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Micropaleontological data from the Upper Jurassic–Lower Cretaceous Chia Gara Formation (northeastern Iraq) – preliminary results

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Key words: Arabian Plate, open marine, biostratigraphy, radiolarians, calcareous dinocysts, calpionellids, foraminifera.

Abstract. The Upper Jurassic–Lower Cretaceous Chia Gara Formation from northeastern Iraq (Surdash and Zeni Warte sections) is composed mainly of shales and limestones. The shales contain phacoid compressional structures in the lower part, while the limestones are rich in ammonites, which are mostly pyritized and oxidized. Poorly preserved microfossils include numerous radiolarians, as well as rare calcareous dinoflagellate cysts, benthic and planktic foraminifera, and – in the upper part of the sections – numerous nannoconids. Calcareous dinocysts, such as *Colomisphaera tenuis* (Nagy), *Colomisphaera lucida* Borza, and *Colomisphaera* cf. *heliosphaera* (Vogler) confirm the Late Tithonian and Berriasian age of the formation. The planktonic foraminifera *Globuligerina bathoniana* (Pazdrowa) suggests the (Middle? Upper?) Jurassic age of the lower part of the formation. In the upper part, the presence of *Lilliputianella eocretacea* (Neagu) and *Hedbergella* ?*handousi* (Salaj) confirmes the Early (?) Cretaceous age. The radiolarians obtained represent the Nassellaria order. The first occurrence of *Pseudodicytomitra* cf. *carpatica* (Lozyniak) and *Holocryptocanium barbui* Dumitrica, together with *Loopus* cf. *primitivus* (Matsuoka et Yao) and the genus *Zhamoidellum* confirm the latest Tithonian age in the lower part of the Zeni Warte section. A transition from predominantly clay-rich radiolarian facies to more calcareous nannoconus facies is noted. The presence of pelagic microfossils, along with the lithology, a limited influx of siliciclastic silt, and an absence of coarser siliciclastic materials, indicates that deposition occurred in an open marine, at least a deep shelf, environment.

INTRODUCTION

The Jurassic–Cretaceous (J/K) transition is marked by considerable geological and environmental changes, coupled with increased tectonic activity on both regional and global levels, as well as significant palaeoceanographic changes (Wimbledon, 2008; Wimbledon *et al.*, 2016; Barragán *et al.*, 2020; Michalík *et al.*, 2021). The study of various microfossils offers crucial insights into relative water depth, temperature variations, sea level changes, and shifts in palaeoceanography, which can be utilized to understand major palaeoceanographic transformations at the J/K boundary (Bjørklund, Swanberg, 1987; Erbacher *et al.*, 1996; Dubicka, Peryt, 2012; Scott, 2019). The Chia Gara Formation was deposited in the Late Jurassic and Early Cretaceous and its recognition is important for determination of palaeoenvi-

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ronmental conditions during the J/K boundary on the Arabian Plate.

The first description of the Chia Gara Formation by Wetzel (1950 in Van Bellen *et al.*, 1959) was achieved at the type locality in the Chia Gara Anticline, south of Amadia town, High Folded Zone of Iraq (Fig. 1a). The formation has a thickness of 232 meters, consisting of a sequence of thinly bedded limestones and shales that host abundant ammonite faunas (Al-Abbasi *et al.*, 2018). The Chia Gara Formation passes upwards into a unit of yellowish marly limestone and shale, which includes a 21-meter thick layer of compressional (phacoid) structures at its base (Van Bellen *et al.*,

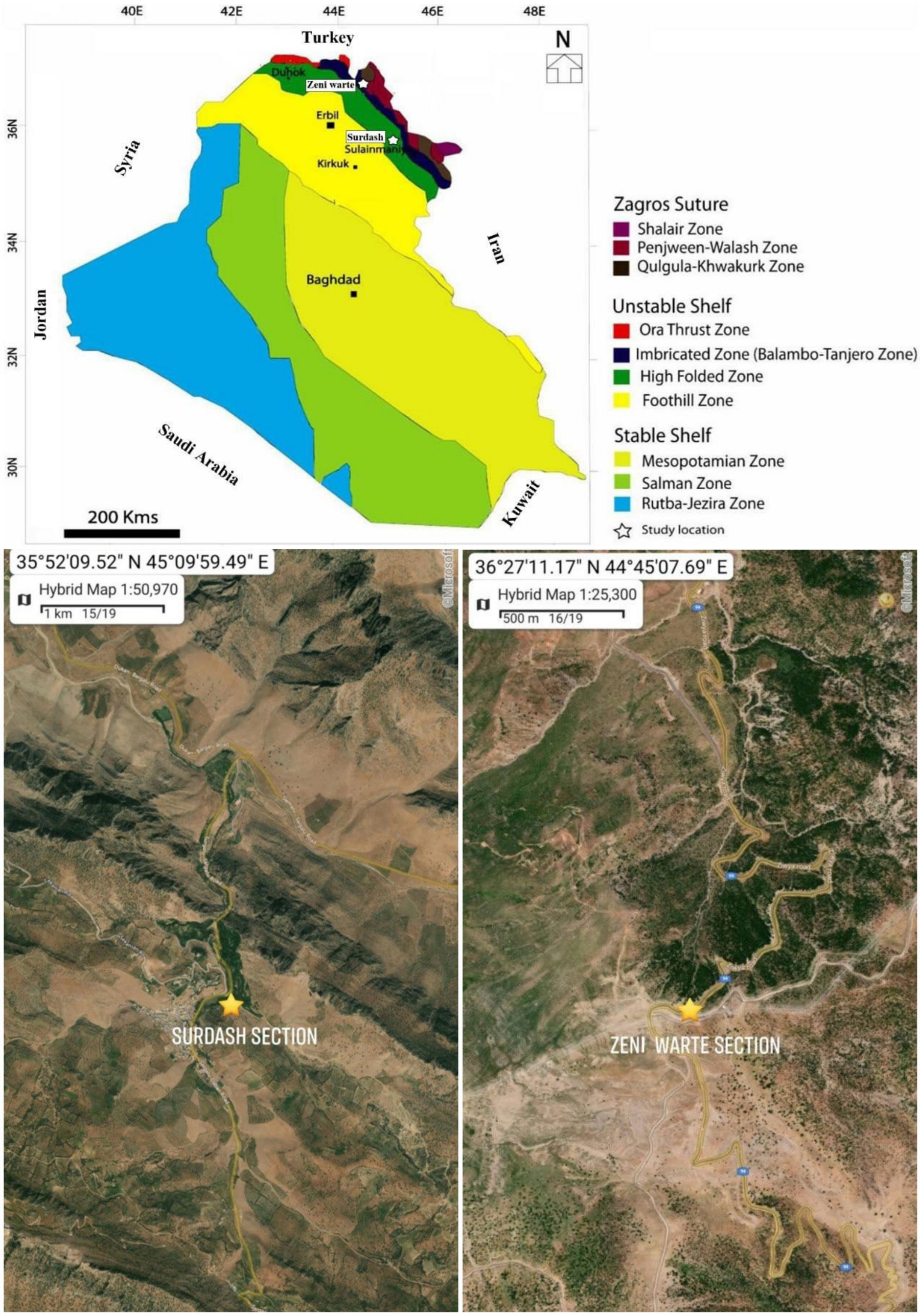

Fig. 1A. Tectonic map of Iraq with the location of the studied sections within the High Folded and Imbricated Zones (modified from Jassim, Buday, 2006) and with google maps with the position of the studied sections: **B.** Surdash section; **C.** Zeni Warte section

1959). Based on petrographic and facies descriptions, the depositional environment was considered as deep marine (Al-Qayim, Saadallah, 1992; Sherwani, Edilbi, 2019) within deep outer shelf to carbonate slope environments (Mohialdeen, 2008). A deep marine environment was also determined using palynofacies description of the Chia Gara Formation (Naqishbandi, 1999). The formation has been investigated in terms of sedimentology, petroleum potentiality and geochemical proxies (Hakimi *et al.*, 2016; Sherwani, Edilbi, 2019; Omar *et al.*, 2023).

The aim of the present research is to obtain new information about the formation and to complement its characterization by integrated micropaleontological data based on calcareous dinocysts, foraminifera and radiolarians, in order to precisely determine its age and the palaeoenvironmental implications.

STUDY AREA AND GEOLOGICAL BACKGROUND

The investigations of the microfossil content of the Chia Gara Formation took place in two outcrops at Surdash and Zeni Warte (Fig. 1A–C). They are situated in northeastern Iraq, at the northeastern boundary of the Arabian Plate. The Surdash section lies in the Surdash Anticline of the Dokan area, Sulaimaniya Governorate at Longitude 45°09'59"E, Latitude 35°52'09"N (Fig. 1B), while the Zeni Warte section is located in the Hendreen Anticline, Erbil Governorate at Longitude 44°45'07"E, Latitude 36°27'11"N (Fig. 1C). This area signifies the intersection where the continental regions of the Eurasian margin collide with the Arabian Plate (Stampfli, Borel, 2002). Tectonically, these sections are located in the High Folded and Imbricated Zone of Iraq (Fig. 1A), which form a part of the tripartite tectonic divisions of Iraq. These tectonic units are characterized by intense folding and faulting of Mesozoic and Paleozoic successions (Jassim, Buday, 2006).

The sedimentation processes in the Mesopotamian Basin and the Zagros Fold Belt were affected by local tectonic activities, fluctuations in eustatic sea levels, and climatic variations during the Late Mesozoic and Early Cenozoic. From the Jurassic period to the Late Cretaceous, variations in sea-level, along with gradual subsidence, led to the formation of extensive, shallow intrashelf basins along the passive margins of the Neo-Tethys Ocean and the Arabian Plate (Murris, 1980; Alsharhan, Nairn, 1997; Kameran *et al.*, 2023). The Chia Gara Formation originated during the Late Jurassic to Early Cretaceous period, a time characterized by general extension within the deep outer shelf of the Arabian Plate Margins (Numan, 1997). In the Kurdistan region, the Tithonian to Berriasian Chia Gara Formation is observed to be continuous in certain sections, while Berriasian to Valanginian ages are indicated by ammonites (Van Bellen *et al.*, 1959; Howarth, 1992). Six species of ammonites representing a Late Tithonian age were described by Al-Abbasi *et al.* (2018) from the Mateen anticline, Dohuk Governorate, Northern Iraq, these are; *Berriasella privasensis* (Pictet, 1867), *Parodontoceras calistoid* (Behrendsen, 1891), *Parodontoceras* sp., *Spiticeras* (*Kilianiceras*) sp., *Substeueroceras* sp. and *Haploceras* sp.

The Upper Jurassic Barsarin Formation is composed of stromatolitic and dolomitic limestone, argillaceous shales and alternating layers of contorted and brecciated beds (*e.g.*, Al-Banna, Al-Neimi, 2025). The Lower Cretaceous Balambo Formation (*e.g.*, Al-Mutwali *et al.*, 2018) consists of alternating thin, grey marly limestone, limestone, dark grey to black shales, and grey to green marl and nodules of chert (Jassim, Buday, 2006). The upper part of the Balambo Formation might belong to the lowermost upper Cretaceous (Abdullah, Balaky, 2022).

MATERIALS AND METHODOLOGY

Detailed field work in the two sections was conducted to describe the lithology and sedimentary structures and to distinguish the contacts of the Chia Gara Formation with the underlying Barsarin and the overlying Balambo formations. Fifty samples were taken from both sections and some of them were selected for the current micropaleontological study.

Standard thin sections were prepared of 13 samples of the Surdash section and 12 samples of the Zeni Warte section. They were microscopically analysed at the Department of General Geology and Geotourism, Faculty of Geology, Geophysics, and Environmental Protection, AGH University of Krakow, using a Nikon Eclipse LV100 POL optical microscope and micropaleontological analysis were conducted.

Attempts were made to isolate radiolarians from those samples in which they had been observed in the thin sections. For better results three methods of dissolving were used. The first method was dissolving in 10% hydrochloric acid for 6 hours, second method was dissolving in 10% acetic acid for 24 hours, and third method was dissolving of the samples in 8% acetic acid for 2 hours. Afterwards samples were wet sieved through meshes of size 250 and 63 μm and the residue was observed under a binocular microscope. The radiolarians so obtained were badly preserved and were poor in diversity. Scanning electron microscopic imaging was achieved at the Slovak Academy of Sciences in Banská Bystrica, Slovakia. The radiolarians were analyzed by Marína Molčan Matejová, the calpionellids and calcareous dinocysts by Justyna Kowal-Kasprzyk and the foraminifers by Anna Waśkowska.

RESULTS

LITHOLOGICAL COMPONENTS

The analysed sections consist of mixed calcareous-clayey rocks (calcareous shale, marl, marly limestone). The content of clay is largest in the lower part of the sections and decreases towards the top. The distribution of the lithological components and their description is indicated on the lithologic logs and photo documentation in Figures 2–4.

In the Surdash section, the Chia Gara Formation is built of a 114-meter-thick sequence of dark limestone and black shale (Fig. 2). Its lower part contains the phacoid structures within the shale sequences. The limestones are rich in ammonites, which mostly are pyritized and oxidized (Fig. 3A–C).

In the Zeni Warte section (Fig. 4), the formation consists of a 107-meter-thick complex of black shale rich in organic matter. The black shale is intercalated by hard, thin-layered limestones containing ammonites (Fig. 3D, E). The compressional spherical or semi-spherical structures (phacoid) are

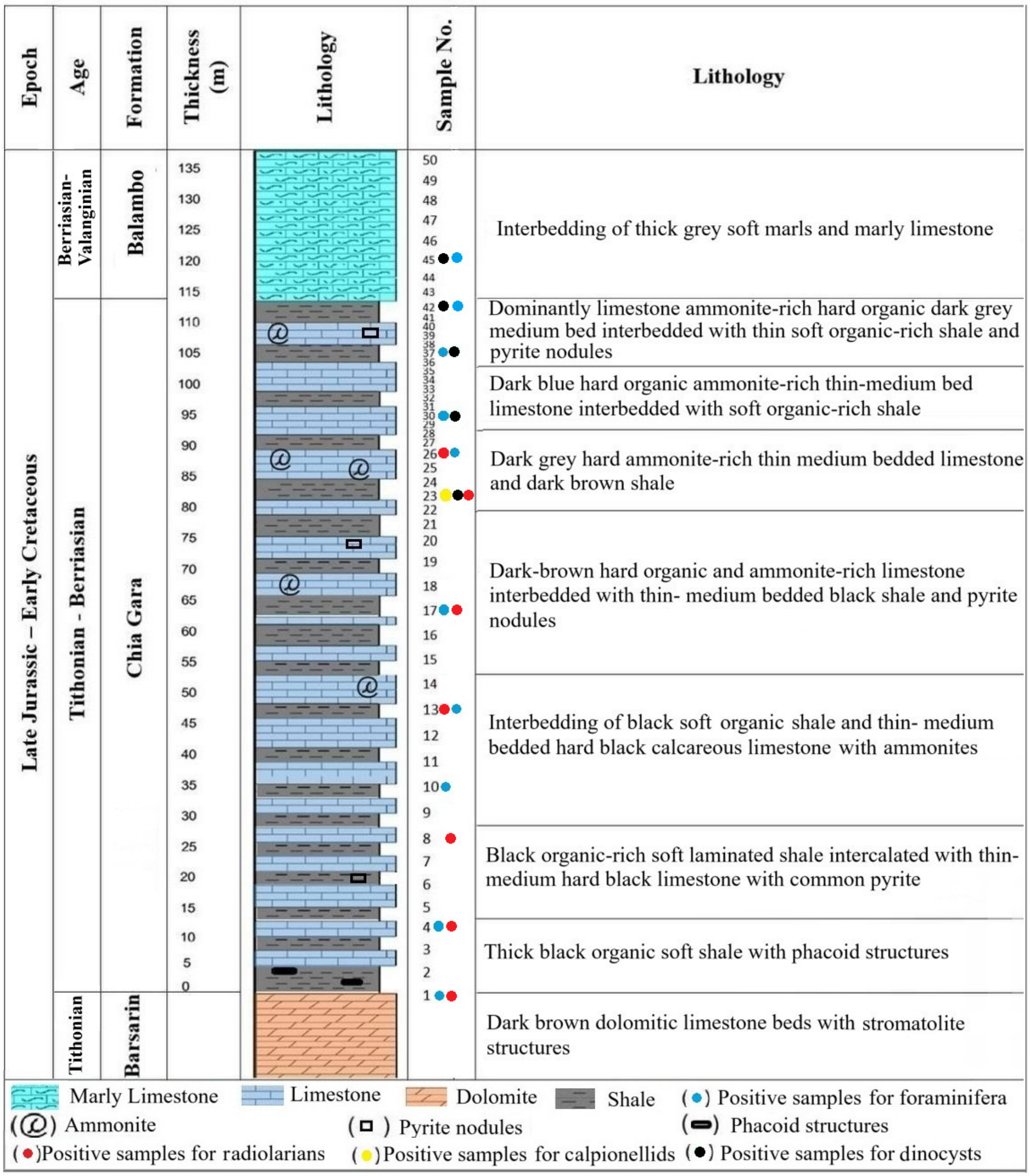

Fig. 2. Lithological log of the Chia Gara Formation, Surdash section and positive samples for microfossils (based on the thin sections study)

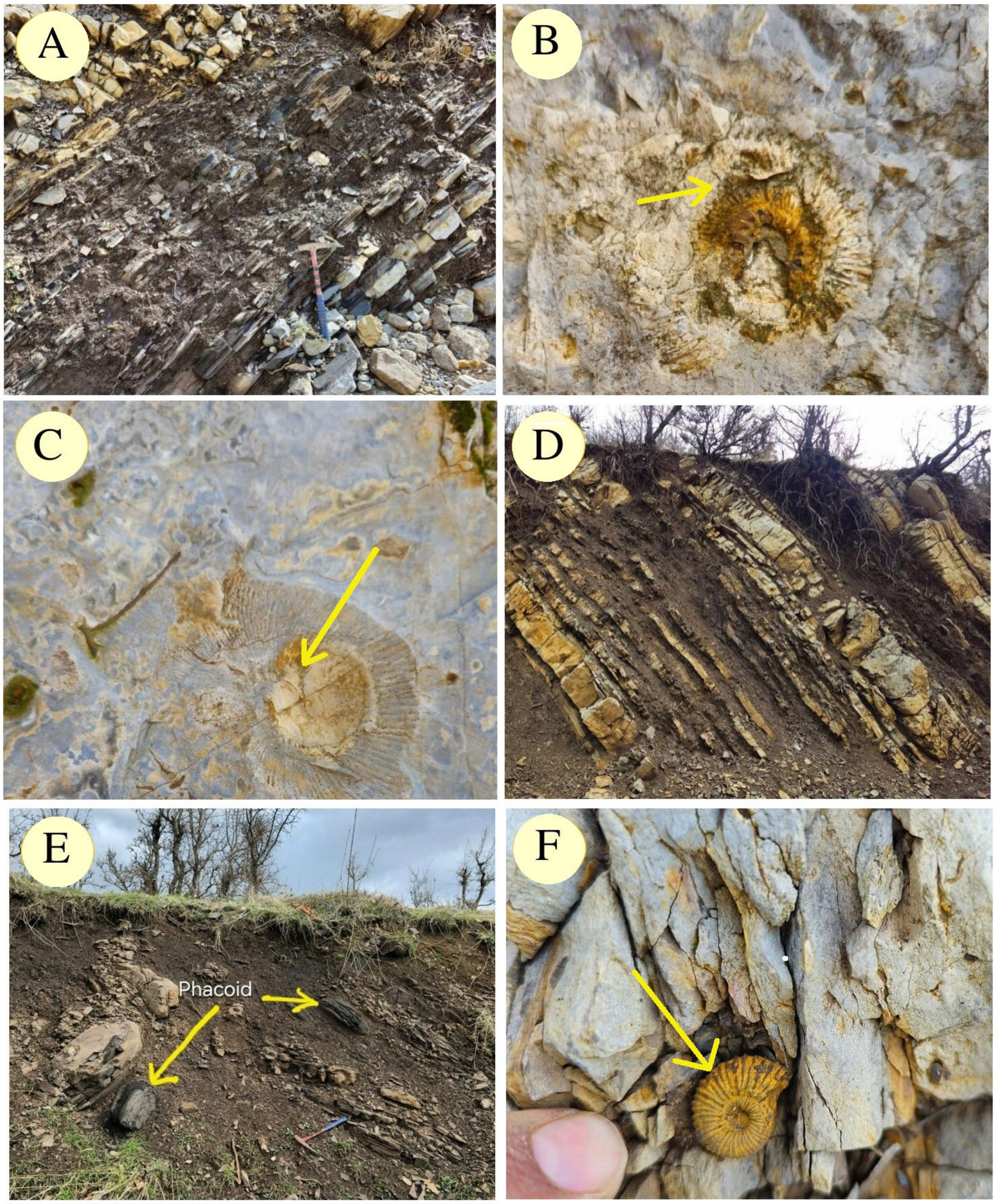

Fig. 3. Field views of the Chia Gara Formation

A. Black organic rich shale alternated with thin-bedded limestone in the Surdash section; **B, C.** Partly oxidized ammonite shells (arrows) common in the limestone and marly limestone of the Surdash section; **D.** Alternating thin to medium bedded limestone with black shale in the Chia Gara Formation, Zeni Warte section; **E.** Phacoid (arrows) in semi-spherical shapes common in the shale of the lower part of the Chia Gara Formation in Zeni Warte section; **F.** Ammonite (arrow) in marly limestone of the Zeni Warte section

present in the lower part of the formation (Fig. 3F). Ball-like bodies within the host rocks are a defining feature of these structures. The size of phacoids is between 20 and 120 cm in diameter. They are more resistant than the host rock. Compression stress and diagenesis processes on the carbonate/shale successions are linked to the mechanism of forming of these carbonate phacoid structures (Ahmed *et al*., 2020).

The abundance of ammonites increases in the limestone layers towards the top of the formation along with the increasing presence of pyrite nodules and organic matter.

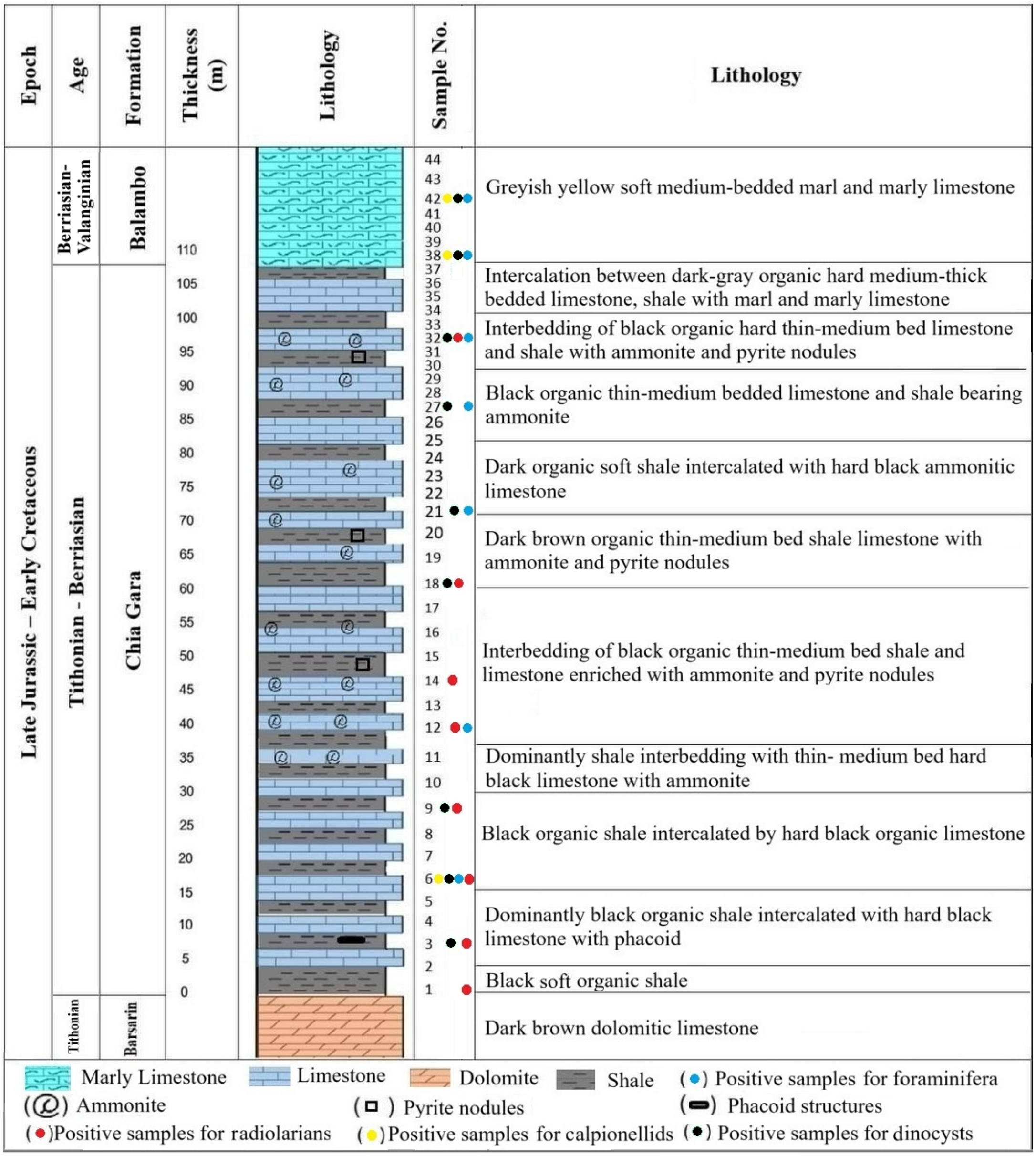

Fig. 4. Lithological log of the Chia Gara Formation, Zeni Warte section and positive samples for microfossils (based on the thin sections study)

BIOSTRATIGRAPHY

Micropaleontological analysis of the Chia Gara Formation in the Surdash (Fig. 5) and Zeni Warte (Fig. 6) sections revealed the occurrence of microfossils representing different groups of organisms. They are dominated by calcified radiolarians (Fig. 7) of various species and genera (Fig. 8), much less common are calcareous dinocysts (Fig. 9.1–9.13). A few specimens that may represent poorly preserved calpionellids were also found (Fig. 9.14, 9.15). Their ranges are indicated in Fig. 10. Rare ostracods are observed in lower parts of the sections (Fig. 9.16) while in their upper parts, numerous nannoconids are observed (Fig. 9.17). Foraminifera are represented by rare planktic and benthic forms (Fig. 11). The overlying Balambo Formation is richer in calcareous microfossils.

Radiolarians

Radiolarians are common in the lower parts of the sections and less frequent in the upper parts (Figs. 2, 4, 7).

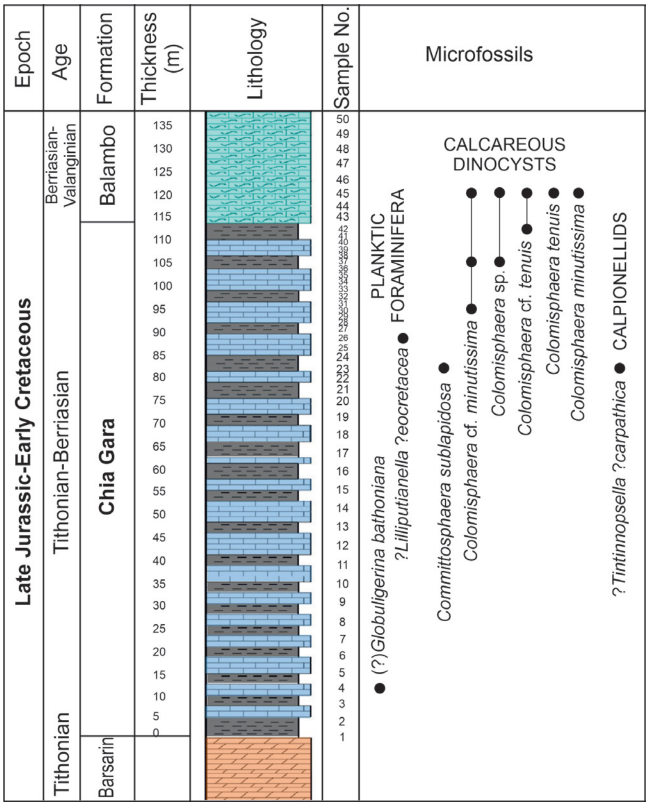

Fig. 5. The most important microfossils of the Surdash section

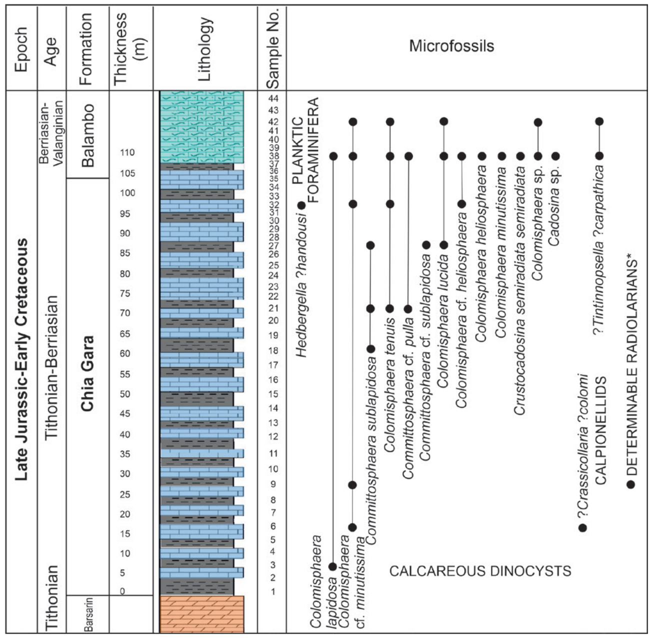

Fig. 6. The most important microfossils of the Zeni Warte section

*taxonomic names of radiolarians – see text and Appendix

Their preservation state and diversity are very poor. An attempt was made to isolate radiolarians from almost all of the samples in which they had been observed in thin sections. A total of 10 samples (No. S13, S14, S18, S26, S36, Z9, Z16, Z18, Z27, Z38) were processed for radiolarian extraction from grey-beige limestone and marly limestone. The radiolarians were mostly calcified, rarely silicified with badly preserved primary structures. Only sample Z9 from the Zeni Warte section was positive in determinable radiolarians.

The studied assemblage is very poor in genera and species, a total of 8 genera being recognized. All of the identified radiolarian genera, obtained in sieved material, belong to the order Nassellaria, the order Spumellaria being missing completely. On the other hand, radiolarians in the thin sections show the prevalence of Spumellarians.

The age assignment is based on the Unitary Association Zones (UAZ) established by Baumgartner *et al.* (1995), for the Tethyan middle Jurassic–Lower Cretaceous.

Sample Z9 from the Zeni Warte section contains a number of forms known to appear in the Upper Jurassic (Fig. 8). Species *Pseudodictyomitra carpatica* (Lozyniak) has been determined to first appear in the upper Tithonian (Goričan, 1994), however other authors describe its first occurrence already in the lower Tithonian (Baumgartner *et al.*, 1995; Dumitrică *et al.*, 2022). Similarly, the species *Xitus* aff. *gifuensis* Mizutani already appears in the upper Kimmeridigan–lower Tithonian (Baumgartner *et al.*, 1995). The assemblage includes the species *Praeparvicingula cosmoconica* (Foreman) (Goričan, 1994) and *Holocryptocanium barbui* Dumitrica (Baumgartner *et al.*, 1995) distinctively appearing in the uppermost Tithonian. In the lower Tithonian the genus *Cryptamphorella*, documented in sample Z9, also starts to appear (O'Dogherty *et al*., 2009). The upper age boundary of the assemblage is characterized by radiolarian species comparable to *Loopus primitivus* (Matsuoka et Yao), ranging up to the early Late Tithonian (Baumgartner *et al.*, 1995), or even Valanginian (Dumitrică *et al.*, 2022). Other determined species and genera in the sample are wide ranging. Based on the occurrence of *Pseudodictyomitra* cf. *carpatica* (Lozyniak) and of the frequently present *Holocryptocanium barbui* Dumitrică appearing in the uppermost Tithonian, together with *Loopus* cf. *primitivus* (Matsuoka et Yao), the age of the sample is set as probably latest Tithonian (UA Zone 13; Baumgartner *et al.*, 1995). The studied radiolarian assemblage is not only poor in preservation (many specimens determined as *conformis*) but also poor in species diversity, therefore the precise age determination is difficult.

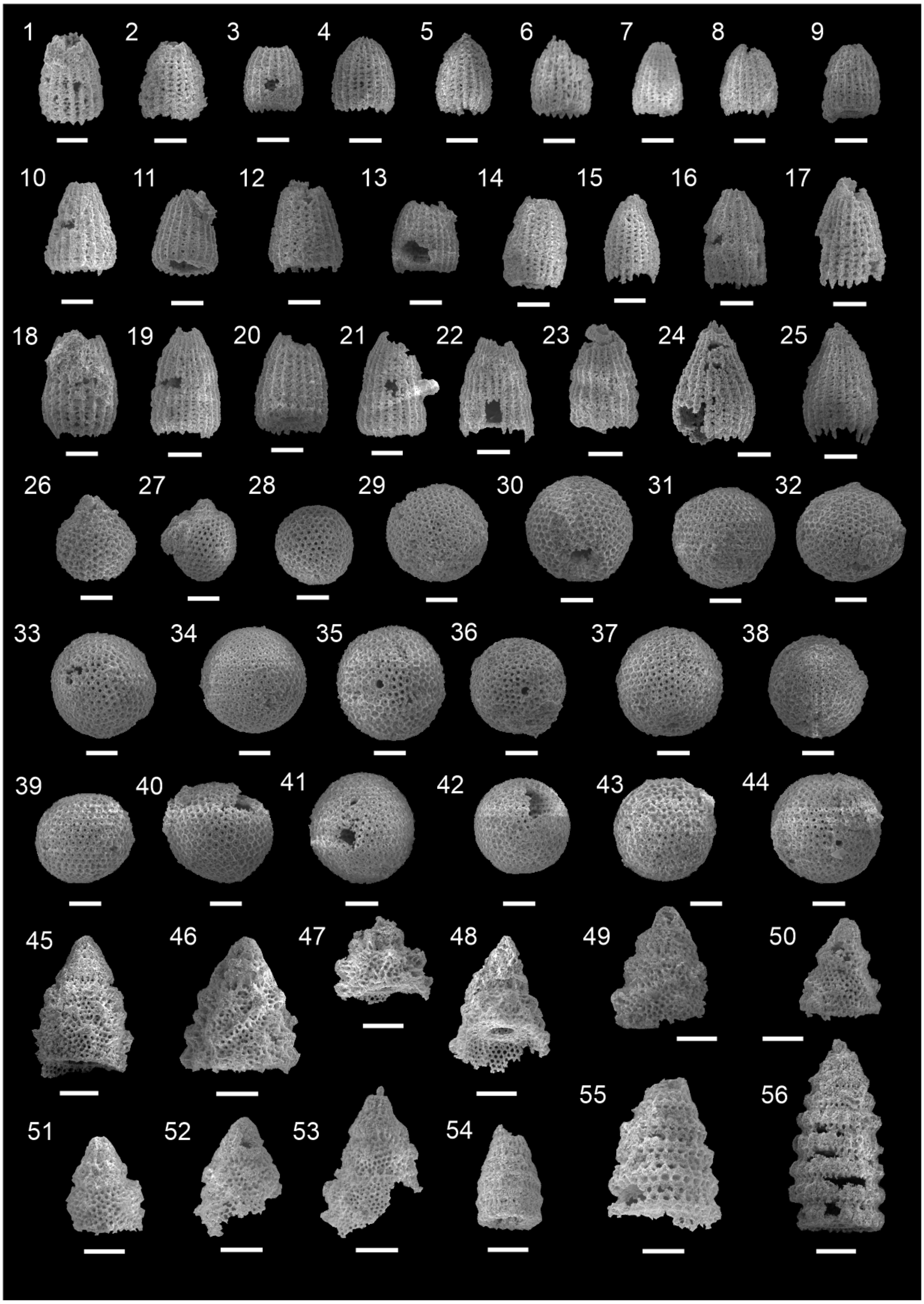

Fig. 7. Radiolarians from the Chia Gara Formation at Zeni Warte section, Z9 sample

1–9. *Thanarla patricki* (Kocher); **10, 11.** *Thanarla* cf. *patricki* (Kocher); **12–25.** *Archaeodictyomitridae* sp.; **26, 27.** *Cryptamphorella* sp.; **28–44.** *Holocryptocanium barbui* Dumitrică; **45.** *Xitus* aff. *gifuensis* Mizutani; **46–49.** *Xitus* sp.; **50–53.** *Eucyrtidiiae* sp.; **54.** *Loopus primitivus* (Matsuoka et Yao); **55.** *Praeparvicingula cosmoconica* (Foreman); **56.** *Pseudodictyomitra* cf. *carpatica* (Loyzniak). Scale bar is 50 μm

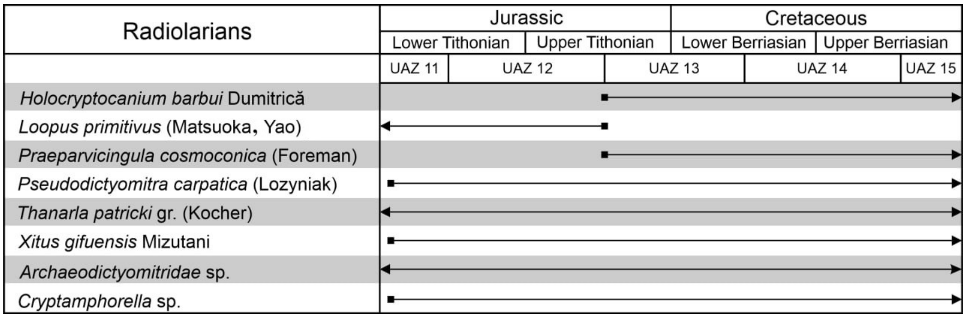

Fig. 8. Known ranges of radiolarian species and genera from the sample Z9, Chia Gara Formation

Calcareous dinocysts

Surdash section. In the samples of the lower part of the section, calcareous dinocysts were not found (Fig. 5). In sample S23 *Committosphaera sublapidosa* appears. *Colomisphaera* cf. *minutissima* was found in samples S30 and S37. In the uppermost studied sample of the Chia Gara Formation (S42) *Colomisphaera* cf. *tenuis* was observed. In sample S45, representing the lower part of the overlying Balambo Formation, calcareous dinocysts are quite common and represented by *Colomisphaera* cf. *tenuis*, *Colomisphaera tenuis*, *Colomisphaera* cf. *minutissima*, *Colomisphaera minutissima* and *Colomisphaera* sp.

Zeni Warte section. In sample Z3 *Colomisphaera lapidosa* (Vogler) was found (Fig. 6). *Colomisphaera* cf. *minutissima sensu* Borza was observed in samples Z6 and Z9. Sample Z18 included *Committosphaera sublapidosa* (Vogler). Specimens of this species were observed also in sample Z21, together with *Colomisphaera tenuis* (Nagy) and *Committosphaera* cf. *pulla* (Borza). In sample Z27 *Committosphaera sublapidosa* co-occurs with *Committosphaera* cf. *sublapidosa* and *Colomisphaera lucida* Borza. Sample Z32 includes *Colomisphaera* cf. *minutissima*, *Colomisphaera* cf. *heliosphaera* (Vogler) and *Colomisphaera tenuis*. Samples representing the lower part of the overlying Balambo Formation are richer in calcareous dinocysts, such as *Colomisphaera lucida*, *Colomisphaera tenuis*, *Colomisphaera* cf. *minutissima*, *Colomisphaera minutissima*, *Colomisphaera heliosphaera*, *Colomisphaera* cf. *heliosphaera*, *Colomisphaera lapidosa*, *Crustocadosina semiradiata semiradiata* (Wanner), *Committosphaera* cf. *pulla*, *Colomisphaera* sp., *Cadosina* sp.

Generally calcareous dinocysts are rare and present mainly in the upper part of the section, especially in the overlying lower part of the Balambo Formation. They are represented mainly by relatively long ranged species (known ranges after *e.g.*, Reháková, 2000; Olszewska, 2005; Grabowski *et al.*, 2016; Petrova *et al.*, 2019; Kietzmann *et al.*, 2023; Lodowski *et al.*, 2025) (Fig. 10) *Committosphaera sublapidosa*, *Colomisphaera* cf. *minutissima*, *Colomisphaera lapidosa*, are known from the Upper Jurassic and lowermost Cretaceous deposits. Stratigraphically more significant are *Colomisphaera tenuis* typical for the upper Tithonian and Berriasian, *Colomisphaera lucida* Borza known from the Berriasian and Valanginian, and *Colomisphaera* cf. *heliosphaera* described from the middle part of the Berriasian up to the lower Albian. The occurrence of *Committosphaera* cf. *pulla* – probably in the Berriasian part of the section – may be explained by reworking or a longer range of the species in this area, as generally *C. pulla* is known from the upper Kimmeridgian to the middle part of the Tithonian.

Calpionellids

A few specimens resembling poorly preserved calpionellids were found in both studied sections (Fig. 9.14, 9.15). In the lower part of the Zeni Warte section (Z6) a specimen resembling a silicified *Crassicollaria colomi* Doben – known from the uppermost Tithonian and, less often, the lowest Berriasian – was recognized. In the overlying Balambo Formation. (samples Z38, Z42) specimens that can be related to *Tintinnopsella carpathica* (Murgeanu et Filipescu) – typical for the upper Tithonian and lowest Cretaceous – appear (ranges of calpionellids after *e.g.*, Reháková, Michalík, 1997; Lakova, Petrova, 2013). In the Surdash section the occurrence of calpionellids is even more problematic (Figs. 5, 9).

Foraminifera

Foraminifera are very rare and very poorly preserved (Fig. 11). Benthic foraminifera occur more frequently and have been observed in both sections in samples S4, S10, S30, S37, Z6, Z21, and Z27 (Figs. 2, 4). They are represented by stratigraphically irrelevant calcareous forms, mostly

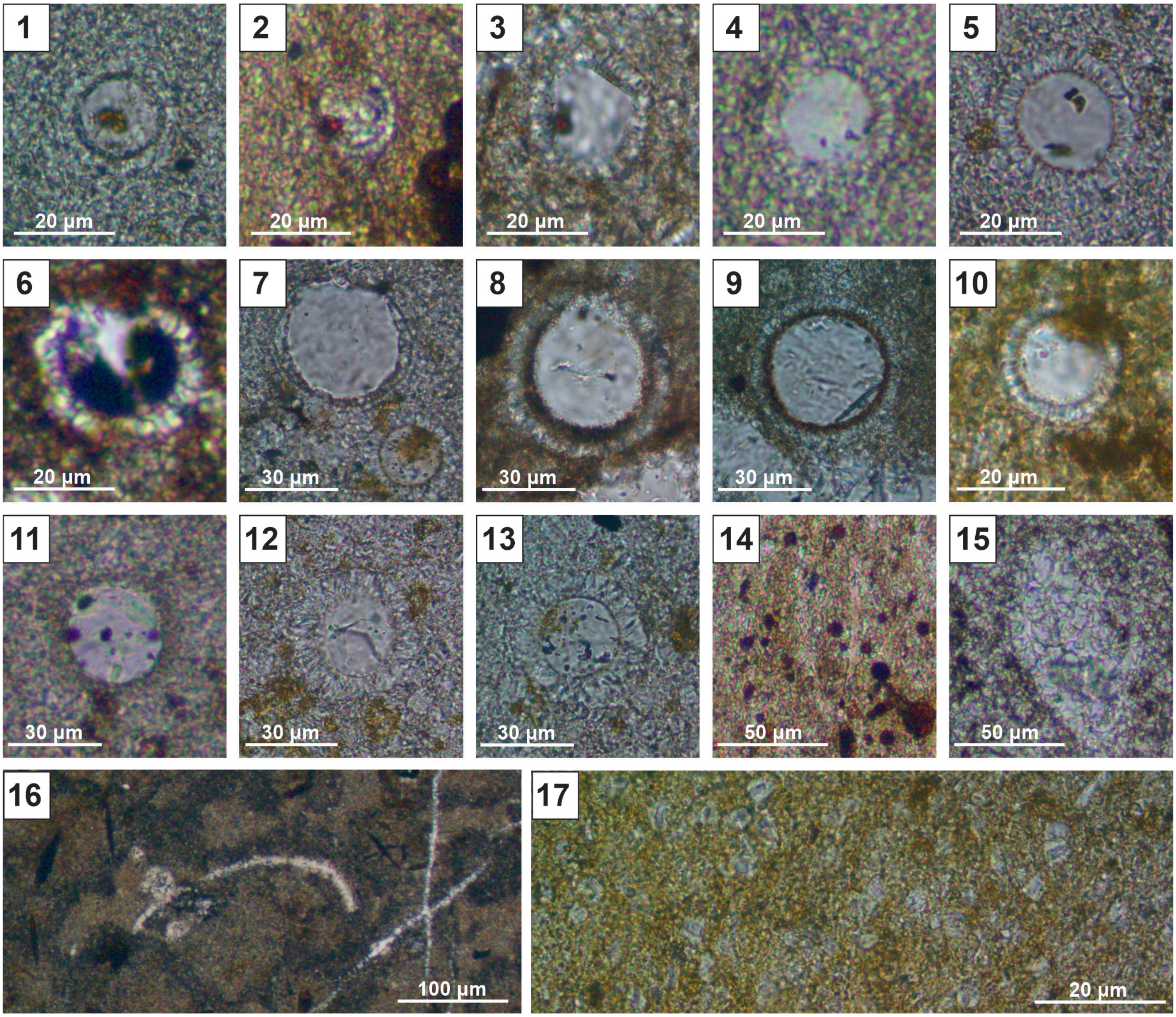

Fig. 9. Calcareous microfossils

1. *Committosphaera* sp. (sample S37 – Chia Gara Formation); **2.** *Colomisphaera* cf. *tenuis* (sample S42 – Balambo Formation); **3.** *Colomisphaera tenuis (*Nagy) (sample Z21 – Chia Gara Formation); **4.** *Colomisphaera* cf. *minutissima sensu* Borza (sample S37 – Chia Gara Formation); **5.** *Colomisphaera minutissima sensu* Borza (sample Z38 – Balambo Formation); **6.** *Colomisphaera lapidosa* (Vogler) (sample Z3 – Chia Gara Formation); **7.** *Crustocadosina semiradiata semiradiata* (Wanner) and *Colomisphaera minutissima sensu* Borza in the lower right corner (sample Z38 – Balambo Formation); **8.** *Committosphaera sublapidosa* (Vogler) (sample Z18 – Chia Gara Formation); **9.** *Committosphaera* cf. *pulla* (Borza) (sample Z21 – Chia Gara Formation); **10.** *Colomisphaera lucida* Borza (sample Z27 – Chia Gara Formation); **11.** *Cadosina* sp. (sample Z38 – Balambo Formation); **12.** *Colomisphaera* cf. *heliosphaera* (Vogler) (sample Z38 – Balambo Formation); **13.** *Colomisphaera heliosphaera* (Vogler) (sample Z38 – Balambo Formation); **14.** Silicified calpionellid? (?*Crassicollaria* ?*colomi* Doben) (sample Z6 – Chia Gara Formation); **15.** Calpionellid? (?*Tintinnopsella* ?*carpathica* (Murgeanu et Filipescu)) (sample S23 – Chia Gara Formation); **16.** Ostracod carapace (sample S10 – Chia Gara Formation); **17.** Nannoconids (sample Z27 – Chia Gara Formation)

Lenticulininae, Nodosariana, and *Involutina* and belong to long-ranged and common taxa in the Upper Jurassic and the Lower Cretaceous.

Planktic foraminifera occur in both studied sections, in samples S1, S4, S17, S26, Z12, Z32, and Z38. They are strongly recrystallized, locally pyritized, and mostly preserved as internal fillings of *Hedbergella-Lilliputianella* and *Globigerinelloides*-type morphotypes. Due to their state of preservation, all determinations are uncertain. Among the highspired foraminifera, a pyritized (?)*Globuligerina ba-*

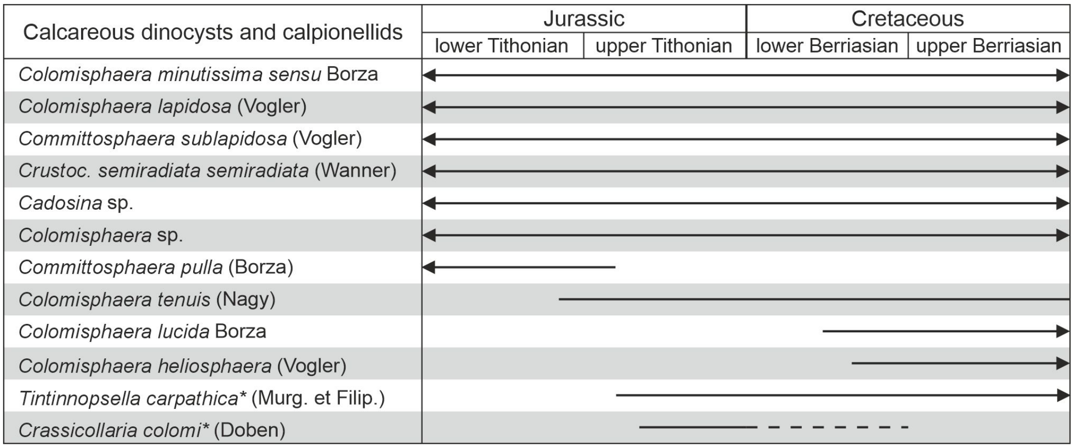

Fig. 10. Known ranges of calcareous dinocysts and calpionellids recognized in the studied sections

*doubtful occurrence in the studied samples

thoninana (Pazdrowa) was identified in the lower part of the Surdash section (S4 sample) indicating the Jurassic age of the deposits, while in upper part of the section ?*Lilliputianella* ?*eocretacea* (Neagu) (sample S26) and *Hedbergella* ?*handousi* (Salaj) (sample Z32) suggest a Cretaceous age (Fig. 11). A pyritized and very small specimen resembling ?*Hedbergella* ?*handousi* (Salaj) occurred in S1 sample. In the samples from the Balambo Formation (Zeni Warte section), *Hedbergella*-type, *Globigerinelloides*-type and *Favusella*-type planktonic foraminifera are present suggesting an Early Cretaceous age.

The known ranges of the planktonic foraminifera observed in the two studied sections are (after Gradstein *et al.*, 2017a, 2019; Huber *et al.*, 2022):

Favusella sp. (Berriasian–Cenomanian)

Hedbergella handousi (Salaj) (Berriasian–Hauterivian)

Lilliputianella sp. (Berriasian–Aptian)

Lilliputianella eocretacea (Neagu) (Berriasian–lower Aptian)

Globigerinelloides sp. (Valanginian–upper Albian)

Globuligerina bathoniana (Pazdrowa) (Bajocian–Tithonian).

DISCUSSION

STRATIGRAPHICAL AGE

Previous studies have shown that the age of the Chia Gara Formation is considered as Late Jurassic–Early Cretaceous based on ammonites (Van Bellen *et al.*, 1959; Howarth, 1992). The Late Jurassic age is also suggested based on a palynological study from subsurface sections in central Iraq (Naqishbandi, 1999).

The presented results confirm the previous study on the biostratigraphy of the Chia Gara Formation, although due to the restricted number of microfossils and their state of preservation, their resolution is limited. A fairly distinct signal based on radiolarians originates from sample Z9 of the lower part of the Zani Warte section. Based on the first occurrence of *P. carpatica* and of the frequently present *H. barbui* appearing in the latest Tithonian, together with *L. primitivus* and genus *Zhamoidellum* having its last occurrence in the Late Tithonian, the age of the sample is set as probably latest Tithonian (UAZ 13).

Calcareous dinocyst data provide only limited biostratigraphic data for the Surdash section. They are missing in the lower part of the section, and in the upper part only long-ranged Upper Jurassic–lowermost Cretaceous species are present. The uppermost studied sample (S45), representing lowest part of the overlying Balambo Formation (Fig. 4) – included *Colomisphaera tenuis* typical for the upper Tithonian–Berriasian. Slightly more data was provided by the dinocysts from the Zani Warte section. In the samples of the lower part of the section only rare, relatively long-ranged specimens of calcareous dinocysts were observed, but the occurrence of single fossils resembling calpionellid species *Crassicollaria colomi* suggests most probably a latest Tithonian age. In the higher part of the Chia Gara Formation the dinocyst *C. tenuis* indicates a Late Tithonian or Berriasian age. The occurrence of *Colomisphaera* cf. *heliosphaera* and *Colomisphaera lucida* in the upper part of the Chia Gara Fm. suggest an age not older than Berriasian.

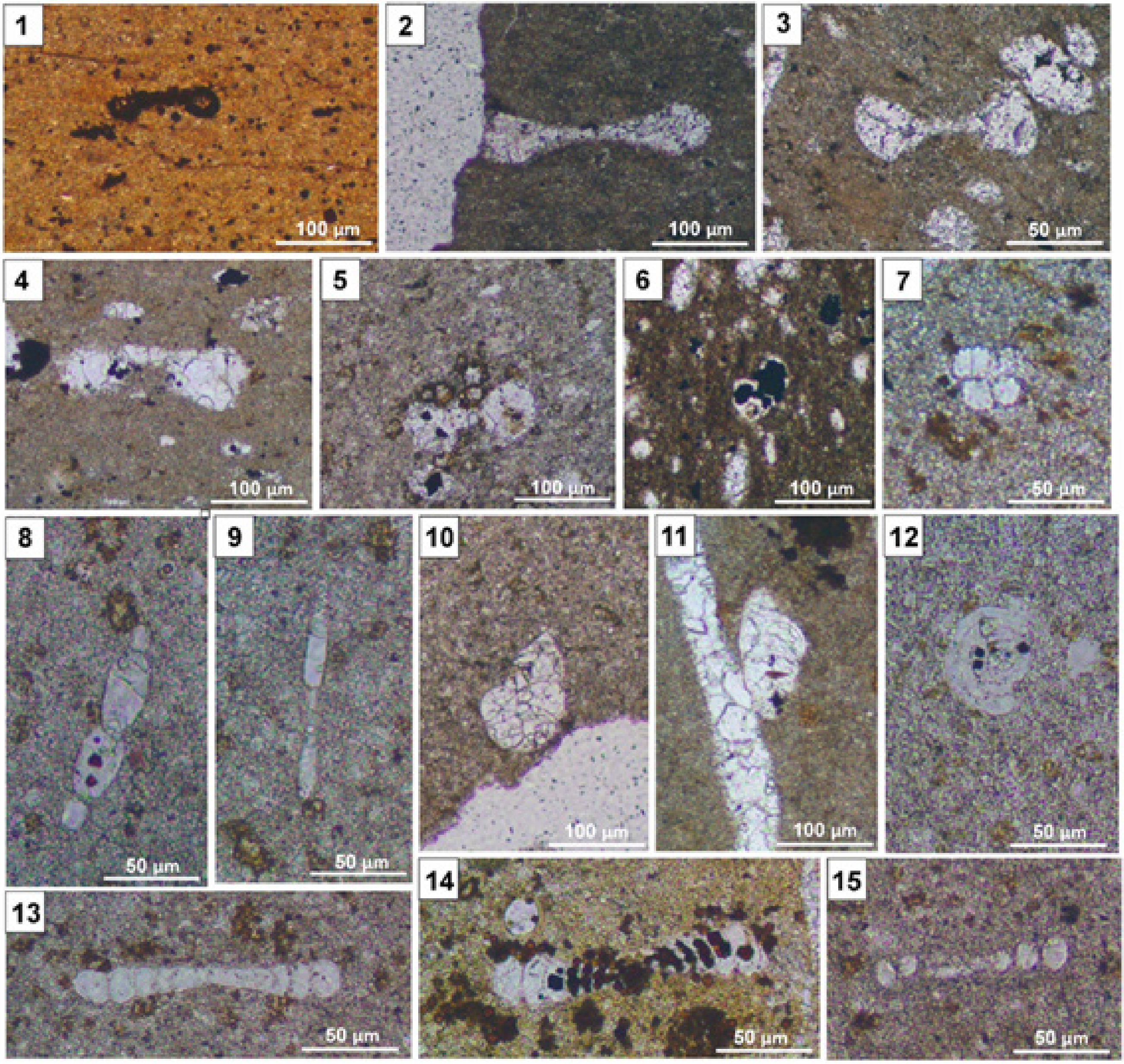

Fig. 11. Foraminifera of the studied sections

1. ?*Hedbergella* ?*handousi* (Salaj) (sample S1 – Chia Gara Formation); **2.** ?*Lilliputianella* sp. (sample S26 – Chia Gara Formation); **3.** ?*Lilliputianella* ?*eocretacea* (Neagu) (sample S26 – Chia Gara Formation); **4.** *Hedbergella* ?*handousi* (Salaj) (sample Z32 – Chia Gara Formation); **5.** ?*Globigerinelloides* sp. (sample Z38 – Balambo Formation); **6.** ?*Globuligerina bathoniana* (Pazdrowa) (sample S4 – Chia Gara Formation); **7.** ?*Globuligerina* sp. (sample S37 – Chia Gara Formation); **8, 9.** Nodosariinae (sample Z38 – Balambo Formation); **10.** *Saracenaria* sp. (sample Z38 – Balambo Formation); **11.** *Vaginulinida* sp. (sample S10 – Chia Gara Formation); **12–15.** *Involutina* sp. (12, 14, 15 – sample Z38, 13 – sample Z43; Balambo Formation)

Among the foraminifera (?)*Globuligerina bathoninana* (Pazdrowa) – a typical middle–upper Jurassic form – was identified in the lower part of the Surdash section (S4 sample) confirming the Jurassic age of the deposits. The Cretaceous foraminifera ?*Lilliputianella* ?*eocretacea* (Neagu) and *Hedbergella* ?*handousi* (Salaj) are noted in the upper part of the studied sections (samples S26 and Z32). The uncertain determination of ?*Hedbergella* ?*handousi* (Salaj) from S9 sample lacks strong biostratigraphic value and may only serve as an indication.

To sum up, the Tithonian age of the lower part of the Chia Gara Formation and the Berriasian age of its upper parts are confirmed by biostratigraphical data, but based on the presented data it is not possible to point more precisely to the J/K boundary (= the base of the Calpionella alpina Subzone). In the Zeni Warte section that transition is situated somewhere in the middle part of the section – above 30 meters, that is, above radiolarian UAZ 13, and below 85 meters in the section, where *Colomisphaera lucida* was found. Considering the uncertain identification of the specimen of ?*Hedbergella* ?*handousi* (Salaj), there is an indication of a transition from the Jurassic to the Cretaceous at approximately the 30 meter level of the section. However, due to the uncertainty of the taxonomic determination, this assumption should also be regarded as tentative.

PALAEOENVIRONMENTAL INDICATIONS

In Iraq, the end of the Jurassic and the beginning of the Cretaceous is the sedimentation period of the Chia Gara Formation under study. Marine conditions with tectonic instability prevailed, and the Late Tithonian–Early Berriasian represents the geodynamic reflection of the tectonic behaviour of the Arabian plate edge, from extension to compression (Numan, 2000).

There are several studies mentioning that the Chia Gara Formation was deposited on a passive margin of the Tethys Ocean, in a quiet pelagic and oxygen-depleted basin in a shelf to slope environment (Sharland *et al*., 2001; Mohialdeen, 2008; Ahmed *et al.*, 2016; Edilbi, Sherwani, 2019). Marine conditions for the deposition of the Chia Gara Formation have been indicated from sedimentological and geochemical proxies (Sherwani, Edilbi, 2019; Omar *et al.*, 2023; Rasool *et al.*, 2025a, b).

The presence of radiolarians from the order Nassellaria, identified in this study, usually indicates similarities to the well-known Tethyan radiolarites found in the Sistan Suture of eastern Iran (Babazadeh, De Wever, 2004) and to the Samail radiolarites (Sultanat of Oman; Beurrier *et al.*, 1987). Other studies concerning the Chia Gara Formation in different areas of northeastern Iraq have also documented radiolarians. The abundance of organic matter suggests that the deposition of the Chia Gara Formation occurred in a productive environment (Delizy *et al.*, 2024).

Generally, radiolarians are interpreted as corresponding with relatively productive sea surface or areas with strong upwelling (DeWever *et al.*, 2014). Their occurrence is frequent in intervals with low abundance of other microfossils (*e.g.*, Reháková, Michalík, 1994).

Calcareous dinocysts are present in the lower and upper parts of the Chia Gara Formation in both studied sections. Mesozoic and Cenozoic so-called "calcisphaeres" are interpreted as resting and vegetative cysts of calcareous dinoflagellates, and they are included to the Thoracosphaeraceae family in the Peridiniales order of the Superclass Dinoflagellata (*e.g.*, Meier *et al.*, 2007; Elbrächter *et al.*, 2008). They are described from normal marine environments, mainly from low and middle latitudes, especially from the Tethys realm. Calcareous dinocysts often co-occur with planktic foraminifera, calpionellids and radiolarians in the Upper Jurassic and Lower Cretaceous sediments of shelf to basinal settings (*e.g.*, Reháková, 2000; Grabowski *et al.*, 2016; Petrova *et al.*, 2019; Kietzmann *et al.*, 2023).

A few poorly preserved specimens, probably representing calpionellids, were found in both studied sections. These planktonic calcareous microfossils are numerous in the Tithonian and Lower Cretaceous pelagic carbonate deposits of the whole Tethys realm (*e.g.*, Remane, 1989), and usually are interpreted as an extinct group of Tintinnida (*e.g.*, Tappan, 1993). Calpionellids were previously observed in the Chia Gara Formation in NE Iraq (Mohialdeen, Raza, 2013) and studied in the Chia Gara Formation in Kurdistan (Wimbledon *et al.*, 2016). However, generally, calpionellids preferred rather oligotrophic conditions (*e.g.*, Michalík *et al.*, 2009), which may explain their rarity in the sections studied, especially in combination with the mixed, calcareous-siliciclastic sedimentary regime. In the Revišné section in the Western Carpathians, there was documented the prevalence of radiolarians and calcareous dinoflagellates and the absence of the calpionellids typical for the Upper Jurassic–Lower Cretaceous limestone of the Tethyan realm, probably connected with an upwelling (Molčan Matejová *et al.*, 2022). Michalík *et al.* (1995) suggests that the maximum development of calpionellids may represent a warm period, while the maximum development of radiolarians and dinoflagellates may indicate a period with an increased intensity of upwelling. This may support an upwelling regime in the area of deposition of the Chia Gara Formation.

The palaeoenvironmental marine conditions of the Chia Gara Formation as noted above, are also indicated by the presence of the planktic foraminifera distinguished in the current study (Fig. 11). The preservation of the delicate thin and very fragile tests of planktic foraminifers required pelagic and reducing basin conditions. Those Late Jurassic and Berriasian planktonic foraminifera known preferred marine continental margin conditions and did not enter the austral or boreal regions (Gradstein *et al.*, 2017b, 2019).

In the upper part of the studied sections, common nannoconids are observed. They represent a group of calcareous nannofossils, which occurred from the Tithonian to the Campanian and are common in the Lower Cretaceous Tethyan carbonates (*e.g.*, Erba, 1994). Busson and Nöel (1991) suggest their occurrence mainly in epicontinental basins, as well as inverse correlation between the number of nannoconids and number of other coccoliths, their scarcity in clay-rich sediments, and abundance in pelagic carbonates. Nannoconids are interpreted as organisms of the lower photic zone, expanding in conditions of oligotrophic surface waters (Erba, 1994; Tremolada *et al.*, 2006).

The microfossils, lithology, limited input of siliciclastic silt and lack of coarser siliciclastic material, suggest deposition in an open marine, at least deep shelf environment, possibly with an upwelling regime. A shift from more clay-rich, radiolarian facies towards more calcareous nannoconus facies is observed up the studied sections.

CONCLUSIONS

A late Jurassic to Early Cretaceous (late Tithonian and Berriasian) age is estimated for the Chia Gara Formation in the Surdash and Zeni Warte sections based on radiolarians, calcareous dinocysts, planktic foraminifera, and possibly also calpionellids. Detailed biostratigraphy and determination of the J/K boundary (= base of the C. alpina Subzone) is impossible based on the acquired data. The occurrence of calpionellids – stratigraphically the most important microfossils – is rare and doubtful, which can be explained by the mixed calcareous-siliciclastic character of the depositional environment and the high-productive conditions, preferred rather by radiolarians, numerous especially in the lower part of the studied sections. However, because of the diagenetic impact of calcification andpartial pyritization on the radiolarians, they also provided only fragmentary biostratigraphic data.

The microfossils, lithology, limited input of siliciclastic silt and lack of coarser siliciclastic material, suggest deposition of the Chia Gara Formation in an open marine, at least deep shelf environment. Both foraminifera and calcareous dinocysts are characterised by small sizes. Working up the studied sections, a shift from more clay-rich, radiolarian facies towards a more calcareous nannoconid facies is observed.

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Appendix

LIST OF THE IDENTIFIED MICROFOSSILS

RADIOLARIANS

Archaeodictyomitridae sp.
Cryptamphorella sp.
Holocryptocanium barbui Dumitrică, 1970
Loopus cf. *primitivus* (Matsuoka et Yao, 1985)
Praeparvicingula cosmoconica (Foreman, 1973)
Pseduodictyomitra carpatica (Lozyniak, 1969)
Thanarla patricki gr. (Kocher, 1981)
Xitus aff. g*ifuensis* Mizutani, 1981

CALCAREOUS DINOCYST

Cadosina sp.
Colomisphaera sp.
Colomisphaera heliosphaera (Vogler, 1941)
Colomisphaera lapidosa (Vogler, 1941)
Colomisphaera lucida Borza, 1986
Colomisphaera minutissima sensu Borza, 1980
Colomisphaera tenuis (Nagy, 1966)
Committosphaera cf. *pulla* (Borza, 1964)
Committosphaera sublapidosa (Vogler, 1941)
Crustocadosina semiradiata semiradiata (Wanner, 1940)

CALPIONELLIDS

?*Crassicollaria* ?*colomi* Doben, 1963
?*Tintinnopsella* ?*carpathica* (Murgeanu et Filipescu, 1933)

FORAMINIFERS

?*Globigerinelloides* sp.
?*Globuligerina* sp.
(?)*Globuligerina bathoniana* (Pazdrowa, 1969)
Hedbergella ?*handousi* (Salaj, 1984)
Involutina sp.
?*Lilliputianella* sp.
?*Lilliputianella ?eocretacea* (Neagu, 1975)
Saracenaria sp.
Vaginulinida sp.