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Paleoclimatic Insights on the Paleocene-Eocene Thermal Maximum in Central Iraq, Based on Calcareous Nannofossils, Ostracoda and Geophysical Data

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Abstract

The Paleocene-Eocene Thermal Maximum (PETM) event, which represented a sudden and abnormal rise in temperature during the early Cenozoic Era, is regarded as one of the most important global geologic phenomena. Two important index microfossils (nannoplankton and Ostracoda) were utilised to understand and predict the paleoenvironment and describe the changes during this period. The basis of the study was 12 cutting samples taken from Aaliji and the lower part of Jaddala formations of a subsurface section of (Ba-8) borehole in central Iraq. Some geophysical data were used to determine the upper and lower contacts of the Aaliji Formation and define the shale rate in the studied formations. The micropaleontologic investigation reveals twenty-four nannoplankton species and twenty species belonging to seven genera of Ostracoda. The use of Nannoplankton fossils led to the identification of two types of biozones based on two species belonging to the genus Discoaster, which are ordered from bottom to top as follows; 1- Discoaster nobilis Interval Biozone (CP7) and 2- Discoaster multiraditus Interval Biozone (CP8). The biozones were compared locally and regionally with their equivalent biozones, which deduced the age of the Aaliji Formation as (Late Paleocene-Lower Early Eocene) whereas (Early Eocene) for the studied part of the Jaddala Formation. The determination of the upper and lower boundaries was determined by interpreting the geophysical logs. Ostracoda fossils were used to predict paleoecology and its changes in the area during the PETM episode. The transmutation of nanoplankton fossils from the Paleocene to the Eocene indicates an abnormal rise in global temperatures, flourishing and high diversity of some nanoplankton, such as some species belonging to Discoster, especially those in the CP8 zone.

Keywords: Calcareous nannofossils, Ostracoda, PETM, Paleocene, Eocene, Geophysical data

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رؤى المناخ القديم خلال الارتفاع الحراري الأقصى للباليوسين – الايوسين في وسط العراق باستخدام متحجرات النانو الكلسية والاوستراكودا والبيانات الجيوفيزيائية

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الخلاصة

يعتبر حدث الارتفاع الحراري الأقصى (PETM) في عصر الباليوسين-الايوسين احد الأحداث الجيولوجية العالمية المهمة التي تم تسجيلها في الفترة المبكرة من حقبة الحياة الحديثة والذي مثل ارتفاعًا مفاجئًا وغير طبيعياً في درجة الحرارة في تلك الفترة. تم استخدام نوعين مهمين من المتحجرات الدقيقة الدالة (المتحجرات النانو كلسية و متحجرات الاوستراكودا) والتي تمثل متحجرات دقيقة ذات أهمية كبيرة في التفسير والتنبؤ بالبيئة القديمة , كما تم من خلالهما شرح التغييرات البيئية التي حدثت في تلك الفترة. اعتمدت الدراسة على 12 نموذج فتاتي صخري تمت نمذجتها من تكوين عليجي والجزء السفلي من تكون جدالة في المقطع تحت السطحي من البئر بلد-8 وسط العراق, كما تم استخدام بعض البيانات الجيوفيزيائية في تحديد سطح التماس العلوي والسفلي لتكوين عليجي. أسفرت دراسة المتحجرات الدقيقة عن تسجيل أربعة وعشرين نوعًا من متحجرات النانو الكلسية وعشرين نوعًا تنتمي إلى سبعة أجناس من متحجرات الاوستراكودا. ومن خلال استخدام متحجرات النانو الكلسية, تم تحديد نوعين من الانطقة الأحيائية بالاعتماد على نوعين ينتميان إلى جنس Discoaster ، و تم ترتيب هذه الانطقة من الأسفل إلى الأعلى على النحو التالي ؛ (CP7) نطاق الفترة Discoaster Nobilis و (CP8) نطاق الفترة Discoaster multiraditus , كما تم أجراء مقارنة لهذه الانطقة الأحيائية محليًا وإقليميًا مع الانطقة الأحيائية المكافئة لها والتي استنتج من خلالها عمر تكوين عليجي بانه (الباليوسين الأسفل- الجزء الأسفل من الايوسين المبكر) بينما كان عمر الجزء المدروس من تكوين جدالة يمثل (الايوسين المبكر). ايضا تم استخدام متحجرات الاوستراكودا لتحديد البيئة القديمة للتكاوين وتغيراتها في المنطقة خلال حدث الارتفاع الحراري حيث اشار التحول الذي حصل في متحجرات النانو الكلسية و الاوستراكودا خلال الفترة الانتقالية من عصر الباليوسين إلى عصر الإيوسين إلى ارتفاع غير طبيعي في درجات الحرارة العالمية وهذا مايدل على الازدهار و التنوع العالي لبعض متحجرات النانو الكلسية مثل بعض الأنواع التي تنتمي إلى الجنس Discoaster، وعلى وجه الخصوص ، تلك الموجودة في . CP8

1. Introduction

The present study relied on samples collected from a subsurface section, and it was supplemented by some geophysical well logs data of Balad 8 well in central Iraq (Figure 1). The formations mainly investigated, Aaliji and Jadalah Formations (Paleocene and Eocene age), are regarded as significant geological epochs in Iraq and have attracted the attention of many researchers such as [1, 2]. The Aaliji Formation was described for the first time in NW Syria (latitude 36° 29' 25'' North, longitude. 36° 53' 32'' East). Later in Iraq, a supplementary type section locality was chosen at Kirkuk-109 well (latitude 35° 33' 08 North and longitude 44° 18' 55'' East), with a depth range 2487- 3035 feet), the thickness of 548 feet (167 m) [3].

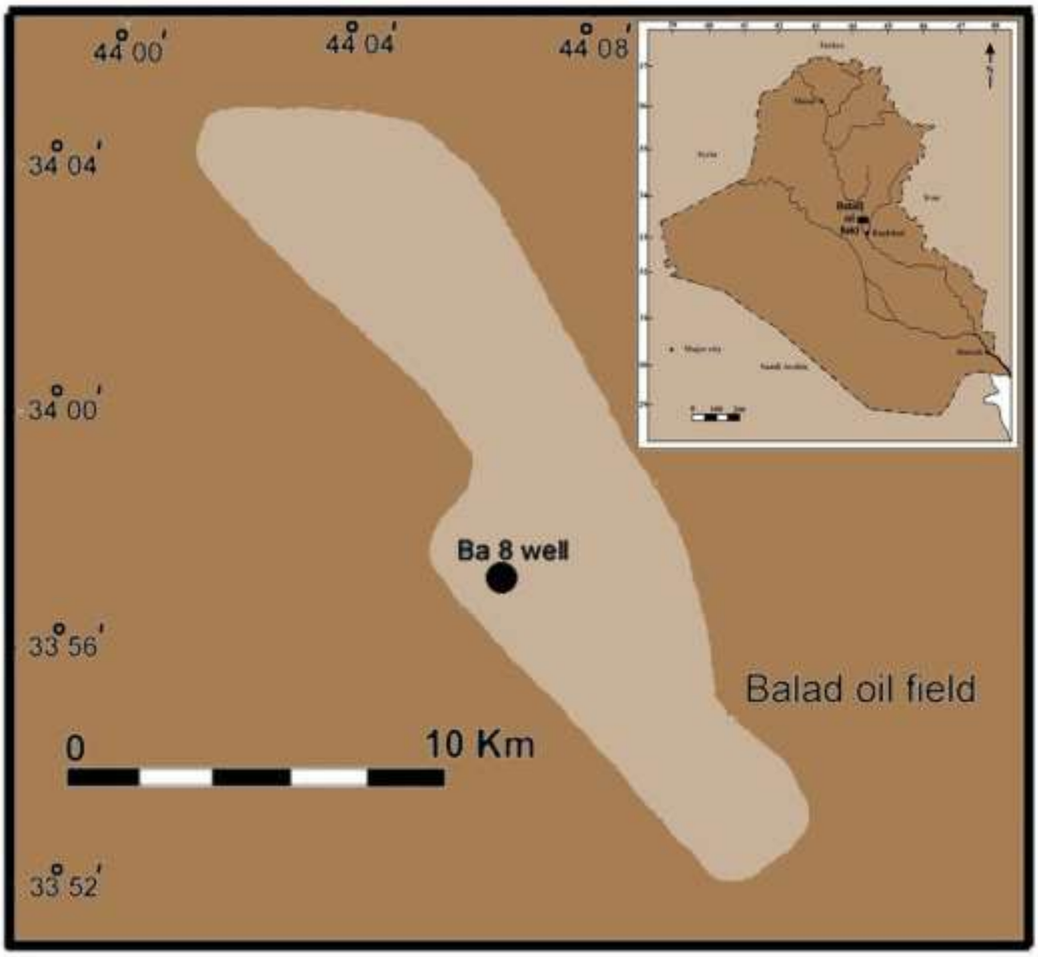

Figure 1: Location map of the studied section

The first description of the Jaddala Formation was done by Henson (1940) in [1]. The type section is situated close to the Jaddala village at Sinjar, NW Iraq, with an age of lower M. Eocene – L.Eocene. The formation in the type locality (2106 feet thick) consisted is of marl and chalky limestone, interfingered with Avana-Jaddala Formations. It is characterised by different fossils assemblages, including Ostracoda, calcareous nannofossils and Foraminifera. The formation extends along the foothill zone and the northern part of the Mesopotamian zone. In N and NE Iraq, the formation is equivalent to the Avanah, Jercus, and Pila Spi formations. At the same time, in southern Iraq, it is equivalent to the Dammam Formation in age but differs from it in facies [2].

The Paleocene-Eocene Thermal Maximum (PETM) event was an important incident within the geological history of the beginning of the Cenozoic, representing the period in which the temperatures increased steadily. This led to obvious and important effects on the nature of the biological content globally, accompanied by the considerable differences in planktonic marine taxa.

This increasingly high temperature is directly proportional to the increase in the volume of gases in the atmosphere (Gasses of the greenhouse). Therefore, this event represents the global warming of the ocean and atmosphere that led to further ocean acidification. During this period, the increase in temperature affected the ice prevalent in the Paleogene. The obvious effects on the various fossil groups and planktonic MG/Ca rate as a representative of past oceanic [3].

The geophysical well logs data is one of the most important methods for determining the characteristics and lithology of the subsurface layers due to high reality [4;5]. Several types of logs are mainly used to determine lithology, such as the gamma-ray log, which depends on natural radioactivity emanating from the sediments and rocks, as the percentage of these emitted rays increases with the increase in the rate of shale [6]. The sonic log is used to estimate the sonic waves velocity (DT) of rocks and the primary porosity (PHIS) of sediments and rocks [7]. Other types of logs are used for different purposes.

The main objective of the current study is to determine the PETM episode and the stratigraphic location of its occurrence through this studied section of central Iraq. Add to that discussing the biological manifestations, life conditions, and paleoenvironmental properties in the sedimentary basin using calcareous nannofossils, Ostracoda fossils, and geophysical data.

2. Materials and Methods

Twelve rocky cutting samples (shale, limestone, and argillaceous limestone) of the Balad-8 well are selected for the current study. Thin sections made in the laboratory according to the Armstrong and Brasier method [8] were used. Nannoplankton was studied by a transmitted light microscope. Ostracoda fossils were provided using the standard techniques as the rock samples of different lithologies were prepared (100-150 grams weight per sample). The samples were crushed until the material passed through a 16-mesh sieve and transferred to a beaker containing H2O2 (24 h for the solid samples). The sample was boiled for 4-6 h with sequential stages of washing and adding water. It was sieved by the wet method for sizes of 16, 40, 80 and 120 mesh and then dried. Ostracoda valves and carapaces were picked up from the residual material and isolated according to their size in specific microfossil slides for the microscopic diagnosis and classification.

A gamma-ray log was used to calculate the percentage of shale in the rocks (Vsh), through the following equations [9]:

$$\mathrm{Vsh} = 0.083 * \left[2^{(2.37*\mathrm{IGR})} - 1\right] ------------[1]$$

$$\mathrm{IGR} = \frac{\mathrm{GRlog} - \mathrm{GRmin}}{\mathrm{GRmax} - \mathrm{GRmin}} --------------[2]$$

The primary rock porosity **[**PHIS**]** was calculated from the sonic log by the following equation:

$$\mathrm{PHIS} = \frac{\Delta\mathrm{tlog} - \Delta\mathrm{tma}}{\Delta\mathrm{tf} - \Delta\mathrm{tma}} ---------------- [3]$$

Where: IGR: Index of gamma-ray, GR_{log}: log gamma-ray signal, GR_{max}: The maximum gamma-ray reading, GRmin: The minimum gamma-ray reading. Δtf is the transit time of the fluid in µsec/ft (189 µsec/ft for water), Δt represents the sonic log transit time in µsec/ft, Δtma is the matrix transit time in µsec/ft (47.5 µsec/ft for limestone).

The interactive petrophysics (IP V3.5) program is used for representing the geophysical results of the well log data.

3. Results

3.1. Calcareous nannofossils

The classification of nannoplankton (calcareous nannofossils) in the rock samples explains twenty-four species representing Aaliji and Jaddala Formations (Plates 1, 2) as shown below:

3.1.1.Heterococcoliths

- Family Helicosphaeraceae
- Genus *Helicosphaera*
- *Helicosphaera compacta*
- *Helicosphaera lophota*
- *Helicosphaera reticulata*
- Family Pontosphaeracae
- Genus *Pontosphaera*
- *Pontosphaera distincta*
- *Pontosphaera plana*
- Family Zygodiscaceae
- Genus *Lophodolithus*
- *Lophodolithus reniformis*
- Family Coccolithaceae
- Genus *Coccolithus*
- *Coccolithus eopelagicus*
- *Coccolithus pelagicus*
- Family Noelaerhabdaceae
- Genus *Cyclicargolithus*
- *Cyclicargolithus floridanus*
- Genus *Dictyococcites*
- *Dictyococcites bisectus*
- *Dictyococcites stavensis*
- Genus *Reticulofenestra*
- *Reticulofenestra dictyoda*

3.1.2.Nannoliths

- Family Braarudosphaeraceae
- Genus *Braarudosphaera*
- *Braarudosphaera bigelowii*
- Family Discoasteraceae
- Genus *Discoaster*
- *Discoaster deflandrei*
- *Discoaster gemmifer*
- *Discoaster mohleri*
- *Discoaster multiradiatus*
- *Discoaster nobilis*
- Family Fasciculithaceae
- Genus *Fasciculithus*
- *Fasciculithus aubertae*
- *Fasciculithus involutus*
- Family Heliolithceae
- Genus *Heliolithus*
- *Heliolithus cantabriae*
- *Heliolithus kleinpelli*
- Family Sphenolithaceae
- Genus *Sphenolithus*
- *Sphenolithus heteromorphus*

- *Sphenolithus primus*

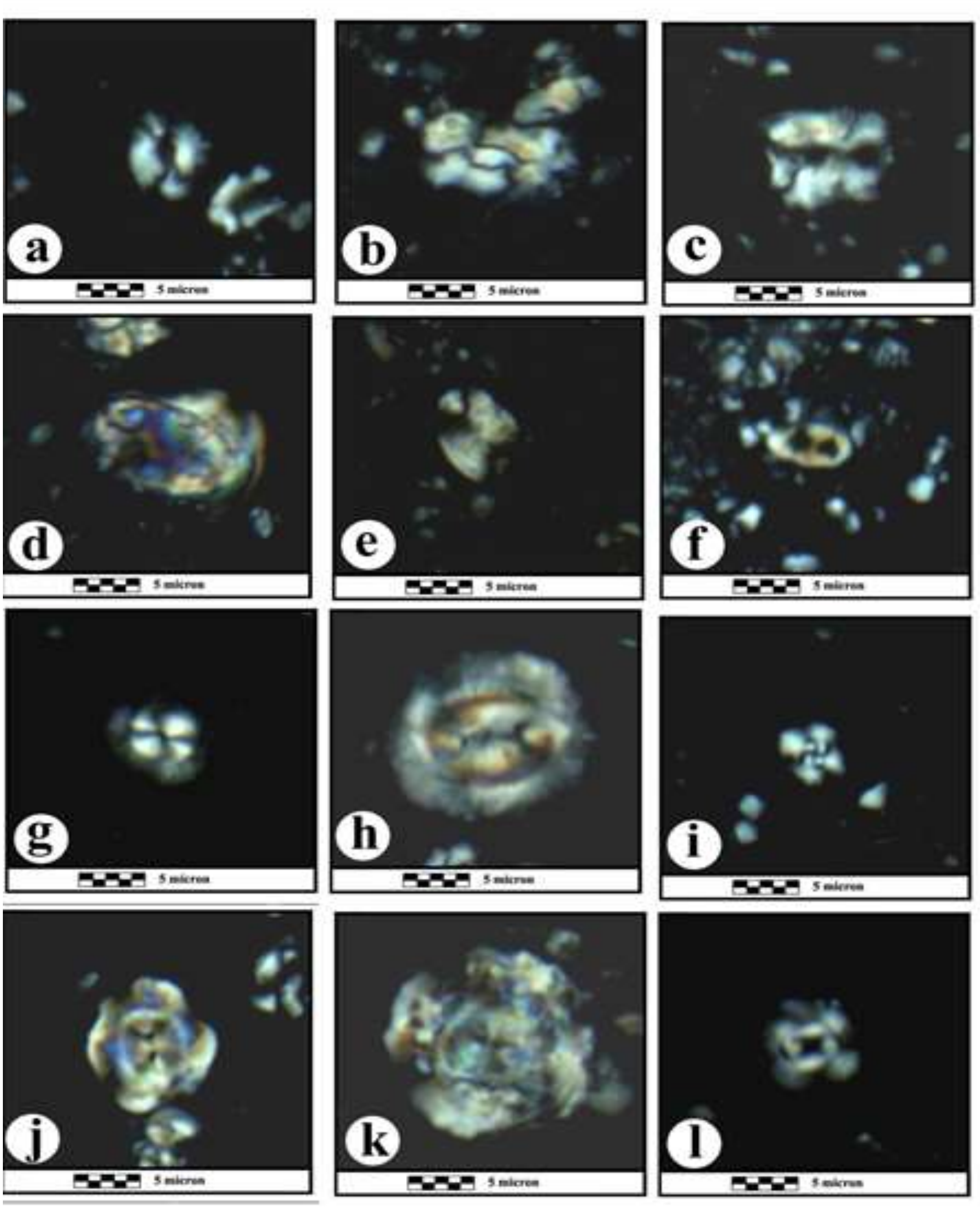

Plate 1: Cross-polarized photos of significant calcareous nannofossil taxa from Aaliji Formation. (a) *Helicosphaera compacta*; (b) *Helicosphaera lophota*; (c) *Helicosphaera reticulata*; (d) *Pontosphaera distincta*; (e) *Pontosphaera plana*; (f) *Lophodolithus reniformis*; (g) *Coccolithus eopelagicus*; (h) *Coccolithus pelagicus*; (i) *Cyclicargolithus floridanus*; (j) *Dictyococcites bisectus*; (k) *Dictyococcites stavensis*; (l) *Reticulofenestra dictyoda*.

3.2. Nannobiostratigraphy

1. *D. nobilis* Zone (CP7): Define as an Interval biozone of *Discoaster nobilis* [10]. The lower boundary is determined by the first appearance of the species D. nobilis [10], and the upper boundary is determined by the first appearance of the species *D. multiradiatus* [10]. This biozone correlated with *D. nobilis* biozone (CP7) by [12], which aged L. Paleocene (Thanetian), and correlated with *D. nobilis* biozone (NP8) by [13], which aged Late Paleocene (Thanetian) too. Therefore, depending on the stratigraphic correlation above, this biozone aged Late Paleocene (Thanetian) [14].

2. *D. multiradiatus* Zone (CP8): Define as an Interval biozone of *Discoaster multiradiatus*. The lower boundary is determined by the first appearance of the species D. multiradiatus, and the upper boundary is determined by the first appearance of the species *D. diastypus*. This biozone correlated with *D. multiradiatus* biozone (CP8) by [14], which aged Late Paleocene to Early Eocene (Thanetian – Ypresian). It is correlated with *D. multiradiatus* biozone (NP9) by [13], which aged L. Paleocene to Early Eocene (Thanetian to Ypresian) too. Therefore, depending on the stratigraphic correlation above, this biozone aged from Late Paleocene to Early Eocene (Thanetian to Ypresian) [14].

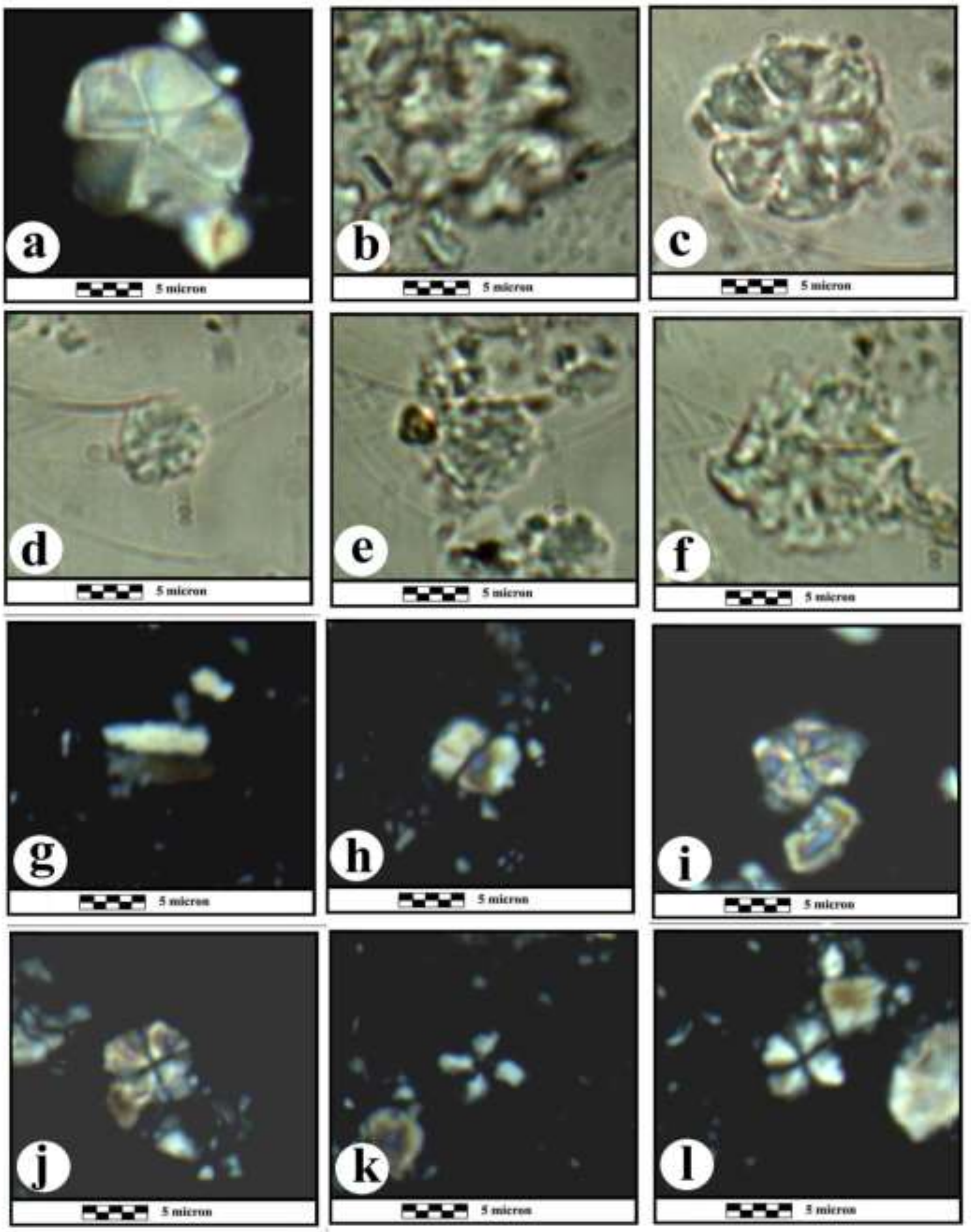

Plate-2 Cross-polarized photos of significant calcareous nannofossil taxa from Aaliji Formation. (a) *Braarudosphaera bigelowii*; (b) *Discoaster deflandrei*; (c) *Discoaster gemmifer*; (d) *Discoaster mohleri*; (e) *Discoaster multiradiatus*; (f) *Discoaster nobilis*; (g) *Fasciculithus aubertae*; (h) *Fasciculithus involutus*; (i) *Heliolithus cantabriae*; (j) *Heliolithus kleinpelli*; (k) *Sphenolithus heteromorphus*; (l) *Sphenolithus primus*.

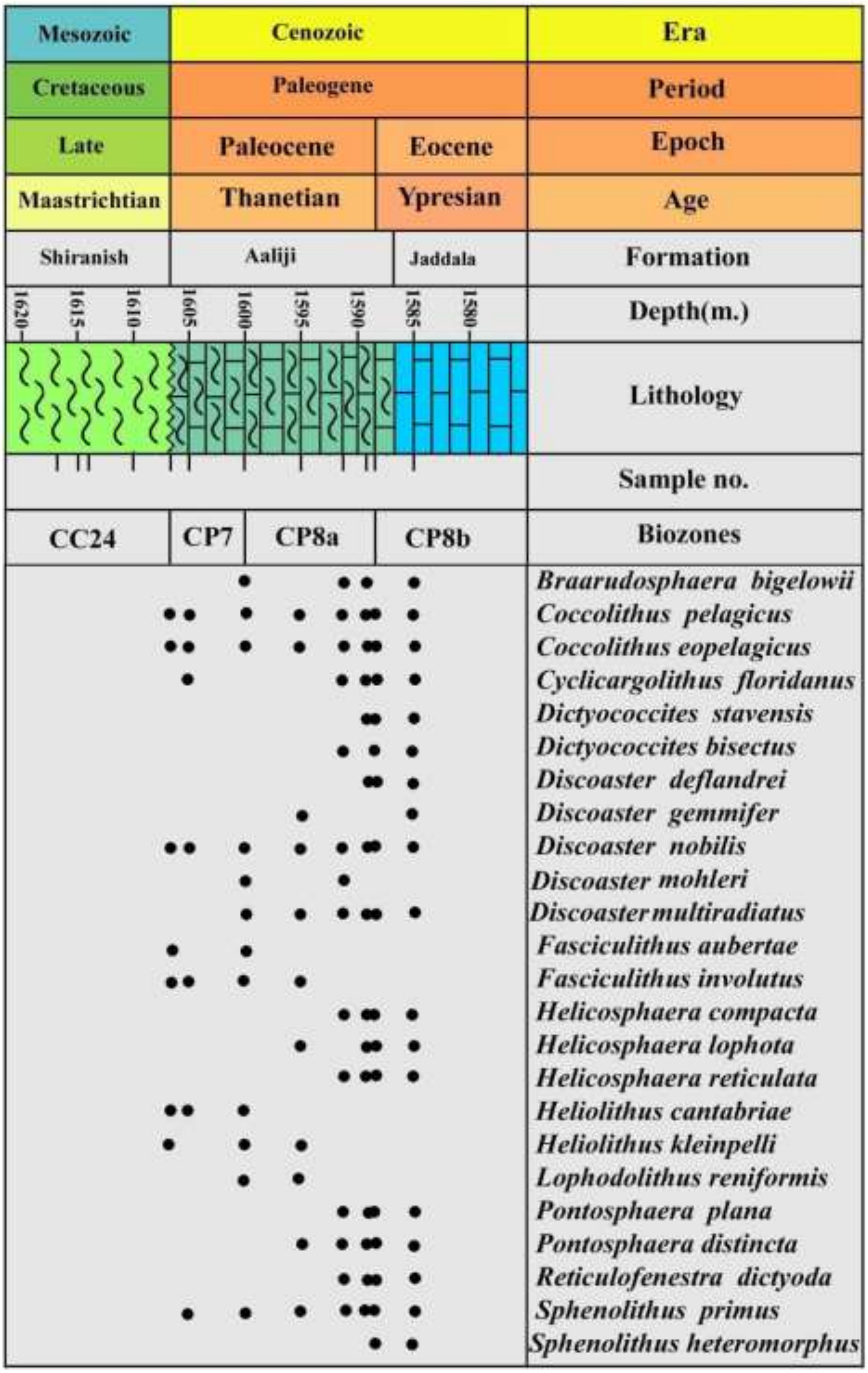

Figure 2 : Distribution chart of calcareous nannofossils in the studied section

3.3. Ostracoda fossils

The diagnosis and classification of Ostracoda was based on the taxonomic system adopted by [15; 16; 17 and 18] and the reliance on recent research and periodicals on trusted sites on the internet.

The study included 20 species belonging to 12 genera from 7 families of Ostracoda (Plate 3).

- Kingdom Animalia Linnaeus

- Superphylum Arthropoda
- Phylum
- Class Ostracoda
- Order Podocopida
- Suborder Platycopa
- Superfamily Cytheracea
- Family Cytherellidae
- Genus *Cytherella*
- *Cytherella navetensis*
- *Cytherella ventroconcava*
- *Cytherella farafraensis*
- *Cytherella barpatharensis*
- *Cytherella sinaensis*
- *Cytherella compressa*
- Suborder Podocopa
- Superfamily Bairdiacea
- Family Bairdidae
- Genus *Bairdia*
- *Bairdia aegyptiaca*
- Genus *Bairdoppilata*
- *Bairdoppilata rakdiensis*
- *Bairdoppilata gilberti*
- Superfamily Cypridacea
- Family Pontocyprididae
- Subfamily Pontocypridinae
- Genus *Abyssocypris*
- *Abyssocypris adunca*
- Genus *Pontocyprella*
- *Pontocyprella recurva*
- Family Paracyprididae
- Subfamily Paracypridinae
- Genus *Paracypris*
- *Paracypris eskeri*
- *Paracypris jonesi*
- *Paracypris* sp.
- Family Krithidae
- Subfamily Krithinae
- Genus *Krithe*

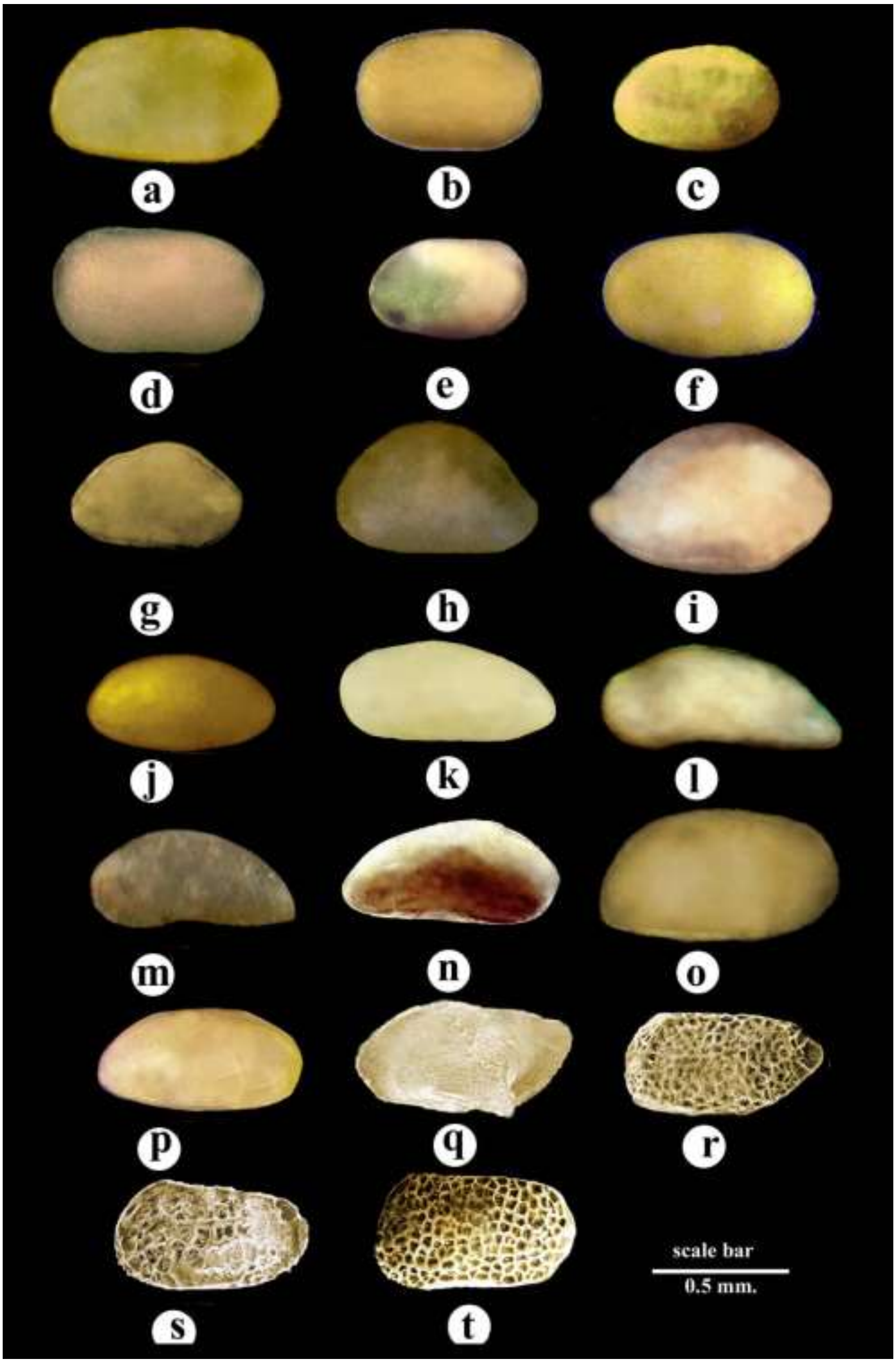

Plate 3: Photos with normal light were snapshotted from Aaliji and Jaddala Formations.(a)*Cytherella navetensis*; (b)*Cytherella ventroconcava*; (c)*Cytherella farafraensis*; (d)*Cytherella barpatharensis*; (e)*Cytherella sinaensis*; (f)*Cytherella compressa* ; (g)*Bairdia aegyptiaca*; (h)*Bairdoppilata rakdiensis*; (i)*Bairdoppilata gilberti*; (j)*Abyssocypris adunca* ; (k)*Pontocyprella recurva*; (l)*Paracypris eskeri*; (m)*Paracypris jonesi*; (n)*Paracypris* sp. B.; (o)*Krithe elongata*; (p) *Parakrithe crolifa*; (q)*Cytheropteron lugeri*; (r)*Eucytherura dentata* ; (s)*Paracosta kefensis*; (t)*Alocopocythere attitogonensis* .

- *Krithe elongata*
- Genus *Parakrithe*
- *Parakrithe crolifa*
- Family Cytheruridae
- Genus *Cytheropteron*
- *Cytheropteron lugeri*
- Genus *Eucytherura*
- *Eucytherura dentata*
- Family Trachyleberididae
- Subfamily Trachyleberidinae
- Genus *Paracosta*
- *Paracosta kefensis*
- Subfamily Campylocytherinae
- Genus *Alocopocythere*
- *Alocopocythere attitogonensis*

3.4. Paleoclimatology

The calcareous nannoplankton taxa, which passed the PETM, is determined from *Discoaster multiraditus* zone. With the increase of *Discoaster*, that increase passes the PETM boundary. The species of the genera *Discoaster* are adaptive to the warm waters, whereas the species of the genus *Chiasmolithus* are adaptive to the water highly cold. The nannoplankton response towards the end of Paleocene to the onset of E. Eocene in the studied section was marked by the excursion taxa (e.g., *Discoaster* spp., *Chiasmolithus* spp.). This nannoplankton is dominated by two flora resemblances (*Discoaster* and *Chiasmolithus*), noting that the second genus was minor. The different taxa groups turnover at the PETM is found that a proof of adaptation and a long-dated alteration in the nannoplankton genera that persevere after the PETM leads to the vanishing of assemblages occur in high latitude. One of the main aims of studying the Aaliji Formation in central Iraq is to identify and investigate the nature of the response shown by the different nannoplankton genera to the variations in paleoclimate in the studied area. These inconstancies are shown obviously in *D. multiraditus* biozone.

It is clear that from the high appearances of nanoplankton, there was a rise in sea temperature (warming) during the late stages of Paleocene and through the Eocene. The ongoing effect on different genera due to passing increases in temperature over the PETM has implications for future climate variation effects on the ecosystem, proposing the potential for identical standing turnovers to nannoplankton structures accompanied by warming in oceans and seas.

3.5. Paleoecology

Ostracoda fossils were used as an assignment to predict the environment characterised at the stage of the deposition of the Aaliji Formation (Late Paleocene-lower Early Eocene) and the PETM. The sedimentation began in the Jaddala Formation (Early Eocene), and the contact between them was conformable in terms of the continuity of species and the age gradation. It mainly depends on the observed changes in Ostracoda in terms of living style and the variations in the depth in which they inhabit and the degree of noticeable variation in the intensity of their abundance as individuals or as assemblages. The disappearance or scarcity of some species and the emergence of others can also highlight some of the changes that occurred in the environment during this period (Figure 3).

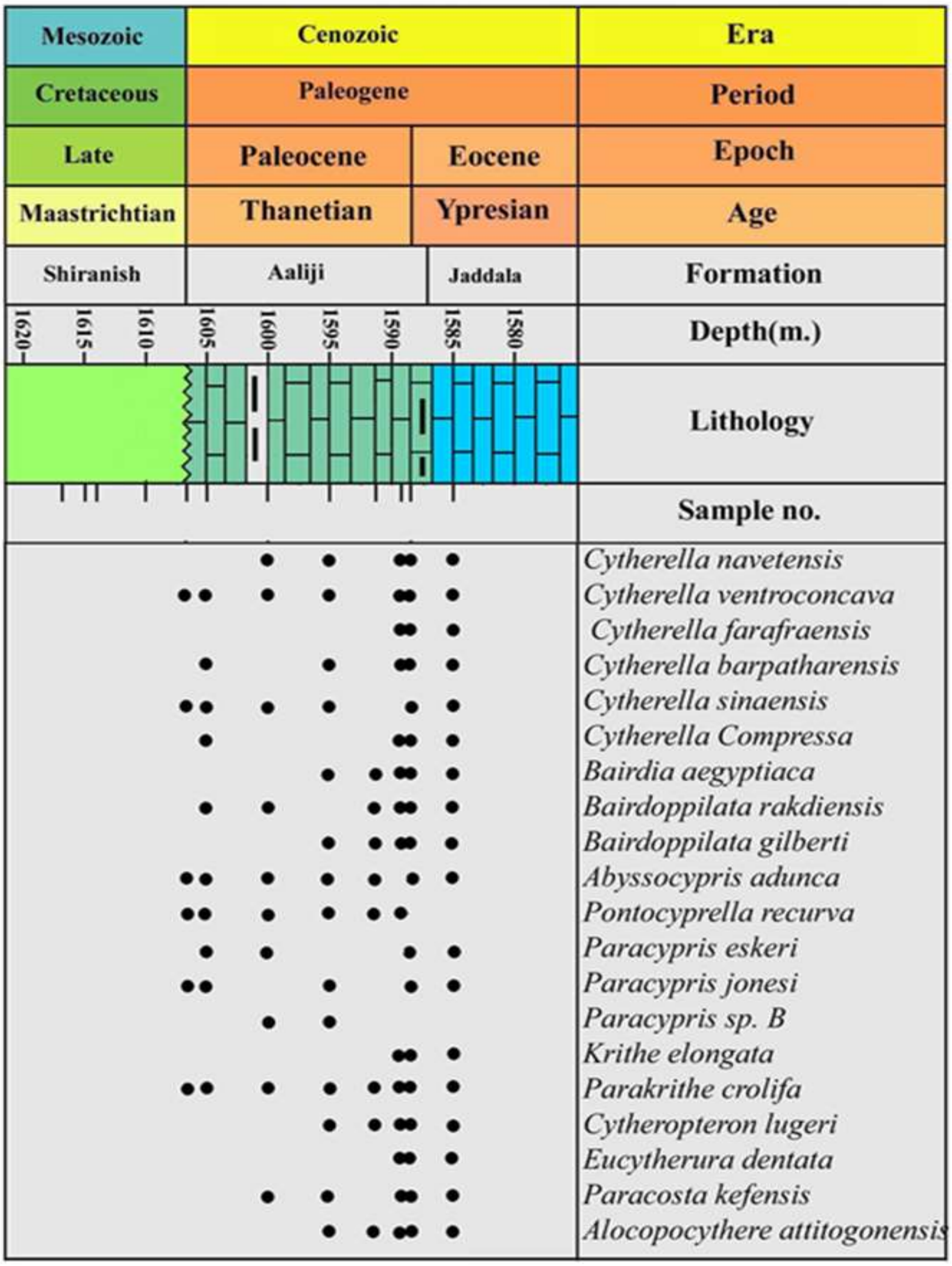

Figure 3: Distribution chart of Ostracoda fossils in the studied section

Many previous researchers have recorded changes in the faunal crowds during this period, including Ostracoda. According to [19], Ostracoda assemblages indicated an ecological response, even if it is limited during PETM, due to the increased nutrition supply on the deep seafloor. Also, the study of Speijer and Morsi [20] showed that the PETM period coincided with certain Ostracoda assemblages, and changes occurred related to the rapid changes in sea level.

The Ostracoda fossils picked up are of different ages between individuals in the instars and adult stages. The nature of the picked materials from the residual was varied between valves and carapaces. Ostracoda taxa collected from the upper parts of the Aaliji Formation through depth varies from 1587 m to 1590 m, almost representing the PETM period. This indicated a relative abundance in species (Figure 4a) in addition to the obvious speciation (20 species), especially in limited thickness such as the studied area. The taxa diversity above and below the study area was fair to good (Figuer4c), but the number of individuals was significantly lower. Most of the diagnosed species differ from those recorded of the same age and environment in other regions of the world, in particular the depth such as those diagnosed by [21] in Tunisia or the identified taxa by [20] on the western side of the Tethys in Egypt or the study of [22] in Spain at southwest Europe. Perhaps the reason is the different biogeographical provinces in the other regions.

It is known that the depth varies in the sedimentary basin from one region to another, and each depth has indicated genera and species in addition to the indicated assemblages of Ostracoda, which is used to infer the depth. Ozawa [23] mentioned that Ostracoda occurs in all aquatic environments and depths. Still, the number of individuals increases on the continental shelf, while it decreases with the increase in depth within the bathyal environment.

In the study section, it turns out that most of the diagnosed Ostracoda species (Plate 3) have adapted themself in deep water, where they are smooth and not highly calcified. Most of them have no eyespot, are significant in size, widespread, low in diversity, and psychosphere, which agrees with Stokke et al. [24].

By tracing the stratigraphic distribution of Ostracoda (Figure 3), it is clear that the species which appeared at the end of Thanetian and the early beginning of Yepresian represented the upper part of the Aliji Formation have good speciation (Figure 4c). They have a good abundance sort (Figure 4a) relative to the same species at the beginning of the L. Paleocene.

Most of the species before and during the episode of PETM episode were present at the bottom. Still, the abundance differed, and there was the beginning of L. Paleocene and then disappeared and reappeared during PETM, such as the species belonging to the genera of *Paracypris*, *Krithe*, and *Parakrithe*. The genus *Paracypris* is observed at the bottom of the studied section with a high abundance ranging between the middle shelf and the middle slope, as mentioned in [25]. Individuals began to gradually decrease in number upwards until the end of the Paleocene indicating changes in their common environment (deep environment) due to the decrease in the water depth due to the decrease in sea level, then the species reappeared again at the end of the upper Late Paleocene -lower Early Eocene, but with sparse numbers than the previous one with a rise in relative sea level and depth increase, and this was also confirmed in the study of [20].

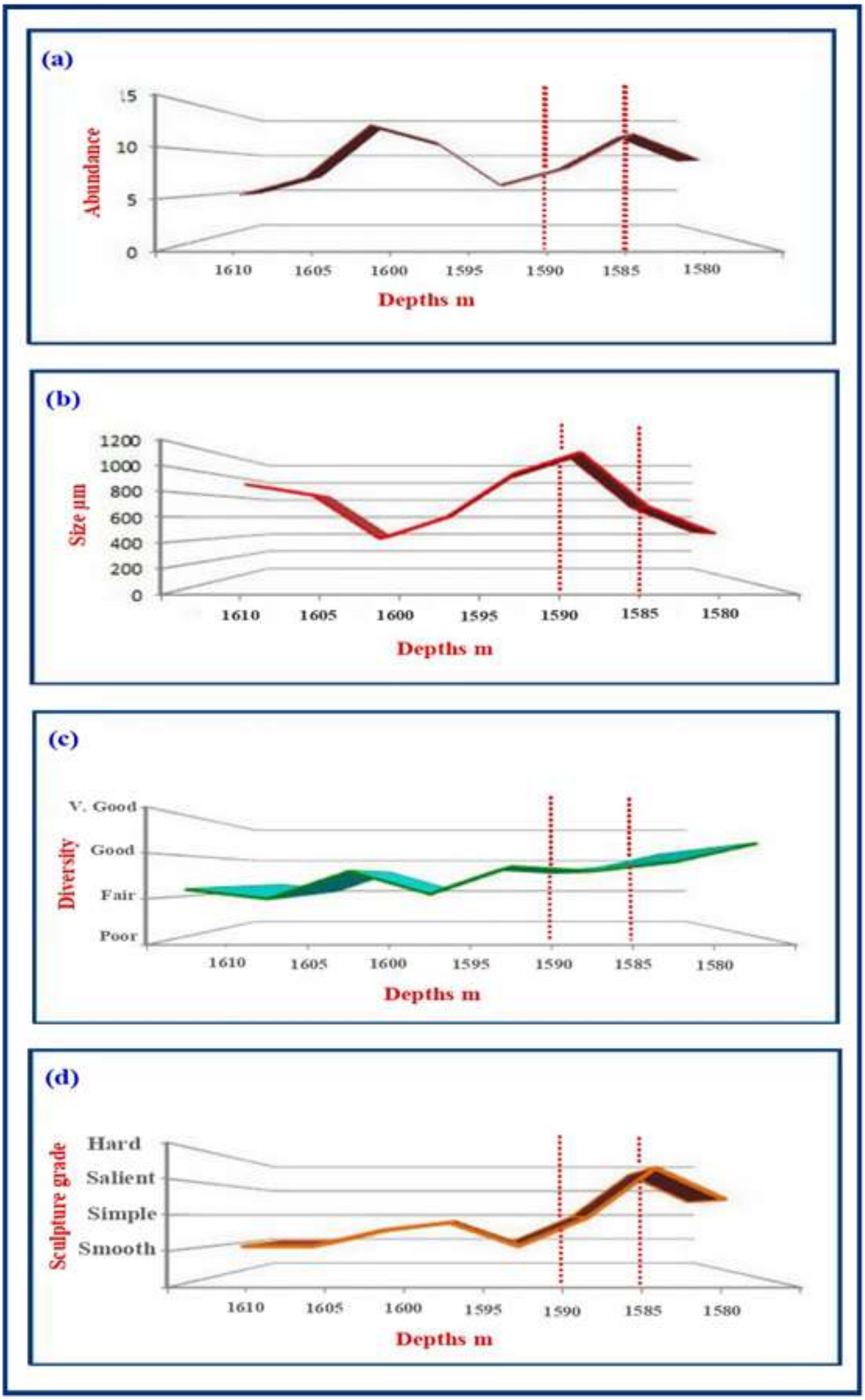

Figure 4: Changes associated with variation in depths in Ostracoda fossils above, during, and below the PETM episode in the studied section. (a) Abundance. (b) Size. (c) Diversity. (d) Sculpture grade.

Likewise, the genera *Krithe* and *Parakrithe* live in an environment with a depth of at least 200 m and up to 1000 m or more [26]. These genera appear again (juvenile and adult individuals) at the end of the Late Paleocene to the beginning of the Early Eocene with large sizes (Figure 4b). The few specimens indicate an increase in the water column during the PETM event, representing an environment of the upper slope and the beginning of the middle slope. The samples from the Early Eocene (lower part of the Jaddala Formation) show that most species remain the same in terms of distribution, speciation, and good abundance (Figuer4a), accompanied by decreasing in the water depth. This is evident through the small size of the valves and the emergence of some species with ornamentation that were not previously recognised on it (Figuer4d), particularly in the genera *Eucytherura*, *Paracosta*, and *Alocopocythere*.

The high occurrence of *Paracosta kefensis* in samples at depths ranging from 1585 to 1592 m indicates the rise in relative water level. It is an indicator of an improvement in the amount of nutrition and low oxygen [20].

The species *Alocopocythere attitogonensis* appeared in few numbers during the PETM event and continued beyond (Early Eocene) with a noticeable increase in the number of its individuals. This was due to the ability to adapt and high endurance to the various changes in environmental conditions [27]. This was represented mainly by the low percentage of oxygen during the PETM, which showed its repercussions on this species in the studied section through the appearance of its valves in a grey colour that often appears on the Ostracoda valves carapaces in the reduction environment.

Bassiouni and Luger [28] observed a relatively slow replacement in the widespread identified Ostracoda assemblages in the southern part of the Tethys, with the species diagnosed in central and southern Egypt. Thus, they provide good evidence that changes in Ostracoda assemblages are part of the evolutionary transition in these assemblages during the PETM episode.

Dickson *et al*. [29] mentioned that the major and trace elements, iron diversity and the biomarker evidence denote an oxygen deficiency (anoxia) in most water masses during PETM time due to the higher POC rate supply and the weathered clastic sediments such as silt and clay. They also elucidate that high oxygen consumption rates may mainly cause anoxia due to the swift supply of nutrients and terrestrial obtained organic substances or the renovation of phosphor from the sediment in the sea and ocean floors.

The predominance of some indicated assemblages during the PETM, such as the assemblage of *Cytherella*, *Bairdia*, *Cytheropteron*, *Krithe*, and *Parakrithe* indicates a deep environment of more than 1000m [30; 31], which is deeper than the environment at the beginning of the section from the bottom. Also, species belonging to the genera *Cytherella*, *Bairdia*, *Argilloecia*, *Parakrithe*, and *Abyssocypris* within the PETM close to the boundary between the Paleocene and a little to the Early Eocene indicate an open marine environment [32]. In addition, the assemblage (*Parakrithe*, *Krithe*, *Argilloiecea*, *Cytherella*, *Bairdia*, and *Bairdoppilata*) are there in the upper slope - middle slope [33].

It is noticeable that most of the identified genera were present at the beginning of the L. Paleocene (Thanetian) with good numbers and fair abundance. Some of them gradually disappear towards the end of the Late Paleocene indicating a decrease in depth. During the

PETM event in the upper Late Paleocene to the beginning of the Early Eocene (Ypresian), the species and assemblages indicate the depth increased due to a rise in the water column.
The Aaliji Formation is dominated by the deep environment. It extends from the middle shelf-the mid of the middle slope. At the same time, limited samples studied from the lower part of the Jaddala Formation indicated a predominant environment is the end of the middle shelf - the beginning of the upper slope.

3.6 Geophysical data

The geophysical analysis of the gamma-ray log (Figuer 5) showed that the zone confined between the depth of 1589-1609 m (Aaliji formation) is characterised by the contact between Aaliji and Jaddalah Formations. The upper contact begins with a relatively significant shale amount to reach about 64%. It then decreases rapidly at a depth of 1589 m to continue gradually decreasing (1601-1601.5 m) until it reaches the lower limits of this zone (1609 m). The shale amount begins to increase uniformly below this depth, which may represent the upper contact of the Shiranish Formation.
The acoustic probe analysis clearly showed the zone limits, as a clear increase in the seismic velocity (Figure 5) ranging between 3400 and 4100 m/sec, and a relative decrease in the primary porosity to reach less than 20 %.

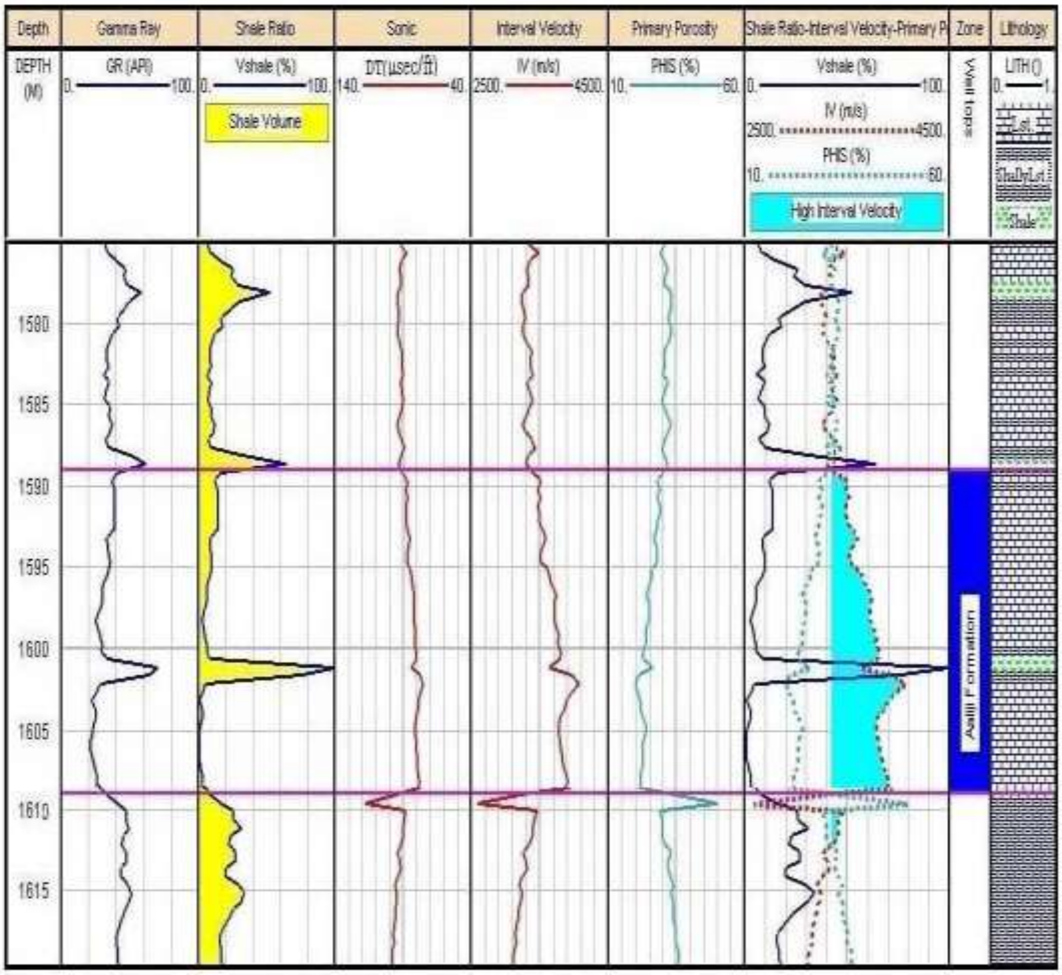

Figure 5: Analysis of geophysical logs

4. Conclusions

This study deals with calcareous nannofossils and Ostracoda in twelve rock samples from Aaliji and Jaddala formations in Balad-8 well, Central Iraq.

The study recorded twenty-four species of calcareous nannofossils and twenty species of Ostracoda fossils. The studied section was divided into two biozones depending on the calcareous nannofossils from the base as follows:

1. *Discoaster nobilis* Interval Biozone (CP7).
2. *Discoaster multiraditus* Interval Biozone (CP8).

The biozones were locally and regionally emulated with their counterpart biozones which inferred the age of Late Paleocene-lower Early Eocene for the Aaliji Formation and Early Eocene for the Jaddala Formation.

Ostracoda fossils highlighted the variations in the paleoenvironment through changes in the living style and abundance of these fossils during the PETM event and pre and post this episode.

A good compatibility in the Aliji Formation thickness from the geophysical well log analysis and the results of the calcareous nannofossils and Ostracoda.

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