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New Biostratigraphic Ideas About the Cretaceous - Paleogene Boundary from Selected Sections in Kurdistan- Mesopotamian Foreland Basin, Northern Iraq

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ABSTRACT

A composite biostratigraphic study has been carried out from four selected sections representing an interval between the Cretaceous/Paleogene (K/Pg) boundary within the Imbricated Zone (Chwarta – Mawat), Sulaimani area, Kurdistan region, northern Iraq. The study covers the Maastrichtian successions, represented by the upper part of the Tanjero and Aqra formations, and the Paleogene succession, represented by the lowermost portion of the Suwais Group. The biostratigraphic study is based on the Large Benthic Foraminifera, supported by planktic foraminifera, Calcareous Nannofossil biozone, and ammonite biozones, which are in turn compared with the local and international biozones. The recorded large benthic foraminifera biozones are: - *Loftusia minor*, *Loftusia coxi*, *Orbitoides media*, *and Lepidorbitoides socialis* Assemblages Zone (indicates early Late Maastrichtian age). *Loftusia morgani*, *Siderolite calcitrapoides*, *Orbitoides apiculatus* Assemblage Zone (indicates middle Late Maastrichtian age). *Loftusia persica*-*Loftusia elongata* Assemblage Zone (indicates late Late Maastrichtian age). *The Pseudoguembelina hariaensis* Partial Range Zone (CF3) recorded in Kato and Maukaba sections shows a middle Late Maastrichtian age. The recorded Calcareous Nannofossils are related to the *Micula murus*-*Micula prinsii* (CC26) Assemblage biozone recorded for the first time in the studied area and almost of Late Maastrichtian age but not extend to the latest Maastrichtian. Also, for the first time, an ammonites biozone was recorded in this area and represented by *Hoploscaphites constrictus crassus* Partial Range Zone (indicates early Late Maastrichtian). As a result, the K/Pg represents a significant gap (about 5my) and unconformity with 500m conglomerates.

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أفكار جديدة حول الطباقيه الحياتيه لحد العصر الطباشيري- الباليوجيني من مقاطع مختارة في حوض فورلاند ميسوبوتامين– كردستان ، شمال العراق

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الملخص

تم إجراء دراسة طباقيه حياتيه متكامله على أربعة مقاطع مختارة تغطي فترة زمنية بين حدود عصر الكريتاسي / الباليوجين (K / Pg) ، داخل المنطقة المتراكبة منطقة جوارتا –ماوت، السليمانية، اقليم كردستان (شمال العراق). تغطي الدراسة تتابعات الماستريختى التي يمثلها الجزء العلوي من تكوينات تانجيرو ، عقرة والتى تعقيها ترسبات والممثله بالجزء السفلي من مجموعة السويس. استندت دراسة الطباقيه الحياتيه على الفورامنيفرا القاعية الكبيرة ، والتى دعمت بوجود الفورمنيفيرا الطافيه، كما تمت الاستفاده من انطقه النانو الكلسيه والأمونايت ، تمت مقارنتها مع الانطقه الحياتيه الممثله محليا ودوليا .ان انطقه الفورامنيفرا الكبيرة المسجلة هي ، (*Loftusia minor- Loftusia coxi– Orbitoides media- Lepidorbitoides socialis* Assemblage Zone) و تشير إلى اوائل الماستريختى–المتاخر (*Loftusia morgani- Siderolites calcitrapoides- Orbitoides apiculatus* Assemblage Zone) و يشير إلى اواسط الماسترختى المتاخر. اما احدث نطاق فممثل بالنطاق التجمعى للانواع (*Loftusia persica*, *Loftusia elongata* Assemblage Zone) تشير إلى أواخر عصر الماسترختى – المتأخر .(ان النطاق الحياتى الجزئي (CF3) *Pseudoguembelina hariaensis* المسجلة من مقطعي الدراسه (كاتو و موكبه) والتي اشارت إلى عصر اواسط الماستريختى المتأخر. تمثلت الحفريات النانوية الجيرية بانطاق الحيوي التجمعي للانواع *Micula murus-Micula prinsii* (CC26) و المسجلة لأول مرة في المنطقة المدروسة وتدل على الماسترختى المتاخر ولكنها لا تمتد إلى نهايه الماسترختي. أيضًا . ، كما تم تسجيل نطاق حياتي للأمونايت لأول مرة في هذه المنطقة وتمثلها النطاق الجزئي (*Hoploscaphites constrictus crassus*) والتى دلت على الماسترختى المتاخر . استنتجت الدراسه الحاليه بان الحدالفاصل K / Pg تميز بالانقراض الجماعي لجميع المكونات الحياتية التي بعمر الماسترختيان وتمثل بوجود عدم توافق كبير تصاحب مع ترسيب تتابعات صخرية من المدملكات (بسمك 500 متر) والتي تمثل فجوة زمنية كبيرة (حوالى 5 مليون سنه) ضمن هذا الحد بين وحدتي الطباقية التكتونية 9 و10 في منطقة الدراسة ضمن اقليم كردستان –شمالي العراق .

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Introduction

The Cretaceous/Paleogene (K/Pg) boundary event is one of geological history's most widely studied fauna and flora crises. The Kurdistan-Mesopotamian Foreland Basin (KFB) hosts key sedimentary and biochemical signs that mark this event and resembles the inversions from underfilled to overfilled accomodation in that basin. During the Maastrichtian and Paleogene, the interplay between sea level rise and fall, carbonates and siliciclastic deposits, Global Maastrichtian warming and cooling cyclicity, syn and post sedimentary tectonic disturbances play an essential role in the total mass extinction of all micro and macro fauna at this K/Pg boundary (Al-Omari, 1966; Lawa, 1983; Al-Ameri and Lawa, 1986; Al-Omari et al., 1989; Lawa, 2004, 2018; Sharbazheri, 2007; Salih et. al., 2013; Al-Dulaimi and Al-Sheikhly, 2015; Görmüş et al., 2017, 2018, 2019; Al-Mutwali, and AL-Doori, 2012; Al-Mutwali, and Ibrahim, 2019; Al Nuaimy et al., 2020). Several previous studies have been carried out in Iraq about this boundary, but those dealing with the studied area. Al-Mehaidi (1975) gave a probable age of Late Maastrichtian based on the evidence of large benthic foraminifera and rudists by comparing them with those of the Aqra Formation. The geological map of the studied area was redrawn, and the lithostratigraphic units are well organized by Lawa et al. (2001), and Stevanovic and Markovic (2003), who clarify the interfingering between the Tanjero and Aqra formations in the studied area. Aziz et al. (2001) recorded the presence of the Aqra Formation in the studied area, too. There are limited lithos and bios stratigraphic studies about the Tanjero Formation and Suwais Group in the study area (Karim, 2004; Al-Barzinjy, 2005; Sharbazheri, 2007; Al-Kubaisy, 2008; Sadiq, 2009; Lawa et al., 2017). Several studies have recently been published about the Large Benthic Foraminifera (LBF) and fauna of the Aqra Formation in the studied area (Görmüş et al., 2017, 2018, 2019; Al-Nuaimy, 2018; Al-Dulaimi and Al-Sheikhly, 2015; Al-Dulaimi and Abdallah, 2019). In addition, (Lawa, 2004, 2018; Karim, 2004; and Karim et al., 2020) clarify their ideas about the depositional basins of the Tanjero Formation and Suwais Group. The studied area covered an area of about 440 km^2, extending from the southeast of Chwarta town to the south, west, and northwest of Mawat town (near the Iraq/Iran border); however, the locations and coordination are clarified in Fig. 1 and Table 1.

Table 1: Geographic coordinations of the selected studied sections and supplementary sections from the Imbricated Zone, Chwarta-Mawat area, Sulaimani area, Kurdistan Region, Iraq.

No.	Section	Start point End point	Latitude	Longitude
1	Sarsuly	Start point End point	35°53'1.98"N 35°53'7.79"N	45°23'54.74"E 45°23'50.92"E
2	Nalashken	Start point End point	35°51'40.06"N 35°51'24.18"N	45°23'45.34"E 45°24'33.05"E
3	Maukaba	Start point End point	35°45'50.65"N 35°46'15.75"N	45°27'13.76"E 45°27'14.19"E
4	Kato	Start point End point	35°38'57.40"N 35°39'44.02"N	45°36'20.67"E 45°35'5.47"E

This study aims to improve the K/Pg boundary and successions relationships based on composite biozonations indicators such as Large Benthic Foraminifera (LBF) biozones, Calcareous Nannofossil biozones, and supported by planktic foraminifera biozonations too. In addition to ammonites biozones. Therefore, conjugates biostratigraphic lines of evidences are integrated to improve the events at the K/Pg boundary. Another aim is to interpret the bio events, such as mass extinctions, in terms of relative sea-level changes and tectonic disturbance.

Materials and Methodology

The measured, studied sections (Table. 1, Fig. 1) followed the standard sedimentary and paleontological field methods (e.g., Stow, 2005) based on the extensive fieldwork across the possible K/Pg boundary and the geological maps of Stevanovic and Markovic (2003); Ma'ala (2008); and Fouad (2015). The carefully sampled and measured sections also

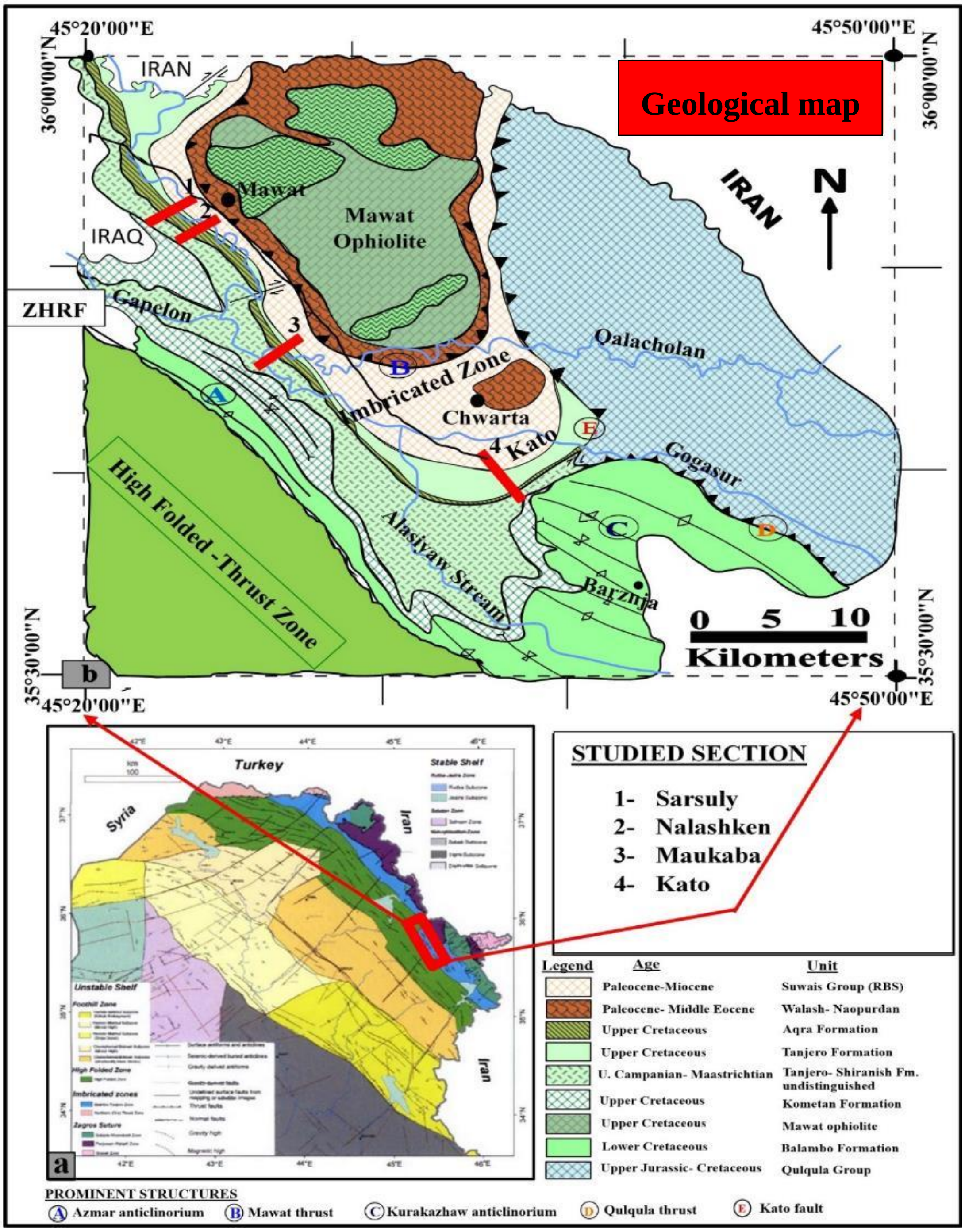

Fig. 1. a. Location and tectonic map of the studied area (after Jassim and Goff, 2006); b. Geological map showing the studied sections (slightly modified after Stevanovic and Markovic, 2003).

Include macrofossils, large benthic foraminifera, and trace fossils. About 200 samples have been collected in variable intervals from a few centimeters to five meters. The samples are prepared for LBF studies using standard and large thin sections, and about 20 samples have been cooked for micro foraminifera and Charophyte studies. The washing and classical cooking methods followed; some samples were heated and washed in 63, 125, and 250-mesh sieves. This procedure was repeated until foraminifera with clean surface textures were recovered. About 45 large benthic foraminifera, 20 planktic foraminifera, 12 small benthic foraminifera, 24 calcareous nannofossils, two ammonite species, and six Rudist species have been identified. The large benthic foraminiferal zonation is based on BouDagher-Fadel, 2015; and the authors of the *pforams@mikrotax* website (Young et al., 2017). At the same time, the planktic foraminiferal biozones are based on Coccioni and Premoli Silva (2015). The Ammonites are first described based on Machalski et al. (2016) and Machalski (2021). The photos were taken by a scanning electron microscope (SEM) (FEI-QUANTA 400) and an ordinary binocular microscope and transmitted light microscopes.

Geological setting

According to Lawa et al. (2013); Fouad (2015); and Omar et al. (2015), the studied area is located within the imbricated zone (IZ) of the Western Zagros Fold Thrust Belt (WZFTB), which is characterized by a relatively complex structural setting and bounded from the north by the Zagros Main Thrust. The selected sections are from the Qaiwan, Welyan, and Kwra kazahaw anticlinorium (Fig.1). The exposed Cretaceous lithostratigraphic units in the Imbricated Zone represent 1. Balambo Formation (Hauterivian-Cenomanian), 2. Kometan Formation (Turonian-Campanian), 3. Shiranish Formation (Campanian-Maastrichtian), 4. Tanjero Formation (Maastrichtian), 5. Aqra Formation (Maastrichtian), and 6. Suwais Group (Paleogene) (Aziz et al., 2001; Stevanovic and Markovic, 2003; Abawi and Hammoudi, 2010; Jaff and Lawa, 2019; Görmüş et al., 2017; 2018; Lawa 2018). The Maastrichtian lithostratigraphic units under consideration represent the upper parts of the Tanjero Formation, the Aqra Formation, and the Tanjero/Aqra Interfingering, while the Paleogene studied unit represents only the lower parts of the Suwais Group (the so-called Red Bed Series).

Tanjero Formation: This unit belongs to the 9th Nineth Arabian Plate Tectonic Megasequence (TMSAP.9), which ranges in age from the Turonian to the Late Maastrichtian, whereas the Suwais Group belongs to the 10th tenth Arabian Plate Tectonic Megasequence (TMSAP.10) (Lawa, 2004; Ameen and Gharib, 2014; Lawa, 2018; Abdallah and Al-Dulaimy, 2019).

Fig. 2. a. Rhythmic alternation of thin sandstone beds and marl within the turbidites facies in the lower part of the Tanjero Formation; b. large Planolites ichnofossils at the top of sandstone beds, Maukaba section, NE-Qaiwan Anticlinorium, about 25km north of Sulaimani city.

This unit is recognized in the studied area, underlain by the Shiranish Formation and overlain by the Suwais Group, which is exposed on both limbs of the Azmer, Qaiwan, and Welyan anticlines. Lawa et al. (2001), in Stevanovic and Marcovic (2003), and Aziz et al. (2001) recorded the Aqra Formation on the upper succession of the Tanjero Formation. They recognized it as a lenticular body (40–200 m thick) that extends as a prominent ridge for about 18 km. The Tanjero Formation is known as turbidite-dominated facies (Al-Rawi, 1981; Al-Rawi and Al-Rawi, 2002). The siliciclastic beds are represented by sandstone, siltstone, and marl, manifesting proximal turbidites (Fig.2).

Aqra Formation: This unit is recognized in the studied area, forming prominent ridges and gorges along the NW anticlinal limb, and consists of a 50–150-meter-thick sequence of alternation of the thickly bedded fossiliferous limestone and occasionally alternated with sandstone, marl, shale, and marly shale interlayers. The limestone beds are rich in rudist reefal fauna, especially rudists (Figs. 3. a, b). It becomes thicker and more massive towards the top. This carbonate shows remarkable increases in thickness and repetition towards the top of the mixed carbonates and siliciclastic successions (Lawa et al., 2017; Lawa, 2018).

Interfingering of the Aqra and Tanjero formations: This part of the studied section is comprised of the interfingering of the bioclastic, fossiliferous limestone, which is characterized by the progressive decrease of the limestone bed both in thickness and in composition from several meters to a few centimeters and from in situ fossils to reworked fossils, with a diagnostic wave and current action. The carbonates may show cross-lamination, as in the Maukaba section (Fig. 4). The sandstone beds offer increasing grain size, almost friable, of calcareous cement and change laterally to pebbly sandstone of lensoidal shapes in the middle and uppermost parts of this succession. The whole fauna and flora are extinct before the boundary with the overlying unit. It’s important to mention that a few pinkish-red to reddish-brown silicate beds are recognized in the upper part of this unit.

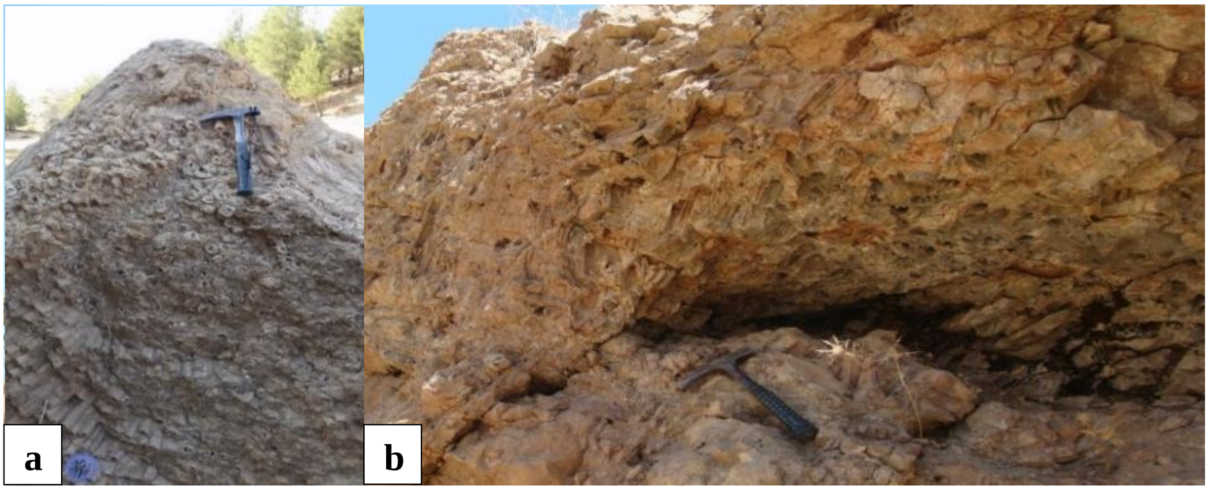

Fig. 3. About 5-meter-thick Rudist beds form patchy reefs with the Aqra Formation, a. from Suraqalat section, and b. from Bazaraw village between the Maukaba and Suraqalat sections.

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Fig. 4. Bioclastic carbonates show cross-lamination and interfingering with marl and sandstone in the interfingering of the Aqra and Tanjero formations, Upper part of the Maukaba section.

Sarsuly Conglomerate Unit: This is a new Paleogene mappable unit (Lawa and Qadir, 2023, in press) which differs from a lithological point of view and in stratigraphic positions from both the underlying Maastrichtian and the overlying Paleogene units (Fig.5). This unit is about 5 meters thick in Kani Sard (Kato section) that changes to about 30 meters in Zarda Bee and extends from Dolbeshky Drey, where it shows a sudden increase in thickness towards 250 meters in Nalashken, then to 500 meters in the Sarsuly section, towards the south of Mawat Town. It's underlain unconformably by the Aqra-Tanjero Interfingering Unit and overlain by the Unit-1 Suwias Group. Most of the conglomerate grains are subangular to subrounded in shape and come from multiple origins (igneous, metamorphic, and sedimentary) rocks and show significant differences in cross-bedding patterns, and can be subdivided into two subunits, namely, Lower Sarsuly unit and Upper Sarsuly unit.

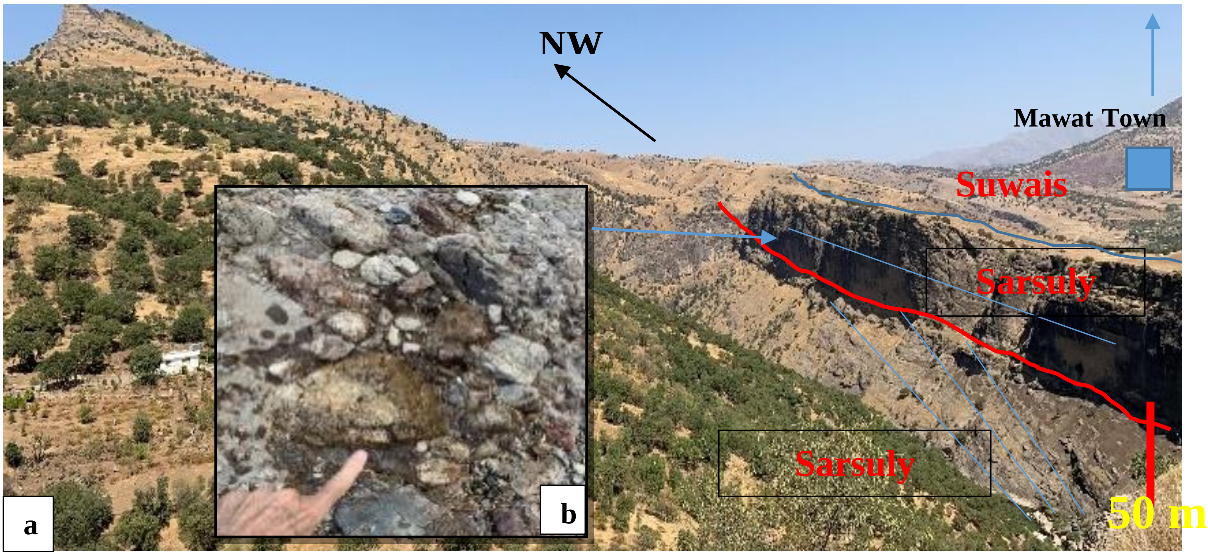

Fig.5. Sarsuly conglomerate unit, a. Composed of massive polymictic conglomerate, Side (Strike) view of Sarsuly conglomerate about 500m thick, b. Poorly sorted, immature conglomerate of the upper part represents massive incised valley deposits at K/Pg boundary.

Suwais Group: The Suwais Group is well exposed along the suture zone in the NW Zagros Fold–Thrust Belt hinterland and overthrust by the Main Zagros fault (Fig.6). The Suwais deposits consist of several NW–SE-oriented discrete outcrops of alternating mudstones. The Suwais Group is considered a nonmarine fluvial deposit (Hassan, 2012; Al-

Sultan and Gayara, 2016). Koshnaw et al. (2019) inferred a maximum depositional age based on the detrital zircon ages as old as the Late Oligocene (26 Ma).

Fig. 6. Shows alternations of the red claystone, green mudstone, sandstone, and lensoidal conglomerates of the Suwais Group from Kani Bewka village, about 2km NW of the Sarsuly section. (Iraq-Iran border).

Results

The Late Maastrichtian age for the upper part of the Tanjero Formation was emphasized by several authors (Lawa et al., 1998 (2017); Sharbazheri, 2007; Abdallah and Al-Dulaimi, 2019; Al -Mutwali and AL-Doori, 2012; Al-Mutwali and Ibrahim, 2019; Al-Nuaimy et al., 2020). Depending on the foraminifera's investigation, three biozones have been recognized; based on the predominated Large Benthic Foraminifera and the fourth zone represented by the planktic foraminifera. About 55 foraminiferal species have been identified in the studied samples. The planktic foraminifera is mostly absent in the studied successions except for some intervals in Kato and Maukaba sections. All the nominated Large benthic foraminifera (LBF) of the Late Maastrichtian age are worth mentioning. The Low Occurrence and High Occurrence of the index foraminifera and their correlation with local and regional recorded biozone is calibrated too. The Late Maastrichtian age is also emphasized by the occurrence of the Late Maastrichtian age Ammonite too. However, the recorded foraminifera biozones in the studied sections are as follows: -

1. *Loftusia minor- Loftusia coxi- Orbitoides media- Lepidorbitoides socialis* **Assemblage Zone.** The *Pseudoguembelina hariaensis* **Partial Range Zone** (CF3) is recorded in the Kato and Maukaba sections.
2. *Loftusia morgani- Siderolites calcitrapoides- Orbitoides apiculatus* **Assemblage Zone.**
3. *Loftusia persica- Loftusia elongata* **Assemblage Zone.** *All the recorded large benthic foraminifera associations indicate the Maastrichtian age and are summarized below: -*

1. *Loftusia minor*, *Loftusia coxi*, *Orbitoides media*, and *Lepidorbitoides socialis* **Assemblage Zone.**

Definitions: This zone is identified based on the low occurrences to high occurrences of the nominated species of this assemblage, represented by *Loftusia minor* (Coxi), *Loftusia coxi* (Henson), *Orbitoides media* (d' Archiac), and *Lepidorbitoides socialis* (Leyrnerie). (Plate 1).

Boundaries: The upper boundary is represented by the high occurrence (HO) of *Loftusia minor* (Coxi), *Loftusia coxi* (Henson), *Orbitoides media* (d'Archiac), and *Lepidorbitoides socialis* (Leyrnerie), and occasionally overlain by the partial range zone of the PF Zone (CF3), as in the Kato section (Fig.10).

Thickness: about 70 meters in the Maukaba section (Fig.9); 25 meters in the Kato section (Fig.10); 50 meters in the Sarsuly section (Fig.7); and 5 meters in the Nalashken section (Fig.8)

Diagnostic characters: *This zone also combined by the predominance of Omphalocyclus macroporus (*Lamarck); *Orbitoides tissoti* (Schlumberger), and *Pseudorbitoides* sp., with small benthic foraminifera; *Fissoelphidium operculiferum* (Smout), *Bolivina incrassata* (Reuss), *Nonionella* sp., *Textularia* sp., *Bolivinoides* sp., and *Gyrodina* sp.

Discussions: This zone shows low occurrence in the strata below the studied sections (Lawa et al., 2017, Görmüş et al., 2017, 2018); therefore, these assemblages manifest the partial taxonomic range zone of the nominated species. The associations of several large benthic foraminifera species like Loftusia minor (Coxi), Loftusia coxi (Henson), Omphalocyclus macroporus (Lamarck); Orbitoides sp.; Sulcoperculina globosa (de Cizancourt); Lepidorbitoides rutteni sp., and Pseudorbitoides sp. and a few planktic foraminifera like Globotruncana stuarti (de Lapparent) might have emphasized the Late Maastrichtian age. This zone shows enrichments of the labyrinthic walled of foraminifera in addition to the hyaline one, where the Loftusia species show higher diversity and more abundance and are represented by several species like Loftusia harrisoni, Loftusia morgani and Loftusia baykali (Görmüş et al., 2018). They are recorded from the Maastrichtian age strata of the Aqra Formation in the Dhouk area by Al-Omari and Sadek, (1976); Lawa (1983); and Al-Omari et al. (1989). In the studied area (Görmüş et al. (2017, 2018) mentioned that the population abundances of L. minor A and L. ketini, Omphalocyclus macroporus, and Orbitoides apiculatus indicate the middle–late Maastrichtian carbonate platforms of northern Iraq. Görmüş et al. (2019) recorded those species from the Late Maastrichtian Maukaba and Suraqalat sections. This assemblage was also recorded from Iran in the Tarbur Formation, indicating the Late Maastrichtian age (Pirbaluti et al., 2013; Afghah and Yaghmour, 2014; Ezampanah et al., 2018). A similar assemblage from the Upper Cretaceous of Turkey is described by Lorenzo Consorti and Köroğlu (2019). They are also recorded from the Late Maastrichtian age in Greece (Boeotia) and Spain by (Zambetakis- Lekkas and Kemeridou., 2006; Caus et al., 2016). The Maastrichtian successions (from S France and NE Spain) it's also recorded by Robles-Salcedo et al. (2018).

Age: early Late Maastrichtian

2. *Loftusia morgani- Siderolites calcitrapoides- Orbitoides apiculatus* **Assemblage zone**

Definitions: This zone is identified based on the low occurrence (LO) to the high event (HO) of the nominated species of this assemblage, represented by *Loftusia morgani* (Douville), *Siderolites calcitrapoides* (Lamarck), *Orbitoides apiculatus* (Schlumberger), with remarkable *Suraqalatia brasieri* (Görmüş et al., 2017) (Plate. 2)

Boundaries: Low to High occurrence of the nominated species. The disappearance of the designated species characterizes the upper boundary.

Thickness: about 60 meters in the Kato section (Fig.10), 15 meters in the Maukaba section (Fig.9), and 5 meters in the Nalashken section (Fig.8); it’s not recorded in Sarsuly section.

Diagnostic characters: The coexistence of the three nominated species of this zone, also combined by the continuation of appearance and abundance of *Omphalocyclus macroporus* (Lamarck), *Lepidorbitoides sp., Orbitoides tissoti* (Schlumberger), indicates that this assemblage is typical in the reef, which habitates macrofauna too, within the massive carbonates without any indications of the planktic foraminifera.

Discussions: The occurrences of *Loftusia morgani* in Upper Maastrichtian deposits of Iran, Iraq, and Turkey (Cox, 1937; Al-Omari and Sadek, 1976; Görmüş, 1992; Al-Dulaimi and Al-Obaidy, 2017; Görmüş et al., 2018, 2019; Abdallah and Al-Dulaimi, 2019) support this interpretation. The range of this zone is based on the low-to-high occurrence of several large benthic foraminifera species like *L. morgani*, *Siderolites calcitrapoides*, and *Suraqalatia brasieri* (Görmüş et al., 2017, 2018). *Loftusia elongata* (Cox); *Loftusia harrisoni* (Cox); *Loftusia morgani* (Douville); *Loftusia baykali* (Meriç) and *Loftusia minor* (Cox); *Lepidorbitoides socialis* (Leymerie); *Orbitoides tissoti* (Schlumberger) and *Orbitoides gensacicus* (Leymerie), *Pseudorbitolina* sp. Abdelghany (2003) has reported this zone (*Orbitoides apiculatus - Siderolites calcitrapoides* zone) from the Simsima Formation in the western part of the Northern Oman Mountains. Mohammed et al. (2021) recorded this assemblage from the Maastrichtian age of the UAE. The associations of the following species are recorded as indicators for the late Maastrichtian by Schlüter et al. (2008); *Omphalocyclus macroporus* (Lamarck), *Orbitoides apiculatus* (Schlumberger), *Orbitoides medius* (d' Archiac), *Siderolites calcitrapoides* (Lamarck), *Sulcoperculina* sp., *Lepidorbitoides* sp., *Cuneolina* sp.

Age: middle-Late Maastrichtian.

3. *Loftusia persica- Loftusia elongata* Assemblage Zone

Definitions: This zone is identified based on the low to high occurrence of the nominated species *Loftusia persica* (Brady), *Loftusia elongata* (Cox). (Plate 2)

Boundaries: Lowest to the highest occurrence of *Loftusia persica* (Brady), *Loftusia elongata* (Cox). It's also associated with the progressive disappearance of all other large benthic foraminiferal species of the *Orbitoides*, *Lepidorbitoides*, *Omphalocyclus*, *Suraqalatia brasieri*.

Thickness: about 50 meters in the Maukaba section (Fig.9) and 45 meters in the Kato section (Fig.10); it's not recorded in the Sarsuly and Nalashken sections.

Diagnostic characters: This zone is also characterized by the appearance of *Suraqalatia brasieri* (Görmüş) only in the Maukaba section (Fig.9).

Discussions: Al-Omari and Al-Sadiq (1976), Lawa (1983), and Al-Omari et al. (1989) recorded the *Loftusia elongate-Loftusia persica* zone as an index for the Late Maastrichtian. The external parameters of the *Loftusia* in the studied sections show a gradual increase in the size and length of the *Loftusia* from 1.5–2 mm for *Loftusia minor* and reaches up to 118 mm for *Loftusia elongata* manifesting the evolutionary trend of this genus during the Maastrichtian. The extinction of all Maastrichtian fauna and flora combines at the top of this zone. All the *Orbitoides* and *Loftusia* species show mass extinction at the level before the mass extinctions of *Omphalocyclus* species, which occurred about 5 meters below the K/Pg boundary.

Age: late Late Maastrichtian.

- *Pseudoguembelina hariaensis* **Partial Range Zone (CF3), (Plate. 3)**

Definitions: This zone was initially defined by Li and Killer (1998a). It is represented by the first occurrence of the *Pseudoguembelina hariaensis* (Nederbragt) and the last occurrence of *Gansserina gansseri* (Bolli).

Boundaries: The lower boundary is marked by the first appearance of *Pseudoguembelina hariaensis* (Nederbragt), whereas its upper boundary is characterized by the last appearance of *Gansserina gansseri* (Bolli). This zone, recorded sporadically, shows interfingering with the above zone in the Kato and Maukaba sections.

Thickness: about 3 meters in the Kato section from the marl layers between the limestone beds of interfingering Tanjero- Aqra formations (Fig.10) and 5 meters in the Maukaba section (Fig.9). it's not recorded in the Nalashken and Sarsuly sections.

Diagnostic characters: This zone alternates with large benthic foraminifera zone (*Loftusia minor- Loftusia coxi- Lepidorbitoides socialis- Siderolite calcitrapoides* Assemblage Zone) in the Kato section and partially in Maukaba section (Figs.9,10).

Discussions: The most common species are related to Globotruncanids and Heterohelicids, which indicate typical Tethyan fauna types. They are represent by *Globotruncana stuarti* (de Lapparent), *Heterohelix globulosa* (Ehrenberg), *Heterohelix striata* (Ehrenberg), *Heterohelix punctulata* (Cushman); *Rugoglobigerina rugosa* (Plummer), *Racemiguembelina fructicosa* (Egger), *Globotruncana stuartiformis* (Dalbiez) and *Heterohelix* spp. They are also combined by benthic foraminifera like *Cibicides* sp., *Gyrodina* sp., *Gyrodinoides* sp., *Textularia* sp., *Buliminia* sp., *Bolivina* sp., and *Bolivinoides* sp.

Correlation: Sharbazheri (2007); Sharbazheri et al. (2009, 2011); Al-Mutwali and Al-Doori (2012), Salih et al. (2013), Al-Mutwali and Ibrahim (2019), Al Nuaimy et al. (2020), Mousa et al. (2020) recorded this zone from different localities in Kurdistan region and Iraq (Fig.13), including the studied area, which assigned it to the early to middle-Late Maastrichtian. The present zone is equivalent to the *Pseudoguembelina hariaensis* Zone, described by Li and Keller, 1998a, b; Abramovich and Keller, 2003, in DSDP Site 525A. Keller et al. (1995) from Tunisia. Keller (2004) from Eastern Tethys. El-Sabbagh et al., 2004; Obaidalla, 2005; Arenillas et al., 2006; Darvishzad et al., 2007; Keller et al., 2009, considered it to be of middle-Late Maastrichtian age. This zone is also equivalent to the Ammonites zone recorded in this study (*Hoploscaphites constrictus crassus*) Partial Range Biozone (Fig.13, 14).

Age: middle Late Maastrichtian

- **Maastrichtian Calcareous Nanno Fossil Biozone:** *Micula murus-Micula prinsii* **(CC26) Assemblage biozone. (Plate 4 and 5)**

Definitions: This zone is based on the presence of High occurrences of *Micula murus* (Martini) and *Micula prinsii* (Perch-Nielsen) as first recorded in the Imbricated Zone.

Boundaries: The lower boundary of this zone is marked by the first occurrence of *Micula murus* within the lower and middle parts of the studied sections.

Biozone thickness: about 50 meters in the Kato section (Fig.11), 15 meters in the Nalashken section (Fig.8), and partially recorded in the Maukaba section; it's reworked or not recorded in the Sarsuly section.

Discussions: *Micula murus*, *Micula prinsii*, *Biantholithus sparsus*, *Lithraphidites carniolensis*, and *Watznaueria barnesae*, all recorded from the Maastrichtian strata, and point to Late Maastrichtian, but don't extend to the Latest Maastrichtian, especially in the Sarsuly and Nalashken sections. The diversity and absolute abundances of calcareous Nannofossils show a significant decrease at the K/Pg boundary in the studied area. The simultaneous presence of all mentioned species highlights an essential gap across the K/Pg boundary of the Tanjero Formation in the Nalashken and Sarsuly sections. This zone correlates with the planktic zone (CF3) and Ammonite zone. The FO of *Micula prinsii* is at Maukaba and Kato sections; Kani sard marks the base of UC20dTP (as CC26). Kharajiani (2019) recorded this zone from the upper part of the Tanjero Formation in the Dokan area. From Iran recorded by Mahanipour et al. (2022); also, by Howe et al. (2003) from Australia, and by Thibault (2016) from Tunisia.

Age: early to middle-Late Maastrichtian (the equivalent of subzones UC20c, d).

Important Note: For all biostratigraphic charts, those symbols are used: 1= Loftusia minor, Loftusia coxi, Orbitoides media, Lepidorbitoides socialis Assemblage Zone. 2= Loftusia morgani, Siderolite calcitrapoides, Orbitoides apiculatus Assemblage Zone. 3= Loftusia persica, Loftusia elongata Assemblage Zone. CF3= Pseudoguembelina hariaensis Partial Range Zone. CF7= Gansserina gansseri Interval zone. CF8= Globotruncana aegyptiaca Interval Zone. (CF7 and CF8 are based on previous studies). Thickness not to scale.

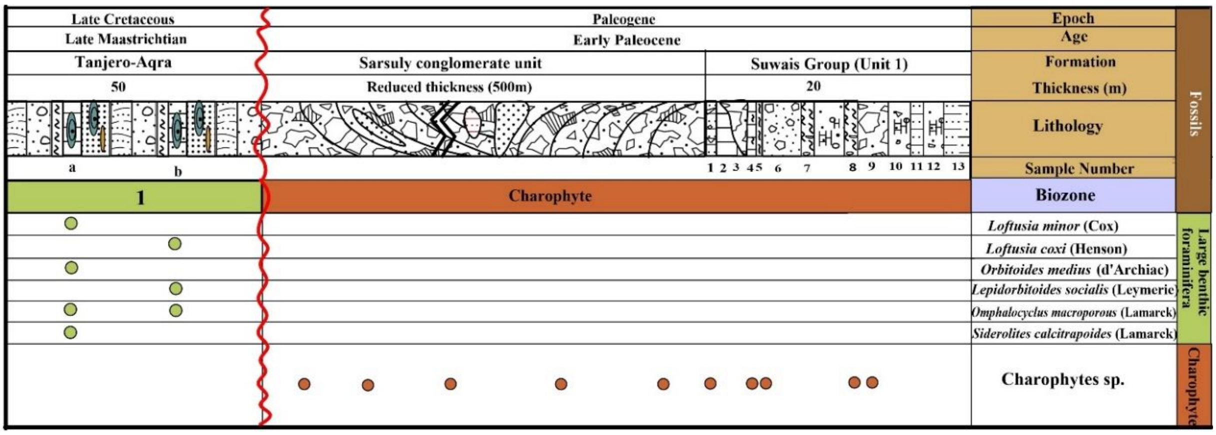

Fig. 7. Biostratigraphic chart at the K/Pg boundary in the Sarsuly section (Mawat. KFB.).

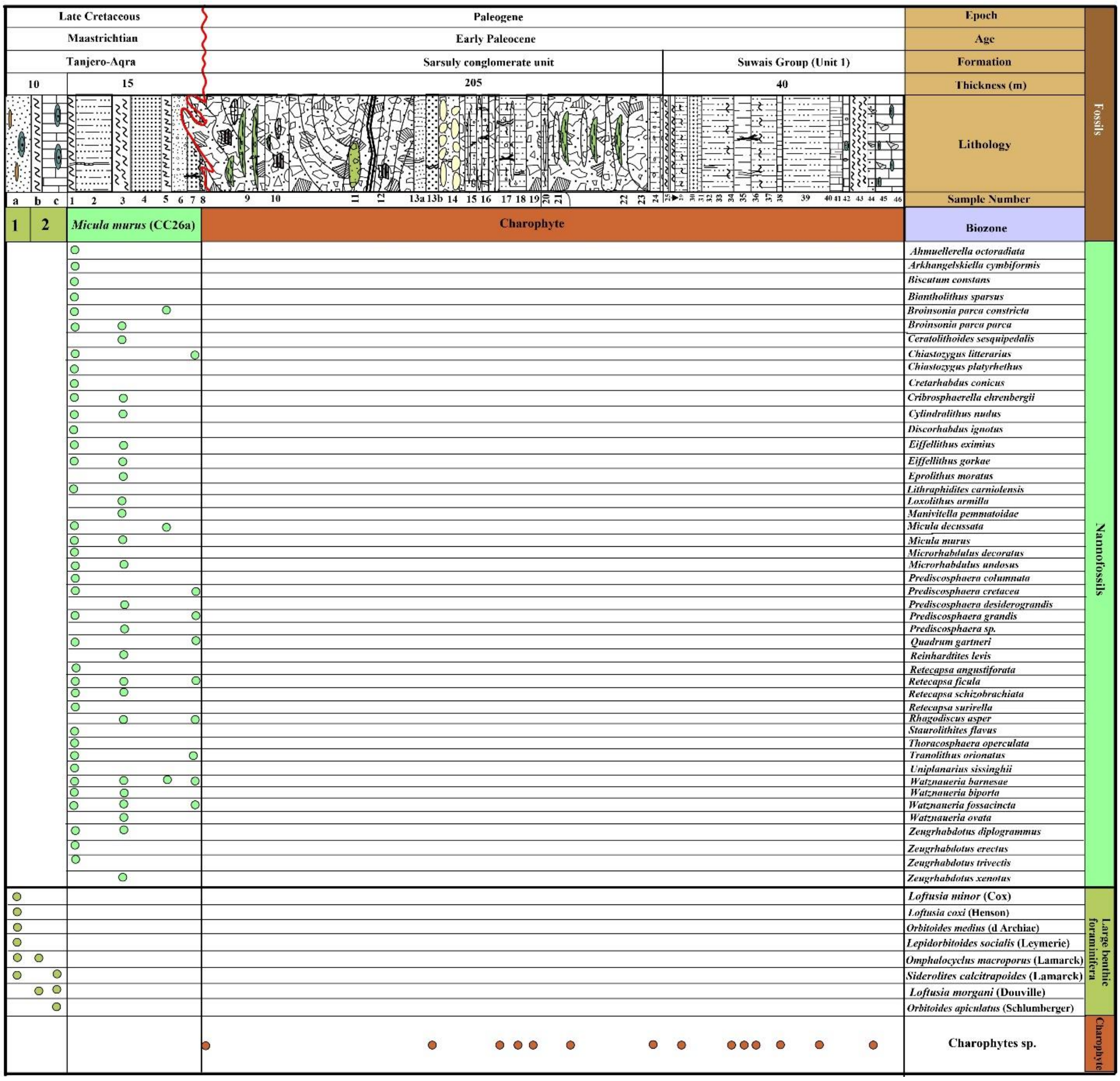

Fig. 8. Biostratigraphic range chart (showing the distribution of index fossils and estimated biozone) at the K/Pg boundary in the Nalashken section.

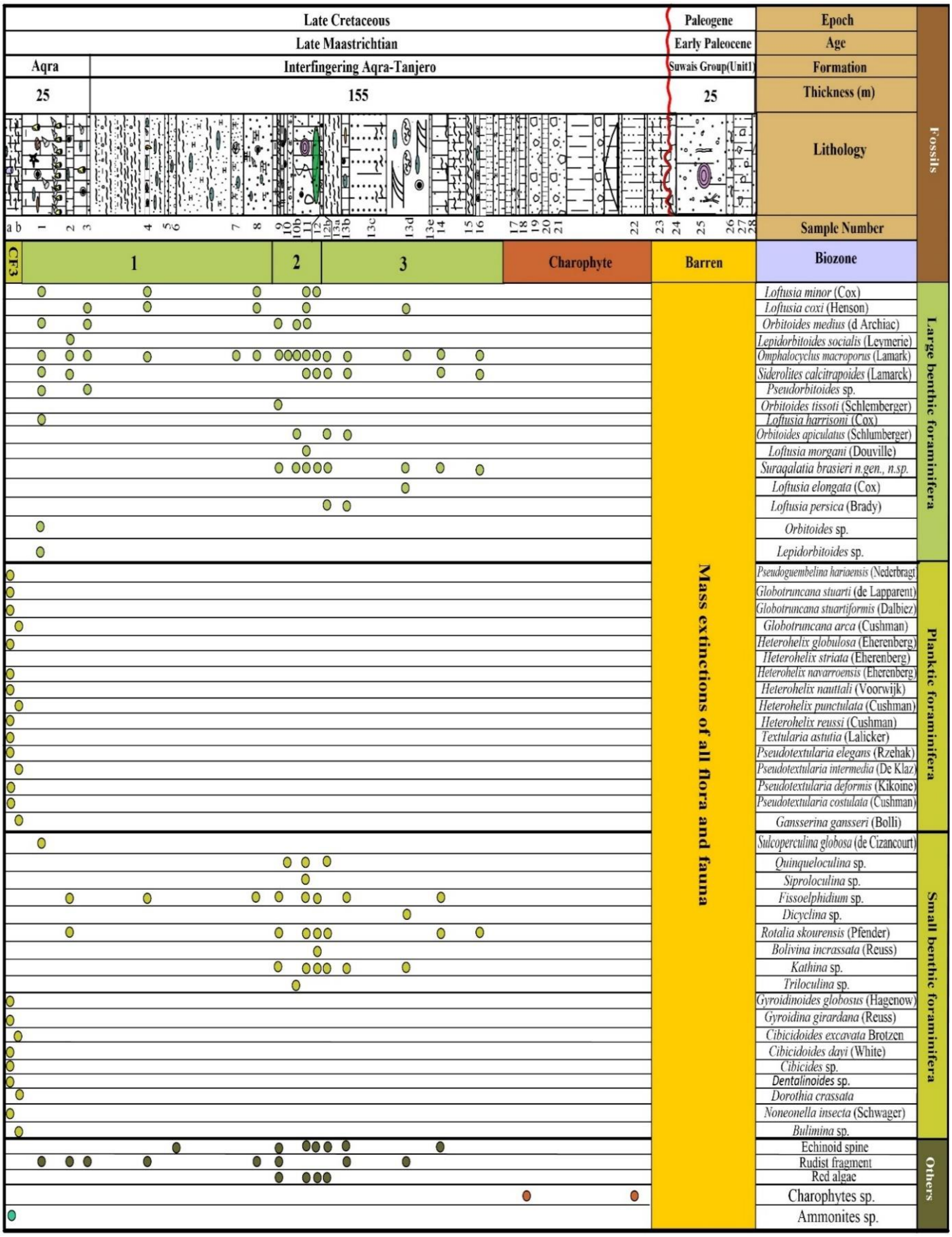

Fig. 9. Biostratigraphic range chart (showing the distribution of index fossils and estimated biozone) at the K/Pg boundary in the Maukaba section.

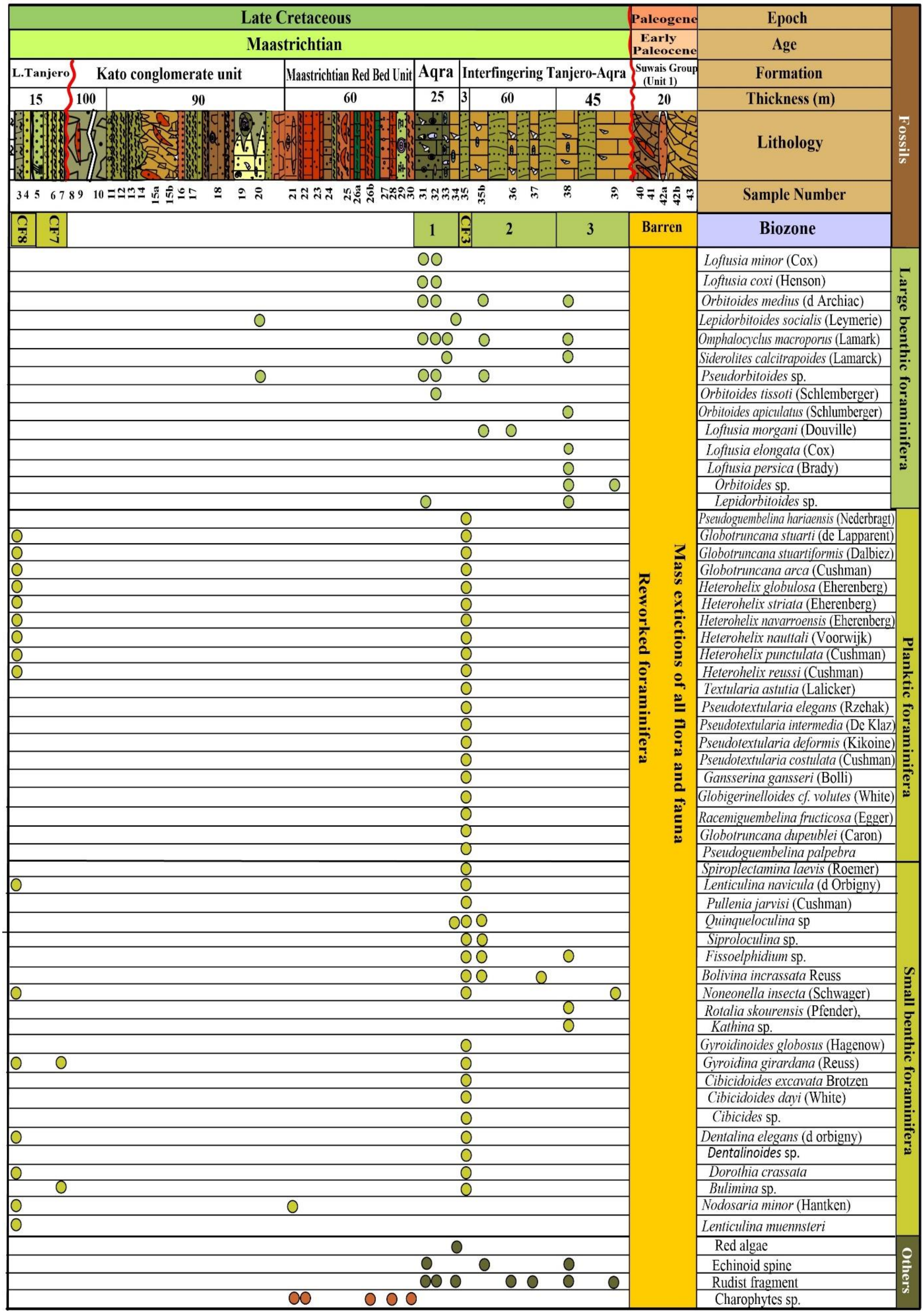

Fig. 10. Biostratigraphic range chart (showing the distribution of index fossils and estimated biozone) at the K/Pg boundary in the Kato section.

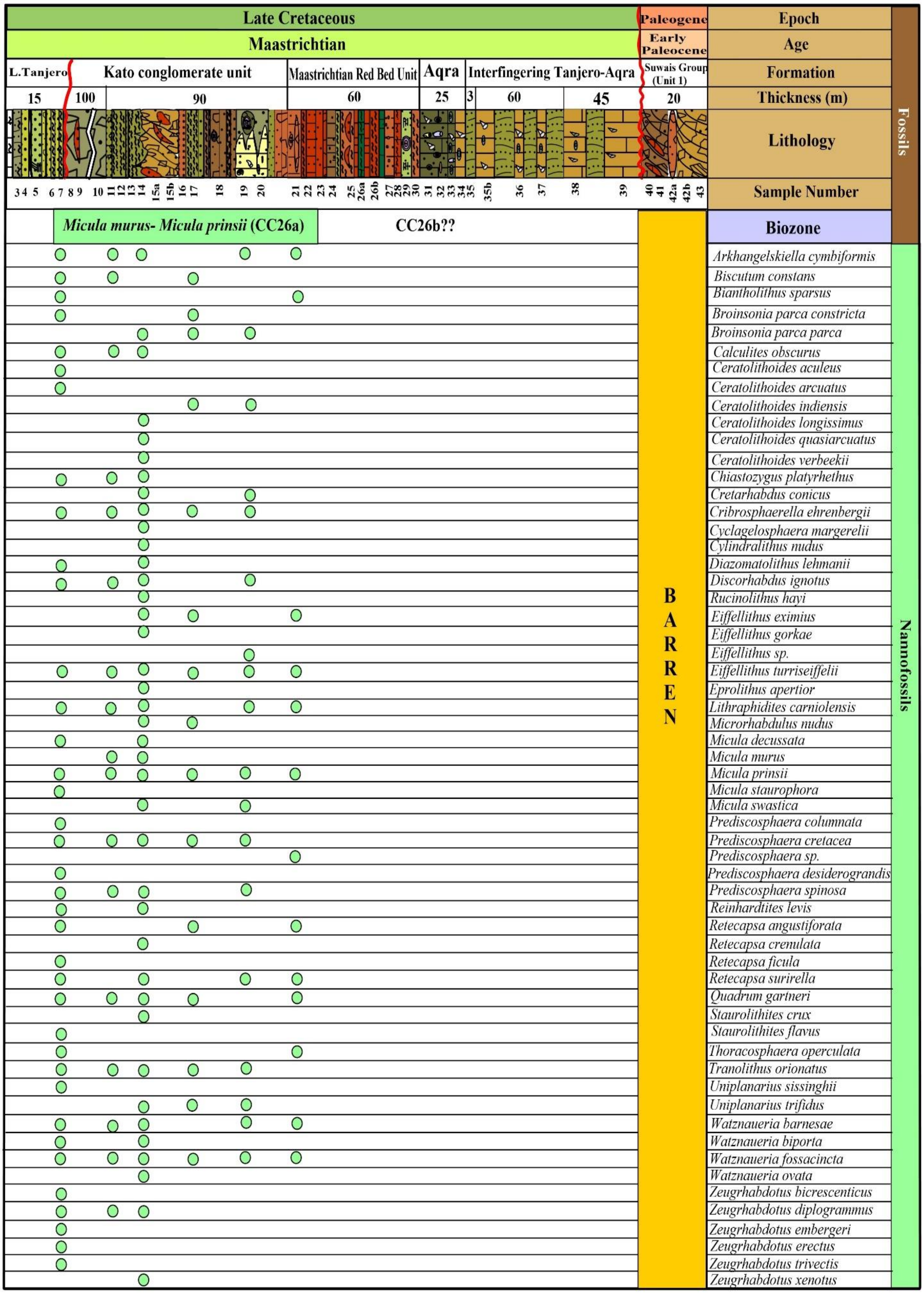

Fig. 11. Biostratigraphic range chart (showing the distribution of index fossils and estimated biozone) for the calcareous-Nanno fossils at the K/Pg boundary in the Kato section.

- **Ammonite Zone: *Hoploscaphites constrictus crassus* Partial Range Zone**

Definitions: This low to high occurrence of the nominated subspecies zone represent by *Hoploscaphites constrictus crassus* and *Hoploscaphites constrictus constrictus* of (Machalski, 2005, 2020; Machalski et al., 2016) (Fig. 12).

Important note: This zone was recorded from the lower part of the studied sections; Maukaba and subsidiary Zarda bee sections, within 4-meter marl associated by Echinoids. This zone is also correlatable with PLK Zone (CF3). This zone was widely distributed in the Late Maastrichtian epicontinental seas of the Boreal Realm across Europe, also common from the Upper Maastrichtian deposits of Poland and Denmark (Birkelund, 1979, 1993; Blaszkiewicz, 1980; Machalski, 1996, 2020). Machalski (2005) concluded that the successive members of the *Hoploscaphites constrictus* lineage, i.e., *Hoploscaphites constrictus lvivensis* subsp. nov., *H. c. crassus,* and *H. c. johnjagti* subsp. Nov. is valid for the subdivision of upper Maastrichtian deposits.

Age: early Late Maastrichtian

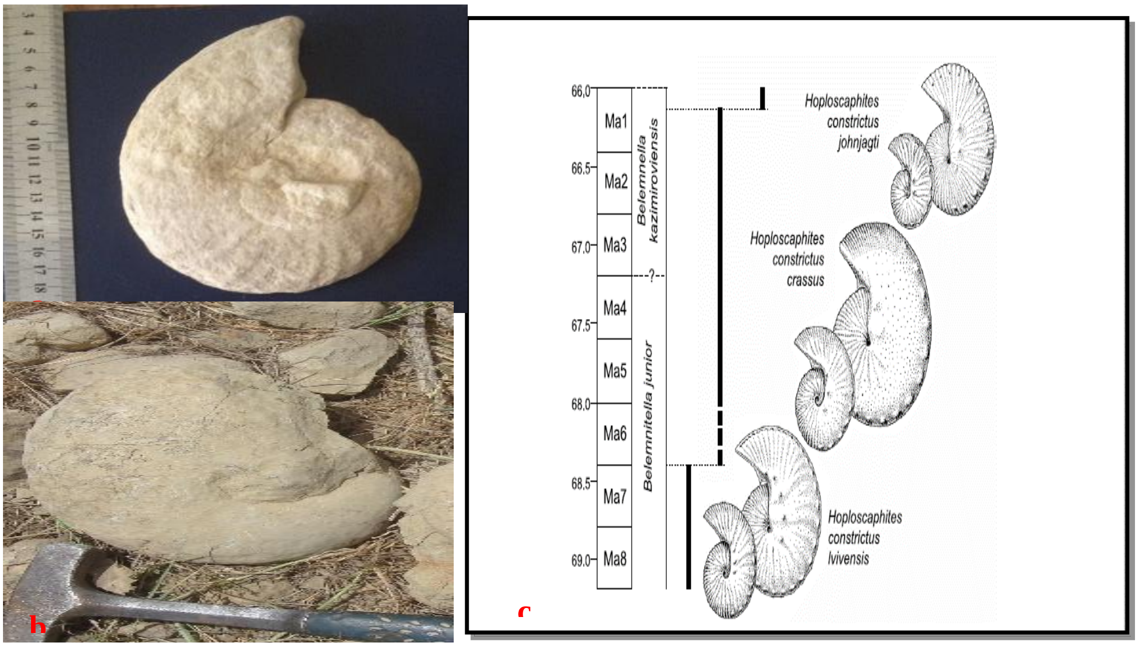

Fig. 12. a. *Hoploscaphites constrictus crassus*. b. *Hoploscaphites constrictus constrictus*. c. Evolutionary lineage and subspecies succession of the scaphitid ammonite *Hoploscaphites constrictus* in the upper Maastrichtian of central Europe (Machalski et al., 2022).

Discussions

The composite biostratigraphic tools (LBF, PLF, Calc-Nanno, Ammonite, Figs.13 and 14) improve the late Maastrichtian age for the studied upper part of the four sections. The remarkable disappearance of the LBF zones 2 and 3, calcareous nannofossils CC26 and Ammonites partial range zone towards the Sarsuly and Nalashken sections is controlled mainly by the interplay between the sediment supply, tectonic influence, and accommodation space. Another significant result is no indication for the early Paleocene foraminifera, calcareous nannofossils in the lower part of the Suwais Group and Sarsuly conglomerate., which expresses the variation from marine (Loftusia and Rudist house) to non-marine (Charophytes) condition at K/Pg boundary. The mass extinction of the Rudist, the most common recorded macrofossils in the studied sections are: *Hippurites cornucopiae, Dictyoptychus morgani* (Douvillé), *Praeradiolites subtoucasi* Toucas, *Sauvagesia somalica*

Tavani, *Lapeirousia jouanneti* (Des Moulins), *Praeradiolites cylindraceus* (Desmoulins), *Gryphaea vesicularis* (LAMARCK), *Exogyrea cancella*, *Turbo* spp., *Clathratus* sp., *Actenonella* spp., *Turritella* spp., *Merinea* spp., occurs before the K/Pg boundary by 0.5 – 1.0 my in two septs (Lawa, 1983, Al-Ameri and Lawa, 1986, Al-Dulaimy, 2013, Lawa et al., 2017). The destruction of the Maastrichtian patchy reefs and mass extinction combines the late Maastrichtian regressions. The main distinguishing characteristics of wedge-top deposits are the abundance of progressive unconformities and various types of growth structures. DeCelles and Giles (1996); DeCelles (2012) mentioned that the fluvial depositional systems, originating on the wedge top, may feed deltas or shallow shelves; these systems can develop on both the orogen and forebulge margin unconformities and progressive deformation. In this work, two progressive unconformities have been recorded; the first one is Tanjero Conglomerate (Kato) and the second is Sarsuly conglomerate. The Tanjero Conglomerate (Kato) and the red clastic within the upper part of the Tanjero Formation show enrichments of freshwater species of Charophytes (Fig.10). Sharbazheri (2007) estimated the duration of the gap of more than 1.23 million years and resembled the disappearance of the planktic foraminiferal biozones CF5 and CF6. The second gap represents by the Sarsuly conglomerates of the Paleocene age.

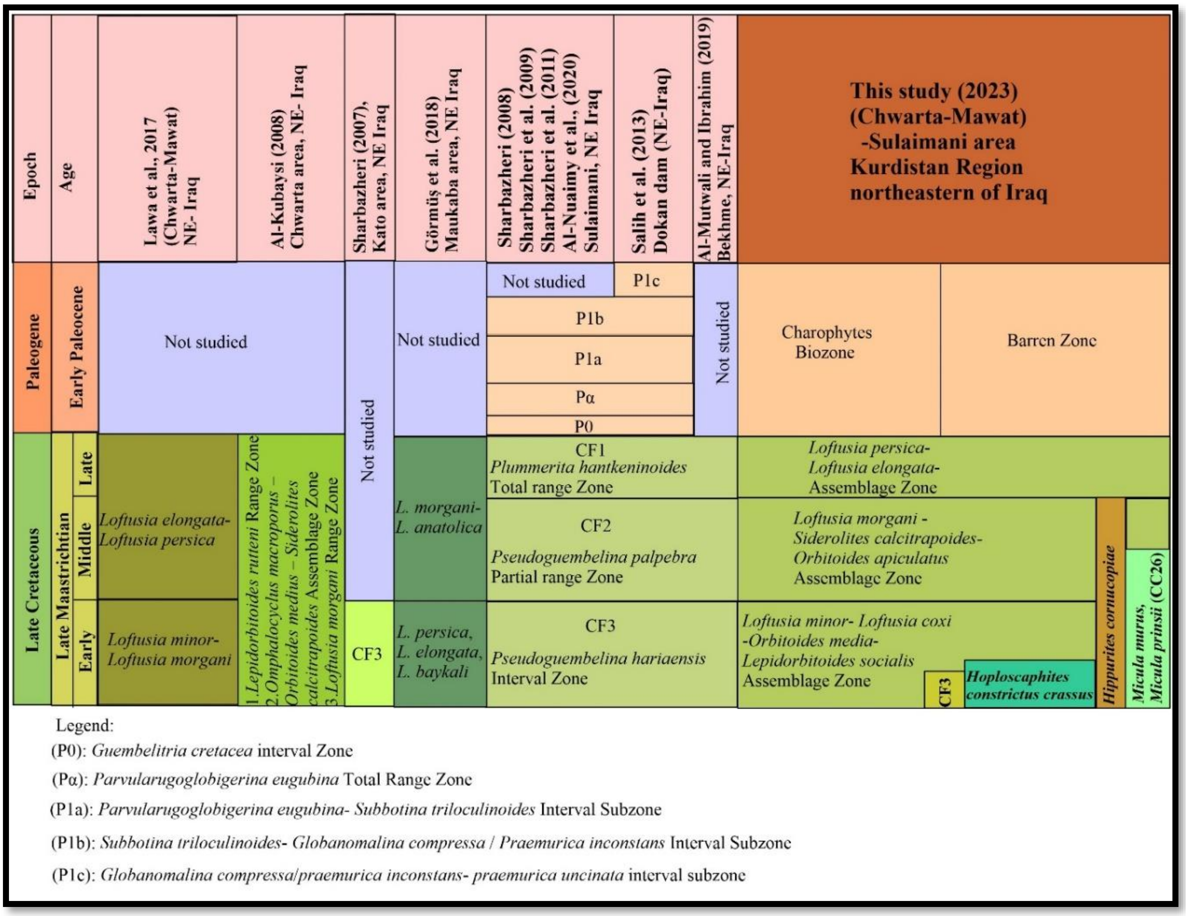

Fig. 13. Biozones: Correlation with other Studies in Kurdistan at the K/Pg Boundary in the wedge top of the Kurdistan Foreland Basin, Sulaimani area, Kurdistan region, Iraq.

An interesting association of the giant foraminifera (*Loftusia*, *Omphalocyclus*, *Suraqalatia*, *Lepidorbitoides*), Giant Mollusca (Rudist, Gastropods), giant Echinodermata, all point to the Late Maastrichtian Warming Event. Therefore, the K/Pg boundary is characterized by the disappearance of all Cretaceous and precisely the Maastrichtian fauna and flora (LBF, Calc -Nanno fossils, PLKF, BFF, all pelecypods, especially Rudist, Gastropods, and Cephalopods) in the overlying units of the Suwais Group. Therefore, the structurally induced unconformities are common and well developed in the studied sections during the late Maastrichtian. The wedge-top clastic deposits generally reflecting only limited transport and are characterized by immature textures controlled by different types of growth structures depending on the increasing proximity to the basin edges and according to the geometry of the thrust ramps upon which they develop (Beaumont, 1981) and that is the case of the Sarsuly conglomerates. Koshnaw et al. (2021) concluded an angular unconformity between the Red Beds Series (RBS) units and the late Cretaceous successions. Such a style is also recognized in the Amiran Foreland Basin in Iran's (Pirbaluti et al., 2013, Razmjooei et al., 2020) and from UAE by Mohammed et al. (2021). The progressive development of the reefal carbonates in the upper part of the Tanjero Formation to Rudist reefal Aqra Formation, and then to the interfingering of Aqra and Tanjero formations mainly reflects the interplay between sea level rise (Early Maastrichtian) and fall (Late Maastrichtian), siliciclastic and carbonates deposits, global Maastrichtian warming (during reefal carbonates), and cooling cyclicity (During the upper interfingering parts), syn -sedimentary tectonic disturbances (as turbidities and Mass Transported Deposits). The most recent study about the K/Pg boundary GSS by Jones et al. (2023) mentioned that our results provide evidence that sedimentation at El- Kef was not as continuous or free from structural complication as previously thought and recorded a gap at K/Pg boundary.

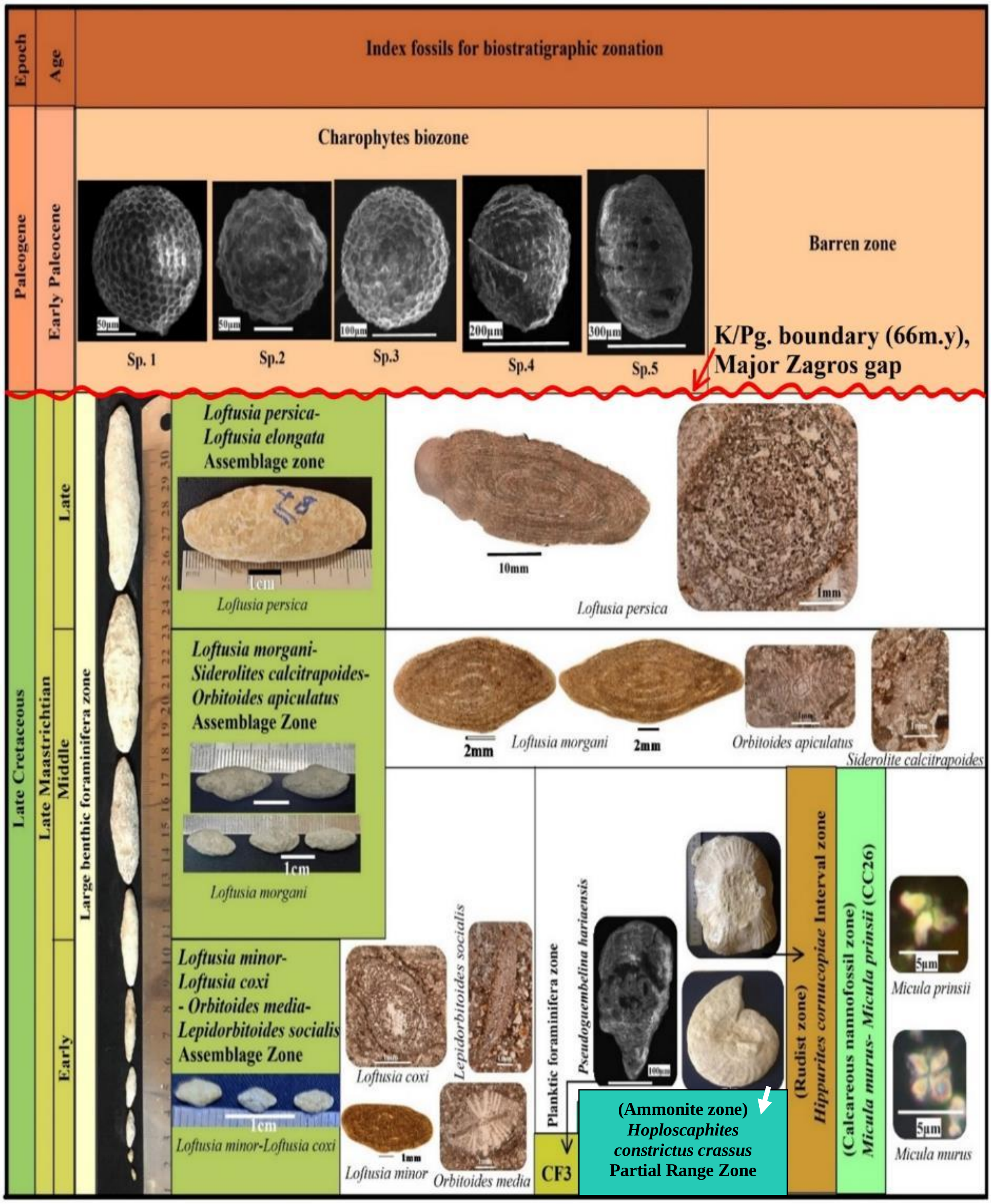

Fig. 14. Generalized recorded large benthic foraminiferal biozones, planktic foraminifera, calcareous nannofossils, and ammonites biozone in the studied sections.

Conclusion

The findings of the current study can be summarized as follows:

- The studied four sections (Sarsuly, Nalashken, Maukaba, and Kato) within the Imbricated Zone (Kurdistan region/N. Iraq) represent wedge-top deposits within the Kurdistan Mesopotamian Foreland Basin.
- The late Maastrichtian age of the studied sections is proved by integrated biostratigraphic biozonations, like Large Benthic and Planktic Foraminifera and Calcareous Nanno Fossil, Ammonites Biozonations, as Follow:

The large benthic foraminifera biozones recorded are *Loftusia minor*, *Loftusia coxi*, *Orbitoides media*, *Lepidorbitoides socialis* Assemblage Zone, which indicates Early Late Maastrichtian age. *Loftusia morgani*, *Siderolites calcitrapoides*, and *Orbitoides apiculatus* Assemblage Zone, which indicates Middle Late Maastrichtian age. *Loftusia persica*, *Loftusia elongata* Assemblage Zone, which shows Late Late Maastrichtian age

- The only recorded planktic foraminiferal zone is: *Pseudoguembelina hariaensis* Partial Range Zone (CF3) is recorded in the Kato and Maukaba sections and indicates middle Late Maastrichtian age.
- The recorded calcareous Nannofossil is related to *Micula murus* and *Micula prinsii* Assemblage zone (CC26a), which indicates a Late Maastrichtian age, mostly without CC26b biozone.
- The recorded ammonites biozone is *Hoploscaphites constrictus crassus* Partial Range Zone, which indicates Early Late Maastrichtian age.

Conflicts of Interest: The author declare that he has no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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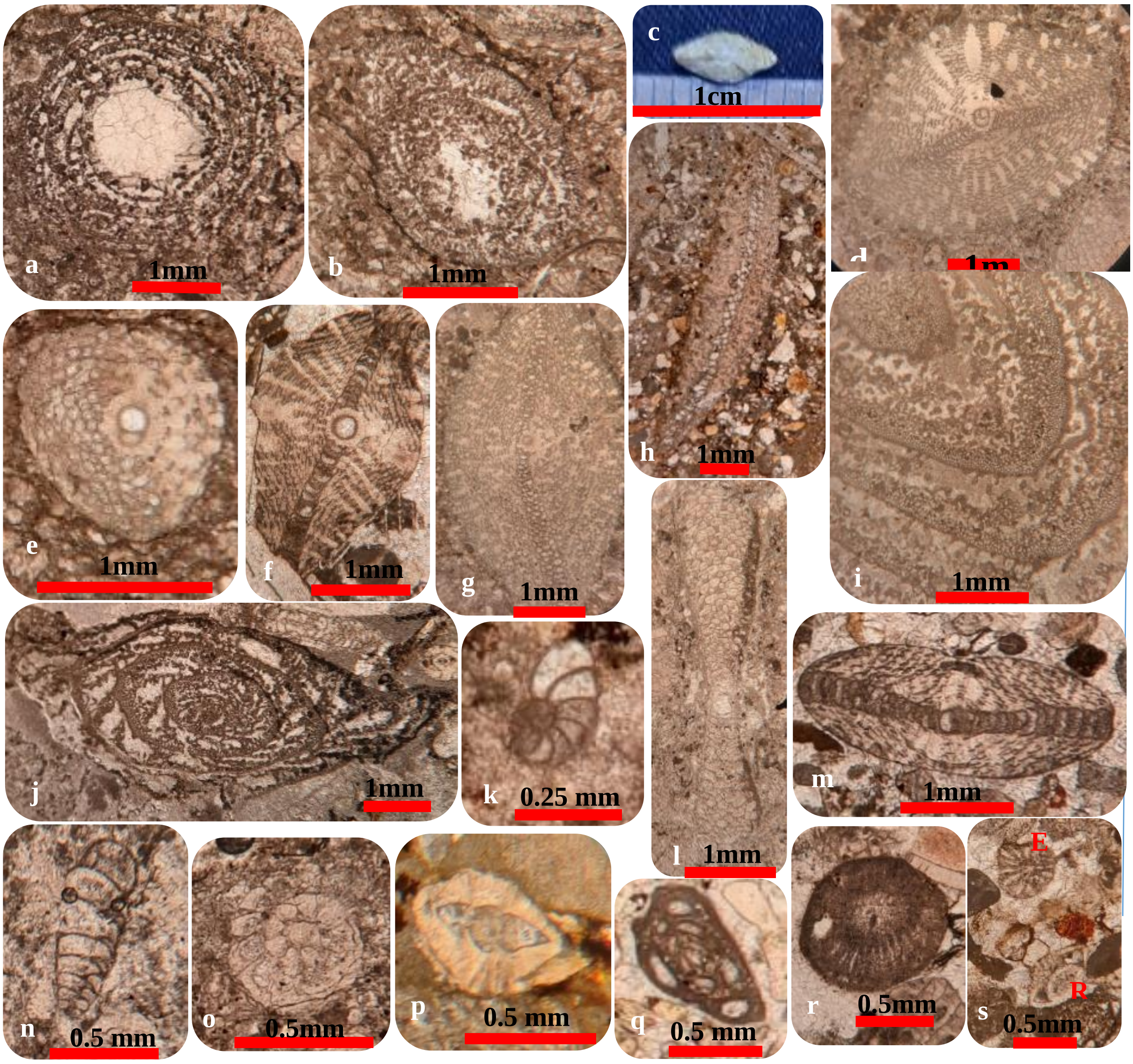
Plate 1: *Loftusia minor*, *Loftusia coxi*, *Orbitoides media*, *Lepidorbitoides socialis* Assemblage Zone

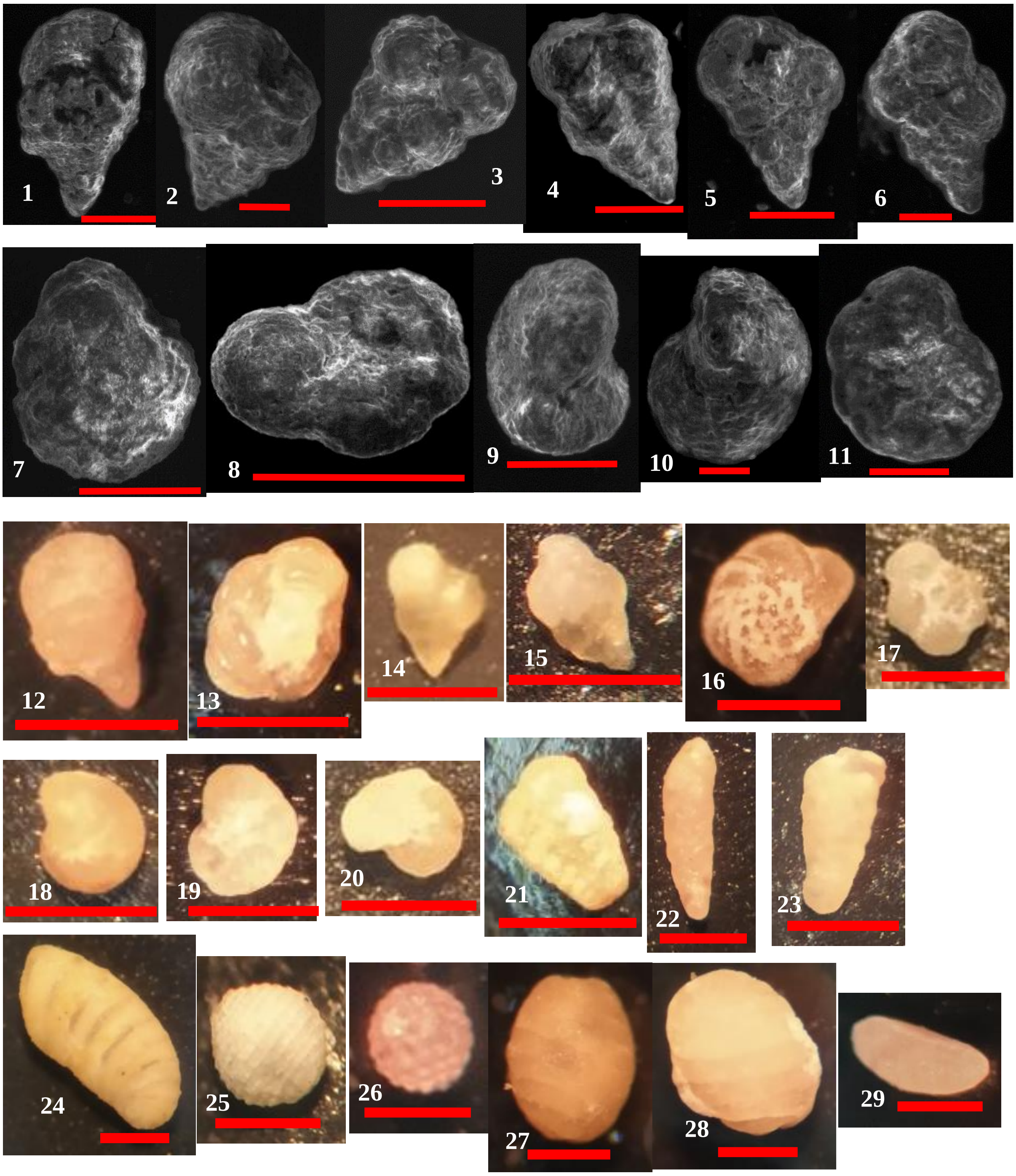


Pl.1, Fig. a. *Loftusia minor* (Cox), Aqra Fn., Maukaba section, sample M.4. **b.** *Loftusia coxi* (Henson), Aqra Formation, Maukaba section, sample M.3. **c**. Isolated *Loftusia minor* (Cox), Interfingering of Tanjero-Aqra fns., Sarsuly section, sample a. **d, e.** *Orbitoides medius* (d'Archiac), Aqra Fn., Maukaba section, samples (M.1, M.3). **f.** *Orbitoides medius* (d'Archiac), Aqra Fn.**,** Kato section, sample K.32. **g.** *Pseudorbitoides* sp., Aqra Fn., Maukaba section, sample M.1. **h.** *Lepidorbitoides socialis* (Leymerie), Aqra Fn., Kato section, sample K.34. **i.** *Loftusia harrisoni*, Aqra Fn., Maukaba section, sample M.1. **j.** *Loftusia baykali* (Meriç), Interfingering Tanjero-Aqra fns., Maukaba section, sample M.13d. **k.** *Nonionella insecta* (Schwager), Interfingering Tanjero-Aqra fns., Kato section, sample K.39. **l.** *Omphalocyclus macroporous* (Lamarck), Aqra Fn. Maukaba section, sample M.2. **m.** *Orbitoides tissoti* (Schlumberger), Aqra Fn., Kato section, sample K.32. **n.** *Bolivina incrassata* (Reuss), Interfingering Tanjero-Aqra fns., Kato section, sample K.35b. **o.** *Fisseolphidium operculum*, Aqra Fn. Maukaba section, samples M.4. **p.** *Kathina* sp., Interfingering Tanjero-Aqra fns., Kato section, sample K.38. **q.** *Quinqueloculina* sp., Interfingering Tanjero-Aqra fns., Maukaba section, sample M.10. **r.** Red algae, Interfingering Tanjero-Aqra fns., Maukaba section, sample M.12b. **s.** (E) Echinoid spine; (R) *Rotalia skourensis* (Pfender), Interfingering Tanjero-Aqra fns., Kato section, sample K.38.

Plate 2: *Loftusia morgani*, *Siderolites calcitrapoides*, and *Orbitoides apiculatus* Assemblage Zone; *Loftusia persica*, *Loftusia elongata* Assemblage Zone

Pl. 2, Fig. a, b. *Loftusia morgani* (Douville), Aqra Fn., Maukaba section, sample M.4. **c.** Isolated *Loftusia morgani* (Douville), Interfingering Tanjero-Aqra fns., Nalashken section, sample b. **d.** *Loftusia morgani* (Douville), Aqra Fn., Kato section, sample K.35b. **e, f**. *Siderolites calcitrapoides* (Lamarck), Interfingering Tanjero-Aqra fns., Kato section, sample K.38. **g.** *Siderolites calcitrapoides* (Lamarck), Interfingering Tanjero-Aqra fns., Maukaba section, sample M.13b**. h.** *Orbitoides apiculatus* (Schlumberger), Interfingering Tanjero-Aqra fns., Kato section, sample K.38. **i, j, k.** *Suraqalatia brasieri* n.gen., n.sp. (**Görmüs),** Interfingering Tanjero-Aqra fns., Maukaba section, sample M.12b. **l, m.** *Loftusia persica* (Brady), Interfingering Tanjero-Aqra fns., Maukaba section, samples (M.12b, M.14). **n.** *Loftusia persica* (Brady), Interfingering Tanjero-Aqra fns., Kato section, sample K.38. **o, p.** Isolated *Loftusia persica* (Brady), Interfingering Tanjero-Aqra fns., Maukaba section, sample M.13d.

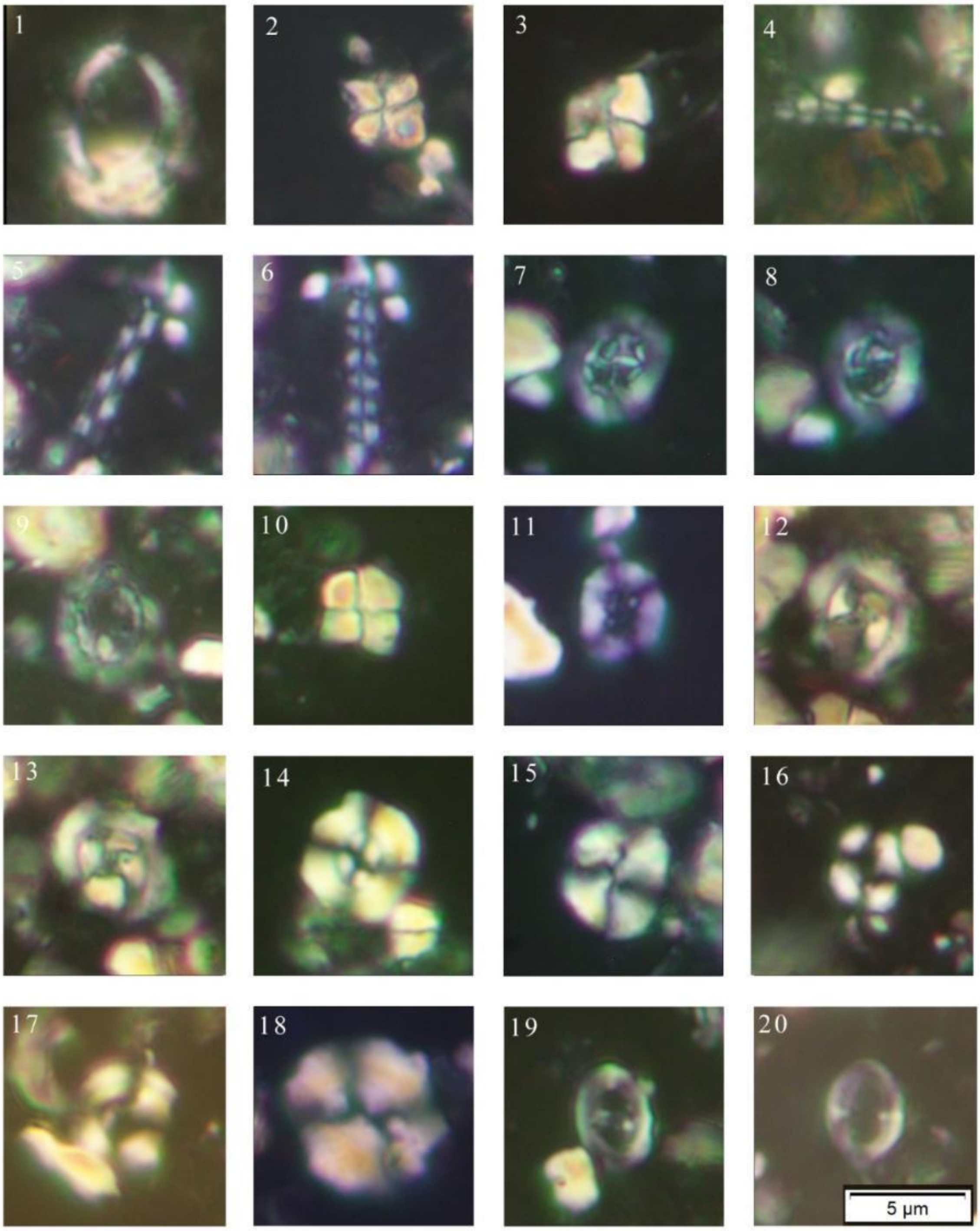
Plate 3: *Pseudoguembelina hariaensis* Partial Range Zone (CF3)



Pl.3, Figs. (1, 12)- *Pseudoguembelina hariaensis* (Nederbragt). (**2, 14)-** *Heterohelix globosa* (Ehrenberg). **3-** *Heterohelix striata* (Ehrenberg). **4-** *Pseudotextularia nuttalli* (Voorwijk). **5-** *Laeviheterohelix* sp. **(6, 15)-** *Pseudoguembelina palpebra* (Bronnimann and Brown). **(7, 16)-** *Globotruncana stuarti* (De Lapparent**)**. (**8, 13)-** *Gansserina gansseri* (Bolli). (**9, 19)-** *Gyroidina sp*. **(10, 18)-** *Gyroidinoides sp*. **11.** *Cibicidoides dayi* (White). **17-** *Globotruncanella pateloidia* (Gandolfi). **20-** *Nonionella sp.* **21.** *Spiroplectamina* sp. **22.** *Dentalinoides* sp. **23**. *Bolivina sp*. **24**. *Loxostomum* sp. (Ehrenberg). **25.** Charophyte sp., Q.25, Nalashken section. **26**. Charophyte sp., samples K.21, K.22, Kato section. **27, 28**. Charophyte sp., samples (Q.1, Q.4, Q.5), Sarsuly section. **29.** Ostracoda sp. **Note: 1.** Scale of figs. (1-5, 9,11) = 100 µm, figs. (6,10) = 50 µm, figs. (7,8) = 200 µm, figs. (12-29) = 0.34mm. **2.** Figs. (1-24, 29) from (CF3), Interfingering Tanjero-Aqra formations, sample K.35, Kato section.

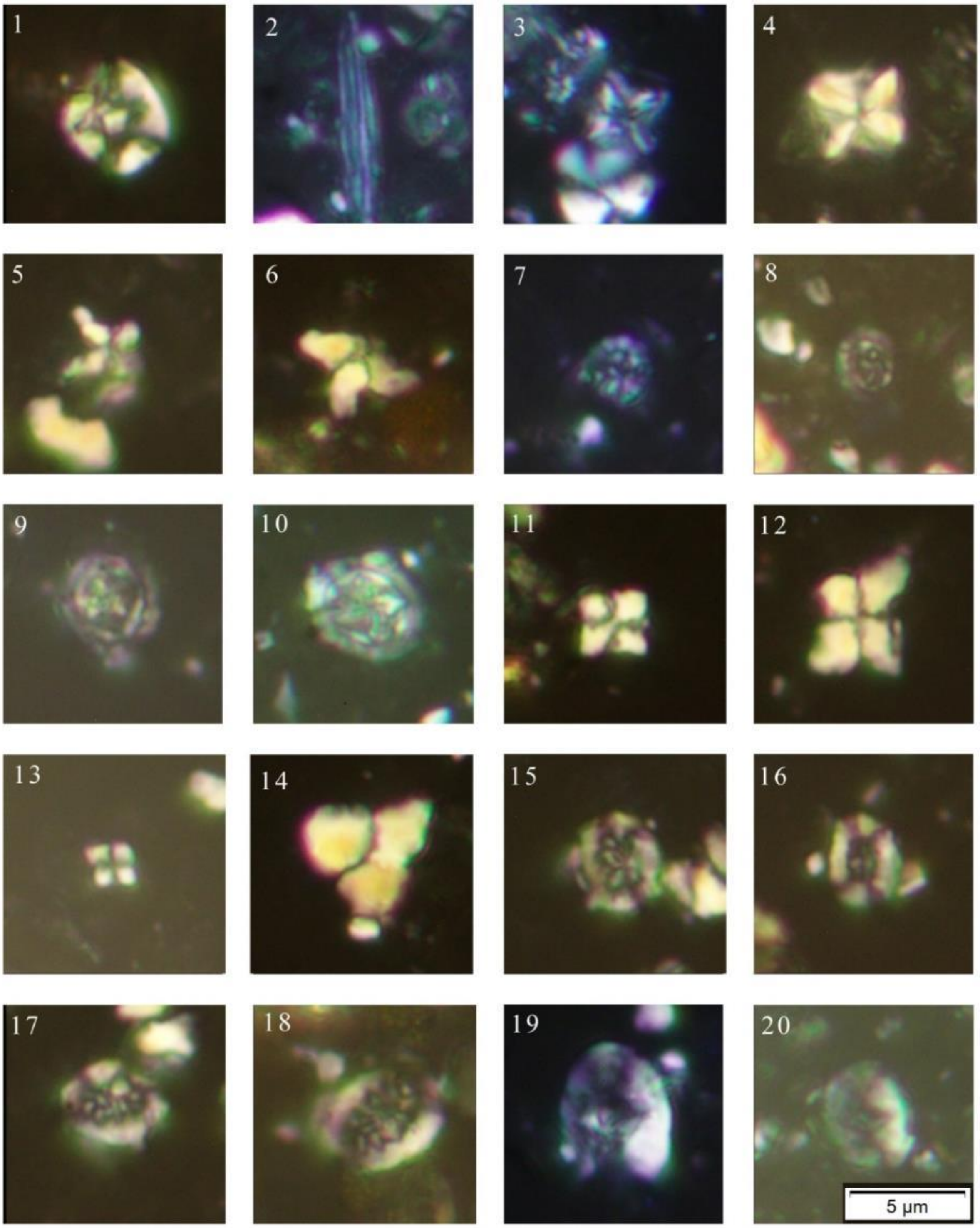
Plate 4: Calcareous Nanno fossils (CC26; Nalashken section)

Plate 4: *Micula murus-Micula prinsii* (CC26) Assemblage biozone; Nalashken section



Pl.4, Fig. **1-** *Manivitella pemmatoidea* (Deflandre *in* Manivit, 1965) Thierstein, 1971, sample Q3; Fig. **2-** *Micula cf. murus* (Martini, 1961) Bukry, 1973, sample Q1; Fig. **3-** *Micula murus* (Martini, 1961) Bukry, 1973, sample Q1; Fig. **4-** *Microrhabdulus decoratus* Deflandre, 1959, sample Q1; Figs. **5, 6-** *Microrhabdulus undosus* Perch-Nielsen, 1973, sample Q1, Q3; Figs. **7, 8-** *Prediscosphaera cretacea* (Arkhangelsky, 1912) Gartner, 1968, sample Q1, Q3; Fig. **9-** *Prediscosphaera cf. cretacea* (Arkhangelsky, 1912) Gartner, 1968, sample Q7; Fig. **10-** *Quadrum gartneri* Prins & Perch-Nielsen *in* Manivit et al., 1977, sample Q1; Fig. **11-** *Retecapsa ficula* (Stover, 1966) Burnett, 1997, sample Q3; Figs. **12, 13-** *Tranolithus orionatus* (Reinhardt, 1966a) Reinhardt, 1966b, sample Q1, Q7; Figs. **14, 15-** *Watznaueria barnesiae* (Black *in* Black & Barnes, 1959) Perch-Nielsen, 1968, sample Q7; Figs. **16, 17-** *Watznaueria fossacincta* (Black, 1971) Bown *in* Bown & Cooper, 1989, sample Q1, Q3; Fig. **18-** *Watznaueria biporta* Bukry, 1969, sample Q1; Fig. **19-** *Zeugrhabdotus erectus* (Deflandre *in* Deflandre & Fert, 1954) Reinhardt, 1965, sample Q1; Fig. **20-** *Zeugrhabdotus* sp., sample Q3; Scale bar 5 µm.

Plate 5: *Micula murus-Micula prinsii* (CC26) Assemblage biozone; Kato section



Pl.5, Fig. **1-** *Eiffellithus turriseiffelii* (Deflandre *in* Deflandre & Fert, 1954) Reinhardt, 1965, sample K14; Fig. **2-** *Lithraphidites carniolensis* Deflandre, 1963, sample K7; Figs. **3, 4-** *Micula staurophora* (Gardet, 1955) Stradner, 1963, sample K7; Figs. **5, 6-** *Micula prinsii* Perch-Nielsen, 1979, samples K7, K14; Fig. **7-** *Prediscosphaera spinosa* (Bramlette & Martini, 1964) Gartner, 1968, sample K7; Fig. **8-** *Prediscosphaera cretacea* (Arkhangelsky, 1912) Gartner, 1968, sample K7; Figs. **9, 10-** *Prediscosphaera desiderograndis* Blair & Watkins 2009, sample K7; Figs., **11-13-** *Quadrum gartneri* Prins & Perch-Nielsen *in* Manivit et al., 1977, samples K14, K7; Fig. **14-** *Uniplanarius trifidus* (Stradner *in* Stradner & Papp, 1961) Hattner & Wise, in Wind & Wise 1983, sample K19; Fig. **15-** *Retecapsa angustiforata* Black, 1971, sample K7; Fig. **16-** *Retecapsa ficula* (Stover, 1966) Burnett, 1997, sample K7; Figs. **17, 18-** *Retecapsa surirella* (Deflandre & Fert, 1954) Grün *in* Grün and Allemann, 1975, K7, K14; Figs. **19, 20-** *Reinhardtites levis* Prins & Sissingh *in* Sissingh, 1977, sample K7; Scale bar 5 µm.

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