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

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(Manuscript received September 18, 2008; accepted in revised form March 26, 2009)

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. 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. The studied area is located on the southern boundary (in front) of the Zagros Thrust Belt, which developed 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 foraminifera from 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 foraminifera 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...
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 uncinata*, *Globigerina bulloides*, *Gyroidina sol-danii*, *Loxostoma applinae*, *Nodosaria zippei*, *Nuttalides truempi*, *Pseudovalvulinia* sp., *Teredolites* sp., *Ovulites moreleti*, O. cf. elongate, *Trinocladius 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 Ainza-16, -17 from the northwestern part of Iraq, confirmed that the Aaliji Formation overlies the Shiranish Formation un-conformably. 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 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).

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<tr>
<th>Era</th>
<th>Period</th>
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<th>Lithology</th>
<th>Lithologic description</th>
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<tr>
<td>CENozoic</td>
<td>PALEOcene</td>
<td>PALEOcene</td>
<td>Kolosh</td>
<td>210</td>
<td>24.0 m — alternation of dark grey organic rich shale with marl and thin siltstone, fine sandstone intervened by thin marly limestone layers</td>
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<td>205</td>
<td>10.0 m — pale grey, yellowish friable conglomerate</td>
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<td>200</td>
<td>21.0 m — consists mainly of dark grey organic rich shale alternate with marl and thin layer of siltstone intervened by thin marly limestone layers and friable sandstone layer in the lower and middle part</td>
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<td>195</td>
<td>3.0 m — pale grey, yellowish friable conglomerate</td>
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<td>190</td>
<td>8.0 m — consists mainly of dark grey organic rich shale alternate with marl and thin layer of siltstone intervened by thin marly limestone layers</td>
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<td>185</td>
<td>10.0 m — consists mainly of dark grey organic rich shale and marl alternations</td>
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<td>180</td>
<td>9.0 m — olive to dark green marl with streaks of calcareous veins</td>
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<td>175</td>
<td>7.0 m — of dark grey shale, olive green marl interlayered with siltstone</td>
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<td>170</td>
<td>2.0 m — friable weathered, sandstone occasionally silty with clay ball and pillow</td>
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<td>165</td>
<td>9.0 m — consists of olive green sandstone alternate with dark grey shale and marl</td>
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<td>160</td>
<td>18.0 m — alternation of thin olive green bed of marl, dark grey shale, occasionally silty and three thick friable weathered sandstone beds at the base, middle and top of this interval</td>
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<td>155</td>
<td>11.0 m — alternation of olive green to dark grey calcareous shale, marl, thin bed of weathered sand and sandy siltstone</td>
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<td>150</td>
<td>1.0 m — friable conglomerate with pebbly sandstone</td>
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<td>145</td>
<td>8.0 m — alternation of thin bedded grey sandstone, dark organic rich shale and marl with streak of calcareous veins</td>
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<td>140</td>
<td>3.5 m — medium to hard conglomerate with two meters of friable sandstone pebbly sandstone at the middle part of this interval</td>
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<td>135</td>
<td>6.0 m — alternation of bluish white marl, marly siltstone and grey shale</td>
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<td>130</td>
<td>4.5 m — consists occasionally of two weathered pale sandstone pebbly sandstone separated by 2.0 m, grey shale and marl in the middle part</td>
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<td>125</td>
<td>10.0 m — alternation of dark grey organic rich shale, grey marl with thin-bedded sandstone and silty sandstone</td>
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<td>120</td>
<td>5.0 m — consists of olive pebbly sandstone at the top occasionally silty with common ball and pillow structure, 1.5 m weathered conglomerate at the base with marl and marly siltstone at the middle part</td>
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<td>115</td>
<td>11.5 m — consists mainly of dark grey organic rich shale alternate with marl and thin layer of siltstone intervened by thin marly limestone layers</td>
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<td>110</td>
<td>1.2 m — friable conglomerate with pebbly sandstone</td>
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<td>105</td>
<td>7.0 m — alternation of bluish white marl, marly siltstone and grey shale</td>
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<td>100</td>
<td>5.0 m — alternation of bluish marl, marly siltstone and grey weathered sandstone</td>
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<td>95</td>
<td>1.5 m — medium to hard conglomerate with pebbly sandstone</td>
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<td>90</td>
<td>45.0 m — of olive green marl and bluish white calcareous marl intervened by very thin layer of limestone</td>
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<td>85</td>
<td>11.5 m — alternation of bluish white marl, marly siltstone and dark grey weathered sandstone with clay ball and pillow structure occasionally with pebbly sandstone interlayers</td>
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<td>80</td>
<td>1.0 m — friable conglomerate with pebbly sandstone</td>
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<td>75</td>
<td>50.0 m — alternation of bluish white marl, marly siltstone and grey weathered sandstone with clay ball and pillow structure occasionally with pebbly sandstone interlayers</td>
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Fig. 3. Lithostratigraphic column of Sirwan Valley showing lithologic characters. (Not to scale, the thickness shown on each portion of discussion).
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).

Fig. 6. Biostratigraphic range chart of planktonic foraminifera at Cretaceous/Tertiary boundary, Sirwan area, (Sirwan section).
Keller (2003), Obaidalla (2005), Smit (2005), and Sharbazhier (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 magnetostratigraphic 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 dilated 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, Krasheninnikov 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 fruticosa (Egger) at the top. Nederbragt (1990) originally introduced this biozone as the interval from the FAD of Planoglobulina acervulinoidea at the base to the FAD Racemiguembelina fruticosa 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. nautallii (Voorwijk), H. reussi (Cushman), H. pulchra (Brotzen), Lavigueterohelix glabrans (Cushman) (Fig. 8c), Planoglobulina acervulinoidea (Egger), Rugoglobigerina hexacamerata (Bromimann), R. macrocephala (Bromimann), Gansserina gansseri (Reuss), G. wiedenyaery (Gandolfi), Globotruncanita stauri (de Lapparent), G. stuartiformis (Dalbez), G. conica White, G. pettersi Gandolfi, G. angulata Tilev, Globotruncanana aegyptiaca Nakkady, Glt. orientalis El-Naggar, Glt. falsostuari Sigal, Glt. dupeublei Caron et al. (Fig. 8e), Glt. lapparenti Bolli, Glt. arca (Cushman), Glt. bulloides Voghler, Glt. rossetta Caseyr, Glt. insignis (Gandolfi), Contusotruncana contusa (Cushman), C. fornicata Plummer, Ruguotruncanarina circuumodifer (Gandolfi), R. subcircuumodifer (Gandolfi), Globoherlinelloides volutes (White), G. prairehillienss Pessagno, G. bollii Pessango, Pseudotextularia elegans (Rzehak), P. deformis (Kikoine), P. intermedia (De Klaz), Racemifructicosa (Egger), R. poweli Smith & Pessango, Pseudoguembelina costulata (Cushman) (Fig. 8a,b), P. excolata (Cushman) (Fig. 8c), Hedbergella monmouthensis (Olsson), H. holmeleensis Olsson, Abathomphalus mayaroensis (Bolli) (Fig. 8f-g), Archaeoglobigerina blowi Pessagno, A. cretacea (d’Orbigny), Gablerina cavillieri Kikoine, Gumbelitriria cretacea Cushman, G. damdula (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 Rohaszyński et al. (1984), Caron (1985), D’Hont & Keller (1991), Al-Mutuali (1996), Hammoudi (2000), Al-Mutuali & 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. fruticosa 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 magnetostratigraphic time scale, 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 — *Globo- truncanana 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 — *Globo- truncanana falsocalarata* Kerdany & Abdelsalam, Tanjero Formation, Late Maastrichtian, Sirwan. Specimen from *Plummerita hantkeninoides* Zone. j-l — *Contusotruncanana falsocalarata* Kerdany & Abdelsalam, Tanjero Formation, Late Maastrichtian. Sirwan. Specimen from *Plummerita hantkeninoides* Zone.
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 correlative 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 caseyae (Plummer), P. acervulinaeides (Egger), Rugoglobigerina rugosa (Plummer) (Fig. 9d-e), R. scotti (Bronnimann), R. hexamerata Bronnimann, R. macrocephala Bronnimann, R. penyi Bronnimann, R. reichel Bronnimann, R. rotundata Bronnimann, Gansserina gans-
sani (Reuss), Globotruncana stuartiformis Dalbez, G. conica White, G. pettersi Gandolfi, G. angulata Tikev, Globotruncan-
na falsostuarti Sigal, Glt. dupeublie Caron et al., Glt. lappar-
enti Bolli, Contusotruncanca contusa (Cushman), C. plicata White, C. walfischensis Todc, C. sp. (nov. sp.?), Rugotruncan-
na circumnodifier (Gandolfi), R. subcircumnodifier (Gandolfi), Globotruncanella petaloidea (Gandolfi) (Fig 9b), R. pschadae (Keller) (Fig 9a), Globigerinelloides volutes (White), G. prai-
richillensis Pessaggio, Pseudotextularia elegans (Rzebak), P. de-
formis (Kikoine), P. intermediia (De Klase) (Fig 9g), Racem-
igumbelina fructicosa (Egger), Pseudogublerina costulata (Cushman), P. palpebra, P. excolata (Cushman), Hedbergella
mommouthensis (Olsson) (Fig 9f), H. holmdelensis Olsson, Abathomphalus mayaroensis (Bolli), Kuglerina rotundata
(Bronnimann), Costellagerina cf. bulbos Belford, Gublerina
cuvillieria Kikoine, Gumbelitria cretacea Cushman. As de-

cined above, the present Biozone CF3 is correlatable with the
zone recorded by Li & Keller (1998a,b), Abramovich &
from Madagascar, Keller et al. (1995) from Tunisia, Keller
Ohaidalla (2005) from Egypt, Sharbazheri (2007) from NE
Iraq. It is correlated with the middle part of the Aba-
thomphalus 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 magneto-
chron 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 Gansseri-
na gansseri at the base and the FAD of Plummerita hantken-
ioides 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
of species diversity as the underlying Pseudoguembelina hariaensis Zone, and marked by the extinction of Heterohe-
lisis punctulatus (Cushman), Gansserina gansseri, Globiger-
inelloides volutes (White), and Laeviheterohelix glabrans
(Cushman), in the upper part of the zone. Besides, the plank-
tonic foraminiferal species enduring from the underlying
biozones, some species, including Globotruncanca falsoscal-
cara Kerdany & Abdelsalam, Globotruncanca sp. and Tri-
ntella 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 appear-
ance of new species in this zone. The planktonic foraminif-
eral assemblages of this zone in the Sirwan section are rep-
resented by Heterohelix navaroensis Loeblich, H. globu-
losa (Ehrenberg), Laeviheterohelix glabrans (Cushman),
Planoglobulina carseyae (Plummer), P. acervulinoides (EG-
ger), Rugoglobigerina rugosa (Plummer), R. scotti (Bronni-
mann), R. hexacamerata Bronnimann, R. macrocepha-
la Bronnimann, R. pennyi Bronnimann, R. reicheli Bronnimann,
Globotruncanita stuartiformis Dalbez, G. conica White, Glo-

botruncanca aegyptiaca Nakkady, Glt. falsoscalcarata Kerdany
& Abdelsalam (Fig 8g-i), Glt. falsostuarti Sigal, Glt. dupeub-
lie Caron et al., Glt. lapparenti Bolli, C. plicata White, C.
walfischensis Todc, Rugotruncanca circumnodifier (Gandolfi),
R. subcircumnodifier (Gandolfi), Globotruncanella petaloidea
(Gandolfi), G. pschadae (Keller), Globigerinelloides prarie-
hillensis Pessagno, Pseudotextularia elegans (Rzebak), P. de-
formis (Kikoine), Racemigumbelina fructicosa (Egger), Pseu-

doguembelina hariaensis Nederbragt, P. palpebra, P. ex-
colata (Cushman), Hedbergella mommouthensis (Olsson), H.
holmdelensis Olsson, Gublerina cuvillieria Kikoine, Gumbel-
itra 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), Mol-
ina 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 Ohaidalla (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
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 magneto-
chron 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 Plummeri-
ta hantkeninoides Zone from 37 to 29 species in the Sirwan
section.

Heterohelix navaroensis Loeblich, H. globulosa (Ehren-
berg), H. striata (Ehrenberg), Rugoglobigerina rugosa (Plum-
mer), R. scotti (Bronnimann), R. macrocepha Bronnimann,
R. pennyi Bronnimann & Abdelsalam, Globotruncanca falsos-
stuarti Sigal, Glt. dupeublie Caron et al., Contusotruncanca
contusa (Cushman), C. plicata (White), Globotruncanella
petaloidea (Gandolfi), Pseudotextularia elegans (Rzebak),
Pseudoguembelina costulata (Cushman), P. hariaensis Neder-

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As defined above and based on the associated planktonic foraminiferal assemblage, the present *Plummerita hantkenioides* 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 (CF1–2) 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 hantkenioides* 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 hantkenioides* Zone is equivalent to the Kassa-biana falsocalcarata Zone recorded from Shalti 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 magneto-chron ages, providing a high rate of sedimentation (12 ky/m) in the studied area. Age: Late Maastrichtian.

**P0 & P1a:** In the present study, the earliest Paleocene P0 Guembelitria cretacea Cushman, 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 overlaying 12 meters of dark grey organic rich shale alternating with marl, marly limestone and thin layers of silstone, sandstone, are barren of foraminifers. As mentioned previously, the sedimentary succession of the studied sections in the Sirwan Valley shows evidence of three dilated 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 hantkenioides*, and 64.90 Ma, marked by last occurrence of *Parvularugoglobigerina eugubina* (Fig. 10c–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 sedimentostratigraphic 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 & P1a (*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 triloculinae Interval Subzone: Definition: Biostatigraphic interval between the LAD of *Parvularugoglobigerina eugubina* and the FAD of *Subbotina triloculinae* (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 clylonensis* (Loeblich & Tappan), *W. hornerstownensis* (Olsson), *Chiloquembelina morsei* (Kline), *Ch. midwayensis* (Cushman), *Globoconusa daubjergiensis* (Brommimann), *Parasubbotina pseudobulloides* (Plummer), *Subbotina trivalis* (Subbotina), *Globanomalina archeocompressa* (Blow), *G. planocompressa* (Shutskaya), *Eoglobigerina edita* (Subbotina), *E. ebullioides* Morozova, *E. simplicissima* Blow, *Praemurica taurica* (Morozova), *P. pseudoiconconstans* (Blow), *Guembelitria cretacea* Cushman. *Guembelitria cretacea* Cushman is represented in the lower part, while *Woodringina clylonensis* (Loeblich & Tappan), and *Globoconusa daubjergiensis* (Brommimann) 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
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 *Moriczenella 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** — *Pseudothaxtil skeleton intermedia* Interval Zone (CF5) (Tanjero Formation), (Late Maastrichtian).
- **C2** — *Racemiguembelina fructicosa* Interval Zone (CF4) (Tanjero Formation), (Late Maastrichtian).
- **C3** — *Pseudoguembelina haraensis* Zone (CF3) (Tanjero Formation), (Late Maastrichtian).
- **C4** — *Pseudothaxtil skeleton palpebra* Interval Zone (CF2) (Tanjero Formation), (Late Maastrichtian).
- **C5** — *Plummerita cretacea* and *Parvularugoglobigerina eugubina* Interval Zone (P0 & Po), (Kolosh Formation), earliest Paleocene (Danian).
- **C6** — *Guembelitria cretacea* and *Parvularugoglobigerina eugubina* Interval Zone (CF1) (Tanjero Formation), (Late Maastrichtian).
- **C7** — *Parvularugoglobigerina eugubina*—*Subbotina triluculinoidea* Interval Zone (P1a), (Kolosh Formation), Early Paleocene (Early Danian).
- **C8** — *Subbotina triluculinoidea*—*Prasemurica inconstans* Interval Zone (P1b), (Kolosh Formation), Early Paleocene (Danian).

**Acknowledgments:** Our sincere thanks go to the reviewers Dr. Erik Ozcan (Istanbul Technical University) and Dr Ali Al-Juboury (Mosul University, Iraq) for their very useful suggestions and corrections of the present paper.

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


