was covered with water by the Darbandekhan Dam (Fig. 1).

All samples were collected from the studied section in the field after removing the surface contaminated soil and trying to obtain fresh and unweathered materials. Samples were collected at interval ranging between 20–50 cm at or near the Cretaceous/Tertiary contact and at interval of 50 cm to 3 m away from the contact.

The aim of this study includes the complete high resolution biostratigraphic zonation of the section, regional biostratigraphic correlation of the studied section correlation with other similar sequences, ascertaining the age of the sequence, by using the new zonal scheme and the age of planktonic foraminiferal datum events with correlative and relative methods, identifying the nature of the contact between Late Maastrichtian and Early Paleocene.

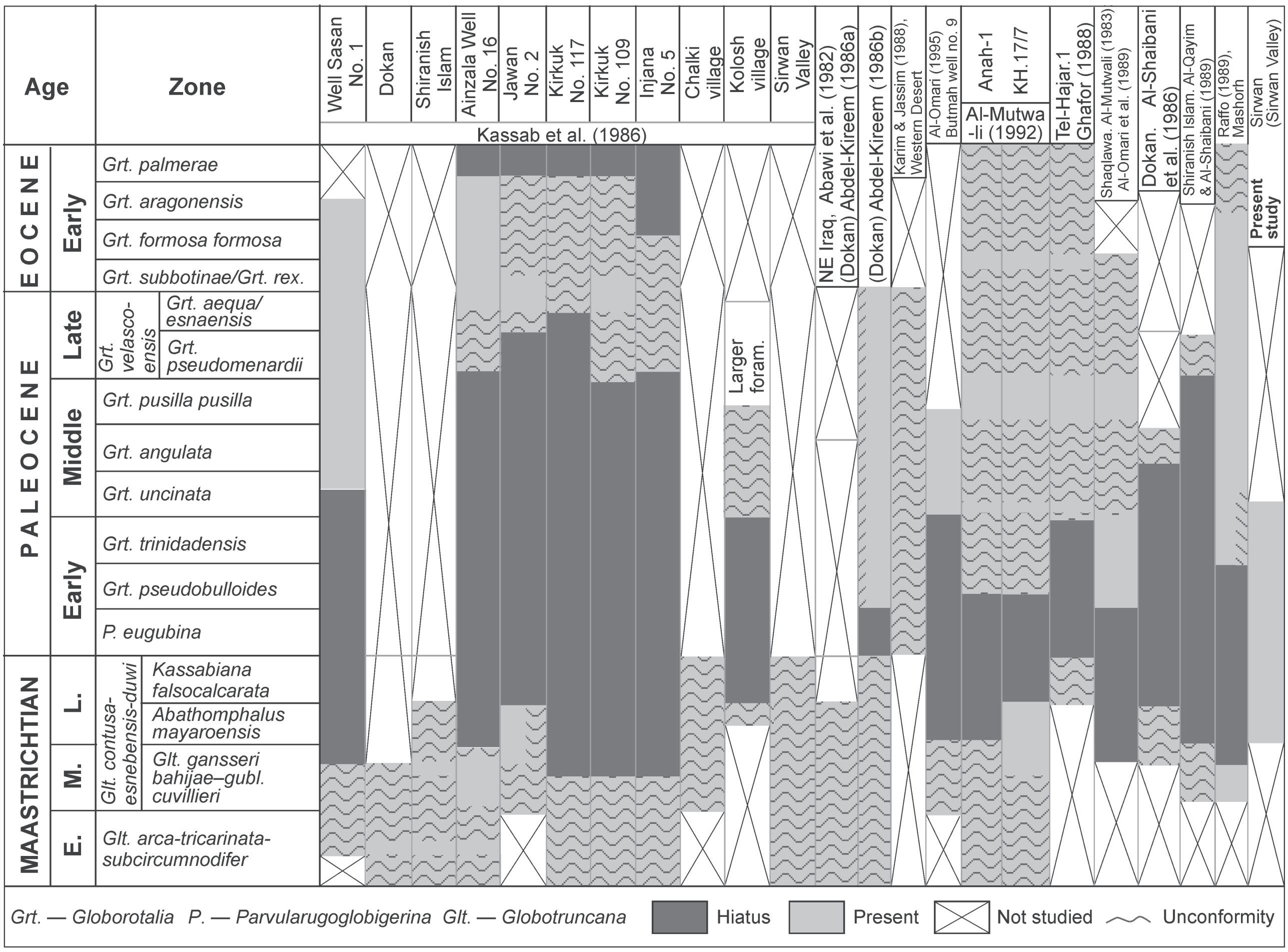


**Fig. 2.** Correlation of the previous biostratigraphic zonation. Cretaceous/Tertiary boundary in the studied region and different localities of Iraq.

## Lithostratigraphy

The studied section in Sirwan Valley includes the uppermost part of the Tanjero Formation which is about 255 m thick and the lower part of the Kolosh Formation about 65 m thick. The description of lithological constituent, and fieldwork investigation is inferred as shown in (Fig. 3). Generally, the Tanjero Formation consists of alternation of bluish marl, marly siltstone, pebbly sandstone, intraformational conglomerate beds distributed along this interval and ranging in thickness from 0.5 m to 2 m (Fig. 4).

The Kolosh Formation (Paleocene) overlies the Tanjero Formation and is separated by a conglomerate bed 3 m thick at the base, biostratigraphic investigation shows evidence of the pebble condition of conformable contact of the Kolosh Formation consisting of alternation of dark grey shale, bluish

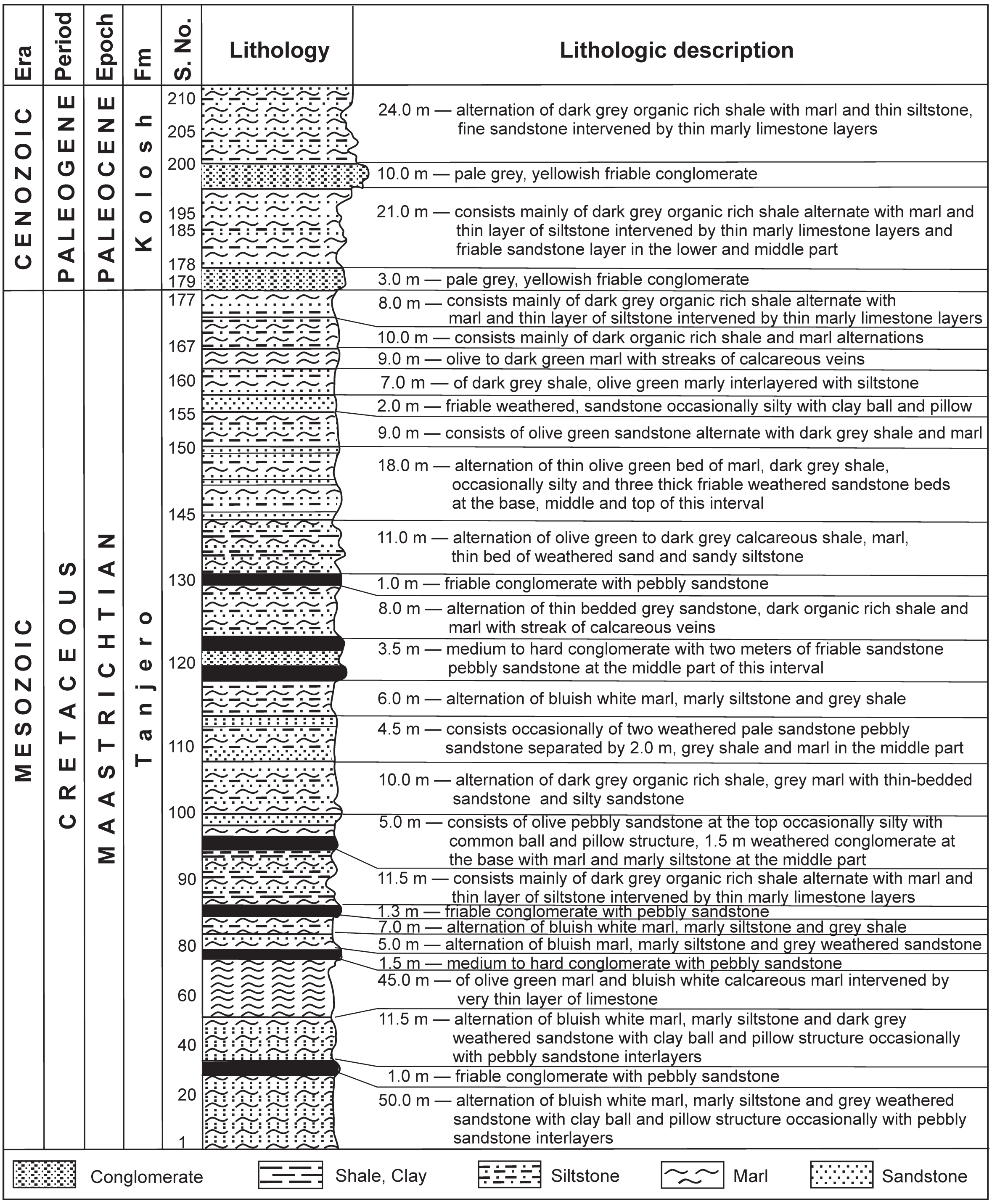


**Fig. 3.** Lithostratigraphic column of Sirwan Valley showing lithologic characters. (Not to scale, the thickness shown on each portion of discussion).

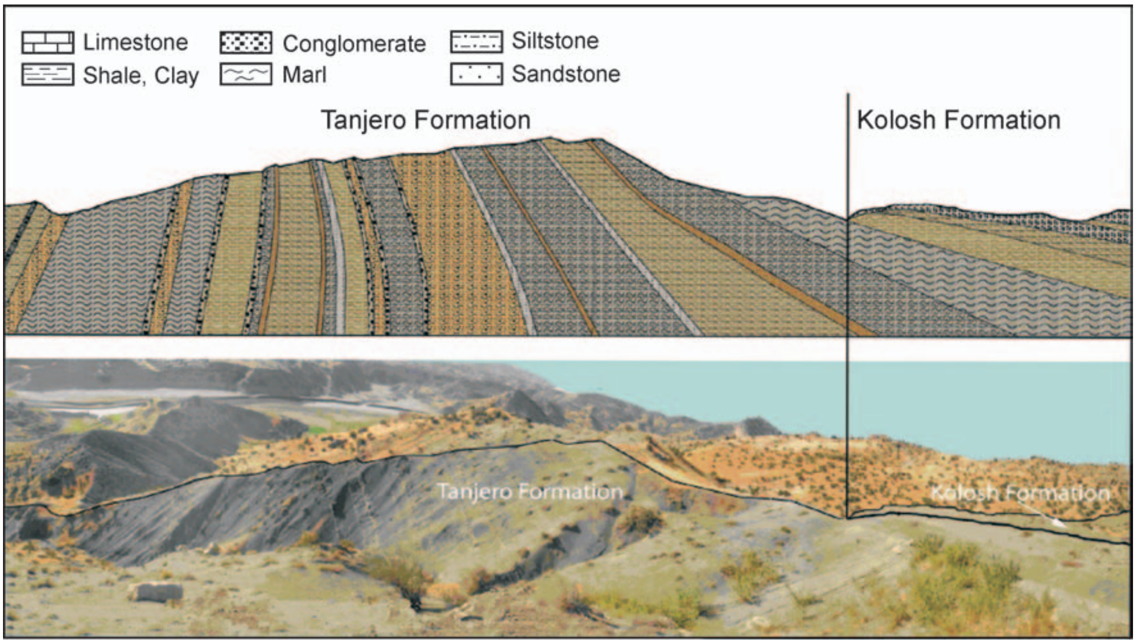


**Fig. 4.** Schematic geologic cross-section of the studied section (Sirwan Valley).

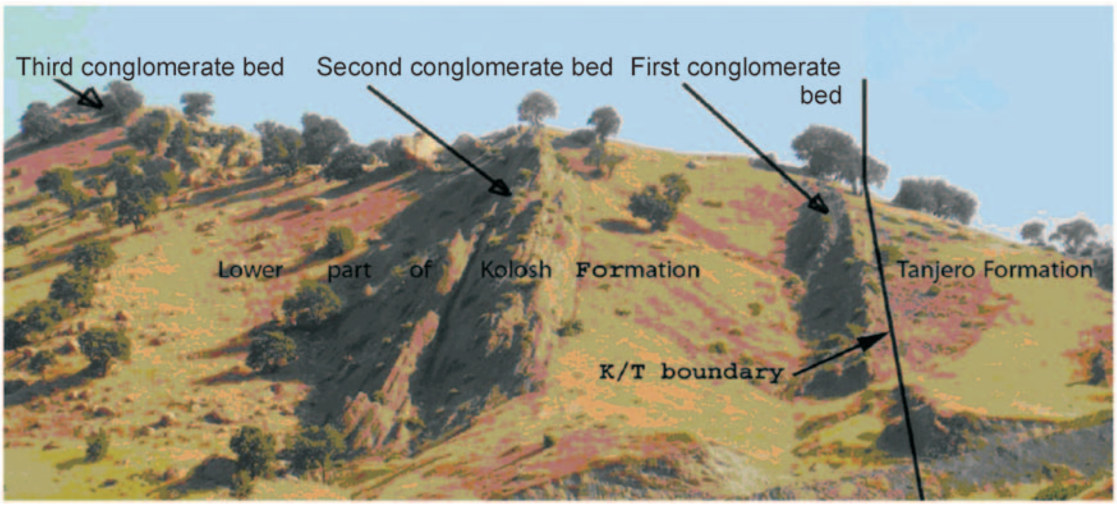


**Fig. 5.** Image showing the Cretaceous/Tertiary contact Tanjero–Kolosh Formations, Sirwan Valley section and three ridge forming conglomerate beds at the lower part of Kolosh Formation.

green marl, occasionally intervened by thin marly limestone layers and sandstone. Three conglomerate beds can be observed in the lower part of the Kolosh Formation, with thicknesses of 3.0 m, 10.0 m and 13 m, respectively (Fig. 5). The distribution of foraminiferal content was recorded from twenty samples ranging from sample 185 to sample 205 taken from the first 14 m of the Kolosh Formation. These samples lacked foraminifers, but contained reworked radiolarians from the underlying Tanjero Formation and rare reworked planktonic foraminifers from the Tanjero Formation. The Kolosh Formation was overlain by the Sinjar Formation gradually in the studied sections and marked by the regular change from fine clastic sediment of the Kolosh Formation to non clastic limestone beds of the Sinjar Formation.

## Biostratigraphy

The comprehensive studies of planktonic foraminiferal biostratigraphy during the last five decades have proved to be more useful and more accurate among the large number of micropaleontological branches, especially than benthonic (Fig. 6).

The comprehensive and motif plan in this work was deduced from the planktonic foraminiferal zonation and correlation for the sediments in tropical/subtropical regions, based on the works of Berggren & Miller (1988), Li & Keller (1998a,b), Liu & Olsson (1992), Berggren et al. (1995), Berggren & Norris (1997), Olsson et al. (2000), Arenillas et al. (2000a), Elnady & Shahin (2001), Abramovich et al. (2002), Samir (2002), Keller (2002, 2004), Abramovich &

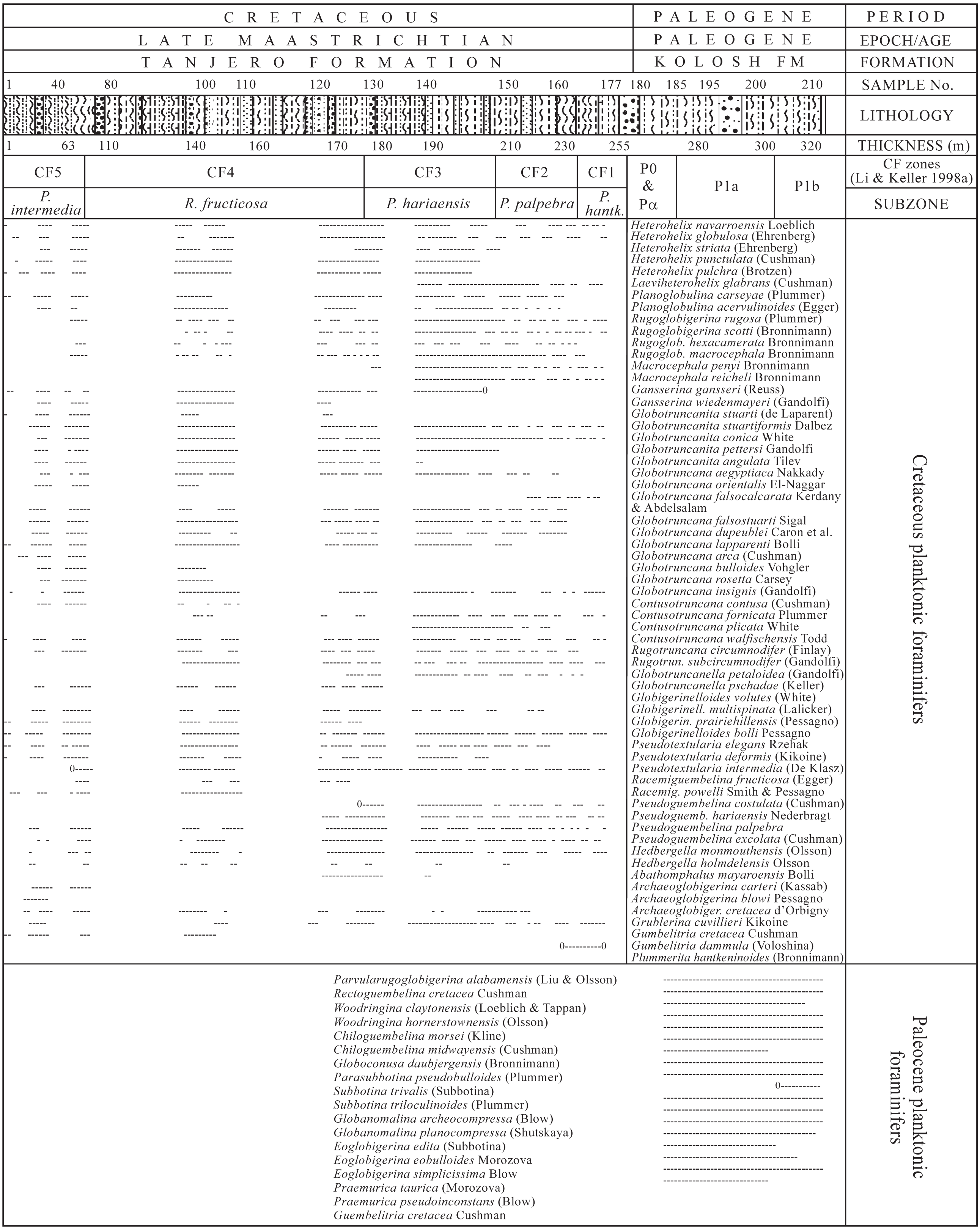


**Fig. 6.** Biostratigraphic range chart of planktonic foraminifera at Cretaceous/Tertiary boundary, Sirwan area, (Sirwan section).

Keller (2003), Obaidalla (2005), Smit (2005), and Sharbazheri (2007). Fortunately, this zonation has proved satisfactory, with successful results achieved in different localities around the world.

Li & Keller (1998a) subdivided the Maastrichtian zonal scheme into eight Cretaceous Foraminiferal (CF) zones labelled CF8 to CF1 from the base to the top; this new biozonation provides accurate and significantly higher biostratigraphic resolution than previous zonal schemes. They calibrated their ranges to the paleomagnetic time scale in the DSDP Site 525A, and on Tunisian sections (Li & Keller 1998b), their age estimations were also correlated with magnetochron ages by Berggren et al. (1995), and consequently the criteria for age estimation and determination of rate of sedimentation can be proved easily through biostratigraphic correlation and datum event comparison.

The biostratigraphic correlation of the studied section is based on planktonic foraminiferal zonations, which show a comparison between the biostratigraphic zones established in this study with other equivalents of the commonly used planktonic zonal scheme around the Cretaceous/Tertiary (K/T) boundary in and outside Iraq (Fig. 7).

The foraminiferal occurrence shows evidence of three diluted intervals of foraminiferal survivorship in the studied upper part of the Tanjero Formation, and the fourth one at the base of the Paleocene just after the extinction catastrophe of organisms at the uppermost part of the Maastrichtian. The Upper Maastrichtian–Lower Paleocene interval in general attracted particular attention because the foraminifers are relatively moderate and mostly well preserved. It is important to mention that the conventional index species *Abathomphalus mayaroensis* of Late Maastrichtian is very rarely found and it is frequently absent in shallow continental shelf sections in all studied regions which may be due to paleoenvironmental conditions of the deeper and more basinal oceanic environment around low latitudes restrictions of the species (Canudo et al. 1991), and in high latitudes disappear prior to the K/T boundary (Blow 1979). Therefore the *A. mayaroensis* Biozone is geographically and ecologically restricted. In such cases it is better to replace the *A. mayaroensis* Biozone by other biozones to avoid any ambiguous and vague situation about the first appearance and last extinction datum event.

For the Paleogene subdivisions, the zonal scheme has previously been developed in two widely separated geographical areas: the eastern hemisphere (Caucasus Mountains, e.g. Subbotina 1953, Krasheninikov 1969 in Samir 2002), and in the western hemisphere (Trinidad, e.g. Bolli 1957a,b in Samir 2002).

A discussion of all subsequent modifications of the original zonal scheme proposed by Bolli (1966), Blow (1979), Berggren & Miller (1988), Berggren et al. (1995), Berggren & Norris (1997), Olsson et al. (2000) with other authors mentioned in (Fig. 7) forms the basis of the Paleocene zonal scheme for this study, which shows a comparison between this zonal scheme and earlier developed schemes. It is worth remembering that the original, genetic radiation, phylogenetic reconstruction of relationships and geological ranges of Paleocene planktonic foraminifers were established by Liu & Olsson (1992) and Olsson et al. (2000). Their work forms the basis for the work of the working group on the Atlas of Paleocene Planktonic Foraminifera by Olsson et al. (2000). The biozones from the lower part to the upper part of the section are as follows (Fig. 6).

***Pseudotextularia intermedia* Interval Zone (CF5):** The *Pseudotextularia intermedia* Zone (CF5) is defined by the LAD of the *Globotruncana linneiana* (d'Orbigny) at the base and the FAD of *Racemiguembelina fructicosa* (Egger) at the top. Nederbragt (1990) originally introduced this biozone as the interval from the FAD of *Planoglobulina acervulinoides* at the base to the FAD *Racemiguembelina fructicosa* at the top. In the present study, the definition is constrained according to Li & Keller (1998a,b).

The recorded planktonic foraminiferal assemblages in this biozone are represented by well diversified forms of *Heterohelix navarroensis* (Loeblich), *H. globulosa* (Ehrenberg), *H. striata* (Ehrenberg), *H. punctulata* (Cushman), *H. nauttalli* (Voorwijk), *H. reussi* (Cushman), *H. pulchra* (Brotzen), *Laeviheterohelix glabrans* (Cushman) (Fig. 8c), *Planoglobulina acervulinoides* (Egger), *Rugoglobigerina hexacamerata* (Bronnimann), *R. macrocephala* (Bronnimann), *Gansserina gansseri* (Reuss), *G. wiedenmayeri* (Gandolfi), *Globotruncanita stuarti* (de Lapparent), *G. stuartiformis* (Dalbez), *G. conica* White, *G. pettersi* Gandolfi, *G. angulata* Tilev, *Globotruncana aegyptiaca* Nakkady, *Glt. orientalis* El-Naggar, *Glt. falsostuarti* Sigal, *Glt. dupeublei* Caron et al. (Fig. 8e), *Glt. lapparenti* Boli, *Glt. arca* (Cushman), *Glt. bulloides* Vohgler, *Glt. rosetta* Carsey, *Glt. insignis* (Gandolfi), *Contusotruncana contusa* (Cushman), *C. fornicata* Plummer, *Rugotruncana circumnodifer* (Gandolfi), *R. subcircumnodifer* (Gandolfi), *Globigerinelloides volutes* (White), *G. prairehillensis* Pessagno, *G. bolli* Pessango, *Pseudotextularia elegans* (Rzehak), *P. deformis* (Kikoine), *P. intermedia* (De Klasz), *Racemifructicosa* (Egger), *R. poweli* Smith & Pessagno, *Pseudoguembelina costulata* (Cushman) (Fig. 8a,b), *P. excolata* (Cushman) (Fig. 8c), *Hedbergella monmouthensis* (Olsson), *H. holmdelensis* Olsson, *Abathomphalus mayaroensis* (Bolli) (Fig. 8f–g), *Archaeoglobigerina blowi* Pessagno, *A. cretacea* (d'Orbigny), *Gublerina cuvillieri* Kikoine, *Gumbelitria cretacea* Cushman, *G. dammula* (Voloshina).

Due to high similarities of foraminiferal occurrence, the present Zone (CF5) is equivalent to that of Li & Keller (1998a,b), Abramovich et al. (2002), Samir (2002). It is most likely equivalent to the upper part of the *Gansserina gansseri* Zone recorded in the North and Northeast of Iraq and different regions of the world by Robaszynski et al. (1984), Caron (1985), D'Hont & Keller (1991), Al-Mutwali (1996), Hammoudi (2000), Al-Mutwali & Al-Jubouri (2005), Obaidalla (2005) and it is equivalent to the upper part of the *Glt. contusa* Zone of Abawi et al. (1982), and Abdel-Kireem (1986), and the *Glt. contusa, R. fructicosa* Zone of Premoli Silva & Sliter (1995, 1999) from Italy, Abdel-Kireem & Samir (1995) from Egypt. The *Pseudotextularia intermedia* Zone spans about 0.73 Myr (69.06–68.33 Ma), its absolute age, based on magnetochron ages, is estimated of about 730 ky/19 m, providing a moderate rate of deposition (38.5 ky/meter). Age: late Early Maastrichtian.

Note: it is important to mention that only the upper part of the *Pseudotextularia intermedia* Zone was recorded from the

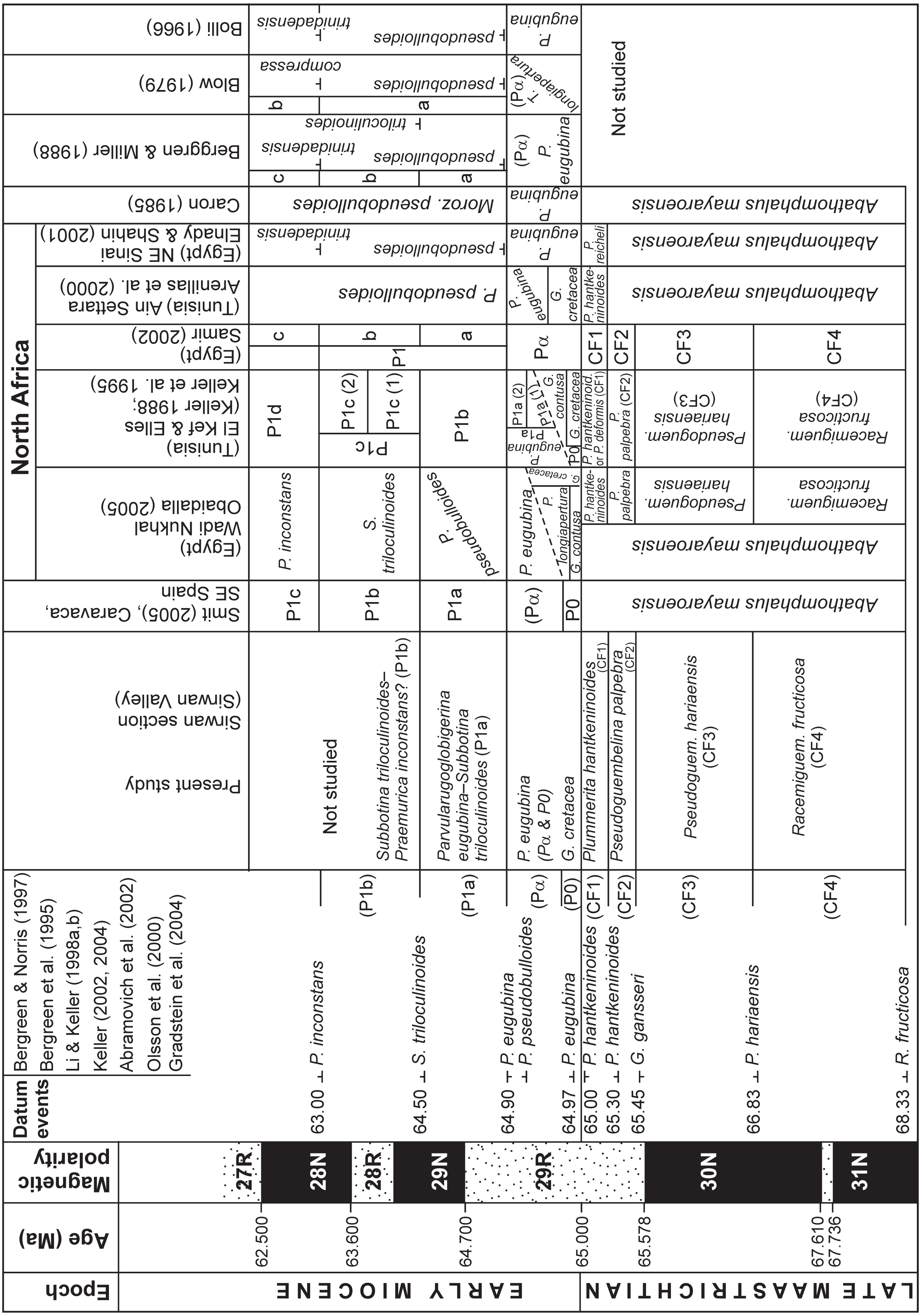


**Fig. 7.** Correlation chart showing the planktonic foraminiferal biostratigraphic zones of zonation commonly used in low, middle and high latitudes, in the new zonal scheme. The age of planktonic foraminiferal datum events shown. (Modified from different authors).

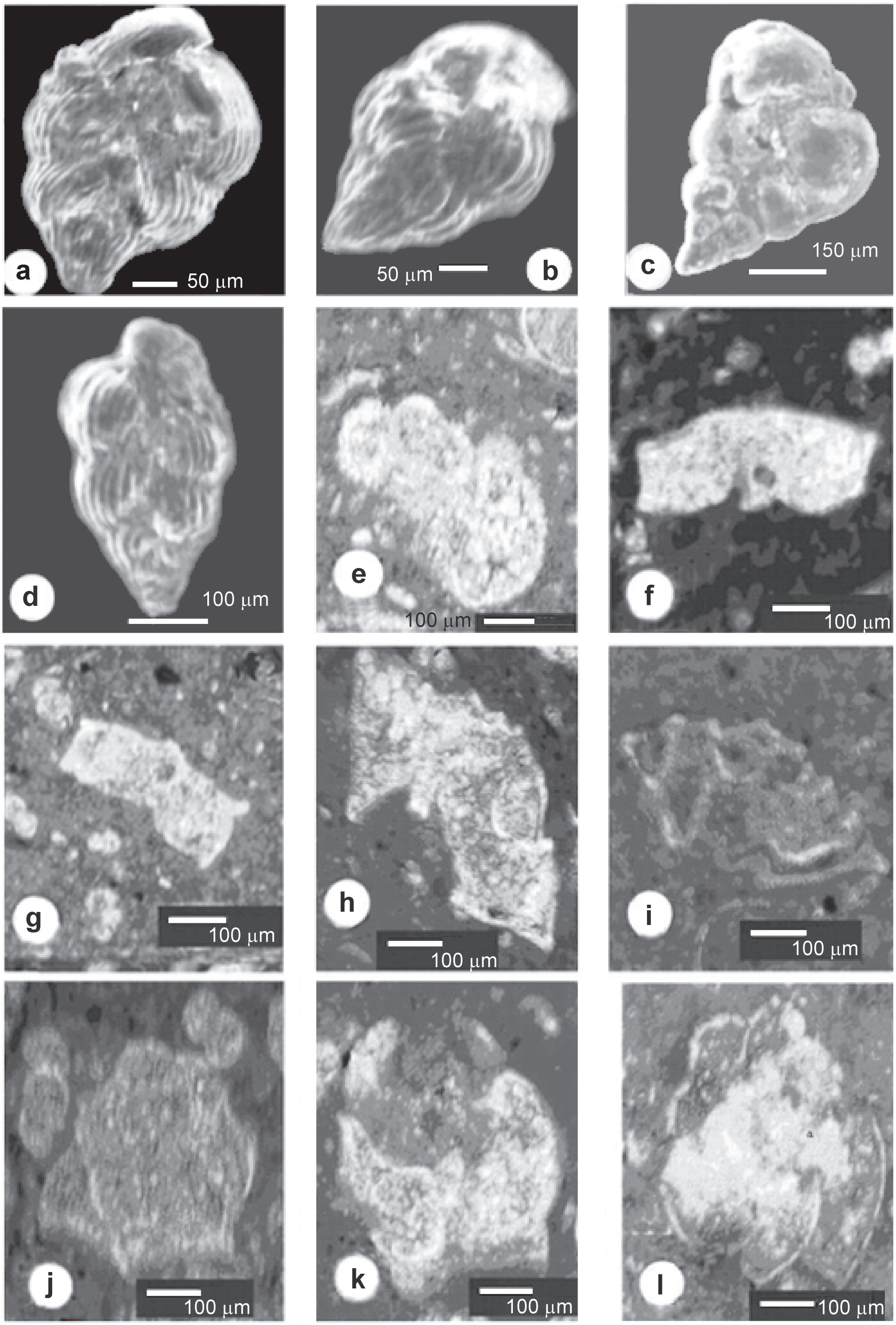


**Fig. 8.** **a–b** — *Pseudoguembelina costulata* (Cushman), Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *P. hariaensis* Zone. **c** — *Laeviheterohelix glabrans* (Cushman), Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *P. hariaensis* Zone. **d** —*Pseudoguembelina excolata* (Cushman), Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *P. hantkeninoides* Zone. **e** — *Globotruncana dupeublei* Caron, Gonzalez, Donoso, Robaszynski & Wonders, Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *P. hariaensis* Zone. **f–g** — *Abathomphalus mayaroensis* (Bolli), Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *P. hariaensis* Zone. **h–i** — *Globotruncana falsocalcarata* Kerdany & Abdelsalam, Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *Plummerita hantkeninoides* Zone. **j–l** — *Contusotruncana falsocalcarata* Kerdany & Abdelsalam, Tanjero Formation, Late Maastrichtian. Sirwan. Specimen from *Plummerita hantkeninoides* Zone.

studied section and its lower limit was not studied. This biozone is represented by moderate diversity of planktonic foraminiferal assemblage with 42 species in the studied area.

***Racemiguembelina fructicosa* Interval Zone (CF4):** *Racemiguembelina fructicosa* Zone (CF4) was introduced by Li & Keller (1998a,b) as a biostratigraphic interval between the FAD of *Racemiguembelina fructicosa* (Egger) at the base and the FAD of *Pseudoguembelina hariaensis* at the top. The FAD of *Racemiguembelina fructicosa* (Egger) in the studied section is recorded from the uppermost part of the reddish to pale brown unit and covers the basal part of the Tanjero Formation (sample no. 38) to the FAD of *Pseudoguembelina hariaensis* Nederbragt within the Tanjero Formation (sample no. 58).

It is important to mention that the zonal scheme of Cretaceous foraminifers (CF) proposed by Li & Keller (1998a,b), which replaces the *Abathomphalus mayaroensis* Zone with four zones (*R. fructicosa* Zone, *P. hariaensis* Zone, *P. palpebra* Zone, *P. hantkeninoides* Zone), provides a much improved age estimate for the Late Maastrichtian. The total range of the *A. mayaroensis* Zone characterized the Late Maastrichtian in low latitude regions as well as the Tethyan paleogeographic realm. However it has been found that *A. mayaroensis* is very rare or absent in high latitude regions (Blow 1979) and in the present section also, consequently it is more accurate to use the new zonal scheme.

Most of the workers in the zonal scheme placed the *Racemiguembelina fructicosa* Zone in the early Late Maastrichtian (Keller et al. 1995 from Tunisia; Li & Keller 1998a,b, Abramovich et al. 2002 at DSDP Site 525A; Samir 2002, and Obaidalla 2005 from Egypt). As defined above, the present Biozone CF4 is correlatable with the lower part of the *A. mayaroensis* of Abawi et al. (1982) and Abdel-Kireem (1986a), Premoli Silva & Sliter (1995, 1999) from Italy.

The age of this biozone, estimated by Li & Keller (1998a), is appropriate for the time span between 68.33 Ma and 66.83 Ma, providing a high sedimentary rate of about 13.5 ky/m in the Sirwan area, and a high sedimentary rate of about 18 ky/m in the Qulka section Dokan area. Age: early Late Maastrichtian.

***Pseudoguembelina hariaensis* Interval Zone (CF3):** The *Pseudoguembelina hariaensis* Zone was defined by Li & Keller (1998a) as a partial range of the nominate species between the FAD of *Pseudoguembelina hariaensis* Nederbragt and the LAD of *Gansserina gansseri* (Bolli). In the studied area this zone also marked by the FAD of the nominate species to the last occurrence of *Gansserina gansseri* (Bolli). The interval of this zone is 30 meters in the Sirwan section (Fig. 7). This zone shows reliable abundance of *Pseudoguembelina hariaensis* Nederbragt and other assemblages' planktonic foraminifers which totally resembles that of the underlying *Racemiguembelina fructicosa* Zone (CF4), in the Gali section with the following planktonic foraminifers of 50 species like: *Heterohelix navarroensis* Loeblich, *H. globulosa* (Ehrenberg), *H. striata* (Ehrenberg), *H. punctulata* (Cushman), *H. nauttalli* (Voorwijk), *Laeviheterohelix glabrans* (Cushman), *Planoglobulina carseyae* (Plummer), *P. acervulinoides* (Egger), *Rugoglobigerina rugosa* (Plummer) (Fig. 9d-e), *R. scotti* (Bronnimann), *R. hexacamerata* Bronnimann, *R. macrocephala* Bronnimann, *R. pennyi* Bronnimann, *R. reicheli* Bronnimann, *R. rotundata* Bronnimann, *Gansserina gans-*

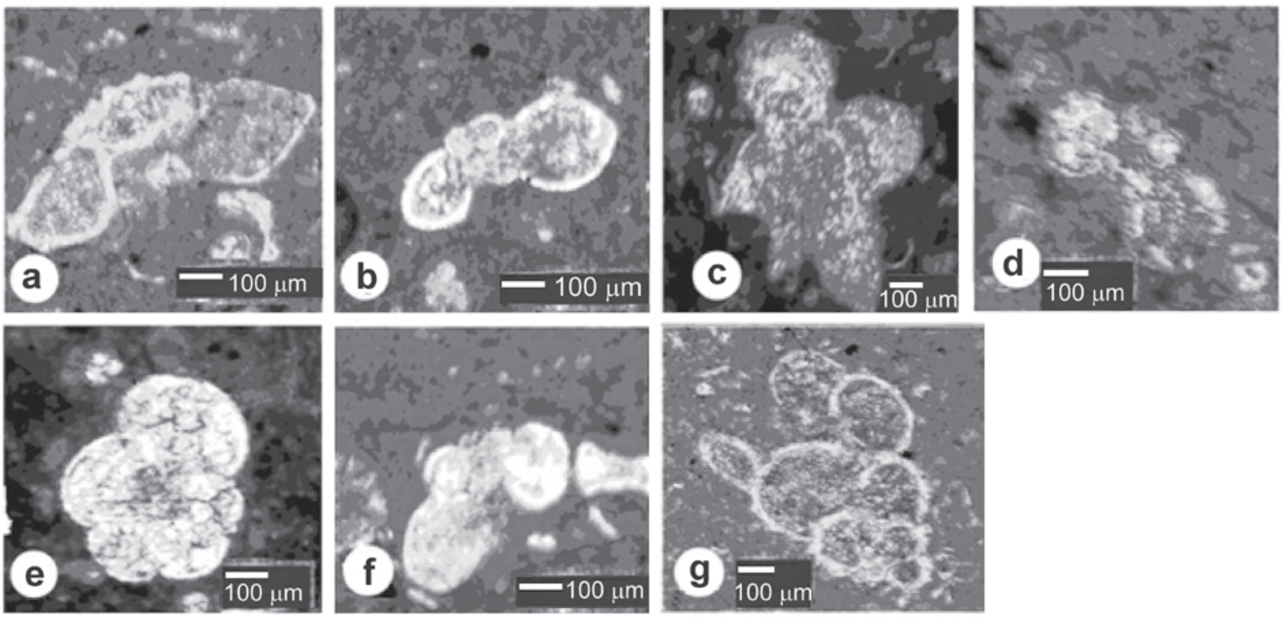


**Fig. 9. a** — *Globotruncanella pschadae* (Keller), Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *P. hariaensis* Zone. **b** — *Globotruncanella petaloidea* (Gandolfi), Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *P. hariaensis* Zone. **c** — *Plummerita hantkeninoides* (Bronnimann), Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *Plummerita hantkeninoides* Zone. **d–e** — *Rugoglobigerina rugosa* (Plummer), Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *P. hariaensis* Zone. **f** — *Hedbergella monmouthensis* (Olsson), Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *Plummerita hantkeninoides* Zone. **g** — *Pseudotextularia intermedia* (De Klasz), Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *P. hariaensis* Zone.

*seri* (Reuss), *Globotruncanita stuartiformis* Dalbez, *G. conica* White, *G. pettersi* Gandolfi, *G. angulata* Tilev, *Globotruncana falsostuarti* Sigal, *Glt. dupeublie* Caron et al., *Glt. lapparenti* Bolli, *Contusotruncana contusa* (Cushman), *C. plicata* White, *C. walfischensis* Todd, *C.* sp. (nov. sp.?), *Rugotruncana circumnodifer* (Gandolfi), *R. subcircumnodifer* (Gandolfi), *Globotruncanella petaloidea* (Gandolfi) (Fig. 9b), *G. pschadae* (Keller) (Fig. 9a), *Globigerinelloides volutes* (White), *G. prairiehillensis* Pessango, *Pseudotextularia elegans* (Rzehak), *P. deformis* (Kikoine), *P. intermedia* (De Klasz) (Fig. 9g), *Racemiguembelina fructicosa* (Egger), *Pseudoguembelina costulata* (Cushman), *P. palpebra*, *P. excolata* (Cushman), *Hedbergella monmouthensis* (Olsson) (Fig. 9f), *H. holmdelensis* Olsson, *Abathomphalus mayaroensis* (Bolli), *Kuglerina rotundata* (Bronnimann), *Costellagerina* cf. *bulbosa* Belford, *Gublerina cuvillieri* Kikoine, *Gumbelitria cretacea* Cushman. As defined above, the present Biozone CF3 is correlatable with the zone recorded by Li & Keller (1998a,b), Abramovich & Keller (2003) in DSDP Site 525A, Abramovich et al. (2002) from Madagascar, Keller et al. (1995) from Tunisia, Keller (2004) from Eastern Tethys, Samir (2002), Keller (2002), Obaidalla (2005) from Egypt, Sharbazheri (2007) from NE Iraq. It is correlated with the middle part of the *Abathomphalus mayaroensis* Zone recorded in the Northeast of Iraq by Abawi et al. (1982) and Abdel-Kireem (1986a); in Italy by Premoli Silva & Sliter (1995, 1999) and Premoli Silva et al. (1998); in Egypt by Abdel-Kireem & Samir (1995).

The age of this biozone, estimated by Li & Keller (1998a), corresponds to the middle Late Maastrichtian, with the time span between 66.83 Ma and 65.45 Ma, based on magnetochron ages, providing a low to moderate rate of sedimentation (46 ky/m) in the Sirwan Valley. Age: middle Late Maastrichtian.

***Pseudoguembelina palpebra* Interval Zone (CF2):** This zone is defined as the interval between the LAD of *Gansserina gansseri* at the base and the FAD of *Plummerita hantkeninoides* at the top. Li & Keller (1998a,b) introduced this zone from DSDP Site 525A and Tunisia. The recorded planktonic assemblage of this zone is characterized by the same number 50 species diversity as the underlying *Pseudoguembelina hariaensis* Zone, and marked by the extinction of *Heterohelix punctulatus* (Cushman), *Gansserina gansseri*, *Globigerinelloides volutes* (White), and *Laeviheterohelix glabrans* (Cushman), in the upper part of the zone. Besides, the planktonic foraminiferal species enduring from the underlying biozones, some species, including *Globotruncana falsoscalcarata* Kerdany & Abdelsalam, *Globotruncanella* sp. and *Trinitella scotti* Bronnimann, have their first appearance in this zone. The *Pseudoguembelina palpebra* Interval Zone (CF2) in the Sirwan Valley displays spans 25 m (Fig. 7), biostratigraphically represented by a decrease in the number of species from 49 to 38 and there is no distinctive appearance of new species in this zone. The planktonic foraminiferal assemblages of this zone in the Sirwan section are represented by *Heterohelix navarroensis* Loeblich, *H. globulosa* (Ehrenberg), *Laeviheterohelix glabrans* (Cushman), *Planoglobulina carseyae* (Plummer), *P. acervulinoides* (Egger), *Rugoglobigerina rugosa* (Plummer), *R. scotti* (Bronnimann), *R. hexacamerata* Bronnimann, *R. macrocephala* Bronnimann, *R. pennyi* Bronnimann, *R. reicheli* Bronnimann, *Globotruncanita stuartiformis* Dalbez, *G. conica* White, *Globotruncana aegyptiaca* Nakkady, *Glt. falsocalcarata* Kerdany & Abdelsalam (Fig. 8g–i), *Glt. falsostuarti* Sigal, *Glt. dupeublie* Caron et al., *Glt. lapparenti* Bolli, *C. plicata* White, *C. walfischensis* Todd, *Rugotruncana circumnodifer* (Gandolfi), *R. subcircumnodifer* (Gandolfi), *Globotruncanella petaloidea* (Gandolfi), *G. pschadae* (Keller), *Globigerinelloides prairiehillensis* Pessagno, *Pseudotextularia elegans* (Rzehak), *P. deformis* (Kikoine), *Racemiguembelina fructicosa* (Egger), *Pseudoguembelina hariaensis* Nederbragt, *P. palpebra*, *P. excolata* (Cushman), *Hedbergella monmouthensis* (Olsson), *H. holmdelensis* Olsson, *Gublerina cuvillieri* Kikoine, *Gumbelitria cretacea* Cushman.

As defined above, the present Zone CF2 of the studied area is equivalent to the same zone of the *P. palpebra* Zone of the South Atlantic DSDP Site 525A by Li & Keller (1998a) and Abramovich et al. (2002); and of Tunisia by Li & Keller (1998b) and Arenillas et al. (2000); eastern Tethys by Keller (2004). The present *P. palpebra* Zone is equivalent to the upper part of *Abathomphalus mayaroensis* Zone recorded from different parts of the world — Premoli Silva & Sliter (1995, 1999); from Spain: Canudo et al. (1991), Molina et al. (1996); from eastern Mediterranean: Premoli Silva et al. (1998); from USA California: Maestas et al. (2003); from Egypt: Luning et al. (1998), Elnady & Shahin (2001), Samir (2002), and Obaidalla (2005). The present *P. palpebra* Zone is equivalent to the upper part of the *Abathomphalus mayaroensis* Zone recorded from different localities in Iraq (Kassab 1972, 1974, 1975a,b, 1976a,b, 1979; Abawi et al. 1982; Abdel-Kireem 1986a; Kassab et al. 1986; Al-Mutwali 1996; Hammoudi 2000; Al-Mutwali & Al Juboury 2005).

The age of this biozone, estimated by Li & Keller (1998a), corresponds to the late Late Maastrichtian, with the time span between 65.45 Ma and 65.30 Ma, based on magnetochron ages, providing a high rate of sedimentation (6 ky/m) in the Sirwan Valley. Age: late Late Maastrichtian.

***Plummerita hantkeninoides* Taxon Range Zone (CF1):** The biostratigraphic interval of this zone is defined by the total range of the nominate taxon *Plummerita hantkeninoides* (Bronnimann) (Fig. 9c). Pardo et al. (1996) introduced the *P. hantkeninoides* Zone for the latest Maastrichtian of Spain. It marks the uppermost Cretaceous biozone, and its top marks the K/P boundary. The upper limit of this zone coincides with the mass extinction of large tropical-subtropical taxa. In the studied sections, this zone covers the top 25 meters of the Maastrichtian in the Sirwan area. The characteristic recorded planktonic foraminiferal assemblage of this zone shows a gradual decrease in both species and individual numbers from the *Pseudoguembelina palpebra* Zone to the *Plummerita hantkeninoides* Zone from 37 to 29 species in the Sirwan section.

*Heterohelix navarroensis* Loeblich, *H. globulosa* (Ehrenberg), *H. striata* (Ehrenberg), *Rugoglobigerina rugosa* (Plummer), *R. scotti* (Bronnimann), *R. macrocephala* Bronnimann, *R. pennyi* Bronnimann & Abdelsalam, *Globotruncana falsostuarti* Sigal, *Glt. dupeublie* Caron et al., *Contusotruncana contusa* (Cushman), *C. plicata* (White), *Globotruncanella petaloidea* (Gandolfi), *Pseudotextularia elegans* (Rzehak), *Pseudoguembelina costulata* (Cushman), *P. hariaensis* Nederbragt, *P. palpebra*, *P. excolata* (Cushman), *Hedbergella monmouthensis* (Olsson), *H. holmdelensis* Olsson, *Gumbelitria cretacea* Cushman, *Plummerita hantkeninoides* (Bronnimann).

As defined above and based on the associated planktonic foraminiferal assemblage, the present *Plummerita hantkeninoides* Total Range Zone (CF1) is equivalent to the same zone recorded from Tunisia by Li & Keller (1998b), Arenillas et al. (2000); from Eastern Tethys Israel by Keller (2004); from Egypt by Keller (2002), Samir (2002) and Obaidalla (2005), Pardo et al. (1996), Keller (1996); and to the upper part of Zone (CF 1–2) from South Atlantic DSDP Site 525A by Li & Keller (1998a); from Madagascar (Abramovich et al. 2002); from DSDP Site 525A by Abramovich & Keller (2003); from USA by Stinnesbeck et al. (2004). The present *Plummerita hantkeninoides* Zone is equivalent to the uppermost part of the *Abathomphalus mayaroensis* Zone recorded from different parts of the world: Spain— Canudo et al. (1991), Smit (2005), Chacon & Martin-Chivelet (2005); Italy — Premoli Silva & Sliter (1995, 1999); eastern Mediterranean — Premoli Silva et al. (1998); India —Govindan et al. (1996); USA, California — Maestas et al. (2003); south USA — Martinez (1989), Luning et al. (1998). It is also equivalent to the *Plummerita reicheli* Zone of Elnady & Shahin (2001), and Shahin (1992) from Egypt. The present *Plummerita hantkeninoides* Zone is equivalent to the *Kassabiana falsocalcarata* Zone recorded from Shalki village and the Sirwan Valley by Kassab (1976b), Kassab et al. (1986), Ghafor (1988 — Tel Hajar no 1 well).

The age of this biozone, estimated by Li & Keller (1998a), corresponds to the latest Late Maastrichtian, with the time span between 65.30 Ma and 65.00 Ma, based on magnetochron ages, providing a high rate of sedimentation (12 ky/m) in the studied area. Age: Late Maastrichtian.

**P0 & Pα:** In the present study, the earliest Paleocene P0 *Guembelitria cretacea* Zone, and *Parvularugoglobigerina eugubina* Zone was not recorded completely or continuously in the Sirwan section.

The Cretaceous/Tertiary boundary is located at the base of 3 meters of pale grey to yellowish, weathered friable conglomerate. This conglomerate and the overlying 12 meters of dark grey organic rich shale alternating with marl, marly limestone and thin layers of siltstone, sandstone, are barren of foraminifers. As mentioned previously, the sedimentary succession of the studied sections in the Sirwan Valley shows evidence of three diluted intervals of foraminiferal survivorship in the studied upper part of the Tanjero Formation, and the fourth one at the base of the Paleocene just after the extinction catastrophe of organisms in the uppermost part of the Maastrichtian.

The age of this interval, estimated on the basis of the magnetic polarity and datum events by Olsson et al. (2000) and Keller (2002, 2004), implies the time span between 65.00 Ma, marked by last appearance of *Plummerita hantkeninoides,* and 64.90 Ma, marked by last occurrence of *Parvularugoglobigerina eugubina* (Fig. 10e–g), considered the magnetochron ages of 100 ky, providing a high rate of deposition (6.5 ky/m) in the Sirwan section (Fig. 7).

No sedimentological evidence of an erosional surface, condensed section or mineralogical record, trace fossils or hard ground was observed beside these significant points. The great lithological similarity between the Tanjero and overlying Kolosh Formations means that no one can observe or distinguish the contact line of the K/T boundary in the field. As there is no sign of the presence of an unconformity, we propose that this interval may be equivalent to both the P0 & Pα (*G. cretacea–P. eugubina* Zone). In addition to these categories, the sedimentation rate of deposition immediately around the Cretaceous/Tertiary boundary recorded high to very high rates of sedimentation which reveal continuous uninterrupted sedimentary sequences. Otherwise the significant amount of conglomerate beds within the studied upper part of the Tanjero Formation represented by 7 repeated beds of 0.5 to 2 meters thickness and three conglomerate beds within the lower part of the Kolosh Formation. This reveals the intraformational conglomerate beds of limited lateral extensions (Figs. 4, 5), which could be attributed to either its extremely short duration, or its restriction to near shore, or diluted in foraminiferal survivorship rather than open ocean environments as outlined by Berggren & Norris (1997).

**(P1a) *Parvularugoglobigerina eugubina–Subbotina triloculinoides* Interval Subzone:** Definition: Biostratigraphic interval between the LAD of *Parvularugoglobigerina eugubina* and the FAD of *Subbotina triloculinoides* (Plummer) (Fig. 10a–d), (P1a; defined in Berggren et al. 1995); emendation of the *Parasubbotina pseudobulloides* Subzone (P1a) in Berggren & Miller (1988). In the present study, the P1a Subzone attains a thickness of 35 m. The associated planktonic foraminiferal assemblage is represented by complete occurrences of the following species in the Sirwan area: *Parvularugoglobigerina alabamensis* (Liu & Olsson), *Rectoguembelina cretacea* Cushman, *Woodringina clytonensis* (Loeblich & Tappan), *W. hornerstownensis* (Olsson), *Chiloguembelina morsei* (Kline), *Ch. midwayensis* (Cushman), *Globoconusa daubjergensis* (Bronnimann), *Parasubbotina pseudobulloides* (Plummer), *Subbotina trivalis* (Subbotina), *Globanomalina archeocompressa* (Blow), *G. planocompressa* (Shutskaya), *Eoglobigerina edita* (Subbotina), *E. eobulloides* Morozova, *E. simplicissima* Blow, *Praemurica taurica* (Morozova), *P. pseudoinconstans* (Blow), *Guembelitria cretacea* Cushman. *Guembelitria cretacea* Cushman is represented in the lower part, while *Woodringina clytonensis* (Loeblich & Tappan), and *Globoconusa daubjergensis* (Bronnimann) extend into the middle part of this biozone. The faunal similarities suggest that the combined P1a Subzones of the studied sections could be equivalent to the lower part of the *Morozovella pseudobulloides* Zone of Bolli (1966), Caron (1985), P1a Subzone of Blow (1979); Elnady & Shahin (2001) from Egypt; Arenillas et al. (2000) — Tunisia. The present subzones are correlatable with P1a Subzones of Berggren & Miller (1988); Samir (2002) in Egypt; the P1b of Keller (1988) and Keller et al. (1995) in Tunisia; the *P. pseudobulloides* of Obaidalla (2005) in Egypt; and also it is equivalent to the P1a of Berggren & Norris (1997), Berggren et al. (1995), Keller (2002, 2004), Abramovich et al. (2002), Olsson (2000); and Smit (2005) in SE Spain.

The age of this interval, estimated on the basis of the magnetic polarity and datum events by Olsson et al. (2000) and

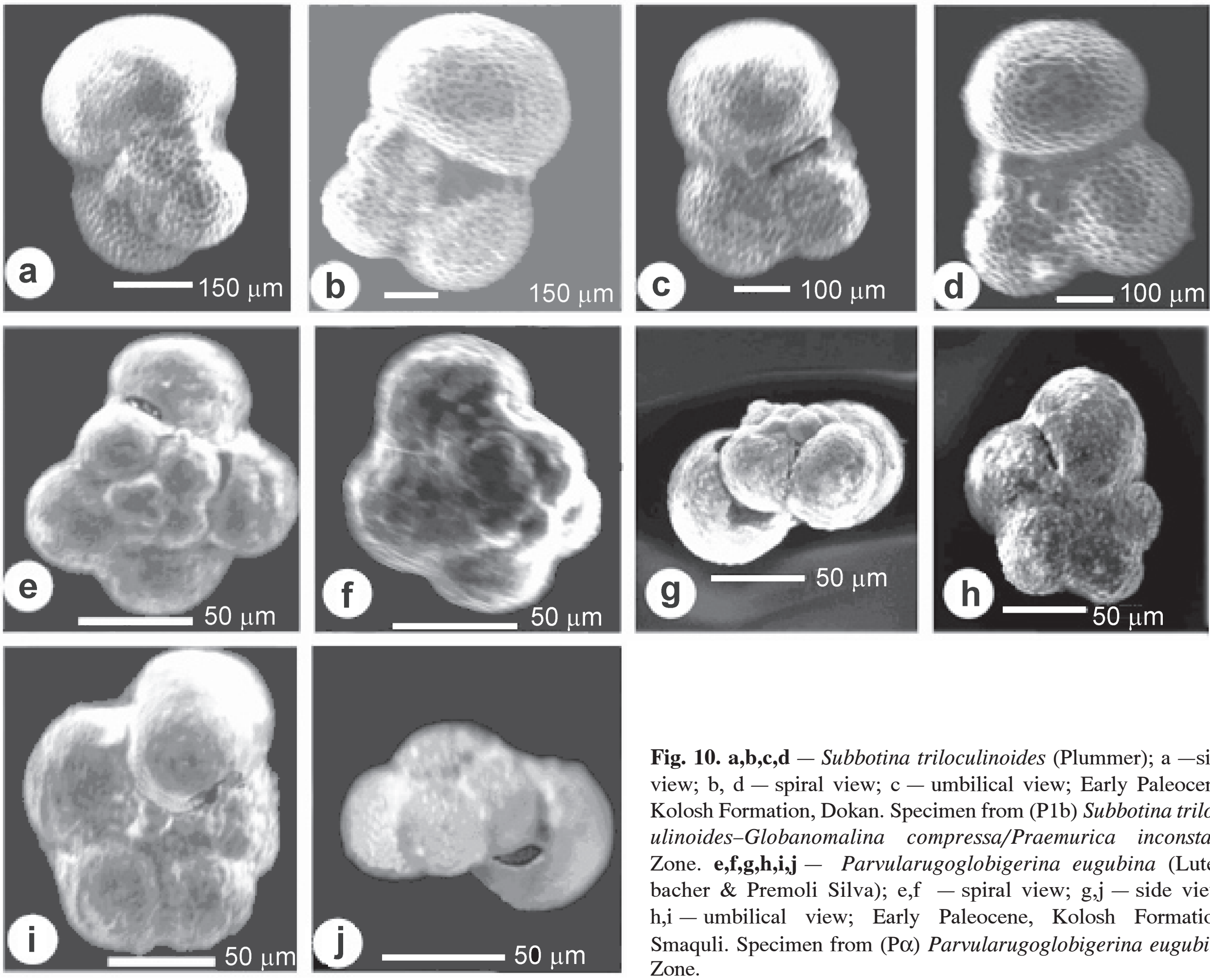


**Fig. 10. a,b,c,d** — *Subbotina triloculinoides* (Plummer); a —side view; b, d — spiral view; c — umbilical view; Early Paleocene, Kolosh Formation, Dokan. Specimen from (P1b) *Subbotina triloculinoides–Globanomalina compressa/Praemurica inconstans* Zone. **e,f,g,h,i,j** — *Parvularugoglobigerina eugubina* (Luterbacher & Premoli Silva); e,f — spiral view; g,j — side view; h,i — umbilical view; Early Paleocene, Kolosh Formation, Smaquli. Specimen from (P$\alpha$) *Parvularugoglobigerina eugubina* Zone.

Keller (2002, 2004), implies the time span between 64.90 Ma, marked by the last appearance of *Parvularugoglobigerina eugubina* and 64.50 Ma, marked by the first appearance of *Subbotina triloculinoides*, considered the magnetochron ages, providing a high rate of deposition (11.5 ky/m) in the Sirwan section. The estimated age is Early Paleocene (Early Danian).

**(P1b)** ***Subbotina triloculinoides–Globanomalina compressa/Praemurica inconstans*** **Interval Subzone:** Definition: Biostratigraphic interval between the FAD of *Subbotina triloculinoides* at the base and the FAD of *Globanomalina compressa* and/or *Praemurica inconstans* at the top. Remarks: Berggren et al. (1995) introduced this subzone to emend the P1b (*Subbotina triloculinoides*) Subzone of Berggren & Miller (1988). In the studied section only the lower part of this subzone is studied. It attains a thickness of 15 meters in the Sirwan section. Faunal similarities suggest that the combined P1b Subzones of the studied section could be equivalent to the upper part of the *Morozovella pseudobulloides* Zone of Bolli (1966) and Blow (1979); to Caron (1985); Elnady & Shahin (2001), Samir (2002) from Egypt; Arenillas et al. (2000) Tunisia; to the P1c of Keller (1988), and Keller et al. (1995) in Tunisia; to the *S. triloculinoides* by Obaidalla (2005) in Egypt; and also it is equivalent to the P1b of Berggren & Norris (1997), Berggren et al. (1995), Keller (2002, 2004), Abramovich et al. (2002), Olsson (2000); and Smit (2005) in SE Spain. The age estimation of this interval depending on magnetic polarity and recorded datum events by Olsson et al. (2000) and Keller (2002, 2004) with the time span of 64.50 Ma from the first occurrence of *Subbotina triloculinoides*, to the FAD of *Globanomalina compressa* and/or *Praemurica inconstans* at the top of 63.00 Ma. The absolute ages are estimated on the basis of magnetochron ages. The estimated age is Early Paleocene (Early Danian).

## Conclusions

The biostratigraphic study of the Cretaceous-Tertiary succession in the studied section from the Sirwan Valley in the Sulaimani area of the Kurdistan region of northeastern Iraq, led to the following conclusions:

**1** — The detailed study has produced a good description and high resolution lithological analysis of the well exposed uppermost Upper Cretaceous and Lower Tertiary successions incorporated in the upper part of the Tanjero Formation in the Sirwan Valley.

**2** — On the basis of the geological range and relative abundance of planktonic foraminiferal species, the studied section along the K/T boundary has been precisely divided into a number of biostratigraphic zones, based on the new zonal scheme derived from high resolution biostratigraphic studies, which are generally adequate and commonly used in low and middle latitudes. In addition to this, these biostratigraphic zones were correlated with their equivalents in and outside the region and with world wide standard biostratigraphic zones with the aid of datum events, which show the age of planktonic foraminiferal zones. The distinguished biostratigraphic zones in the Sirwan section from the base upwards are as follows:

C1 — *Pseudotextularia intermedia* Interval Zone (CF5) (Tanjero Formation), (late Early Maastrichtian).

C2 — *Racemiguembelina fructicosa* Interval Zone (CF4) (Tanjero Formation), (Late Maastrichtian).

C3 — *Pseudoguembelina hariaensis* Zone (CF3) (Tanjero Formation), (Late Maastrichtian).

C4 — *Pseudoguembelina palpebra* Interval Zone (CF2) (Tanjero Formation), (Late Maastrichtian).

C5 — *Plummerita hantkeninoides* Total Range Zone (CF1) (Tanjero Formation), (Late Maastrichtian).

C6 — *Guembelitria cretacea* and *Parvularugoglobigerina eugubina* Interval Zone (P0 & Pα), (Kolosh Formation), earliest Paleocene (Danian).

C7 — *Parvularugoglobigerina eugubina–Subbotina triloculinoides* Interval Zone (P1a), (Kolosh Formation), Early Paleocene (Early Danian).

C8 — *Subbotina triloculinoides–Praemurica inconstans* Interval Zone (P1b), (Kolosh Formation), Early Paleocene (Danian).

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## References

Abawi T.S., Abdel-Kireem M.R. & Yousef G.M. 1982: Planktonic foraminiferal stratigraphy of the Shiranish Formation, Sulaimaniah-Dokan region Northeastern Iraq. *Rev. Espanola de Micropaleontologia* 14, 1, 153–164.

Abdel-Kireem M.R. 1986a: Planktonic foraminifera and stratigraphy of the Tanjero Formation (Maastrichtian), northeastern Iraq. *Micropaleontology* 32, 3, 215–231.

Abdel-Kireem M.R. 1986b: Contribution to the stratigraphy of the Upper Cretaceous and Lower Tertiary of the Sulaimaniya Dokan region, Northeastern Iraq. *Neu. Jb. Geol. Paleont.* 172, 1, 121–139.

Abdel-Kireem M.R. & Samir A.M. 1995: Biostratigraphic implications of Maastrichtian-Lower Eocene sequence at the north Gunna section, Farafra Oasis, Western Desert, Egypt. *Mar. Micropaleontology* 26, 329–340.

Abramovich S. & Keller G. 2003: Planktonic foraminiferal response to the Latest Maastrichtian abrupt warm event: a case study from South Atlantic DSDP Site 525A. *Mar. Micropaleontology* 48, 225–249.

Abramovich S., Keller G., Adatte T., Stinnesbek W., Hottinger L., Stueben D., Berner Z., Ramanivo B. & Randriamanantenasoa A. 2002: Age and paleoenvironment of Maastrichtian to Paleocene of the Mahajanga Basin, Madagascar: a multidisciplinary approach. *Mar. Micropaleontology* 47, 17–70.

Al-Mutwali M.M. 1983: Biostratigraphy of Kolosh Formation and the nature of its contact with upper Cretaceous rocks in Shaqlawq area. *M.Sc. Thesis*, *Mosul Univ.*, Iraq, 1–154.

Al-Mutwali M.M. 1996: Planktonic foraminiferal biostratigraphy of the Shiranish Formation. Khashab well no. 1, Hemren area, Northeastern Iraq. *J. Geol. Sci. Iraq* 7, 1, 129–136.

Al-Mutwali M.M. & Al-Jubouri F.N. 2005: Litho and biostratigraphy of Shiranish Formation (Late Campanian–Late Maastrichtian), in Sinjar area, Northwestern Iraq. *Rafidain J. Sci.*, *Mosul Univ.*, Iraq 16, 1, 152–176.

Al-Omari F.S. 1970: Upper Cretaceous and lower Cenozoic foraminifera of the three Oil wells in northwestern Iraq. *Unpubl. Thesis, Geol. Dept. Univ.*, Missouri at Rolla, 1–208.

Al-Omari F.S. 1995: Biostratigraphy of Upper Cretaceous/Lower Tertiary in Butmah Well no. 9 North West Iraq. *Iraqi Geological Journal* (1997), 28, 2, 112–119.

Al-Omari F.S., Al-Radwani M.A. & Lawa F.A. 1989: Biostratigraphy of Aqra Limestone formation (Upper Cretaceous), northern Iraq. *J. Geol. Soc. Iraq* 22, 2, 44–55.

Al-Qayim B.A. & Al-Shaibani S.K. 1989: Stratigraphic analysis of Cretaceous-Tertiary contact, Northwest Iraq. *J. Geol. Soc. Iraq* 22, 1, 41–52.

Al-Shaibani S.K., Al-Qayim B.A. & Salman L. 1986: Stratigraphic analysis of Tertiary–Cetaceous contact, Dokan area, North Iraq. *J. Geol. Soc. Iraq* 19, 2, 1–26.

Arenillas I., Arz J.A., Molina E. & Dupis C. 2000a: An independent test of planktonic foraminiferal turnover across the Cretaceous/Paleocene (K/P) boundary at EL Kef, Tunisia: Catastrophic mass extinction and possible survivorship. *Micropalentology* 46, 1, 31–49.

Arenillas I., Arz J.A., Molina E. & Dupis C. 2000b: The Cretaceous/Paleocene (K/P) boundary at Ain Settara, Tunisia: sudden catastrophic mass extinction in planktonic foraminifera. *Foram. Res.* 30, 3, 202–218.

Bellen R.C., Van Dunnington H.V., Wetzel R. & Morton D. 1959: Lexique stratigraphique. *Int. Asie*, Iraq 3c, 10a, 1–333.

Berggren W.A. & Miller K.G. 1988: Paleogene tropical planktonic foraminiferal biostratigraphy and magnetobiochronology. *Micropaleontology* 34, 4, 362–380.

Berggren W.A. & Norris R.D. 1997: Biostratigraphy, phylogeny and systematics of Paleocene trochospiral planktonic foraminifera. *Micropaleontology* 43, 1, 1–116.

Berggren W.A., Kent D.V., Swisher C.C. & Aubry M.P. 1995: A revised Cenozoic geochronology and chronostratigraphy. In: Berggren W.A. & Norris R.D. (Eds.): Biostratigraphy, phylogeny and systematics of Paleocene trochospiral planktonic foraminifera. *Micropaleontology* 43, 1, 1–116.

Blow W.H. 1979: The Cenozoic Globigerinidae. *E.J., Brill*, Leiden, 1–3, 1–1413.

Bolli H.M. 1966: Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera. *Bol. Inform. Assoc. Vonezolana Geol. Min. Ret. En* 9, 1, 3–32.

Buday T. 1980: Regional geology of Iraq: Vol. 1. In: Kassab I.I.M. & Jassim S.Z. (Eds.): Stratigraphy. *D.G. Geol. Surv. Min. Invest. Publ.* 1–445.

Buday T. & Jassim S.Z. 1987: The regional geology of Iraq. Vol. 2. Tectonism, magmatism and metamorphism. In: Kassab I.I. & Abbas M.J. (Eds.). *Iraqi Geological Survey and Mineral Investigation Press*, Baghdad, 1–445.

Canudo J.I., Keller G. & Molino E. 1991: Cretaceous/Tertiary boundary extinction pattern and faunal turnover at Agost and Caravaca, S.E. Spain. *Mar. Micropaleontology* 17, 319, 341.

Caron M. 1985: Cretaceous planktic foraminifera. In: Bolli H.M., Saunders J.B. & Perch-Nielsen K. (Eds.): Planktonic stratigraphy. *Cambridge Univ. Press*, London, 17–87.

Chacon B. & Martin-Chivelet J. 2005: Major paleoenvironmental changes in the Campanian to Paleocene sequence of Caravaca (Subbetic Zone, Spain). *J. Iberian Geol.* 31, 2, 299–310.

Ditmar V., Afanasiev J. & Shanakova I. 1971: Geological conditions and hydrocarbon prospects of the Republic of Iraq, northern and central part. Technoexport report. *INOC Library*, Baghdad, Iraq.

D'Hont S. & Keller G. 1991: Some patterns of planktonic foraminiferal assemblage turnover at the Cretaceous/Tertiary boundary. *Mar. Micropaleontology* 17, 77–118.

Dunnington H.V. 1955: The Tertiary Cretaceous boundary problem in N. Iraq. No. IR/HVD/611. Baghdad. *INOC Library, Unpubl. Report*, 1–66.

Dunnington H.V. 1957: The Paleocene Cretaceous unconformity at Aqra. No. IR/MUD/691. Baghdad. *INOC Library, Unpubl. Report.*

Elnady H. & Shahin A. 2001: Planktonic foraminiferal biostratigraphiy and paleobathymetry of the Late Cretaceous–Early Tertiary succession at northeast Sinai, Egypt. *J. Paleontology* 1, 193–227.

Ghafor I.M. 1988: Planktonic foraminifera and biostratigraphy of the Aaliji Formation and the nature of its contact with the Shiranish Formation in Well Tel-Hajar No. 1. Sinjar area, Northwestern Iraq. *Unpubl. Thesis, Geol. Dept. Univ. Salahaddin*, Iraq, 1–206.

Ghafor I.M. & Kareem K.H. 1999: Biostratigraphy of Upper part of the Kolosh Formation from Sartaq-Bamo Northeastern Iraq. *J. Dohok Univ., Spec. Issue* 2, 4, 493–510.

Govindan A., Ravindran C.N. & Rangaraju M.K. 1996: Cretaceous stratigraphy and planktonic foraminifera Zonation of Cauvery Basin, South India. *Mem. Geol. Soc. India* 37, 155–18.

Gradstein F., Ogg J. & Smith A. 2004: A geologic time scale 2004. *Cambridge University Press*, Cambridge, 1–589.

Hammoudi R.A. 2000: Planktonic foraminiferal biostratigraphy of the Shiranish Formation (Upper Cretaceous) in Jambur well no. 13 Northern Iraq. *Raf. J. Sci.* 11, 4, 50–58.

James G.A. & Wynd J.G. 1965: Stratigraphic nomenclature of Iranian Oil Consortium agreement area. *AAPG Bull.* 49, 12, 2182–2245.

Jassim S.Z. & Goff J.C. 2006: Geology of Iraq. *Published by Dolin, Brague Moravian Museum*, Brno, 1–345.

Karim K.H. 2004: Basin analysis of Tanjero Formation in Sulaimaniya area, NE-Iraq. *Unpubl. Thesis, Geol. Dept. Univ. Sulaimani,* Iraq, 1–135.

Karim K.H. 2006: Environment of Tanjero Formation as inferred from sedimentary structures, Sulaimanyia area, NE-Iraq. *JAK* 41, 1–18.

Karim S.A. & Jassim S.Z. 1988: Biostratigraphy and environmental reconstruction of the Paleocene Phosphatic sequence, Western Desert, Iraq. *J. Geol. Soc. Iraq.* (1993), 21, 2, 129–151.

Karim K.H. & Surdashy A.M. 2005a: Paleocurrent analysis of Upper Cretaceous Foreland basin: a case study for Tanjero Formation in Sulaimanyia area, NE-Iraq. *J. Iraqi Sci.* 5, 1, 30–44.

Karim K.H. & Surdashy A.M. 2005b: Tectonic and depositional history of Upper Cretaceous Tanjero Formation in Sulaimaniya area NE-Iraq. *JZS* 8, 1, 47–62.

Karim K.H. & Surdashy A.M. 2006: Sequence stratigraphy of Upper Cretaceous Tanjero Formation in Sulaimaniya area, NE-Iraq. *Kurdistan Acad. J.* 4, 1, 19–43.

Kassab I.I.M. 1972: Ms. Micropaleontology of Upper Cretaceous Lower Tertiary of north Iraq. *Unpubl. Thesis, Geol. Dept. Univ. London*, 1–310.

Kassab I.I.M. 1974: Biostratigraphy of Upper Cretaceous Lower Tertiary of North Iraq, Vol. 1. *Colloque Africaia de Micropaleontology*, Tunis, 277–325.

Kassab I.I.M. 1975a: *Globotruncana falsocalcarata* Kerdany and Abdelsalam from northern Iraq. *Micropaleontology* 21, 3, 346–351.

Kassab I.I.M. 1975b: Biostratigraphic study of the subsurface Upper Cretaceous–Lower Tertiary of Well Injana No. 5, Northeastern Iraq. *J. Geol. Soc. Iraq, Spec. Issue*, 181–199.

Kassab I.I.M. 1976a: Planktonic foraminiferal ranges in the type Kolosh Formation (Middle-Upper Paleocene) of NE Iraq. *J. Geol. Soc. Iraq* 11, 54–99.

Kassab I.I.M. 1976b: Some Upper Cretaceous planktonic foraminiferal genera from northern Iraq. *Micropaleontology* 22, 2, 215–238, pls. 1–4.

Kassab I.I.M. 1978: Planktonic foraminiferal of the subsurface Lower Tertiary of northern Iraq. *J. Geol. Soc. Iraq* 11, 119–159.

Kassab I.I.M. 1979: The genus *Globotruncana* Cushman from the Upper Cretaceous of Northern Iraq. *Geol. Soc. Iraq* 2, 27–127.

Kassab I.I.M., Al-Omari F.S. & Al-Safawee N.M. 1986: The Cretaceous Tertiary boundary in Iraq (represented by the subsurface section of Sasan well No. 1, N.W. Iraq). *J. Geol. Soc. Iraq* 19, 2, 129–167.

Keller G. 1988: Extinction survivorship and evolution of planktonic foraminifera across the Cretaceous/Tertiary boundary at El Kef, Tunisia. *Mar. Micropaleontology* 13, 239–263.

Keller G. 2001: The end-Cretaceous mass extinction in the marine realm: year 2000 assessment: *Planetary and Space Science* 49, 817–830.

Keller G. 2002: *Guembelitria* — dominated Late Maastrichtian planktonic foraminiferal assemblage mimics early Danian in central Egypt. *Mar. Micropaleontology* 47, 129–167.

Keller G. 2004: Low diversity, Late Maastrichtian and Early Danian planktonic foraminiferal assemblages of the eastern Tethys. *J. Foram. Res.* 34, 1, 49–73.

Keller G., Li L. & Maclleod N. 1995: The Cretaceous/Tertiary boundary stratotyp esection at El Kef, Tunisia: how catastrophic was the mass extiniction? *Paleogeogr. Paleoclimatol. Paleoecol.* 199, 221–254.

Li L. & Keller G. 1998a: Maastrichtian climate, productivity and faunal turnover in planktonic foraminifera in South Atlantic DSDP sites 525A and 21. *Mar. Micropaleontology* 33, 55–86.

Li L. & Keller G. 1998b: Diversification and extinction in Campanian Maastrichtian planktonic foraminifera of northwest Tunisia. *Ecol. Geol. Helv.* 91, 75–107.

Liu C. & Olsson R.K. 1992: Evolutionary radiation of microperforate planktonic foraminifera following the K/T mass extinction event. *J. Foram. Res.* 22, 4, 328–346.

Luning S., Kuss J., Bachmann M., Marzouk A.M. & Morsi A.M. 1998: Sedimentary response to basin inversion: Mid Cretaceous–Early Tertiary pre-to syn-deformational deposition at the Areif El Naqa anticline (Sinai, Egypt). Institut fur palaontologie der Universitat Erlangen-Nurnberg. *Facies* 38, 103–136.

Maestas Y., Macleod K.G., Douglas R., Self-Trail J. & Ward P.D. 2003: Late Cretaceous foraminifera, paleoenvironments, and paleoceanography of the Rosario Formation, San Antonio Del Mar, Baja California, Mexico. *J. Foram. Res.* 33, 3, 179–191.

Martinez R.J.I. 1989: Foraminiferal biostratigraphy and paleoenvironments of the Maastrichtian Colon mudstone of northern South America. *Micropaleontology* 35, 2, 97–113.

Molina E., Arenillas I. & Arz J.A. 1996: The Cretaceous/Tertiary boundary mass extinction in planktonic foraminifera at Agost, Spain. *Rev. Micropaleontologie* 39, 225–243.

Nederbragt A.J. 1991: Late Cretaceous biostratigraphy and development of Heterohelicidae (planktonic foraminifera). *Micropaleontology* 37, 4, 329–372.

Obaidalla N.A. 2005: Complete Cretaceous/Paleogene (K/P) boundary section at Wadi Nukhul, southwestern Sinai, Egypt: inference from planktonic foraminiferal biostratigraphy. *Rev. Paleobiologic, Geneve* 24, 1, 201–224.

Olsson R.K., Hemleben C., Berggren W.A. & Huber B. 2000: Atlas of Paleocene Planktonic Foraminifera. http://services.chronos.org/

foramatlas/pages/home.htm. 1–281, with 66 plates, 2 charts and 29 paleogeographic maps.

Premoli Silva I. & Sliter W.V. 1995: Cretaceous planktonic foraminiferal biostratigraphy and evolutionary trends from the Bottaccione section. Gubbio, Italy. *Paleontographia Ital.* 82, 1–89.

Premoli Silva I. & Sliter W.V. 1999: Cretaceous Paleoceanography: Evidence from planktonic foraminiferal evolution. In: Barrera E. & Johnson C.C. (Eds.): Evolution of the Cretaceous ocean-climate system. *Geol. Soc. Amer., Spec. Pap*. 332, 301–328.

Premoli Silva I., Spezzaferri S. & D'Angelantonio A. 1998: Cretaceous foraminiferal bio-isotope stratigraphy of Hole 967E and Paleogene planktonic foraminiferal biostratigraphy of Hole 966E, Eastern Mediterranean. In: Robertson A.H.F., Emeis K.C., Richter C. & Camerlenghi A. (Eds.): Proceedings of Ocean Drilling Program, Scientific Result. Vol. 160. *ODP, College Station,* TX, 377–394.

Raffo S.S.D. 1989: Planktonic foraminifera and biostratigraphy of Aaliji Formation and nature of the contact with Shiranish Formation in Mushorah well No. 1, Northwest Iraq. *Unpubl. MSc. Thesis, Mosul Univ.*, Iraq, 1–140.

Robaszynski F., Caron M., Gonzalez D.J.M. & Wonders A.A.H. 1983–1984P: Atlas of Late Cretaceous globotruncanids. *Rev. Micropaleontology* 26, 3–4, 145–305.

Samir A.M. 2002: Biostratigraphy and paleoenvironmental changes in the Upper Cretaceous–Early Paleogene deposits of Gabal Samara section, Southwestern Sinai, Egypt. *J. Paleontology* 2, 1–40.

Shahin A. 1992: Contribution to the foraminiferal biostratigraphy and paleobathymetry of the Late Cretaceous and Early Tertiary in the western central Sinai, Egypt. *Rev. Micropaleontology* 35, 2, 157–175.

Sharbazheri K.M. 2007: Aging of unconformity within Tanjero Formation in Chwarta Area Northeast of Iraq (Kurdistan Region). *Rafidain J. Sci.*, *Mosul Univ*., Iraq 7, 1, 37–4.

Sissakian V.K. 2000: Geological map of Iraq. Sheets No. 1. Scale 1 : 1,000,000. State establishment of geological survey and mining. *GEOSURV*, Baghdad, Iraq.

Smit J. 2005: The section of Barranco del Gredero (Caravaca, SE Spain): a crucial section for the Cretaceous/Tertiary boundary impact extinction hypothesis. *J. Iberian Geol.* 31, 179–191.

Stinnesbeck W., Keller G., Adatte T., Harting M., Stuben D., Istrate G. & Kramar U. 2004: Yaxcopoil-1 and the Chicxulub impact. *Int. J. Sci., Geol. Rdsch*. 93, 6, 1042–1065. doi:10.1007/s00531-004-431-6.