High-Resolution Biostratigraphic Zonation across the Cretaceous/Paleogene (K/Pg) Boundary from Sulaymaniyah Area, Kurdistan Region, Northeastern Iraq

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Abstract—The present study interprets the high resolution of the biostratigraphy across the Cretaceous/Paleogene (K/Pg) boundary from Sulaymaniyah, Kurdistan Region, and north-east Iraq, based on planktic foraminifera. The Dartw section was selected for this study, within the High Folded Zone. The biozone contact consists of lithostratigraphic resemblance and is represented by the upper part of the Tanjero Formation (late Maastrichtian) with the overlying Kolosh Formation (Danian). Four late Maastrichtian planktic foraminiferal biozones have been recorded from the Tanjero Formation: *Racemiguembelina fructicosa* Interval Zone (CF4), *Pseudoguembelina hariaensis* Concurrent Range Zone (CF3), *Pseudoguembelina palpebra* Partial Range Zone (CF2) and *Plummerita hantkeninoides* Total Range Zone (CF1), while three Danian planktic foraminiferal biozones and two subzones have been recorded from the Kolosh Formation: (*Guembelitria cretacea* (P0) Interval Zone, *Parvularugoglobigerina eugubina* (Pu) Total Range Zone, and *Parasubbotina pseudobulloides* (P1) Partial-Range Zone (*Globococculina archaeoresspess* (P1a) Partial Range Subzone, and *Subbotina triloculinoides* (P1b) Interval Subzone). High biostratigraphic resolution indicates a complete K/Pg transition with no hiatus at the studied section in the Sulaymaniyah area. The ranges of the species recognized in this study are given. Correlations with other sections in Iraq and other parts of the world, including the type Maastrichtian and Danian areas, are discussed and represented in correlation charts, together with the ranges of the important Upper Maastrichtian and Paleocene species.

Index Terms—High Resolution, K/Pg boundary, Kurdistan region of Iraq, Planktic Foraminifera.

I. INTRODUCTION

Mass extinctions have occurred many times throughout the Earth’s history, one of the greatest and biggest extinctions was at the K/Pg boundary (end of Cretaceous 66 Ma) (Renne, et al., 2013). It is one of the best known for the impact triggered extinction at the Yucatan peninsula in Mexico and is known as the Chicxulub impact (Fig. 1) (Hildebrand, et al., 1991). Meteor impact theory was firstly only detected from the enrichment of platinum group elements especially Iridium, later the location of the impact was found (Alvarez, et al., 1980; Smit and Hertogen 1980; Bonté, et al., 1984; Alvarez, Claeyts and Kieffer, 1995; Schulte, et al., 2010; Belza, et al., 2017). Environmental crises of the impact such as sunlight shielding, sulfuric and nitric acid rain, CO₂-induced global warming, ultraviolet penetration, and toxic effects of ground-level ozone made harsh situations across the Earth (Maruoka, 2019). Besides the impact of environmental catastrophe, another theory of the driving mechanism of the extinction is linked to Deccan volcanism in India by recording enrichment of mercury in sediments from the time of the extinction (Fig. 1) (Courtillot, et al., 1984; Hildebrand, Boynton and Zoller, 1984; Madhavaraju and Yong 2010; Font, et al., 2016; Keller, et al., 2020; Mateo, et al., 2020). The controversy between abrupt (meteoric impact) and gradual mass extinction (long-lasting volcanic activity) of which mechanisms had a great effect is still ongoing (Koeberl, 1989; Keller, 2014; Arenillas, et al., 2022). Planktic foraminifera’s species suffered mass extinction from the consequences of the catastrophes, and most of the works on the boundary accepted the extinction (Smit and Ten Kate, 1982; Keller, 1988; Arenillas, et al., 2002). The K/Pg boundary in the Kurdistan Region of Iraq, which is a part of the Zagros Foreland Basin (ZFB), was recorded in sedimentary rocks between various lithostratigraphic units (Shiranish/Kolosh Formations, Shiranish/Aali j formations, Tanjero Formation/

The research on the boundary between the Tanjero and Kolosh Formations and, the Shiranish and Kolosh Formations was mostly focused on biostratigraphy (Kassab, 1972; Ghafor, 2000; Kharajiany, Al-Qayim and Wise, 2019). The studies conducted on the boundary in particular shed light on the nature of sedimentation across the boundary and whether the boundary itself represents an unconformity or a hiatus surface. Most of the recent studies use planktic foraminifera, palynomorphs (Spores and Pollen), and nannofossils emphasizing that the Early Danian sediments exist between Tanjero and Kolosh Formations and mark the boundary as a conformable surface (i.e., without a break in sedimentation) (Al-Qayim and Al-Shaibani, 1989; Ghafor, 2000; Sharbazheri, Ghafor and Muhammed, 2009, 2011; Kharajiany, Al-Qayim and Wise, 2019; Al-Nuaimy, et al., 2020; Al-Qayim, Kharajiany and Wise, 2020; Kharajiany, Wise and Al-Qayim, 2020; Bamerni, et al., 2021), while many other studies mark the boundary as an unconformable surface (Kassab, 1972; Ghafor, 1988; Al-Shaibani, Al-Hashimi and Ghafor, 1993; Jassim and Goff, 2006; Sissakian and Al-Jubouri, 2014; Lawa and Qadir, 2023). One of the prominent works conducted on the contact between Tanjero and Kolosh Formations by Bellen, et al. (1959), concluded that in some areas of Northern Iraq, the boundary could represent conformable surfaces. These authors unfortunately did not specify the localities of these conformable surfaces. Thus, high-resolution biostratigraphic zonation will help to determine the nature of the boundary. Research works on the boundary continue to optimize the best result of recording biozones. This paper presents the high-resolution biostratigraphy of the K/Pg boundary interval to delineate the boundary in a section namely the Dartw section (Kurdistan Region, NE Iraq) between Tanjero and Kolosh Formations, by recognition of planktic foraminifera in thin sections. It is historical usage to determine the ages of marine sequences across the boundary (Sarigül, et al., 2017) and to compare these records with other areas available in the region and across Iraq.

II. GEOLOGICAL SETTING

In Sulaymaniyah Governorate, the Cretaceous and Paleocene succession is well exposed. This succession is exposed in almost all outcrops of the High Folded Zone of the Zagros Thrust-Fold around Sulaymaniyah city in the western part of the Zagros Thrust Fold Belt. The facies variation of K/Pg sections in areas around the Dartw section is between marine marl and argillaceous limestone (marly limestone), while in the furthest NE part (Imbricated Zone) of Sulaymaniyah the variation is between marine and terrestrial sediments (Tanjero and Red Bed Series) (Lawa and Qadir, 2023). At the time of the K/Pg boundary event(s), the study section was located in the ZFB, as a consequence of the convergence of the Arabian Plate with the Iranian Plate (Al-Qayim, Omer and Koyi, 2012). Structurally Dartw section is in a part of the southwestern limb of a small anticline (Yakhyan anticline) which is a part form a larger pyramagrun anticline, more specifically the section is in the SE plunge of the anticline (Fig. 2). Structures around the section are striking SE-NW, parallel to the main trend of ZMB. The section is located at 35° 38’ 55.12” N and 45° 16’ 18.15”E in NE Iraq about 18.5 Km from N60W of the center of Sulaymaniah city, the coordination represents the exact boundary. In the Dartw section, the exposed outcrop of the boundary is between the Tanjero and Kolosh Formations as shown in (Fig. 2). The K/Pg boundary sequence is deposited on a carbonate platform at the northeastern margin of the Arabian Plate. The outcrop of the studied section is subdivided into two formations; based on the lithology, and stratigraphic position, these are Tanjero and Kolosh Formations. The latest Cretaceous unit is the Tanjero Formation, which was deposited by turbidite currents in the deep marine environment (Jaza, 1992; Karim, 2004). It was first described by Dunnington (1952), its type locality is in the Sirwan Valley, near Halabja Governorate, in the Kurdistan Region of Iraq, the Lithology of the Tanjero Formation is mainly composed of alternations between dark grey or olive green clastics (Sandstone and silststone) marlstones, and argillaceous limestone with a massive conglomerate part in the proximal turbidite (Bellen, et al., 1959; Karim, 2004; Ahmed, Qadir and Müller, 2015). The depositional basin of this unit was
parallel to the convergence suture between the Arabian and Iranian plates in a Narrow northwest-southeast direction (Jassim and Goff, 2006). The lower part of the section could be misinterpreted lithologically as the Shiranish Formation since the strata are similar in appearance to the Shiranish Formation. However, in contrast to the Shiranish Formation, this lower part has unique thin beds of sandstone (Fig. 3). Jaza (1992) and Ismael, et al. (2011) in the Sulaymaniyah area have highlighted the problem of differentiating between Tanjero and Shiranish formations since Tanjero Formation contains intervals similar to Shiranish Formation lithologies. Both Tanjero and Shiranish formations were deposited in a single basin at the initial stage of the Zagros Foreland Basin development (Karim, 2004).

In the earliest time of the Paleogene, the basin was nearly the same as at the time of deposition of the Tanjero Formation, the Kolosh Formation started deposition. This formation was first described by Dunnington (1952; in Bellen et al., 1959) and the type locality of the formation is located in the north of Koya Town near Kolosh Village. This unit is a low-density turbidite with rhythmic alternation of sandstone and shale with beds of argillaceous limestone, limestone, and conglomerate (Bellen, et al., 1959; Al-Mashaikie Sa’ad and Mohammed, 2018; Karim and Hamza, 2023). These two formations both have a flysch deposit character deposited in the upper bathyal environment, outer shelf environment, and middle shelf area from bottom to top respectively (Jaza, 1992; Jassim and Goff, 2006; Al-Khalaif and Al-Mutwali, 2020). In the Dartw section, both formations have approximately similar lithological characteristics; the two formations are composed of interbedding between marlstone, argillaceous limestone, and sandstone. The consistency of lithology (no abrupt change) across the section makes a determination of the boundary by the field evidence impossible, especially in narrow intervals (centimeters scale) (Figs. 3 and 4). Color variation is noted in Kolosh Formation as it is darker compared to the Tanjero Formation.

### III. Materials and Methods

Sixty-three rock samples for this study were taken from the Dartw section outcrop in four carried-out field trips. Intervals between individual samples are based on proximity to the boundary, at boundary transition, sample intervals are much smaller compared to distant samples (Fig. 4). Samples were collected in four stages, and especially near the boundary, samples were taken at 10cm intervals. (Fig. 3). Between each stage of field sampling, thin sections of samples were made in the workshop of the Department of Earth Sciences and Petroleum/University of Sulaimani to study planktic foraminifera, this would help us to concentrate samples at strata near the boundary. The samples are representative
of the lithology variation of turbidite cycles. Thin sections from all samples for petrographic study were prepared at the workshop of the Department of Geology/University of Sulaimani. The biozonal schemes of Li and Keller (1998a; 1998b) and Coccioni and Premoli Silva (2015) for the late Maastrichtian were followed and the biochronology of Wade, et al. (2011) was used for the Danian.

IV. RESULTS AND DISCUSSION

A. Biostratigraphic Analysis

The studied section has the highest diversity of late Maastrichtian/Danian planktic foraminifera with a total identification of 71 species from 28 genera of planktic foraminifera (46 species of Maastrichtian from eighteen genera of planktic foraminifera and 25 species of Danian from ten genera of planktic foraminifera). The biozonation of the Dartw section was found on the apportionment of the planktic foraminifera that applied to the Tanjero and Kolosh Formations (Figs. 5-7), seven biozones have been recognized from Maastrichtian - Paleocene age (Fig. 8). For the late Maastrichtian, the biozonation of Li and Keller (1998a; 1998b), was used, which subdivides the *Abathomphalus mayaroensis* zone is subdivided into four Cretaceous Foraminiferal (CF) subzones (CF1, CF2, CF3 and CF4), four for the earliest Danian, the biozonation of Keller, et al. (1995) was subdivided into three biozones (P0, P1a and P1) and 2 subzones (P1a, and P1b) have been recognized. These biozonal schemes are shown in Fig. 9 in comparison with other commonly used biozones.

B. Biostratigraphy of the Tanjero Formation (late Maastrichtian)

Forty-six species from eighteen genera of planktic foraminifera have been identified in the Tanjero Formation (Figs. 5 and 6). Based on the stratigraphic ranges of the recognized species, four subzones of the *A. mayaroensis* zone have been recognized in the Maastrichtian.

Total Range Zone of the nominated by taxon *Abathomphalus mayaroensis*. The *A. mayaroensis* was defined previously as the interval from the first appearance datum (FAD) to the last appearance datum (LAD) of *A. mayaroensis*, which spans the entire late Maastrichtian interval (Caron, 1985; Toumarkine and Lutherbacher, 1985). It is important to mention that the zonal scheme of CF proposed by Li and Keller (1998a; 1998b), which replaces the *A. mayaroensis* Zone, with four subzones (*Racemiguembelina fructicosa* subzone, *Pseudoguembelina hariaensis* subzone, *Pseudoguembelina palpebra* subzone, and *Plummerita hantkeninoides* subzone), for much-improved age estimation for the late Maastrichtian, This zone is coeval with the standard zonation of Caron (1985) and Berregren, et al. (1995), it also coincides with the zones CF4, CF3, CF2, of Li and Keller (1998). The upper and lower boundaries were drawn with the first and last occurrences of the nominate taxon. In the Dartw section of the studied area, the *A. mayaroensis* zone encompasses 19-m thick Maastrichtian limestone with marly limestone, which can be subdivided into the four CF subzones (Li and Keller, 1998a), and were arranged from older to younger (Fig. 8):

*R. fructicosa* interval subzone (CF4)

This zone is defined as the interval from the FAD of *R. fructicosa* and the FAD of *A. mayaroensis* to the FAD of *P. hariaensis* (Li and Keller, 1998). The lower boundary is not covered by this section and the upper boundary is defined by the first appearance of the *A. mayaroensis*. In the Dartw section, subzone CF4 extends from 0 m to 9 m (with a 9 m thick) of the alternation of calcareous shale (Occasionally siltstone) with a 0.5 m thick argillaceous limestone bed. A bed of sandstone 2-cm thick is present at the top. This zone is recognized at the base of the Tanjero Formation and is represented in the Dartw section by an interval extending from the samples DT-9, and DT-15.

The zone is characterized by these species of Planktic foraminifera: *Abathomphalus intermedius*, *A. mayaroensis*, *Gansserina gansseri*, *Globotruncana bulloides*, *Globotruncana pettersi*, *Globotruncana arca*, *Contusotrancana contusa*, *Contusotrancana waifischensis*, *Globotruncanita conica*, *Globotruncanita conica*.
Fig. 4. Stratigraphic column of a Dartw section across the K/Pg boundary near Sulaymaniyah city, Kurdistan region, Iraq.


The age calculation of this biozone by Li and Keller (1998a) recorded the time span between 68.33 Ma and 66.83 Ma. In the studied section, estimating absolute ages based on magnetochron age between a time span between 68.35 Ma and 67.25 Ma, and a high rate of deposition. Its age is early late Maastrichtian with 9-m thick.

P. hariaensis concurrent range subzone (CF3)

This zone defines the interval from the FAD of P. hariaensis at the base to the LAD of G. gansseri at the top (Li and Keller, 1998a; 1998b). This biozone spans 1 m of olive-green calcareous shale (Fig. 8). This zone is recognized at the Tanjero Formation and is represented in the Dartw section by an interval extending from the samples DT-16 to DT-22. It is characterized by these species of Planktic foraminifera: - A. intermedius, A. mayaroensis, G. arca, Globotruncanana calcara, Contusotruncanana contusa, G. conica, G. stuarti, H. holmdelensis, H. monmouthensis, H. globulosa, H. navarroensis, Pseudoguembelina harenensis, R. rugosa, R. reicheli. The P. hariaensis (CF3) Zone was introduced by Li and Keller (1998a). This zone is equivalent to the middle part of the A. mayaroensis zone as recorded by Abawi, Kireem and Yousef (1982) and Abdel-Kireem (1986) in the northeast of Iraq. It is also correlated with the same zone that was recorded by Al-Mutwali and Al-Doori (2012), they recorded this zone as an interval zone of the zonal
marker with a thickness of 3.6 m, and they determined its age as middle late Maastrichtian. The abundant occurrence of these planktic foraminifera has been recognized by Hammoudi (2011), *Globotruncana aegyptiaca*, *Globotruncana*
(a) *Globotruncana orientalis* (El Naggar 1966), sample no. DT-22.  
(b) *Rugoglobigerina pennyi* (Bronnimann, 1952), sample no. DT-22.  
(c) *Abathomphalus mayaroensis* (Bolli, 1951), sample no. DT-27.  
(d) *Globotruncanita falsostuarti* (Sigal, 1952), sample no. DT-27.  
(e) *Globotruncanana dupeublei* (Caron, Gonzalez, Robaszynski & Wonders in Robaszynski, et al., 1984), sample no. DT-27.  
(f) *Globotruncanita angulata* (Tilev, 1951), sample no. DT-27.  
(g) *Globotruncanana stephensoni* (Pessagno 1967), sample no. DT-27.  
(h) *Globotruncanita conica* (White, 1928), sample no. DT-27.  
(i) *Pseudotextularia intermedia* (De Klasz, 1953), sample no. DT-27.  
(j) *Abathomphalus mayaroensis* (Bolli, 1951), sample no. DT-27.  
(k) *Rugoglobigerina rotundata* (Brommann, 1952), sample no. DT-55.  
(l) *Globotruncanella petaloidea* (Gandolfi, 1955), sample no. DT-55.  
(m) *Guembelitria cretacea* (Cushman, 1933), sample no. DT-57.  
(n) *Plummerita hantkeninoidea* (Brommann, 1952), sample no. DT-57.  
(o) *Archaeoglobigerina blowi* (Pessagno 1967), sample no. DT-57.  
(p) *Contusotruncanana contusa* (Cushman, 1926), sample no. DT-57.  
(q) *Globigerinelloides subcarinatus* (Brommann, 1952), sample no. DT-57.  
(r) *Planoheterohelix globulosa* (Ehrenberg, 1840).  
(s) *Globotruncanella petaloidea* (Gandolfi, 1955), sample no. DT-57.  
(t) *Heterohelix globulosa* (Ehrenberg, 1840).  
(u) *Rugoglobigerina hexacamerata* (Brönnimann, 1952), sample no. DT-57.  
(v) *Rugoglobigerina rugosa* (Plummer, 1927), sample no. DT-53  
(w) *Globotruncanita stuartiformis* (Dalbiez, 1955), sample no. DT-19.  
(x) *Planoheterohelix planata*, *Heterohelix glabrans*, *Heterohelix globulosa*, *Heterohelix navaroensis*, and she considered the CF3 Zone as a subzone within the *A. mayaroensis* Zone also

arca, Globotruncana esenhensis, *Contusotruncanana contusa*, *R. rugosa*, *R. macrocephala*, *R. scotti*, *Rugoglobigerina hexacamerata*, *H. holmdelensis*, *H. monmouthensis*, *Hetrohelix planata*, *Hetrohelix glabrans*, *Hetrohelix globulosa*, *Hetrohelix navaroensis*, and she considered the CF3 Zone as a subzone within the *A. mayaroensis* Zone also

Bar scale = 0.5 mm.

Fig. 8. Biostratigraphic range chart of identified planktic foraminifera across K/Pg boundary in the Dartw section. Biozones are based on Li and Keller (1998a; 1998b).

The age calculation of this biozone by Li and Keller (1998a), recorded the time span between 66.83 Ma to 65.45 Ma. In the studied section, estimating absolute ages based on magnetostratigraphic correlation between a time span between 66.80 Ma and 66.44 Ma, and moderate rate of sedimentation. Its age is middle late Maastrichtian with 1 m thick.
**P. palpebra partial range subzone (CF2)**

This zone spans the interval from the LAD of *G. gansseri* to the FAD *P. hantkeninoides* (Li and Keller, 1998a; 1998b). In the Dartw section, this zone spans 4.5 m of grey shale (Fig. 8). It is recognized at the Tanjero Formation and is represented in the Dartw section by an interval extending from the samples DT-22, and DT-32. The assemblage includes this planktic foraminifera: *A. intermedius, A. mayaroensis, C. contusa, Globotruncanina conica, Globotruncanana dupeulebi, Contusotruncanana marginotruncanana, hexacamerata Globotruncanina arca, G. stuarti, G. stuartiformis, Globotruncanana duplhuberti, G. bulloides, Globotruncanana stephensi, H. holmdelensis, H. monmouthensis, H. globulosa, Heterohelix moremani, Heterohelix punctulate; H. navarroensis, P. hariaensis, Rugotruncanana rotundata, P. hantkeninoides, R. hexacamerata, R. reicheli, R. rugosa, pseudotextularia elegans. Marginotruncanana cf. marianosi.

The age estimation of this biozone by Li and Keller (1998a) records the upper late Maastrichtian, with a time span of 65.45 Ma to 65.30 Ma. In the studied section, estimating absolute ages based on magnetochnor age between a time span between 65.4 Ma and 65.30 Ma, providing a high rate of sedimentation, its age is upper late Maastrichtian with 4.5 m thick.

**P. hantkeninoides total range subzone (CF1)**

The biozone CF1 is defined by the total range of *P. hantkeninoides*, which marks the last 300 ky of the Maastrichtian (Li and Keller, 1998a; 1998b and Olsson, et al., 1999). In the Dartw section, zone CF1 spans the uppermost 4.5 m of dark green calcareous shale. It is recognized at the Tanjero Formation and is represented in the Dartw section by an interval extending from the samples DT-32 and DT-58. Species identified in this interval include: *A. mayaroensis, G. aegytica, P. hantkeninoides, Globotruncanina arca, Globotruncanina esnehensis, Globotruncanina falsostauri, Globotruncanina. petteri, Globotruncanina. petteri, Globotruncanina. petteri, H. globulosa, H. navarroensis, H. monmouthensis, Kassabiana falsocalcarata, P. hantkeninoides, P. hariaensis, P. palpebra, P. elegans, R. macrocephala, Rugoglobigerina riecheli, R. rugosa, G. cretacea, R. hexacamerata, G. subcarinata (Fig. 3). The CF1 subzone was introduced by Masters (1984), at the K-Pg boundary in Tunisia and Egypt. Cocconi and Premoli Silva (2015) stated that the zonal marker is very rare and sporadic in the classic Tethyan Gubbio section (Italy). Sharbazheri, Ghafar and Muhammed (2009; 2011) and Al-Nuaiym, et al. (2020) recorded the CF1 Zone in their study from the upper part of the Maastrichtian deposits in Kurdistan region/Iraq. They also stated that the characteristic planktic foraminiferal assemblage of this zone gradually decreased in both species richness and individual numbers from the *P. palpebra* Zone to the *P. hantkeninoides* Zone. Mousa, Al-Dulaimi, and Mohammed (2020) recorded the C1 zone in the Western Desert of Iraq and they documented common occurrences of *A. intermedius, A. mayaroensis, Glla. pschadae, H. monmouthensis, P. palpebra, R. hexacamerata*, the age of this zone estimated by the latest Maastrichtian. Recently *P. hantkeninoides* Zone was recorded by Bamerni et al. (2020) in the Dohuk area, North-east Iraq, with high-resolution biostratigraphic analysis of the K-Pg boundary and shows a great diversity of the planktic foraminiferal assemblages compared to the CF2 and CF3 biozones. They recorded planktic foraminifera: the most abundant taxa are *P. hantkeninoides, Plummerita reicheli, Plummerita cf. hantkeninoides, P. elegans, Pseudotextularia nutalli, P. intermedia, Globotruncanina. conica, Globotruncanina. stuartiformis, Rastemegumbelina. powelli, Plummerita. criteria, Plummerita. brazoensis, Plummerita. acervulinooides, H. striata, H. globulosa, Heterohelix labelosa, Heterohelix. reussi, Heterohelix. navarroensis, Heterohelix. carinata, R. rugosa, R. macrocephala, Rastemegumbelina. fructicosa, Pseudigumbelina. costulata, P. hariaensis, P. palpebra, Pseudogumbelina kemensis, Gansserina. arca, Ganserina. rosetta, C. contusa, C. esnehensis, C. falscalcarata, C. patelliformis, H. monmouthensis, Ruggoglobigerina hexacamerata, Archaeoglobigerina. blowi, and Gublerina. caviilleri.


The present zone of *P. hantkeninoides* is equal to *A. mayaroensis* in their upper majority from all parts of the world (Canudo, Keller and Molina, 1991); Chacon and Martin-Chivelet, (2005) in Spain; Premoli Silva and Sliter (1999) from Italy; Abramovich, et al. (2005) in the eastern Mediterranean; Govindan, Ravindran and Rangaraju (1996) from India; Maestas, et al. (2003) in USA, California; Martinez (1989) and Molina, et al. (2005) from south USA, and corresponding to *Plummerita. richly Zone of Elnady and Shahin (2001) from Egypt.

The estimation of this zone age indicates the uppermost late Maastrichtian (Li and Keller, 1998a), with a complete estimate of absolute ages based on magnetochnor ages 65.30 Ma to 65.00 Ma. In the studied section, estimating absolute ages based on magnetochnor age between a time span between 65.35 Ma and 65.10 Ma, high rate of sedimentation, its age is latest Maastrichtian with 4.5 m thick.

**C. Biostratigraphy of Kolosh Formation-Early Danian**

Twenty-five species from ten genera of planktic foraminifera have been identified in the Kolosh Formation (Fig. 7). Based on the stratigraphic ranges of the recognized species, three biozones have been recognized and were arranged from older to younger (Fig. 8), the recognized biozones in this study were correlated with different locations (Fig. 9).

The Early Danian Zones in the studied section started from the *G. cretacea* zone (P0) to the Parasubbotina
The age estimation of this biozone by Olsson, et al. (2000) and Keller and Pardo (2004), Keller (2002) they record the earliest Paleocene (Danian), with the period of 65.00 Ma to 64.97 Ma estimating absolute ages based on magnetochron ages. In the current study, estimating absolute ages based on magnetochron age between a time span from 65.05 Ma to 64.09 Ma. Its age is the Earliest Paleocene (Danian) with 0.5 m thick.

P. eugubina (Pα) total range zone

The Pα is a biozone defined by the total range of the nominal taxon P. eugubina. The P. eugubina Total Range Zone is identified in the studied section from the sample DT-65 to DT-68, with a thickness of 19.5 m of alternation of dark grey calcareous shale, alternation of calcareous shale with argillaceous limestone and sandstone. This zone has an increase in the diversity and abundance of the Danian cosmopolitan planktic foraminifera including: Parvularugoglobigerina eugubina, G. cretacea - P. pseudobulloides, Globorocosa daubjergensis, Woodringina hornerstonensis, Woodringina claytonensis, Chiloguembelina midwayensis, Chiloguembelina cubensis, besides the abundant and continuous extension of G. cretacea, this zone also has minute-sized, simple late Cretaceous taxa such as Heterohelix globulosa, H. punctulata, and H. monmouthensis.

The Pα in the section correlated to Bamerni, et al. (2021) in northeastern Iraq, Sharbazheri, Ghafor and Muhammed (2009; 2011), and Al Nuaimy, et al. (2020) in northeastern Iraq, Bamerni, et al. (2021) recorded 52 and 27 cm thickness for two sections in Duhok and documented the occurrence of Globorocosa daubjergensis, Woodringina hornerstonensis, Woodringina claytonensis Eoglobigerina bulloides, Eoglobigerina fringa, Eoglobigerina edita, Chiloguembelina midwayensis, Chiloguembelina trinitatensis, Chiloguembelina cubensis, Globanomalina archaeocompressa, Globanomalina australiformis, Globanomalina chapmani, Globanomalina planocompressa, Guembelitria trifolia, Parasubbotina aff. pseudobulloides Besides the abundant and continuous extension of G. cretacea, this zone also has minute-sized, simple late Cretaceous taxa such as H. globulosa, H. striata, H. punctulata, Heterohelix labelosa, Heterohelix navarroensis, H. monmouthensis, Pseudigumbelina costulata, Archaglobigerina blowi and R. hexacamerata. The age estimation of this biozone by Olsson, et al. (2000); Li and Keller (1998a); Keller and Pardo (2004), Keller (2002), they record the earliest Paleocene (Danian), with the period of 64.97 Ma to 64.90 Ma estimating absolute ages based on magnetochron ages. In the current study, estimating absolute ages based on magnetochron age between a time-span between 64.96 Ma and 64.90 Ma. Its age is the Earliest Paleocene (Danian) with 19.5-m thick.

P. pseudobulloides (P1) total range zone

P. pseudobulloides zone is defined by the total Range zone of Parasubbotina pseudobulloides, this zone is subdivided into two subzones (P1a, and P1b), 6.2 m thick from the sample numbers DT-68 to DT0-71. Leonov and Alimarin (1961) introduced Globorotalia (Turborotalia)
Gumbelirita cretacea, and estimating absolute ages based on magnetochron age between a time span of 64.50 Ma and 63.01 Ma. Its age is the Earliest Paleocene (Danian), with 0.2 m thick.

S. triloculinoides (P1b) interval subzone

The age estimation of this interval depends on Magnetic polarity and recorded datum events by (Olsson, et al. 2000) and Keller and Pardo (2004), Keller (2002) with the time span of 64.5 Ma from the first occurrence of, S. triloculinoides, to FAD of Globanomalina compressa and/or Praemurica inconstans at the top of 63 Ma. In the current study, estimating absolute ages based on magnetochron age between a time-span between 64.50 Ma and 63.01 Ma, Its age is the Earliest Paleocene (Danian), with 0.2 m thick.

V. Conclusion

The Cretaceous/Plaegene boundary in the Dartw section, south-west of Sulaymaniyah, reveals an expanded late Maastrichtian to Early Danian, and the boundary transition covers the uppermost part of the Tanjero Formation (late Maastrichtian) and the entire Kolosh Formation (Danian). Planktic foraminifera were very abundant and diversified during the late Cretaceous and early Danian in the studied section. The biozonation of the K-Pg boundary in the Dartw section shows continuous sedimentation based on the recognized planktic foraminifera, which subdivided into four zones of the Upper Cretaceous Tanjero Formation:

(i). R. fructicosa Interval Zone (CF4).
(ii). P. hariaensis Concurrent Range Zone (CF3).
(iii). P. palpebra Partial Range Zone (CF2).
(iv). P. hankeninoides Total Range Zone (CF1).

While three Danian planktic foraminiferal biozones and two subzones have been recorded from the Kolosh Formation:

(i). G. cretacea (P0) Interval Zone,
(ii). P. eugubina (Pα) Total Range Zone, and
(iii). P. pseudobulloides (P1) Partial-Range Zone

(a). G. archaeocopressa (P1a) Partial Range Subzone, and
(b). S. triloculinoides (P1b) Interval Subzone.

Late Maastrichtian planktic foraminifera were much diversified and some species reached a very large size. The present biostratigraphic study provides compelling evidence for a complete K/Pg transition at the studied locality in the Dartw section.
A. Declaration

The authors declare that they have no conflicts of interest.

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