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The biostratigraphy and palaeobiogeography of Cambrian and Ordovician acritarchs and chitinozoa from the Simeh-Kuh, NW Damghan City, the Alborz Mountains, northern Iran

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ABSTRACT

A study in Simeh-Kuh, northern Iran, focuses on Ordovician strata, documenting acritarchs and chitinozoa, and has helped to understand ancient environments. The aim is chronostratigraphical calibration, using palaeontological data including brachiopods, trilobites, and graptolites. Ninety-three surface samples were collected and analysed, yielding a rich collection of 117 morphotypes, including 59 acritarch species and 58 chitinozoan species. Eight acritarch assemblage biozones (A–H) and 14 chitinozoan biozones (1–14) were established. Biozones A–F indicate Late Cambrian to Middle Ordovician ages in the Lashkarak Formation, while biozones G–H indicate the Late Ordovician in the Ghelli Formation. The *Eremochitina brevis-Linocithina pissotensis* biozones suggest late Floian to late Darriwilian ages, and the *Belonechitina robusta-Armoricochitina nigerica* biozones support a Late Ordovician age. These findings place the Alborz Mountains in the North Gondwana Domain during the Ordovician. Palynomorphs with a thermal alteration index of 4.0–4.5 indicate overmature organic matter in Lower Palaeozoic deposits, potentially linked to the Ordovician metamorphic event in the southern Caspian Sea. Additionally, four new species were identified: *Cyathochitina* sp. A, *Tanuchitina hosseini-nezhadi* sp. nov., *Dactylofusa kazzazii* sp. nov., and *Inflatarium alborzensis* sp. nov.

HIGHLIGHTS

- A palynological study at Simeh-Kuh in the Alborz Mountains, northern Iran has uncovered a richly preserved assortment of Cambrian–Ordovician acritarchs and chitinozoa.
- Fifty-eight chitinozoan species, spanning 22 genera, were identified from the Lashkarak and Ghelli formations at Simeh-Kuh. This facilitated the delineation of 14 distinct chitinozoan biozones.
- Fifty-nine acritarch species across 33 genera were identified from the Late Cambrian to Late Ordovician strata, contributing to recognising eight distinct assemblage biozones.
- The Lashkarak Formation has yielded four distinctive acritarch genera: *Arbusculidium*, *Coryphidium*, *Striatotheca*, and *Arkonia*. These genera hold notable significance as they are characteristic elements of the Peri-Gondwanan palaeoprovince.
- The identification of chitinozoans in the Lashkarak and Ghelli formations has facilitated the establishment of 14 chitinozoan biozones. Notably, these biozones are considered classical elements of the Northern Gondwana Domain/Peri-Gondwana palaeoprovince.
- The *Belonechitina robusta*, *Tanuchitina fistulosa*, *Acanthochitina barbata*, and *Armoricochitina nigerica* biozones were recognised in the Ordovician deposits at Simeh-Kuh. This discovery marks the region's first confirmation of Sandbian–Katian strata.
- A significant hiatus exists between the Ghelli and Geirud formations, spanning the Late Ordovician (latest Katian–Hirnantian), Silurian, and Early–Middle Devonian periods.
- Four new species have been established: *Cyathochitina* sp. A, *Tanuchitina hosseini-nezhadi* sp. nov., *Dactylofusa kazzazii* sp. nov., and *Inflatarium alborzensis* sp. nov.

KEYWORDS

Marine microflora and microfauna; biostratigraphy; Cambrian–Ordovician; Gondwana/Peri-Gondwana; Alborz Mountains (northern Iran); palaeobiogeography

1. Introduction

Ordovician strata are present throughout the Alborz Mountains in northern Iran (Gansser and Huber 1962; Glaus 1965; Afshar-Harb 1979; Shahrabi 1991, 1992). However, the lithostratigraphical naming of the Iranian Ordovician poses a challenge, primarily due to the introduction of numerous local unit names lacking sufficient biostratigraphical support. Efforts to standardise previous nomenclature with the aid of

high-resolution biostratigraphy have been undertaken, as seen in initiatives such as those by Popov and Cocks (2017) and Evans et al. (2021).

For the current investigation, the lithostratigraphical terminology established for Ordovician deposits in the Alborz Mountains (Gansser and Huber 1962; Glaus 1965; Afshar-Harb 1979; Shahrabi 1991, 1992) is preferred due to its comprehensive and well-documented nature, serving as the standard for rock

units in this mountain range. Newly proposed rock units, such as the Simeh-Kuh and Pelamis formations, are considered informal and should not be utilised until approval from 'the National Iranian Stratigraphical Committee'. The lithostratigraphical Ordovician rock units identified in the Alborz Mountains include the Lashkarak, Abastu, Abarsaj, and Ghelli formations and the Gorgan Schists. Notably, the Abastu Formation is equivalent to the Lashkarak Formation, while the Abarsaj Formation correlates with the Ghelli Formation (Ghavidel-Syooki 2008, 2016). The Lashkarak Formation comprises Lower–Middle Ordovician sediments, which are well-developed in the Alborz Mountains. In contrast, exposures of the Ghelli, Abastu, and Abarsaj formations and the Gorgan Schists are observed in the southern Caspian Sea and the northern parts of Khorasan province (Figure 1).

Except for the Gorgan Schists in the Deraznau area south of the Caspian Sea, characterised by a low metamorphic grade (greenschists), the Ordovician rock units in the region are non-metamorphosed. The research site is situated in the southern foothills of the Simeh-Kuh locality within the Alborz Mountains. A comprehensive stratigraphical column for Precambrian to Ordovician deposits in Simeh-Kuh has been provided to document the occurrences of chitinozoan and acritarch assemblages, enabling correlation with other localities in the Alborz Mountains (Figures 1 and 4). The lithology of the studied succession is dominated by siliciclastic sediments, ranging from shales to sandstones with a few limestone interbeds. The Ordovician deposits at Simeh-Kuh contain diverse faunas, including trilobites, brachiopods, graptolites (Figures 2 and 3), and conodonts, indicative of an Early–Middle Ordovician age (Yazdi and Hosseini-Nezhad 2002; Ghobadi Pour 2006; Ghobadi Pour et al. 2007, 2011, 2022; Popov et al. 2008, 2016; Bassett et al. 2013; Popov and Cocks 2017; Rushton et al. 2021).

In this research, our objectives are as follows: (i) to record the presence of chitinozoa and acritarchs at the genus and species levels in the Mila, Lashkarak, and Ghelli formations, to investigate the continuity or discontinuity of deposits from the Cambrian through the Ordovician; (ii) to establish a biostratigraphical framework applicable to the Early–Middle Ordovician (Dapingian–Darriwilian) and Late Ordovician (Sandbian–Katian) stages at a local scale; (iii) to determine the biostratigraphical ages of the measured and sampled succession based on species ranges in Gondwana, Baltica, and Laurentia; (iv) to correlate acritarch and chitinozoan bio-zones with associated brachiopods and trilobites, aiming to establish precise age relationships between these groups; (v) to identify Upper Ordovician deposits using chitinozoan fauna and acritarch marine flora; (vi) to detect terrestrial cryptospores; and (vii) to compare biogeographical affinities with Gondwana, Baltica, Laurentia, and South China.

2. Geological setting and lithostratigraphy

The research focuses on the Simeh-Kuh area, a relief syncline approximately 13 km north-west of Damghan City within the Alborz Mountains, northern Iran (Figure 1). In this region, a well-exposed and developed Precambrian–Palaeozoic succession is observed. The Lower Palaeozoic strata, with a total thickness of 625 m, encompass 104 m from the upper part of the Upper Cambrian Mila Formation and 521 m from Ordovician deposits. The geographical coordinates of the study locality are approximately $36^{\circ}12'47.6''N$, $54^{\circ}13'25''E$, at 1429 m above sea level. The primary access route to the study area from Damghan City is an unpaved road leading to the Simeh-Kuh locality. This unpaved road is the main link to the research site. Despite being part of the Alborz Mountains, the Palaeozoic succession in this region has



Figure 1. The geographical setting of the study area (Simeh-Kuh locality) along with other localities of Palaeozoic outcrops throughout the Alborz Mountains. 1. Alam Kuh; 2. Hasanakdar; 3. Gerdkuh; 4. Simeh-Kuh; 5. Deh-Molla; 6. Deraznow (Gorgan Schists); 7. Kuh-e Shahvar (Abarsaj village); 8. Fazel Abad (Kholid Darreh); 9. Kuh-e Saluk (Ghelli village and Plermis Gorge). Source: Ghavidel-Syooki and Piri-Kangarshahi, 2023.

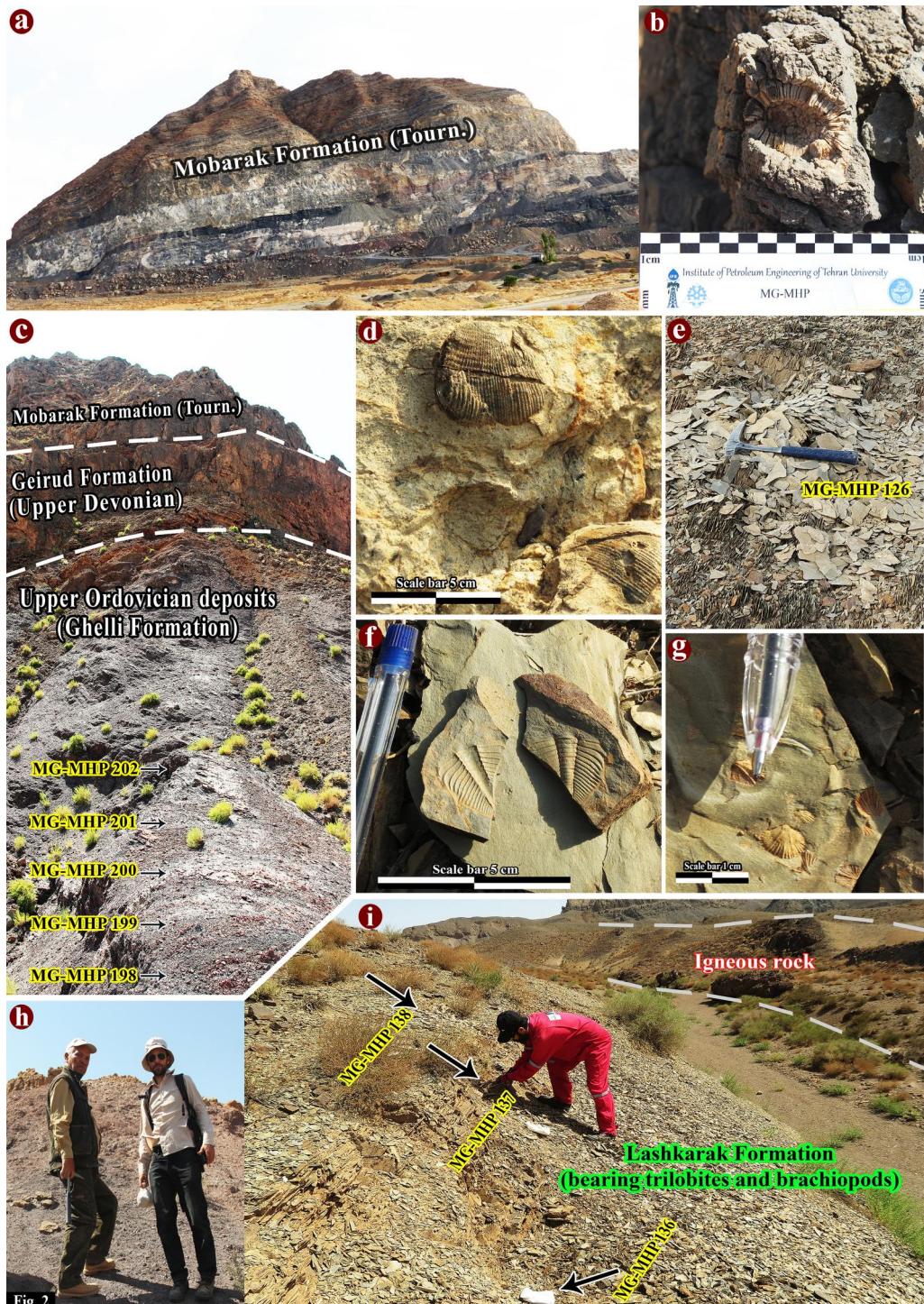


Figure 2. The Simeh-Kuh locality, north-west of Damghan City: a. Lithological outcrop of the Mobarak Formation; b. Mobarak Formation with fossiliferous limestone bearing *Zaphrentis*; c. boundary between the Geirud and Ghelli formations; d. Mobarak Formation with fossiliferous limestone bearing brachiopods; e. calcareous olive-grey papery shales of the Lashkarak Formation; f–g. Lashkarak Formation with the olive-grey fossiliferous siltstone bearing brachiopods and trilobites; h. field geologists (Ghavidel-Syooki and Piri-Kangarshahi collecting samples. i., contact of the igneous sill with the olive-grey fossiliferous siltstone of the Lashkarak Formation.

not undergone prior investigations for palynomorphs. Consequently, a detailed description is provided in this study to contribute additional palaeontological data to the geological context.

Within the study area, the Precambrian–Palaeozoic succession is categorised into distinct formations, listed in ascending stratigraphical order as Barut (Precambrian), Mila

(Cambrian), Lashkarak (Ordovician), Geirud (Devonian), and Mobarak (Carboniferous) (Figure 4). The Barut Formation, identified as 714 m thick at its type locality, is characterised by alternating green-purple siltstone, sandstone, and shale. It includes intercalations of dolomite, chert, and stromatolitic limestone. The presence of stromatolites and the holoturoid *Binoculites* led to the dating of the Barut Formation to the



Figure 3. The Simeh-Kuh locality, 13 km north-west of Damghan City, Alborz Mountains, northern Iran: a. White lines indicate the boundaries between the Lashkarak, Ghelli, and Geirud formations; b. contact of the igneous sill with the olive-grey fossiliferous siltstone of the Lashkarak Formation; c. Dark-grey shales of the Ghelli Formation; d-f. calcareous olive-grey shales and interbed of limestone in the Lashkarak Formation; g. alternation of light grey mottled sandstone with dark grey shales of the Ghelli Formation; h. olive-grey calcareous papery shales of the Lashkarak Formation). Source: Author.

Late Precambrian (Glaus 1965). Within the Simeh-Kuh region, the Barut Formation comprises dark grey to black stromatolitic limestones, overlain by a few metres of red-purple siliciclastic sediments in the uppermost layer. This colour change indicates the presence of a hiatus between the Barut and Mila formations (the absence of the Zaigun and Lalun formations) (Figure 4). The second rock unit, the Mila Formation, is positioned with a disconformable contact overlying the Barut

Formation. This formation is 104 m thick and predominantly composed of medium- to thickly bedded, fossiliferous limestone, notably containing brachiopods. Palynological data led to the placement of the Mila Formation within the late Middle-Late Cambrian across both the Zagros and the Alborz Mountains (Ghavidel-Syooki 2006, 2019; Ghavidel-Syooki and Vecoli 2008; Spina et al. 2021). Subsequently, the Lashkarak Formation is situated above the Mila Formation,

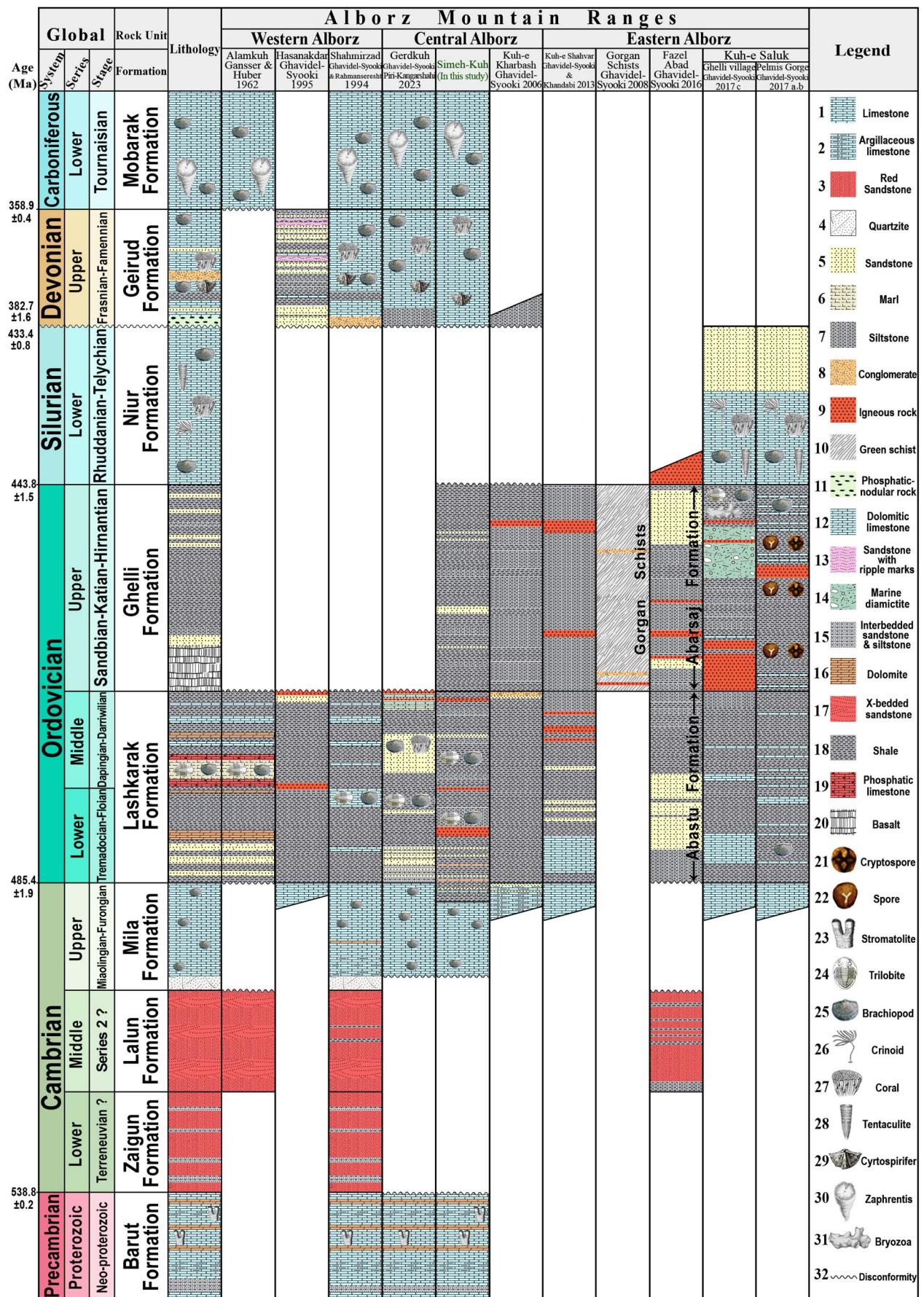


Figure 4. Regional stratigraphical distribution of Palaeozoic rock units throughout the Alborz Mountain Ranges, northern Iran, after various field geologists (e.g. Gansser and Huber 1962; Glau 1965; Alavi-Naini and Salehi-Rad 1975; Afshar-Harb 1979; Ghavidel-Syooki and Rahman-Reresht 1994; Ghavidel-Syooki 1995, 2006, 2008, 2016, 2017a, 2017b, 2017c; Aghanabati 2008; Ghavidel-Syooki and Khandabi 2013; Ghavidel-Syooki and Piri-Kangarshahi 2023) (modified from Ghavidel-Syooki and Piri-Kangarshahi 2023).

and the Geirud Formation is positioned with a disconformable contact at the uppermost layer (Figure 4). The Ordovician deposits, represented by the Lashkarak and Ghelli formations, constitute a 521 m siliciclastic succession. This succession is characterised by siltstone, sandstone, papery silty shale, occasional shell bed horizons, and a 2–3 m igneous sill situated in the middle, just below the trilobite-bearing horizon within the Lashkarak Formation (Figures 2 and 3). Notably, in the Simeh-Kuh locality, the boundary between the Lashkarak and Ghelli formations is distinguished by the alternation of dark grey micaceous shales and mottled sandstone interbeds within the Ghelli Formation (Figure 2g). The Geirud Formation is characterised by a 50 m sequence of grey-black siliciclastic sediments (e.g. mudstone, siltstone, and sandstone), transitioning to dark grey fossiliferous limestone as the succession ascends into the Mobarak Formation. Palynological data support a Late Devonian age for the Geirud Formation (Ghavidel-Syooki 1994, 1995, 2001a). The Mobarak Formation is dated to the Early Carboniferous based on palynological data (Ghavidel-Syooki and Owens 2007).

It is noteworthy that, until now, strata younger than Lower–Middle Ordovician deposits have not been documented in the Simeh-Kuh. For the first time, Upper Ordovician deposits have been identified above Lower–Middle Ordovician deposits in this region, marking a significant addition to the geological record (Popov et al. 2008, 2016; Ghobadi Pour et al. 2011, 2022; Popov and Cocks 2017). A distinctive lithological shift is observed above the rocks containing acritarch assemblages from the uppermost Cambrian, characterised by olive-grey shales resulting from the weathering of originally dark shales of the Lower–Middle Ordovician (Figures 2 and 3). In contrast, the Upper Ordovician deposits, specifically the Ghelli Formation, consist of dark grey shales and light grey mottled sandstone interbeds (Figure 3a and g). It is important to note that weathering processes can potentially impact the preservation of acritarchs and chitinozoa, influencing their abundance and diversity.

3. Materials and methods

The material examined in this paper is sourced from the Palaeozoic succession located at the Simeh-Kuh locality, 13 km north-west of Damghan City in the Alborz Mountains of northern Iran. Ninety-three surface samples were systematically collected along the entire Lower Palaeozoic succession at the Simeh-Kuh locality (Figure 1). Comprehensive field and laboratory descriptions of these samples are detailed in Figures 4–6. The surface samples were carefully extracted from depths ranging between 15 and 20 cm to mitigate the impact of weathering. Each sample, weighing 100 g, was assigned a number (MG-MHP 116 to 208). These numbers were prefixed with codes corresponding to the collectors, where MG represents Mohammad Ghavidel-Syooki and MHP stands for Mohammad Hossein Piri-Kangarshahi. In total, 93 samples were collected and subsequently processed at the Palynological Laboratory of the Institute of Petroleum Engineering, the School of Chemical Engineering, College of Engineering, at the University of Tehran. Palynomorphs were

extracted from shale, siltstone, and fine-grained sandstone utilising a palynological treatment involving hydrochloric (HCl) and hydrofluoric (HF) acids. The purpose of this treatment was to eliminate carbonates and silicates, respectively. Following each acid treatment, the residue was neutralised using distilled water. Notably, the samples were not subjected to oxidation. The resulting residues from each sample underwent treatment with 30 mL of saturated zinc bromide ($ZnBr_2$), characterised by a specific gravity of 1.95.

The organic residues were sieved through 10–20 μm nylon meshes to facilitate palynological analyses, eliminating finer debris. Subsequently, the palynological residues were mounted on glass slides for examination using optical microscopy and scanning electron microscopy (SEM). Extensive studies employing SEM and transmitted light microscopy were conducted on selected specimens. All samples were confirmed to be palyniferous, yielding well-preserved and abundant chitinozoans, acritarchs, scolecodonts, and graptolite remains, each associated with a repository code number (MG-MHP 116 to 208). Counts were conducted for the palynomorph groups in all productive samples, and the results are documented in Tables 1 and 2. Our analysis extended beyond marine palynomorphs to include terrestrial cryptospores. However, cryptospores were absent in the examined samples. The observed acritarchs ranged from dark brown to black, indicating a high thermal alteration index ($TAI = 4.0\text{--}4.5$). This suggests a low metamorphic grade, comparable to conditions associated with greenschist, and implies potential gas generation in the shaly beds of the Lashkarak and Ghelli formations (Batten 1982, see Figure 1).

For reference and future research, the samples, slides, and SEM stubs from this study have been deposited in the Iranian Natural History Museum, Department of Organisational Environment (DOE), under specific accession numbers ranging from DOEMG-MHP 116 to DOEMG-MHP 208 for samples and DOESubMG-MHP 116 to DOESubMG-MHP 208 for related stubs.

4. Systematics and biostratigraphy of palynomorph taxa

The Simeh-Kuh locality yielded a total of 8745 palynomorph specimens, with the following composition: 3879 acritarchs, 4490 chitinozoans, 89 scolecodonts, and 287 graptolite remains (Tables 1a–c and 2a–c). These specimens encompassed 59 acritarch species belonging to 33 genera and 58 chitinozoan species representing 22 genera. A detailed list of acritarchs arranged alphabetically can be found in Appendix 1, while chitinozoans are documented using the suprageneric classification of Paris et al. (1999) in Appendix 2.

4.1. Systematics of new acritarch species

Almost all recovered acritarch taxa are assigned to well-known species. Therefore, their formal systematic treatment is not given here, and a detailed description is provided for the new species. Measurements are given in micrometres

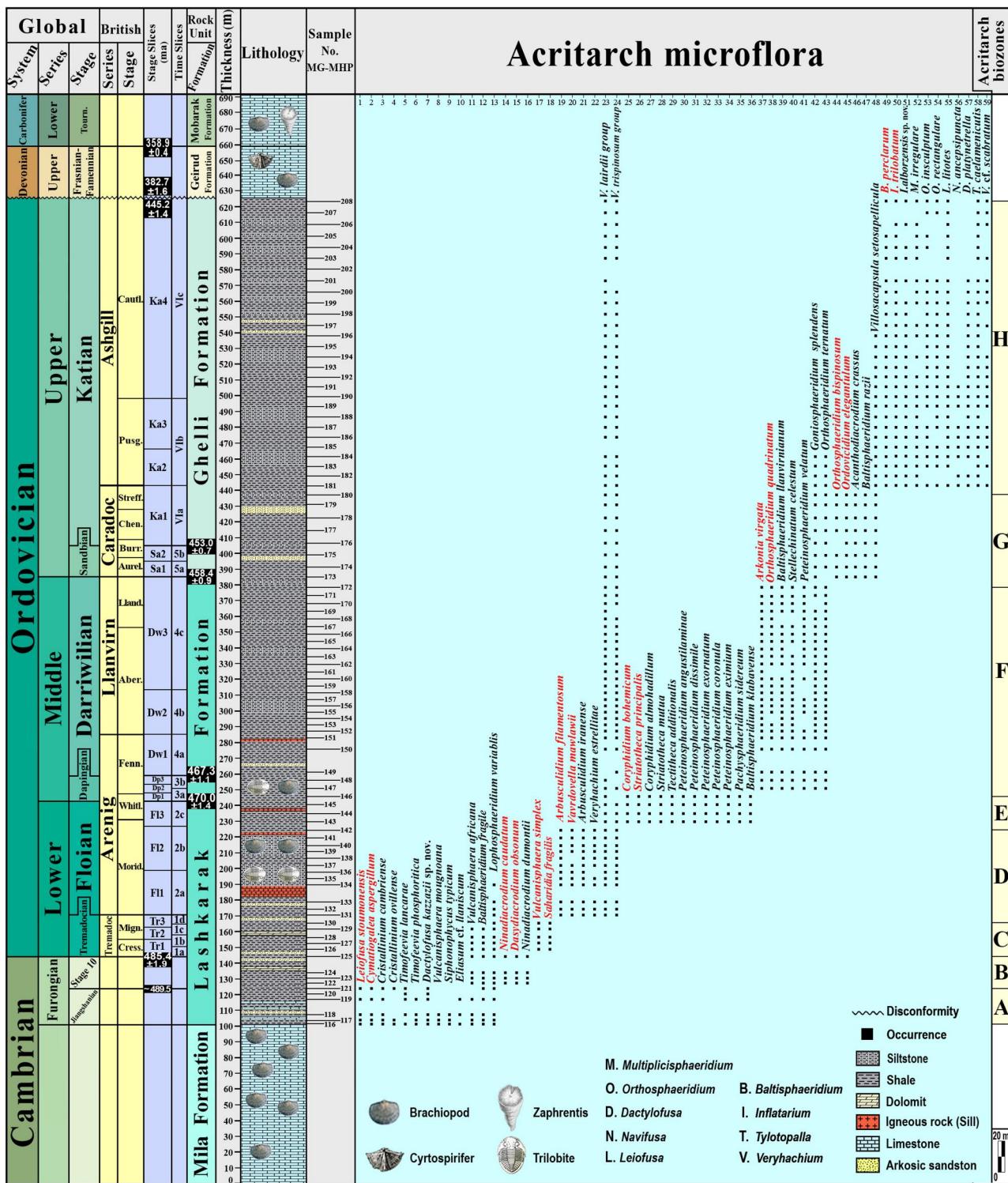


Figure 5. Lithology and stratigraphical distribution of acritarch taxa throughout the Lashkarak and Ghelli formations at the Simeh-Kuh locality (red font indicates some biostratigraphically significant species), north-west of Damghan City, the Alborz Mountains, northern Iran (numbers preceding species names relate to those at the bottom of Figure 5). 1. *Leiofusa stoumonensis*; 2. *Cymatiogalea aspergillum*; 3. *Crystallinum cambriense*; 4. *Cristallinum ovilense*; 5. *Timofeevia lancrae*; 6. *Timofeevia phosphoritica*; 7. *Dactylofusa kazzazii* sp. nov.; 8. *Vulcanisphaera mougoana*; 9. *Siphonophycus typicum*; 10. *Eliasum cf. llaniscum*; 11. *Vulcanisphaera africana*; 12. *Baltisphaeridium fragilis*; 13. *Lophosphaeridium variabilis*; 14. *Ninadiacrodium caudatum*; 15. *Dasydiacrodium obsonum*; 16. *Ninadiacrodium dumontii*; 17. *Vulcanisphaera simplex*; 18. *Saharidia fragilis*; 19. *Arbusculidium filamentosum*; 20. *Vavrdovella mawlawii*; 21. *Arbusculidium iranense*; 22. *Veryhachium estrellitae*; 23. *Veryhachium lairdii* group; 24. *Veryhachium trispinosum* group; 25. *Coryphidium bohemicum*; 26. *Striatotheca principalis*; 27. *Coryphidium almohadillum*; 28. *Striatotheca mutua*; 29. *Tectitheca additionalis*; 30. *Peteinosphaeridium angustilaminae*; 31. *Peteinosphaeridium dissimile*; 32. *Peteinosphaeridium exornatum*; 33. *Peteinosphaeridium coronula*; 34. *Peteinosphaeridium eximum*; 35. *Pachysphaeridium sidereum*; 36. *Baltisphaeridium klabavense*; 37. *Arkonia virgata*; 38. *Orthosphaeridium quadrinatum*; 39. *Baltisphaeridium llanvirnianum*; 40. *Stellechinatum celestum*; 41. *Peteinosphaeridium velatum*; 42. *Goniosphaeridium splendens*; 43. *Orthosphaeridium ternatum*; 44. *Orthosphaeridium bispinosum*; 45. *Ordovicidium elegantulum*; 46. *Acanthodiacerodium crassus*; 47. *Baltisphaeridium razii*; 48. *Villosacapsula setosapellicula*; 49. *Baltisphaeridium perclarum*; 50. *Inflatarium trilobatum*; 51. *Inflatarium alborzensis* sp. nov.; 52. *Multiplicisphaeridium irregularare*; 53. *Orthosphaeridium insculptum*; 54. *Orthosphaeridium rectangulare*; 55. *Leiofusa litotes*; 56. *Navifusa ancepsipuncta*; 57. *Dactylofusa platynetrella*; 58. *Tylotopalla caelimenicus*; 59. *Veryhachium cf. scabratum*.

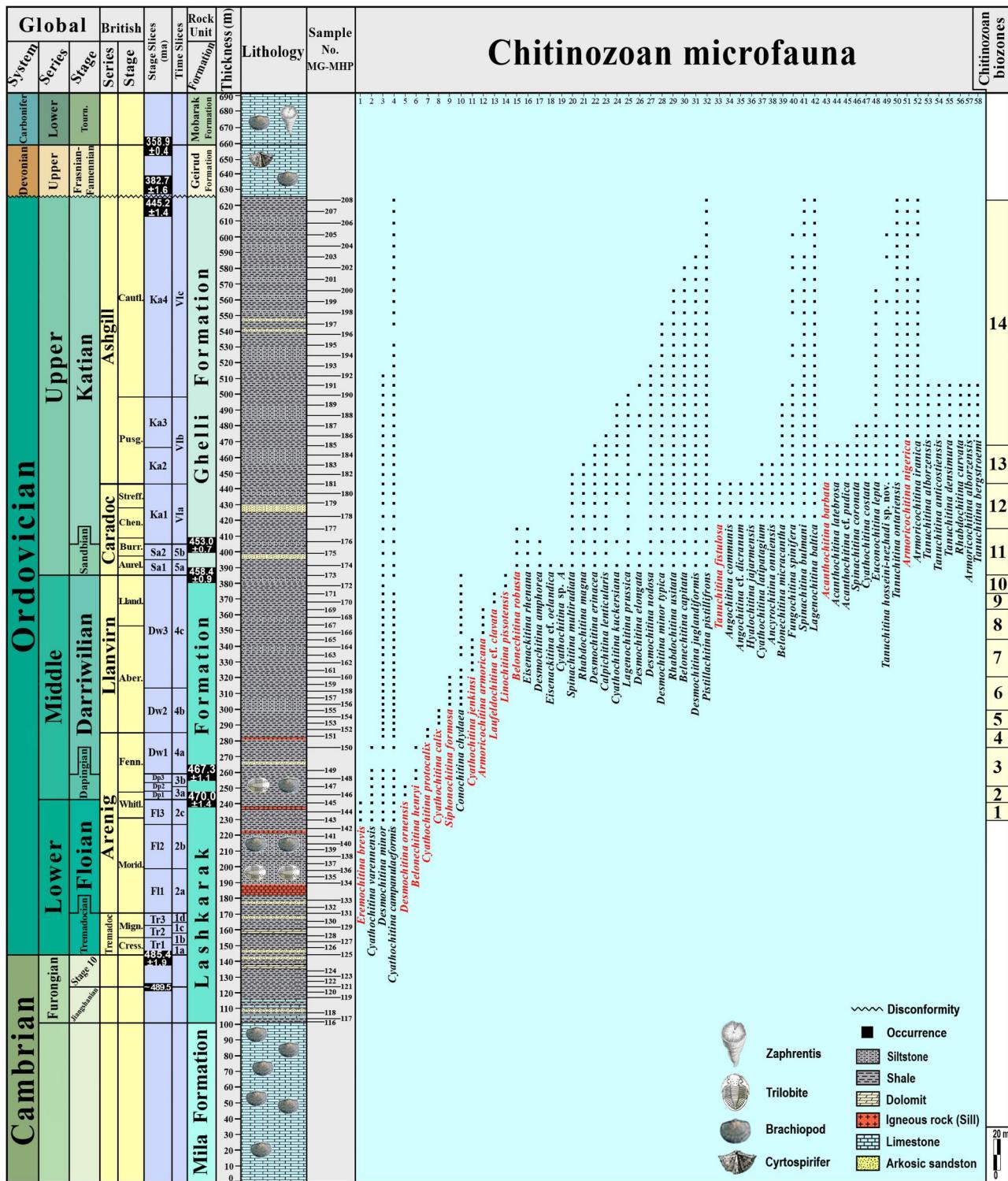


Figure 6. Lithology and stratigraphical distribution of chitinozoan taxa throughout the Lashkarak and Ghelli formations at the Simeh-Kuh locality (red font indicates some biostratigraphically significant species), north-western Damghan City, the Alborz Mountains, northern Iran (numbers preceding species names relate to those at the bottom of the figure). 1. *Eremochitina brevis*; 2. *Cyathochitina varenensis*; 3. *Desmochitina minor*; 4. *Cyathochitina campanulaeformis*; 5. *Desmochitina ornensis*; 6. *Belonechitina henryi*; 7. *Cyathochitina protocolix*; 8. *Cyathochitina calix*; 9. *Siphonochitina formosa*; 10. *Conochitina chydaea*; 11. *Cyathochitina jenkinsi*; 12. *Armoricochitina americana*; 13. *Laufeldochitina cf. clavata*; 14. *Linochitina pissotensis*; 15. *Belonechitina robusta*; 16. *Eisenackitina rhenana*; 17. *Desmochitina amphorea*; 18. *Eisenackitina cf. oelandica*; 19. *Cyathochitina sp. A*; 20. *Spinachitina multiradiata*; 21. *Rhabdochitina magna*; 22. *Desmochitina erinacea*; 23. *Calpichitina lenticularis*; 24. *Cyathochitina kuckersiana*; 25. *Lagenochitina prussica*; 26. *Desmochitina elongata*; 27. *Desmochitina nodosa*; 28. *Desmochitina minor typica*; 29. *Rhabdochitina usitata*; 30. *Belonechitina capitata*; 31. *Desmochitina juglandiformis*; 32. *Pistillachitina pistillifrons*; 33. *Tanuchitina fistulosa*; 34. *Angochitina communis*; 35. *Angochitina cf. dicranum*; 36. *Hyalochitina jajarmensis*; 37. *Cyathochitina latipatagium*; 38. *Ancyrochitina onniensis*; 39. *Belonechitina micracantha*; 40. *Fungochitina spinifera*; 41. *Spinachitina bulmani*; 42. *Lagenochitina baltica*; 43. *Acanthochitina barbata*; 44. *Acanthochitina latebrosa*; 45. *Acanthochitina cf. pudica*; 46. *Spinachitina coronata*; 47. *Cyathochitina costata*; 48. *Euconochitina lepta*; 49. *Tanuchitina hosseini-nezhadi sp. nov.*; 50. *Tanuchitina ontariensis*; 51. *Armoricochitina nigerica*; 52. *Armoricochitina iranica*; 53. *Tanuchitina alborzensis*; 54. *Tanuchitina anticostiensis*; 55. *Tanuchitina densimura*; 56. *Rhabdochitina curvata*; 57. *Armoricochitina alborzensis*; 58. *Tanuchitina bergstroemi*.

(μm), and their values are expressed as minimum (mean) maximum.

Incertae sedis Group Acritarcha Evitt 1963.

Genus *Dactylofusa* Brito & Santos 1965 emend. Cramer 1970

Type species. *Dactylofusa maranhensis* Brito & Santos 1965

Dactylofusa kazzazii sp. nov.

Plate 12, figures 1, 5; 2, 6; 3, 4, 9.

Holotype. Plate 12, figure 9.

Type stratum. The siliciclastic sediments of the lowermost Lashkarak Formation (samples DOESTubMG-MHP-116 to DOESTubMG-MHP-118).

Type locality. Simeh-Kuh locality, 13 km north-west of Damghan city, the Alborz Mountains, northern Iran.

Derivation of name. The name of this species is derived in honour of Jalaleddin Kazzazi, renowned as Mir Jalaleddin Kazzazi, who was born on 19 January 1949, in Kermanshah city. A distinguished professor and researcher at Tehran University, he is credited for translating Ferdowsi's epic poem 'Shahnameh' into Persian prose. Information about Mir Jalaleddin Kazzazi can be found on his website: <https://www.kazzazi.com>.

Description. The vesicle is fusiform and slightly tapers towards the poles but does not have processes at the poles. The holotype is 137.5 μm in length and 50.5 μm in width. The wall appears to be unilayered. The vesicle has 12–20 continuous ridges that are subparallel and extend from one pole to another. The vesicle surface is laevigate. No preferential splitting patterns or other pylome structures are present.

Dimensions. Length 119.8 (128.65) 137.5 μm ; width 46.2 (48.35) 50.5 μm ; number of ridges 12 (16) 20 μm ; width of ridges 1.7 (2.35) 3 μm ; 10 specimens measured.

Diagnosis. A species of *Dactylofusa* with a fusiform vesicle outline and numerous continuous ridges. The vesicle surface is laevigate and without processes at the poles.

Comparison. The specimens of *Dactylofusa kazzazii* sp. nov. differ from other species of *Dactylofusa* in having a smaller size and prominent, continuous ridges converging towards the poles. Until now, the genus *Dactylofusa* and its species have been recorded from Ordovician and younger Palaeozoic strata (see Cramer 1969; Loeblich and Tappan 1978), but this study documents for the first time an Upper Cambrian (Furongian) occurrence from northern Iran.

Genus *Inflatarium* Le Hérisse et al. 2015

Type species. *Inflatarium trilobatum* Le Hérisse et al. 2015

Inflatarium alborzensis sp. nov.

Plate 17, figures 6, 7

Holotype. Plate 17, figure 6.

Type stratum. The siliciclastic sediments of the Ghelli Formation (samples DOESTubMG-MHP-181 to DOESTubMG-MHP-208).

Type locality. Simeh-Kuh locality, 13 km north-west of Damghan city, the Alborz Mountains, northern Iran.

Table 1a. Quantitative distribution of acritarch taxa and algal clusters in the Mila, Lashkarak, and Ghelli formations at the Simeh-Kuh locality, 13 km north-western Damghan city in the Alborz Mountains, northern Iran (red colour indicates biostratigraphically significant taxa).

| List of encountered morphotypes | MG- MHP 116 | MG- MHP 117 | MG- MHP 118 | MG- MHP 119 | MG- MHP 120 | MG- MHP 121 | MG- MHP 122 | MG- MHP 123 | MG- MHP 124 | MG- MHP 125 | MG- MHP 126 | MG- MHP 127 | MG- MHP 128 | MG- MHP 129 | MG- MHP 130 | MG- MHP 131 | MG- MHP 132 | MG- MHP 133 | MG- MHP 134 | MG- MHP 135 | MG- MHP 136 | MG- MHP 137 | MG- MHP 138 | MG- MHP 139 | MG- MHP 140 | MG- MHP 141 | MG- MHP 142 | MG- MHP 143 | MG- MHP 144 | MG- MHP 145 | MG- MHP 146 | |
|--|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|---|
| 1 <i>Leiostoma stutmanni</i> | 1 | 3 | 2 | 5 | 2 | 4 | 2 | 5 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 2 <i>Cymatiogalea aspergillum</i> | 2 | 3 | 4 | 11 | 10 | 20 | 7 | 2 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 3 <i>Cristallinum cambriense</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 4 <i>Cristallinum avilense</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 5 <i>Timofeevia lancariae</i> | 8 | 3 | 18 | 10 | 6 | 2 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 6 <i>Timofeevia phosphoritica</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 7 <i>Eupoikilofusa kazzazii</i> sp. nov. | 4 | 20 | 15 | 9 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | |
| 8 <i>Vulcanisphaera mougganina</i> | 4 | 3 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | |
| 9 <i>Siphonophycus typicum</i> | 30 | 22 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | | |
| 10 <i>Elatostom ct. latiscum</i> | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 11 Algal cluster | 2 | 7 | 2 | 10 | 0 | 15 | 17 | 0 | 15 | 17 | 0 | 15 | 17 | 0 | 15 | 17 | 0 | 15 | 17 | 0 | 15 | 17 | 0 | 15 | 17 | 0 | 15 | 17 | 0 | 15 | 17 | |
| 12 <i>Vulcanisphaera africana</i> | 2 | 2 | 25 | 14 | 0 | 9 | 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 13 <i>Sahandia fragilis</i> | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 <i>Laphosphaeridium variabilis</i> | 40 | 6 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 15 <i>Laphosphaeridium sp.</i> | 46 | 16 | 10 | 10 | 1 | 16 | 1 | 16 | 1 | 16 | 1 | 16 | 1 | 16 | 1 | 16 | 1 | 16 | 1 | 16 | 1 | 16 | 1 | 16 | 1 | 16 | 1 | 16 | 1 | 16 | 1 | |
| 16 <i>Ninadicrodium caudatum</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 17 <i>Dasydiacrodium obsonum</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 18 <i>Ninadicrodium dumontii</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 19 <i>Vulcanisphaera simplex</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 20 <i>Sahandia fragilis</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 21 <i>Arbusculidium filamentosum</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 22 <i>Arbusculidium iranense</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 23 <i>Vavrdovella mawlawii</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 24 <i>Venhyachium astelliae</i> | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 25 <i>Venhyachium tardii</i> group | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 26 <i>Venhyachium trispinosum</i> group | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Total | 147 | 94 | 114 | 88 | 39 | 64 | 72 | 50 | 31 | 44 | 53 | 37 | 36 | 22 | 17 | 20 | 20 | 20 | 13 | 11 | 13 | 2 | 1 | 2 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | |

Table 1b. Continued.

| List of encountered morphotypes | Morphological traits | | | | | | | | | | Ecological traits | | | | | | | | | | |
|---|----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----|
| | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | MG-MH | |
| 25 <i>Veryhachium lairdii</i> group | 8 | 5 | 5 | 2 | 1 | 2 | 0 | 1 | 1 | 5 | 2 | 3 | 10 | 5 | 8 | 9 | 6 | 5 | 1 | 10 | 12 |
| 26 <i>Veryhachium trispinosum</i> group | 5 | 6 | 8 | 0 | 1 | 0 | 5 | 2 | 2 | 6 | 1 | 4 | 5 | 9 | 5 | 6 | 5 | 4 | 2 | 1 | 6 |
| 27 <i>Coryphidium bohemicum</i> | 11 | 20 | 18 | 11 | | | | | | | | | | | | | | | | | 0 |
| 28 <i>Striatotheca principalis</i> | 20 | 29 | 31 | 17 | | | | | | | | | | | | | | | | | 7 |
| 29 <i>Coryphidium almoedallum</i> | 6 | 9 | 6 | 5 | | | | | | | | | | | | | | | | | 6 |
| 30 <i>Striatotheca mutua</i> | 17 | 20 | 18 | 16 | | | | | | | | | | | | | | | | | 1 |
| 31 <i>Fecithaea additionalis</i> | 11 | 14 | 8 | 7 | | | | | | | | | | | | | | | | | 1 |
| 32 <i>Peteinosphaeridium angustilaminae</i> | 11 | 10 | 16 | 5 | | | | | | | | | | | | | | | | | 1 |
| 33 <i>Peteinosphaeridium dissimile</i> | 7 | 9 | 13 | 11 | | | | | | | | | | | | | | | | | 1 |
| 34 <i>Peteinosphaeridium exornatum</i> | 15 | 16 | 12 | 10 | | | | | | | | | | | | | | | | | 1 |
| 35 <i>Peteinosphaeridium coronula</i> | 25 | 19 | 32 | 15 | | | | | | | | | | | | | | | | | 1 |
| 36 <i>Peteinosphaeridium eximium</i> | 12 | 11 | 9 | 16 | | | | | | | | | | | | | | | | | 2 |
| 37 <i>Pachysphaeridium sidereum</i> | 19 | 25 | 11 | 14 | | | | | | | | | | | | | | | | | 1 |
| 38 <i>Baltisphaeridium klabavense</i> | 9 | 14 | 9 | 8 | | | | | | | | | | | | | | | | | 1 |
| 39 <i>Arkonia virgata</i> | | | | | | | | | | | | | | | | | | | | | 1 |
| 40 <i>Orthosphaeridium quadrinatum</i> | 1 | 2 | 3 | 2 | 1 | 2 | 2 | 0 | 1 | 1 | 1 | 2 | 1 | 2 | 0 | 1 | 2 | 1 | 1 | 3 | 1 |
| 41 <i>Baltisphaeridium llanvirnianum</i> | 1 | 2 | 2 | 4 | 2 | 2 | 3 | 1 | 1 | 3 | 1 | 2 | 4 | 1 | 0 | 2 | 1 | 0 | 1 | 1 | 1 |
| 42 <i>Stelliotheca celestum</i> | 3 | 1 | 4 | 2 | 5 | 1 | 5 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 0 | 1 | 2 | 1 | 1 | 2 | 2 |
| 43 <i>Peteinosphaeridium velutum</i> | 1 | 2 | 1 | 0 | 0 | 1 | 4 | 1 | 1 | 0 | 1 | 2 | 1 | 0 | 1 | 2 | 0 | 1 | 1 | 4 | 5 |
| 44 <i>Goniophaeridium splendens</i> | 1 | 3 | 2 | 3 | 2 | 1 | 2 | 3 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 2 | 1 | 1 | 1 |
| 45 <i>Orthosphaeridium ternatum</i> | 2 | 8 | 5 | 2 | 7 | 15 | 11 | 13 | 15 | 6 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 5 | 4 |
| 46 <i>Orthosphaeridium bispinosum</i> | | | | | | | | | | | | | | | | | | | | 7 | 9 |
| 47 <i>Ordivicidium elegantulum</i> | | | | | | | | | | | | | | | | | | | | 3 | 0 |
| 48 <i>Acanthidiocladrum crassus</i> | | | | | | | | | | | | | | | | | | | | 8 | 10 |
| 49 <i>Baltisphaeridium razi</i> | | | | | | | | | | | | | | | | | | | | 7 | 9 |
| 50 <i>Villosacapsula setospellicula</i> | | | | | | | | | | | | | | | | | | | | 3 | 6 |
| Total | 176 | 207 | 196 | 137 | 13 | 21 | 23 | 18 | 22 | 38 | 29 | 27 | 41 | 35 | 21 | 26 | 25 | 15 | 32 | 23 | 35 |

Table 1c. Continued.

Table 2a. Quantitative analysis of chitinozoan taxa, scolecodonts, and graptolite remains and their distribution in the Lashkarak and Ghelli formations at the Simeh-Kuh locality, 13 km north-western Damghan city in the

Table 2b. Continued.

Table 2c. Continued.

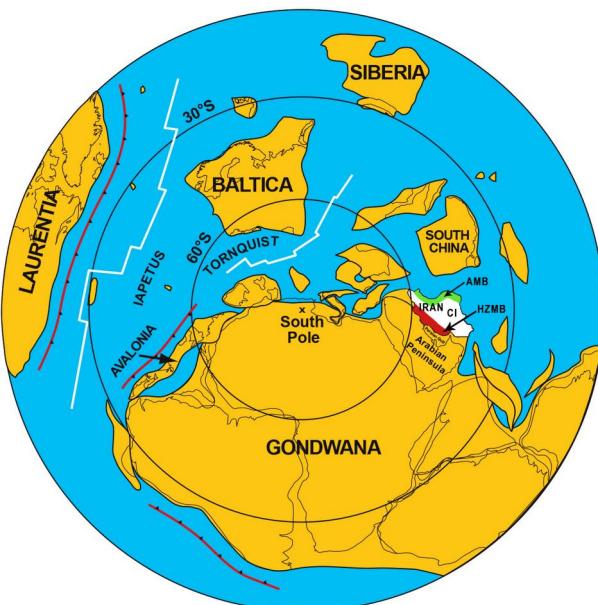


Figure 7. Palaeogeographical reconstruction of continental mass distribution during Ordovician times and position of different parts of Iran (modified slightly from Servais et al. (2009, fig. 2) and Cocks and Torsvik (2002, fig. 1)). HZMB denotes the Zagros Mountain Belt (Ghavidel-Syooki 2021, 2023); AMB indicates the Alborz Mountain Belt (Ghavidel-Syooki 2016, 2017a, 2017b, 2017c); CI refers to Central Iran (Ghavidel-Syooki 2003; Ghavidel-Syooki and Piri-Kangarshahi 2021) (after Ghavidel-Syooki and Piri-Kangarshahi 2023).

Derivation of name. Referring to the Alborz Mountain Ranges, which stretch from the north-west to the north-east of Iran.

Description. The vesicle is hollow, inflated, and formed from three rounded lobes, which all lie in the same plane. Three lobes are equal in size and perpendicular to the vesicle's axis. The vesicle wall is thin and smooth. The pylome is split and located in the central part of the vesicle. Each lobe has a spinose ornament in the terminating lobe.

Dimensions. Total length of each lobe: 38.9 (41.1) 43.3 µm; width of each lobe: 22.3 (25.95) 29.6 µm; spinose ornament length: 18.2 (11.8) 15.4 µm; 15 specimens were measured.

Diagnosis. The vesicle is lobate, formed by the coalescence of three lobes. The rounded terminations of the lobes each bear one spinose ornament. This species is similar to *Inflatarium trilobatum* Le Hérissé et al. 2015 in having inflated vesicles and coalescence of lobes and one spinose ornament in terminating lobes. However, the new Iranian species differs from *I. trilobatum* in Saudi Arabia in having a small size and equivalent lobes.

4.2. Acritarch biostratigraphy

The Lower Palaeozoic rock units within the Alborz Mountains, including the Mila, Lashkarak, Ghelli, and Niur formations, have been subject to previous investigations by various palynologists (Ghavidel-Syooki 1995, 2001a, 2006, 2008, 2016, 2017a, 2017b, 2017c; Ghavidel-Syooki and Winchester-Seeto 2002; Ghavidel-Syooki and Vecoli 2007; Ghavidel-Syooki and Piri-Kangarshahi 2023). In the current study, the Mila Formation (Upper Cambrian), Lashkarak Formation (Lower and Middle Ordovician), and Ghelli Formation (Upper Ordovician) were systematically measured

and sampled to contribute data on the first appearance datum (FAD) and last appearance datum (LAD) of identified acritarch taxa. Fifty-nine acritarch species representing 33 genera were identified, facilitating the recognition of eight acritarch assemblage biozones. These acritarch biozones and their corresponding ages are discussed in ascending stratigraphical order (Figure 5 and Table 1a–c). Additionally, it is important to note that in aligning with the acritarch biostratigraphy of the Mila, Lashkarak, and Ghelli formations in the Simeh-Kuh section, the global time scale terminology follows the format for the global stage and stage slices established by Bergström et al. (2009), and for the time slices by Paris 1990 in Webby et al. (2004), and Videt et al. (2010).

4.2.1. *Leiofusa stoumonensis*-*Cymatiogalea aspergillum* assemblage biozone (A)

This acritarch assemblage biozone is characterised by the simultaneous presence of *Leiofusa stoumonensis* Vanguystaine 1973 and *Cymatiogalea aspergillum* Martin and Dean 1988, marking the onset of siliciclastic sediments within the Lashkarak Formation. This biozone includes the lowest 26 m of the study section in the Simeh-Kuh locality, with its upper boundary aligning with the base of the succeeding assemblage biozone (B) (Figure 5, Table 1a–c). In the present study, *Leiofusa stoumonensis* (Plate 13, figure 4) is identified in samples MG-MHP 116 to 121 of the Lashkarak Formation, representing the first recorded instance of its presence in the Alborz Mountains.

Leiofusa stoumonensis is a reliable indicator of the Late Cambrian (Furongian) age. Its presence is predominantly observed within Furongian strata elsewhere, including eastern Newfoundland, ranging from the uppermost part of the upper A2 Zone above the *Parabolina spinulosa*-*Acerocare* trilobite zone (Martin and Dean 1988; Parsons and Anderson 2000). To date, this species has been recorded from numerous localities, including the Furongian *Peltura scarabaeoides* Zone, Öland, Sweden (Di Milia et al. 1989); Furongian, Belgium (Ribecai and Vanguystaine 1993), Spain (Palacios 2015), the UK (Martin in Young et al. 1994; Potter et al. 2012), Oman (Molyneux et al. 2006), and southern Iran (Ghavidel-Syooki and Vecoli 2008; Ghavidel-Syooki 2019; Spina et al. 2021). Another noteworthy acritarch indicative of this zone is *Cymatiogalea aspergillum* (Plate 13, figure 11; Plate 16, figures 6, 10). Its presence in the Alborz Mountains is recorded for the first time. Other acritarch taxa present within this assemblage biozone include *Cristalinium cambriense* (Plate 12, figure 12; Plate 16, figure 5; Plate 17, figure 10), *C. ovillense* (Plate 12, figure 11), *Dactylofusa kazzazii* sp. nov. (Plate 12, figures 1, 5; 2, 6; 3, 4, 9), *Eliasum llaniscum* (Plate 12, figure 10), *Leiosphaeridia* sp. (Plate 12, figure 7), *Lophosphaeridium variable* (Plate 12, figure 8), *Siphonophycus typicum* (Plate 17, figure 17), *Timofeevia lancarae* (Plate 12, figures 17, 21; 18, 22; Plate 14, figures 23, 24), *T. phosphoritica* (refer to Plate 12, figure 16), *Vulcanisphaera mougnoana* (Plate 12, figures 20, 24; Plate 16, figure 9; Plate 17, figure 9), and *V. africana* (Plate 12, figures 19, 23).

The associated acritarch taxa within this assemblage biozone exhibit cosmopolitan distributions and are long-ranging, spanning from the Cambrian to the Early Ordovician

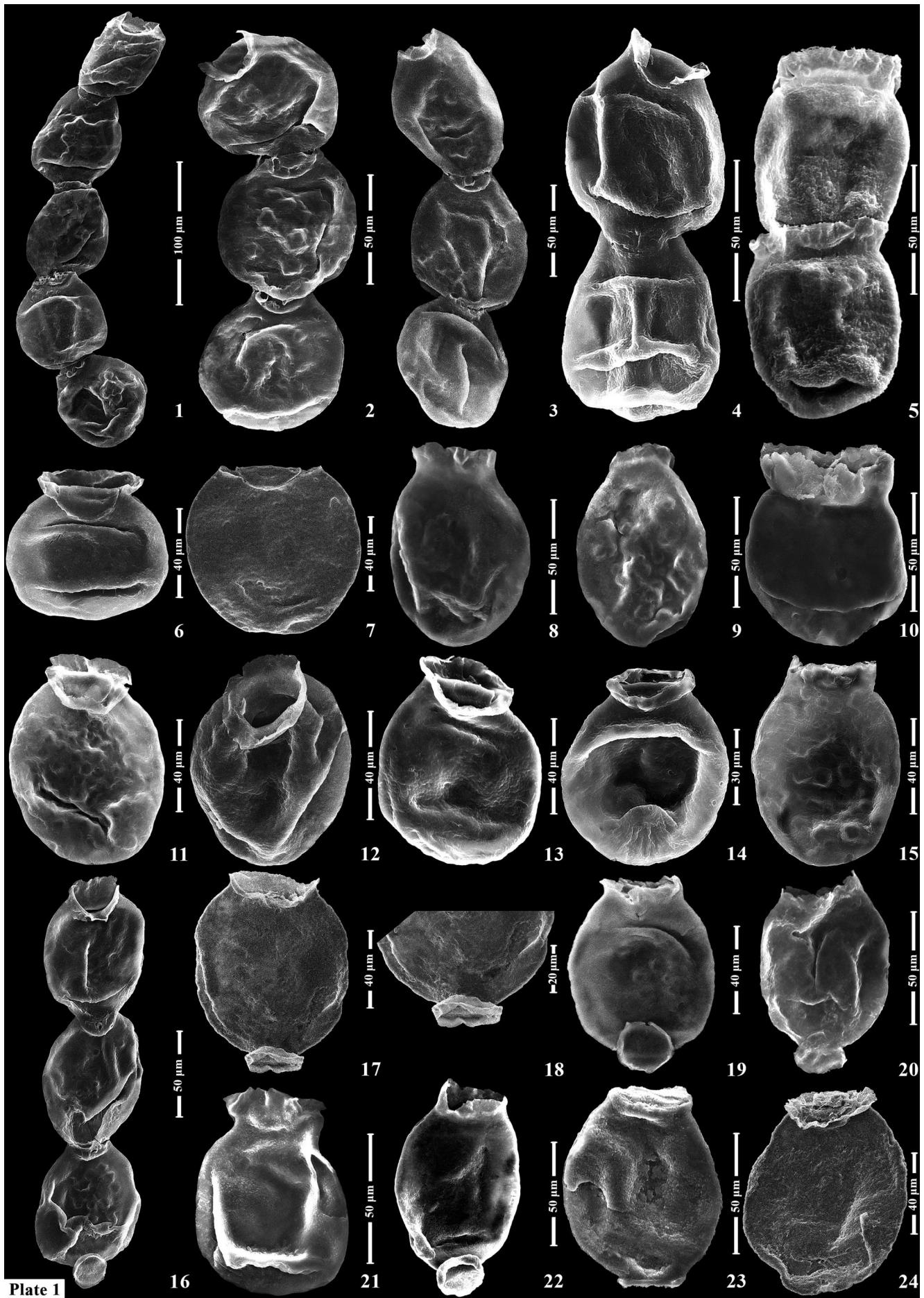


Plate 1. Figures 1–3; 6, 7. *Desmochitina minor* Eisenack 1931; figure 4. *Desmochitina ornensis* Paris 1981; figures 5, 10, 21. *Desmochitina nodosa* Eisenack 1931; figures 8, 9. *Desmochitina amphorea* Eisenack 1931; figures 11–15 and 24. *Desmochitina minor typica* Eisenack 1931; figures 16–20; 22–23. *Desmochitina juglandiformis* Laufeld 1967.

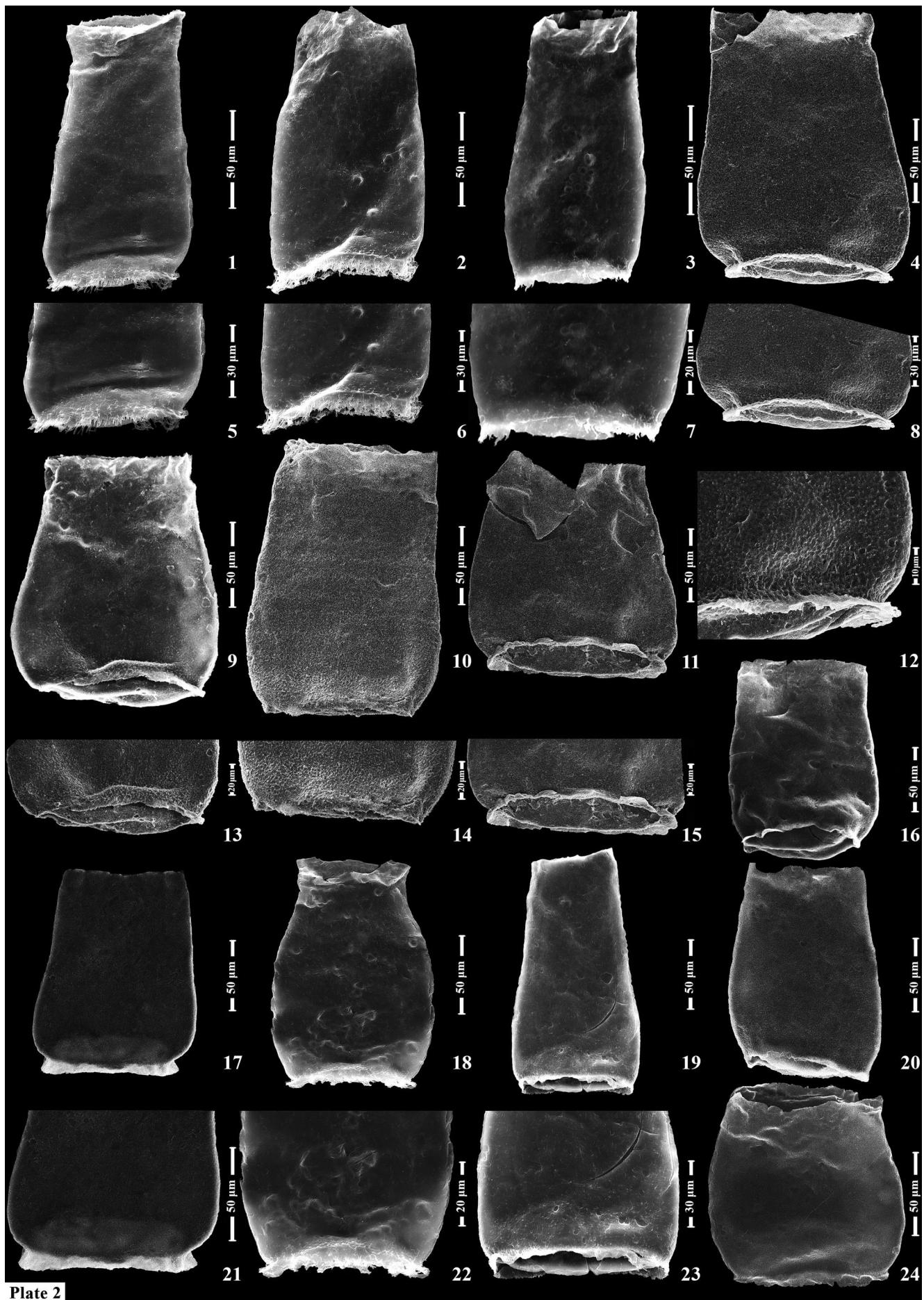


Plate 2

Plate 2. Figures 1, 5; 2, 6; 3, 7; 19, 23. *Armoricochitina alborzensis* Ghavidel-Syooki and Winchester-Seeto 2002; figures 4, 8, 12; 9, 13; 10, 14; 11, 15. *Armoricochitina iranica* Ghavidel-Syooki and Winchester-Seeto 2002; figures 16, 24. *Armoricochitina armoricana* (Rauscher and Doubinger 1967); figure 17, 21; 20; 18, 22. *Armoricochitina nigerica* (Bouché 1965).

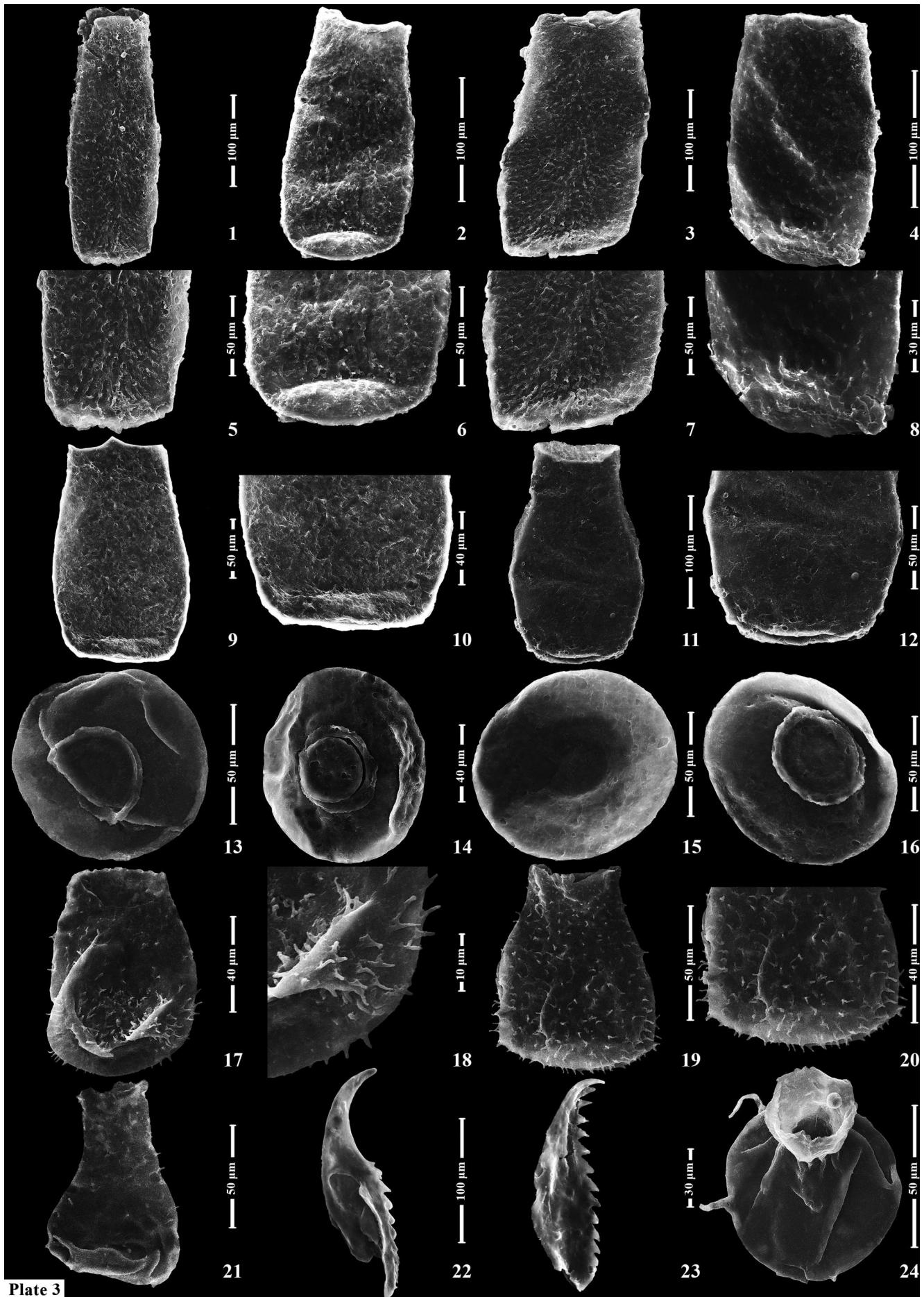


Plate 3. Figures 1, 5; 2, 6; 3, 7; 4, 8. *Acanthochitina barbata* Eisenack 1931; figures 9, 10; 11, 12. *Acanthochitina* cf. *pudica* Vandebroucke 2008; figures 13–16. *Calpichitina lenticularis* (Bouché 1965); figures 17, 18; 19, 20; 21. *Angochitina communis* Jenkins 1967; figures 22–23. scolocodont forms; figure 24. *Spinachitina multi-radiata* (Eisenack 1959).

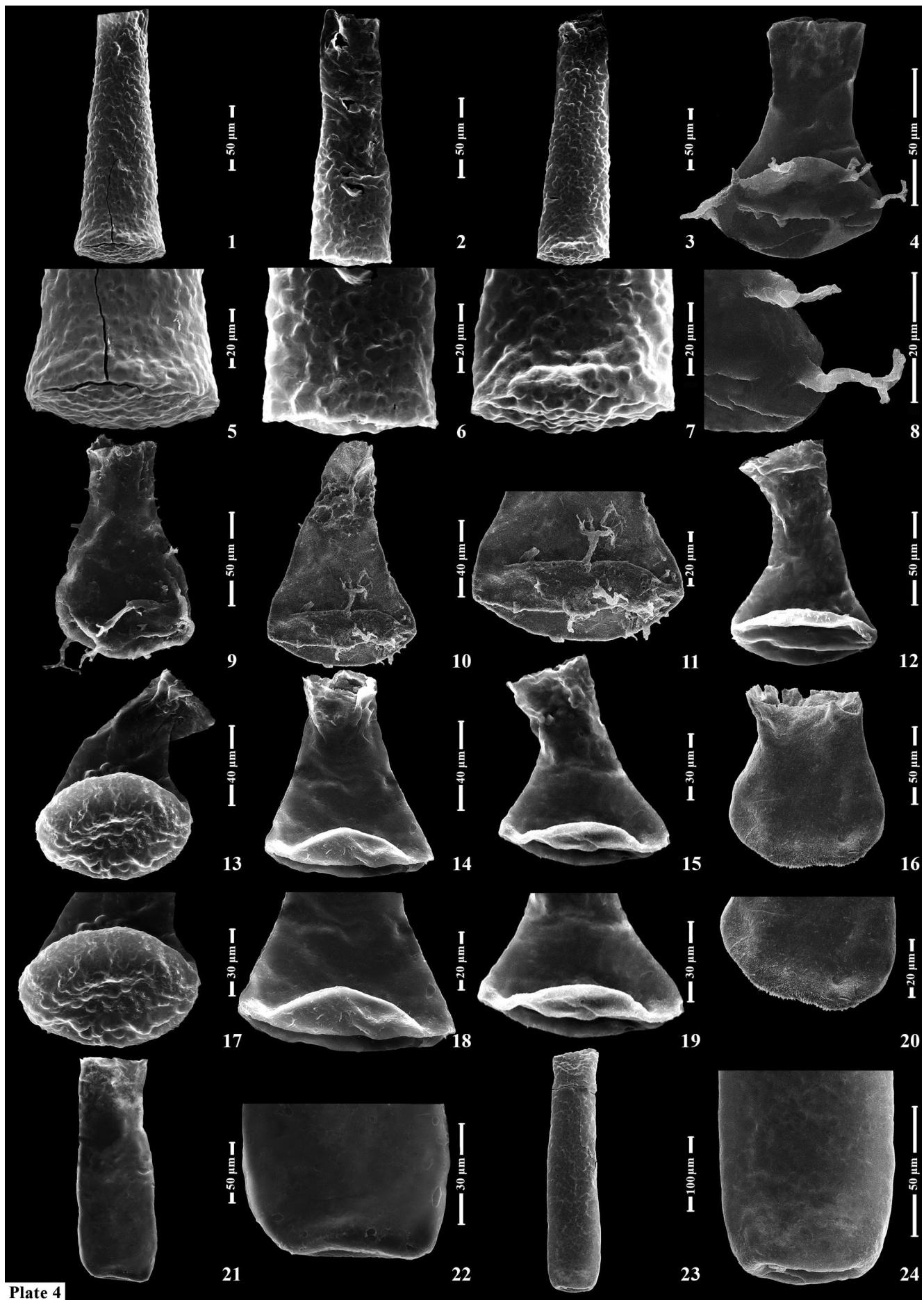


Plate 4

Plate 4. Figures 1, 5; 2, 6; 3, 7. *Hyalochitina jajarmensis* Ghavidel-Syooki 2017c; figures 4, 8; 9; 10, 11. *Ancyrochitina onniensis* Jenkins 1967; figures 12; 13; 17; 14; 18; 15, 19. *Fungochitina spinifera* Eisenack 1962; figures 16, 20. *Eisenackitina rhenana* (Eisenack 1939); figures 21, 22. *Conochitina chydaea* Jenkins 1967; figures 23, 24. *Rhabdochitina usitata* Jenkins 1967.

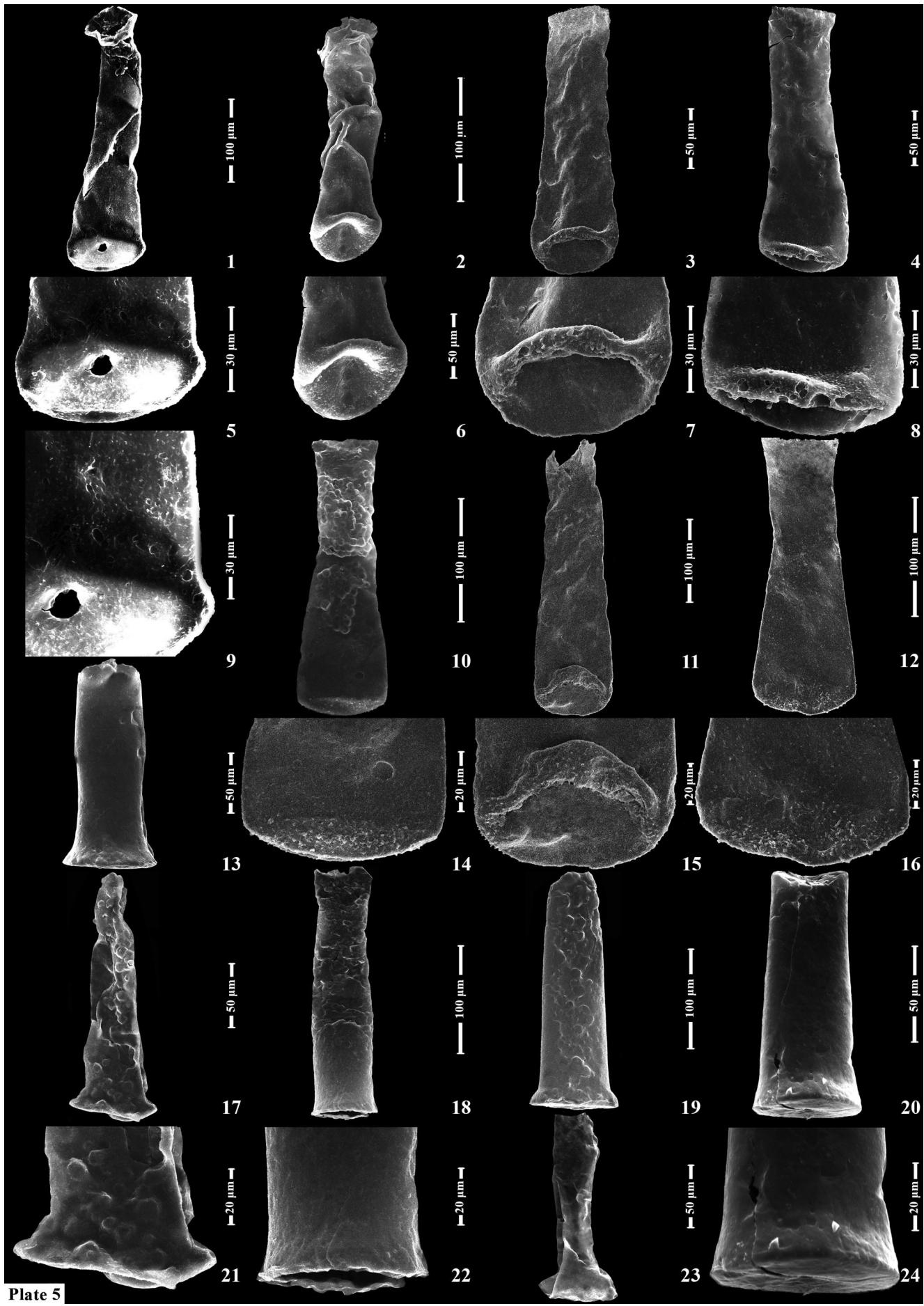


Plate 5. Figures 1, 5, 9; 2, 6. *Belonechitina capitata* Eisenack 1962; figures 3, 7; 4, 8; 10, 14; 11, 15; 12, 16. *Belonechitina micracantha* (Eisenack 1931); figures 13; 17; 21; 19, 23. *Pistillachitina pistillifrons* Eisenack 1939; figures 18, 22. *Cyathochitina calix* (Eisenack 1931); figures 20, 24. *Spinachitina coronata* (Eisenack 1931).

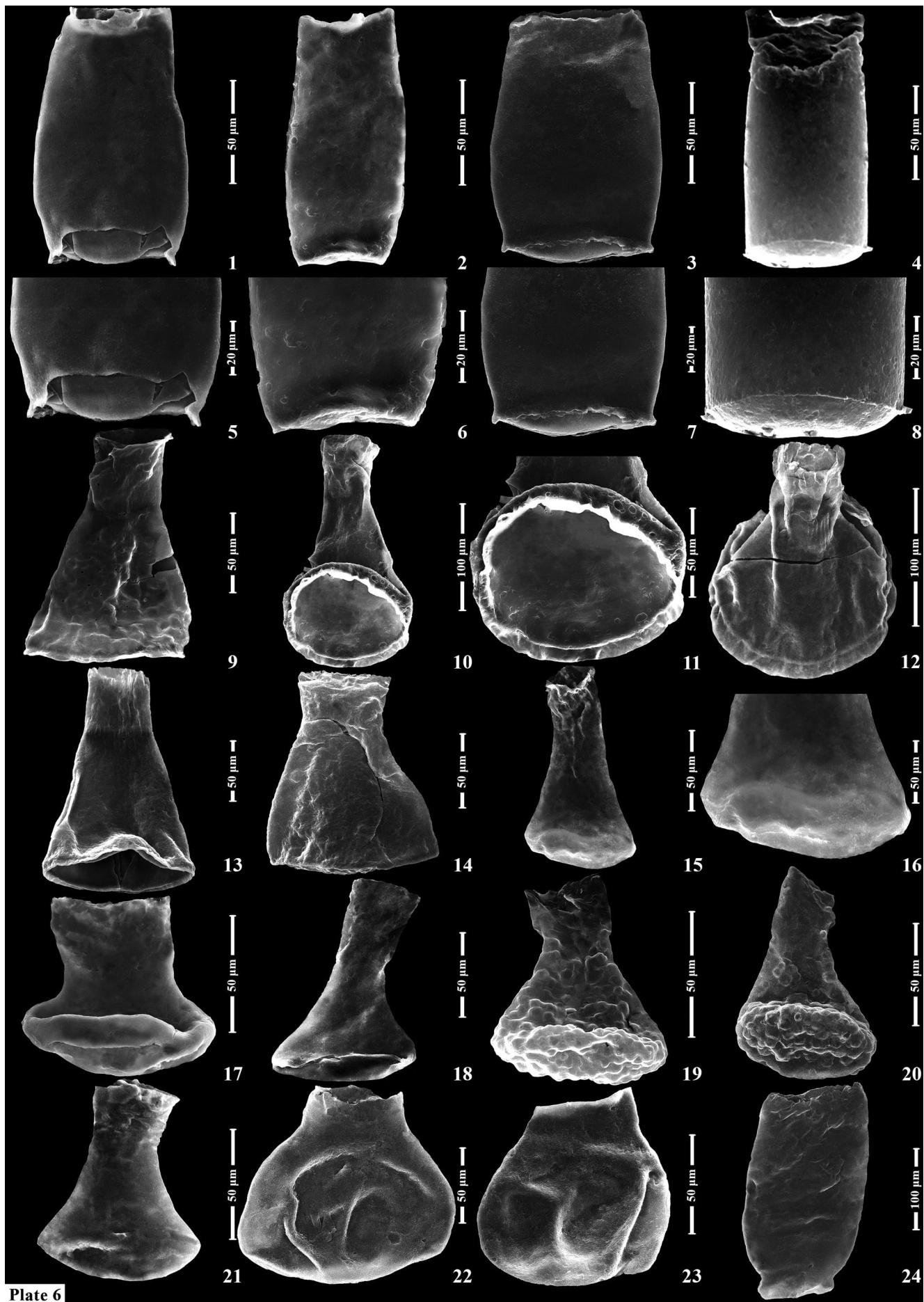


Plate 6

Plate 6. Figures 1, 5; 2, 6; 3, 7. *Cyathochitina jenkinsi* Neville 1974; figures 4, 8. *Cyathochitina protocalix* Paris 1981; figures 10, 11. *Cyathochitina kuckersiana* (Eisenack 1934); figure 12. *Cyathochitina campanulaeformis* (Eisenack 1931); figures 9, 13, 14. *Cyathochitina varenensis* Paris 1981; figures 15, 16; 17–21. *Eunochochitina lepta* (Jenkins 1970); figures 22, 23. *Lagenochitina prussica* Eisenack 1931; figure 24. *Laufeldochitina cf. clavata* (Jenkins 1967).

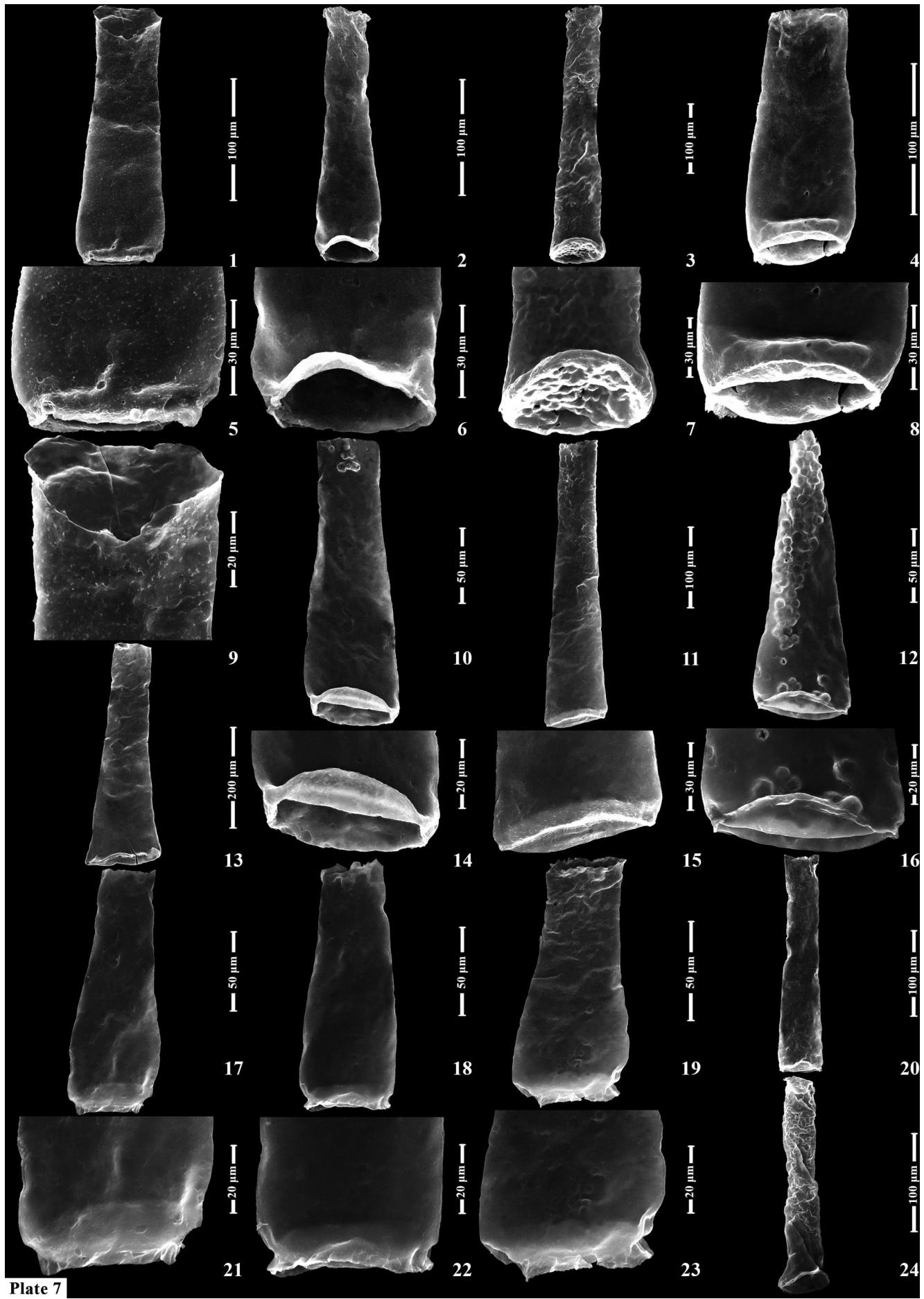


Plate 7. Figures 1, 5, 9. *Tanuchitina alborzensis* Ghavidel-Syooki 2017c; figures 2, 6. *Tanuchitina anticostiensis* (Achab 1977); figures 3, 7. *Tanuchitina bergstroemi* Laufeld 1967; figures 4, 8; 10, 14; 11, 15; 12, 16; 17, 21; 18, 22; 19, 23; 13, 20, 24. *Tanuchitina ontariensis* Jansonius 1964.

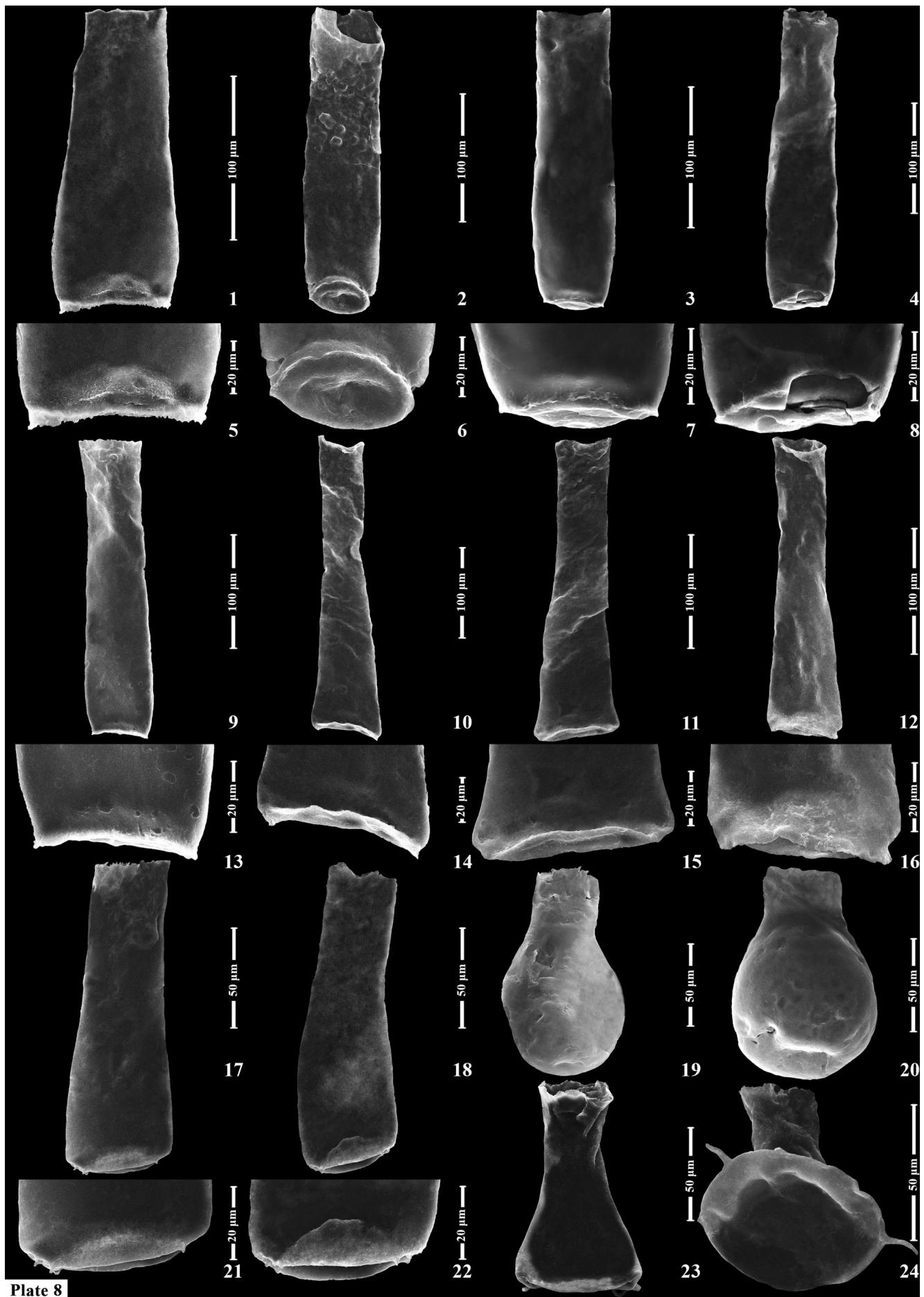


Plate 8. Figures 1, 5. *Tanuchitina fistulosa* Taugourdeau and de Jekhovsky, 1960; figures 2, 6; 3, 7; 4, 8; 9, 13. *Tanuchitina hosseini-nezhadi* sp. nov. (holotype: Plate 8, figure 2); figures 10, 14; 11, 15; 12, 16. *Tanuchitina ontariensis* Jansonius 1964; figures 17, 21; 18, 22. *Spinachitina bulmani* (Jansonius 1964); figures 19, 20. *Lagenochitina baltica* Eisenack 1931; figures 23, 24. *Spinachitina multiradiata* (Eisenack 1959).

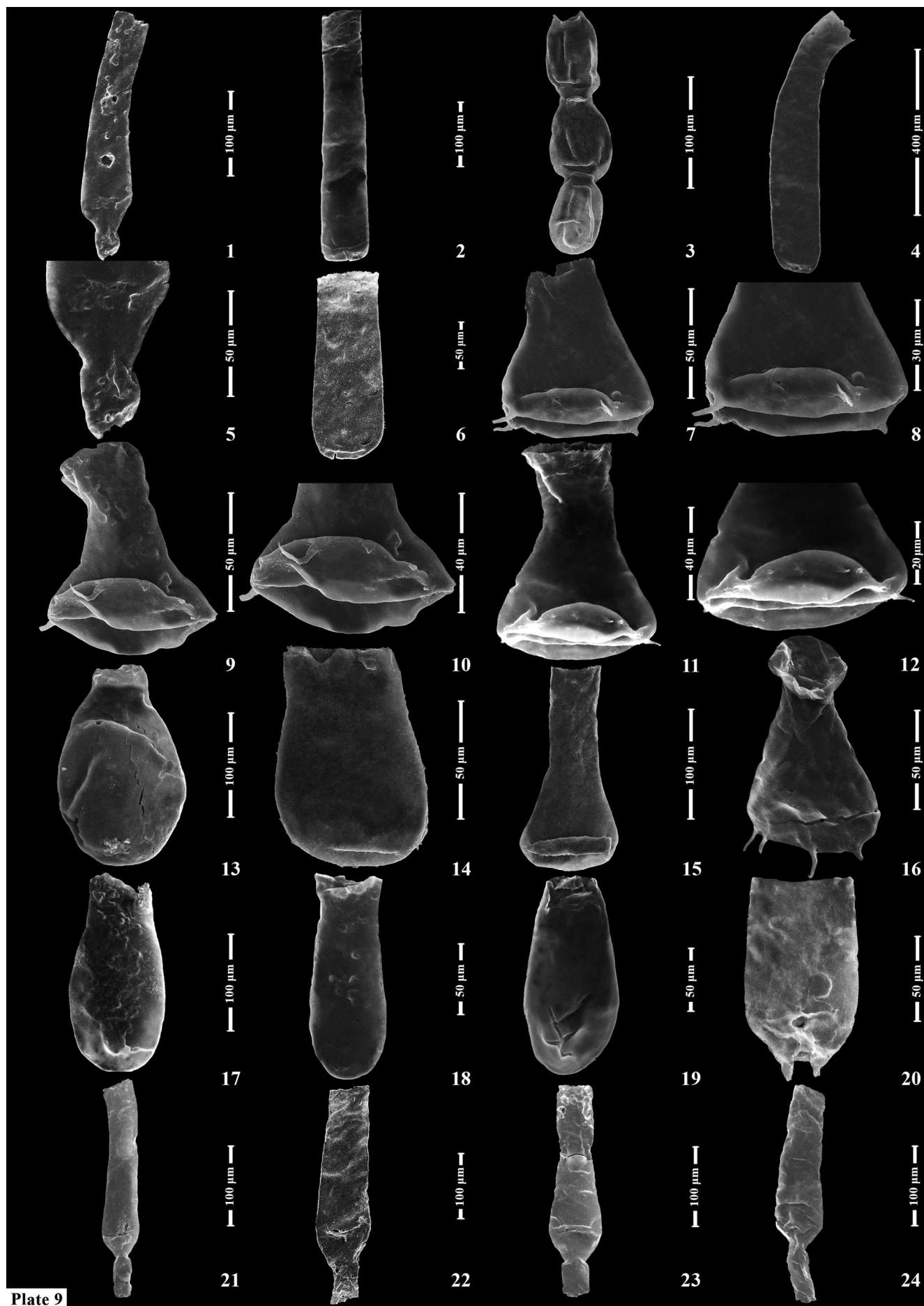


Plate 9. Figures 1, 5; 20, 22. *Eremochitina brevis* Benoit and Taugourdeau 1961; figure 2. *Rhabdochitina magna* Eisenack 1931; figure 3. *Desmochitina ornensis* Paris 1981; figure 4. *Rhabdochitina curvata* Al-Shawareb et al. 2017; figure 6. *Belonechitina henryi* Paris 1981; figures 7, 8; 9, 10; 11, 12; 16. *Spinachitina multiradiata* (Eisenack 1959); figure 13. *Lagenochitina baltica* Eisenack 1931; figure 14. *Eisenackitina* cf. *oelandica* (Eisenack 1955); figure 15. *Euconochitina lepta* (Jenkins 1970); figures 17, 18, 19. *Linochitina pissotensis* Paris 1981; figures 21, 23, 24. *Siphonochitina formosa* Jenkins 1967.

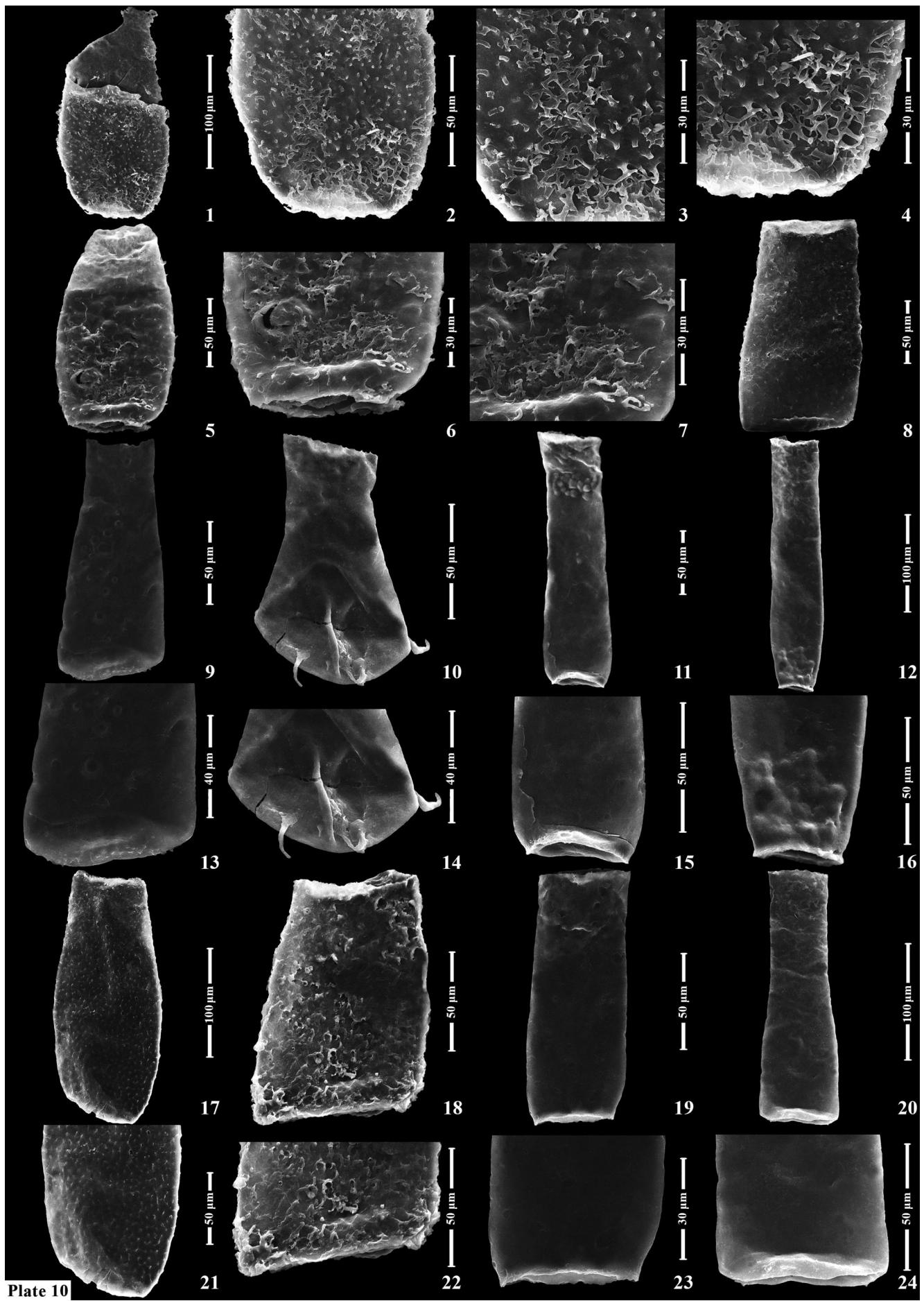


Plate 10. Figures 1, 2, 3, 4; 5, 6, 7; 8; 18, 22. *Acanthochitina latebrosa* Vandenbroucke 2008; figures 9, 13; 20, 24. *Spinachitina bulmani* (Jansonius 1964); figures 10, 14. *Spinachitina multiradiata* (Eisenack 1939); figures 11, 15; 19, 23. *Tanuchitina hosseini-nezhadi* sp. nov. (holotype: Plate 8, figure 2); figures 12, 16. *Tanuchitina densimura* Al-Shawereb et al. 2017; figures 17, 21. *Belonechitina robusta* (Eisenack 1959).

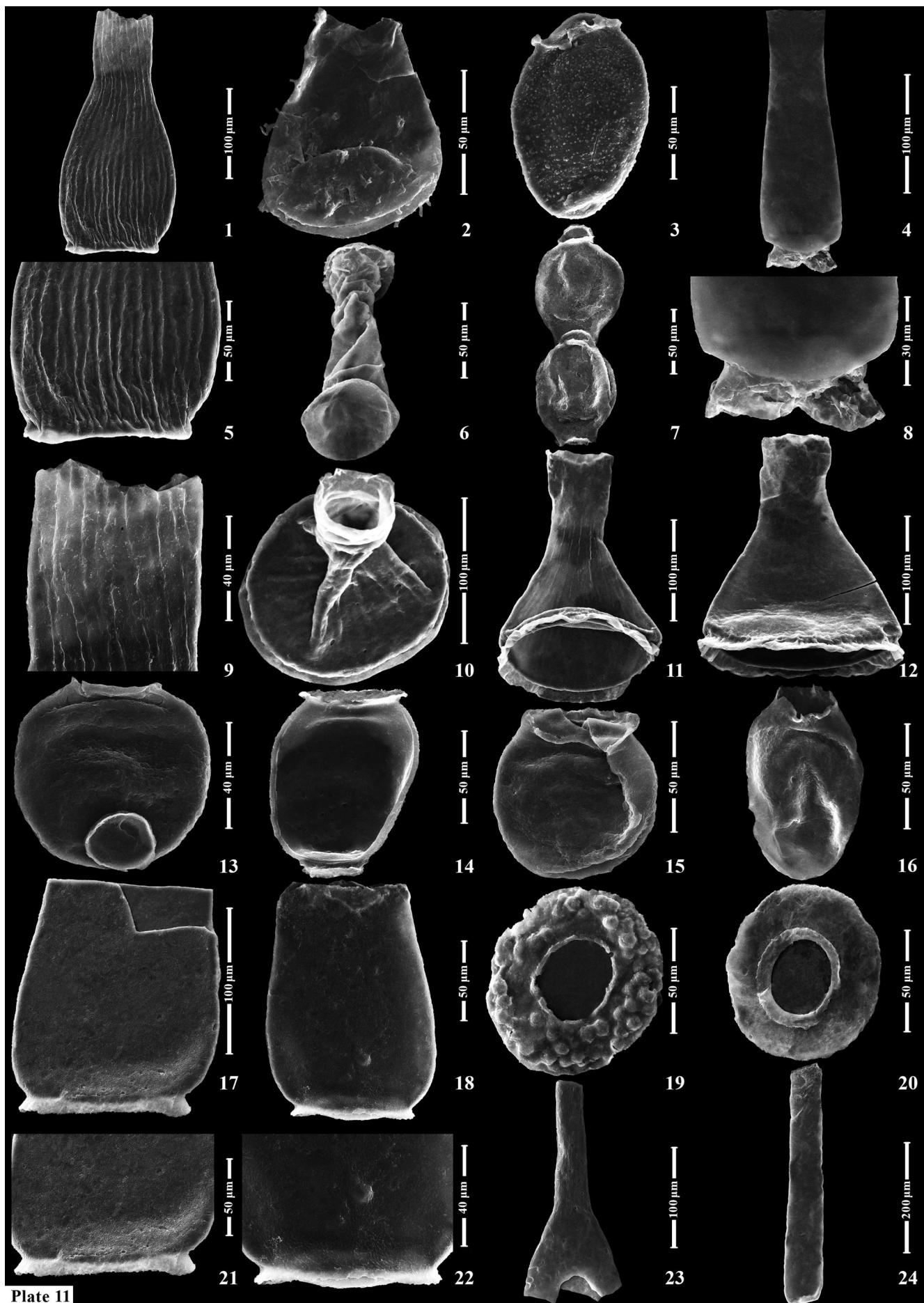


Plate 11

Plate 11. Figures 1, 5, 9. *Cyathochitina* sp. A (Plate 11, figure 1); figure 2. *Angochitina* cf. *dicranum* Jenkins 1967; figure 3. *Desmochitina erinacea* Eisenack 1931; figures 4, 8. *Tanuchitina fistulosa* Taugourdeau and de Jekhovsky, 1960; figure 6. *Pistillachitina pistillifrons* (Eisenack 1939); figures 7, 13, 14. *Desmochitina juglandiformis* Laufeld 1967; figures 10, 11. *Cyathochitina costata* Grahn 1982; figure 12. *Cyathochitina latipatagium* (Jenkins 1969); figure 15. *Desmochitina minor typica* Eisenack 1931; figure 16. *Desmochitina elongata* Eisenack 1958; figures 17, 21; 18, 22. *Armoricochitina nigerica* (Bouché 1965); figures 19, 20. *Calpichitina lenticularis* (Bouché 1965); figure 23. chitinous graptolite remains; figure 24. *Rhabdochitina magna* Eisenack 1931.

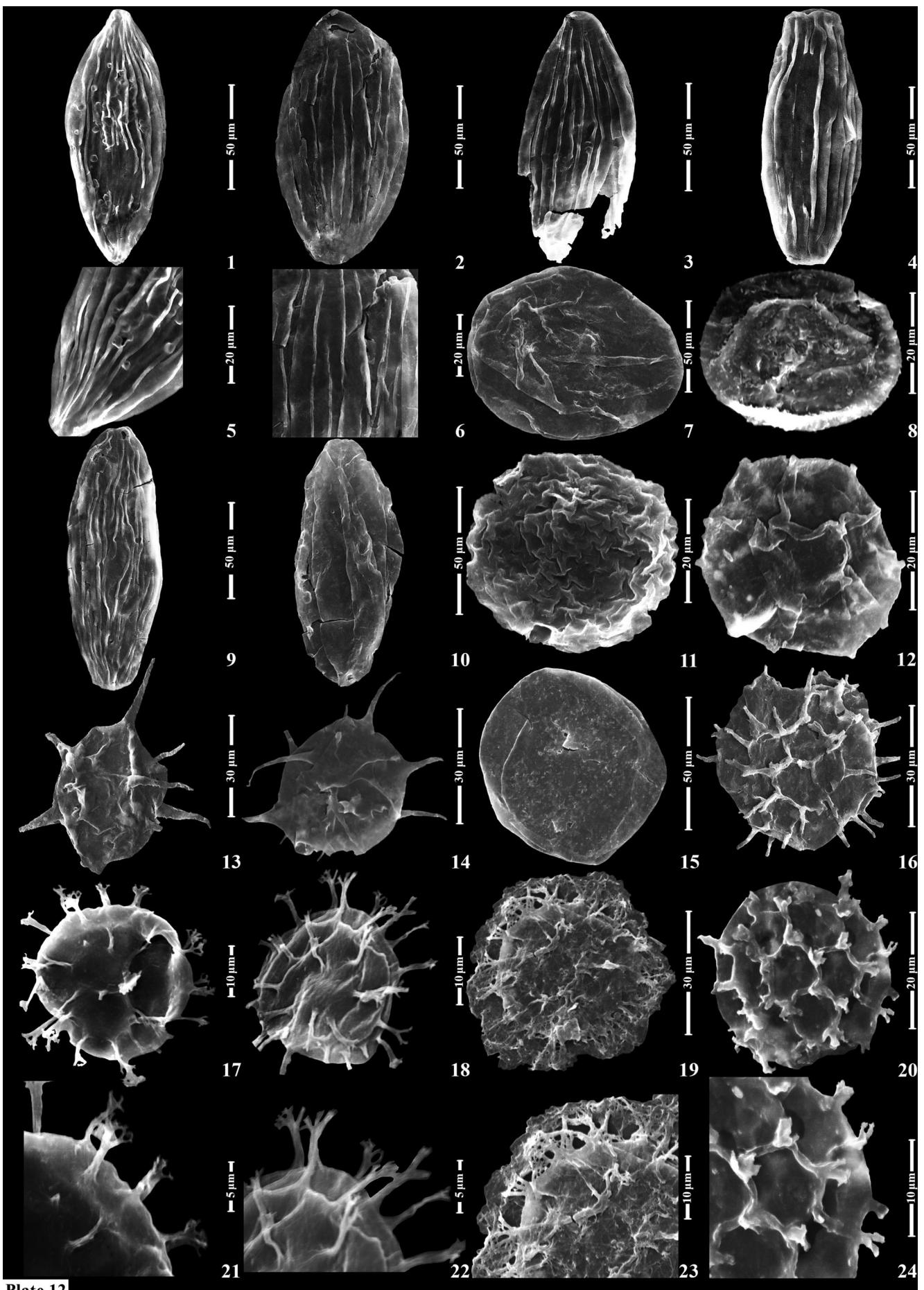


Plate 12

Plate 12. Figures 1, 5; 2, 6; 3, 4, 9. *Dactylofusa kazzazii* sp. nov. (holotype: Plate 12, [figures 9](#)); figure 7. *Leiosphaeridia* sp.; figure 8. *Lophosphaeridium variable* Volkova 1974; figure 10. *Eliasum* cf. *Ilaniscum* Fombella 1977; figure 11. *Cristallinum ovillense* (Cramer and Díez 1972) Martin in Martin and Dean 1981; figure 12. *Cristallinum cambriense* (Slovikoya 1968) Vanguystaine 1978; figures 13, 14. *Ninadiacrodium caudatum* (Vanguystaine 1973) Raevskaya and Servais 2009; figure 15. *Saharidia fragilis* (Downie) Combaz 1967; figure 16. *Timofeevia phosphoritica* Vanguystaine 1978; figures 17, 21; 18, 22. *Timofeevia lancarae* (Cramer and Díez 1972) Vanguystaine 1978; figures 19, 23. *Vulcanisphaera africana* Deunff 1961 emend. Kroeck et al. 2020; figures 20, 24. *Vulcanisphaera mougnoana* (Martin 1973) emend. Kroeck et al. 2020.

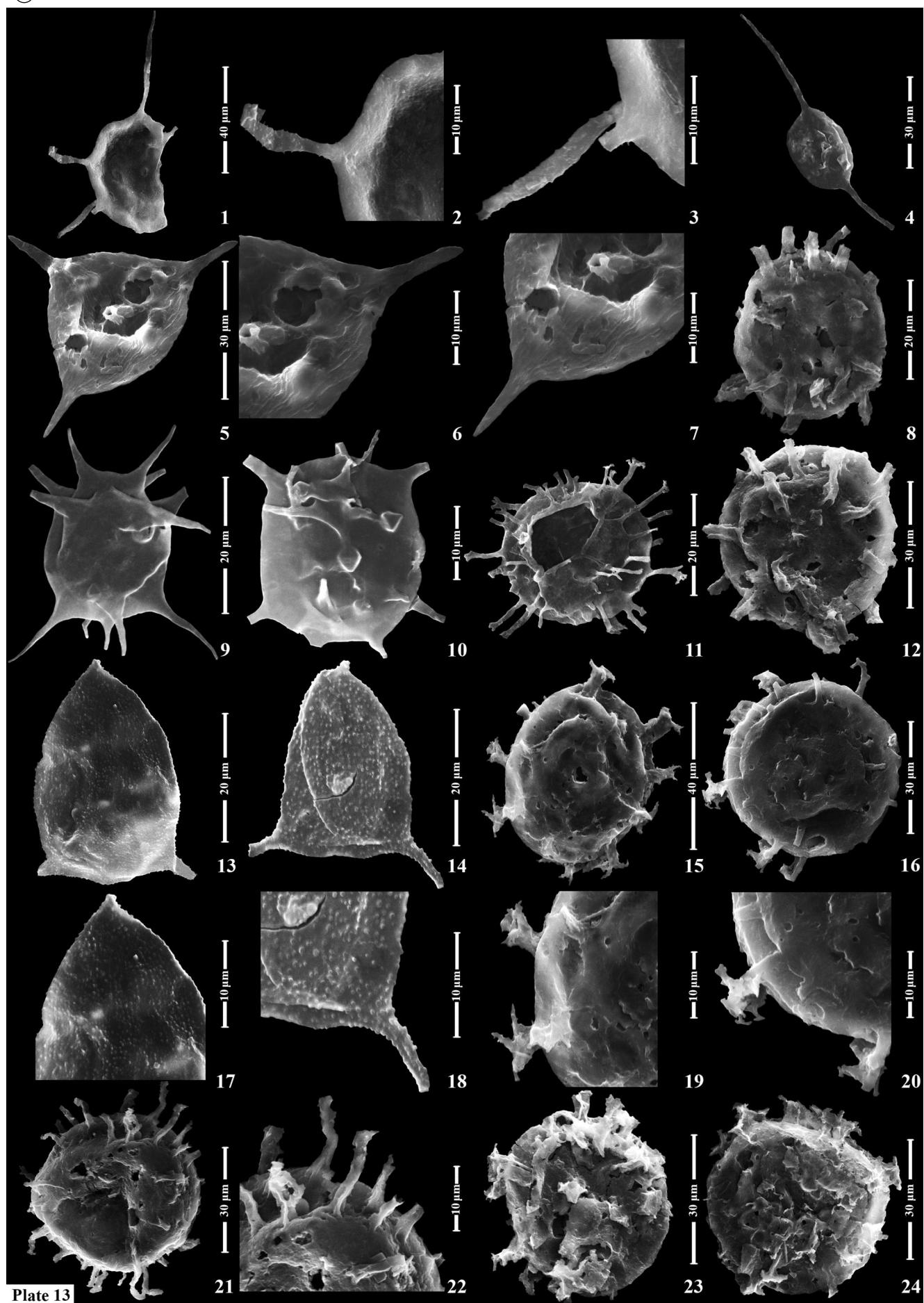


Plate 13. Figures 1, 2, 3. *Baltisphaeridium klabavense* (Vavrdovà, 1965) Kjellström 1976; figure 4. *Leiofusa stoumonensis* Vanguestaine 1973; figures 5, 6, 7. *Arknoria virgata* Burmann 1970; figures 8, 12. *Peteinosphaeridium dissimile* (Górka 1969) Yin 1995; figures 9, 10. *Dasydiacrodium obsonum* Martin in Martin and Dean 1988; figure 11. *Cymatiogalea aspergillum* Martin in Martin and Dean 1988; figures 13, 17, 18. *Ninadiacrodium dumontii* (Vanguestaine 1973) Raevskaya and Servais 2009; figures 15, 19, 16, 20; 23, 24. *Peteinosphaeridium coronula* Yin et al. 1998; figures 21, 22. *Peteinosphaeridium angustilaminae* Playford et al. 1995.

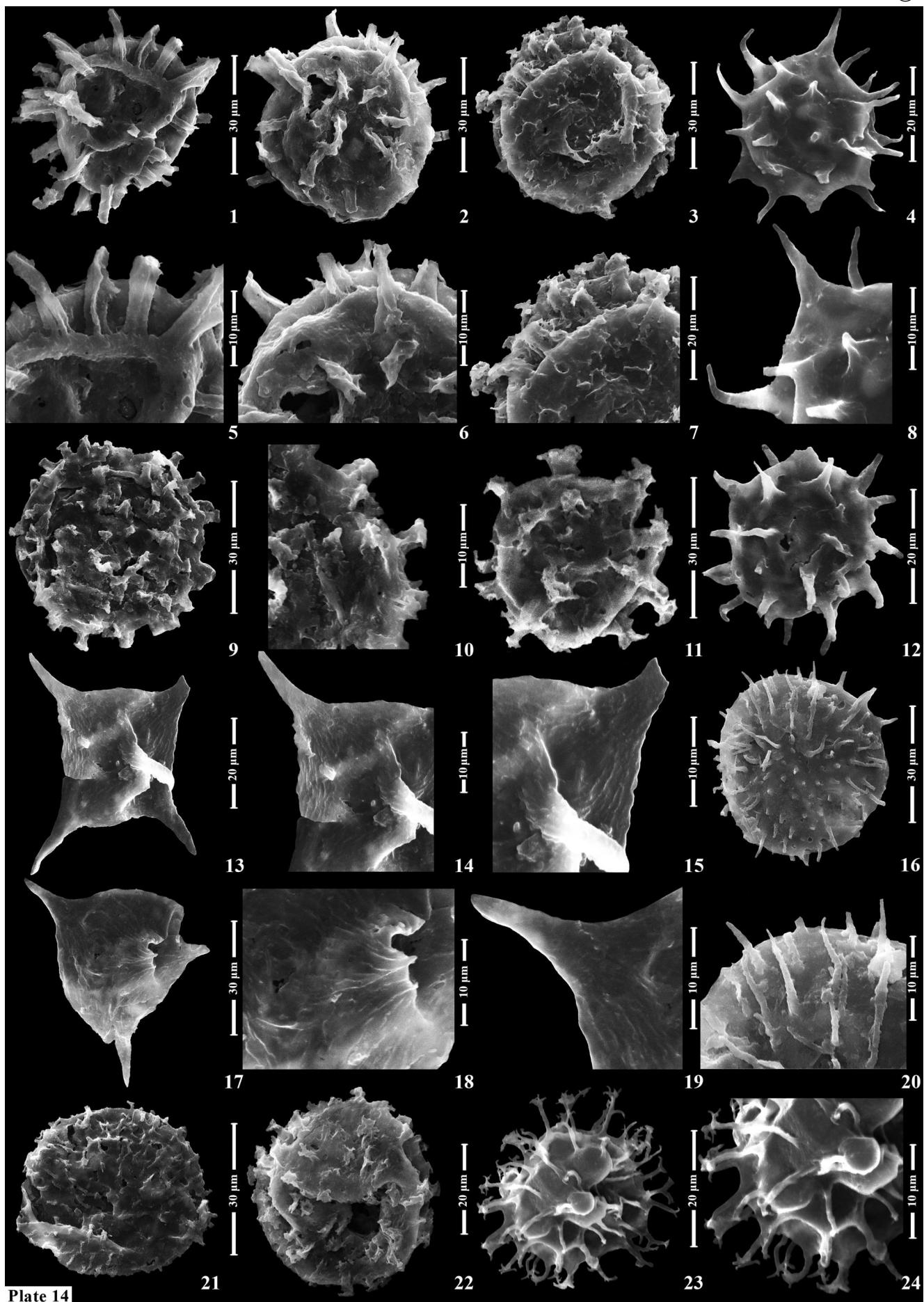


Plate 14. Figures 1, 5; 2, 6. *Peteinosphaeridium dissimile* Górka 1969; figures 3, 7. *Peteinosphaeridium exornatum* Tongiorgi et al. 1995; figures 4, 8; 12. *Pachysphaeridium sidereum* Ribecai and Tongiorgi 1999; figures 9, 10; 11, 22. *Peteinosphaeridium velatum* Kjellström 1971 emend. Playford et al. 1995; figures 13, 15. *Striatotheca mutua* Burmann 1970; figures 16, 20. *Baltisphaeridium razii* Ghavidel-Syooki and Piri-Kangarshahi 2023; figures 17, 18, 19. *Arknia virgata* Burmann 1970; figure 21. *Peteinosphaeridium eximum* Playford et al. 1995; figures 23, 24. *Timofeevia lancarae* (Cramer and Díez 1972) Vanguetaine 1978.

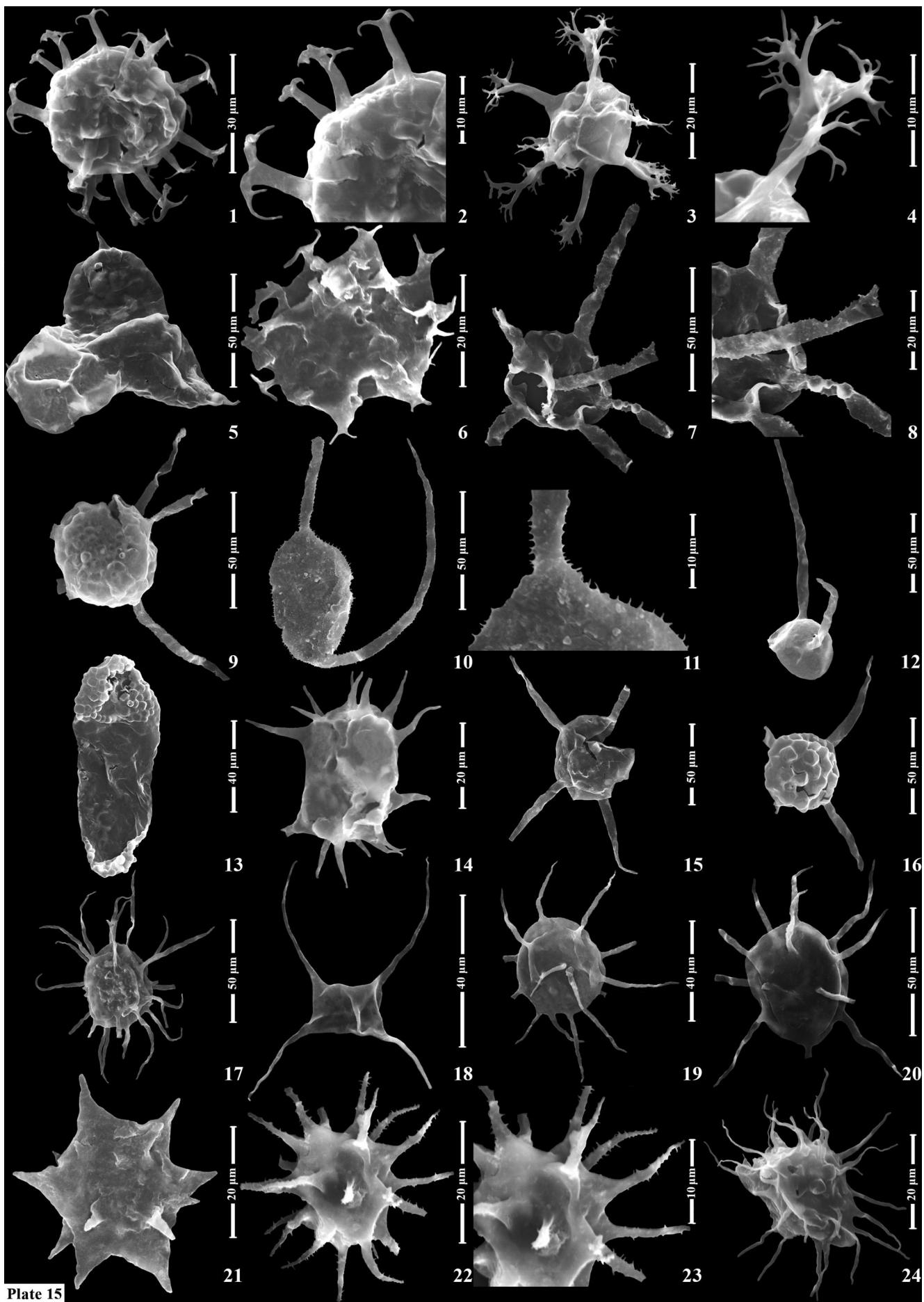


Plate 15

Plate 15. Figures 1, 2. *Ordoviciidium elegantulum* Tappan and Loeblich 1971; figures 3, 4. *Multiplicisphaeridium irregulare* Staplin et al. 1965; figure 5. *Inflatarium trilobatum* Le Hérisse et al. 2015; figure 6. *Vulcanisphaera simplex* (Jardiné et al. 1974) emend. Kroeck et al. 2020; figures 7, 8. *Baltisphaeridium llanvirnianum*; figure 9. *Baltisphaeridium perclarum* Loeblich and Tappan 1978; figures 10, 11. *Orthosphaeridium bispinosum* Turner 1984; figure 12. *Orthosphaeridium ternatum* (Burmann 1970) Eisenack et al. 1976; figure 13. *Navifusa ancepsipuncta* Loeblich 1970; figure 14. *Acanthodiacrodiun crassus* (Loeblich and Tappan 1978) Vecoli 1999; figures 15, 16. *Orthosphaeridium quadrinatum* (Burmann 1970) Eisenack et al. 1976; figure 17. *Orthosphaeridium insculptum* Loeblich 1970; figure 18. *Veryhachium lairdii* group (Servais et al. 2007); figures 19, 20. *Baltisphaeridium klabavense* (Vavrdová, 1965) Kjellström 1971; figure 21. *Goniosphaeridium splendens* (Eisenack 1931) Turner 1984; figures 22, 23. *Stellechinatum celestum* (Martin) Turner 1984; figure 24. *Baltisphaeridium fragile* Tongiorgi et al. 1995.

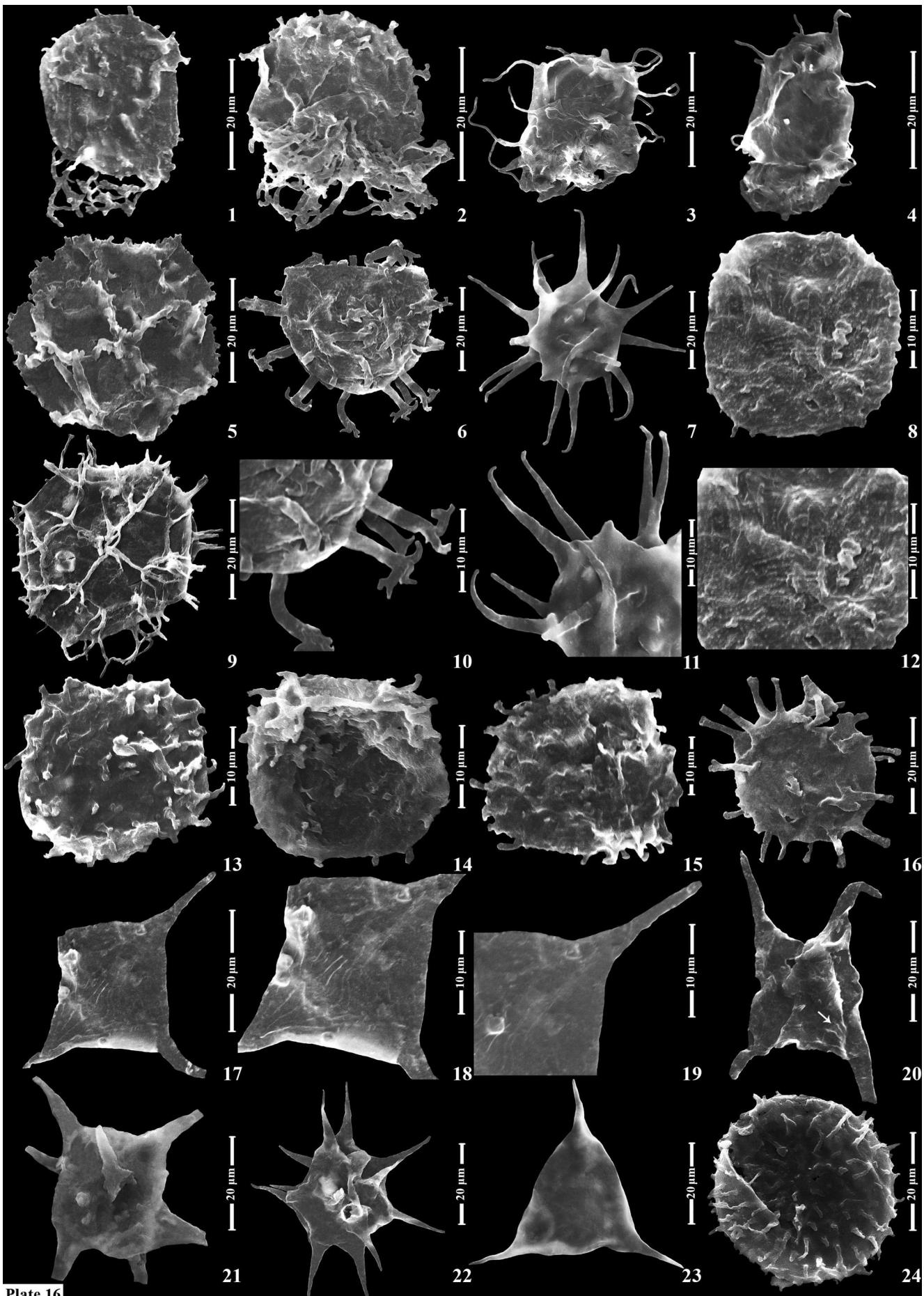


Plate 16

Plate 16. Figures 1, 2. *Arbusculidium iranense* (Ghavidel-Syooki 1990) emend. Ghavidel-Syooki 2021; figures 3, 4. *Arbusculidium filamentosum* (Vavrdová 1972; figure 5. *Cristallinum cambriense* (Slovikova, 1968) Vanguestaine 1978; figures 6, 10. *Cymatiogalea aspergillum* Martin in Martin and Dean 1988; figures 7, 11; 22. *Tectitheca additionalis* (Burmann 1968); figures 8, 12. *Coryphidium almohadillum* (Cramer and Diez 1972) Servais et al. 2008; figure 9. *Vulcanisphaera moungana* (Martin 1973) emend. Krocek et al. 2020; figures 13, 14, 15. *Coryphidium bohemicum* Vavrdová 1972 emend. Servais et al. 2008; figure 16. *Vavrdovella mawlawii* Ghavidel-Syooki 2021; figures 17, 18, 19; 20. *Striatotheca principalis* var. *parva* Burmann 1970; figure 21. *Veryhachium estrellitae* Cramer 1964; figure 23. *Veryhachium trispinosum* group (Servais et al. 2007); figure 24. *Baltisphaeridium razii* Ghavidel-Syooki and Piri-Kangarshahi 2023.

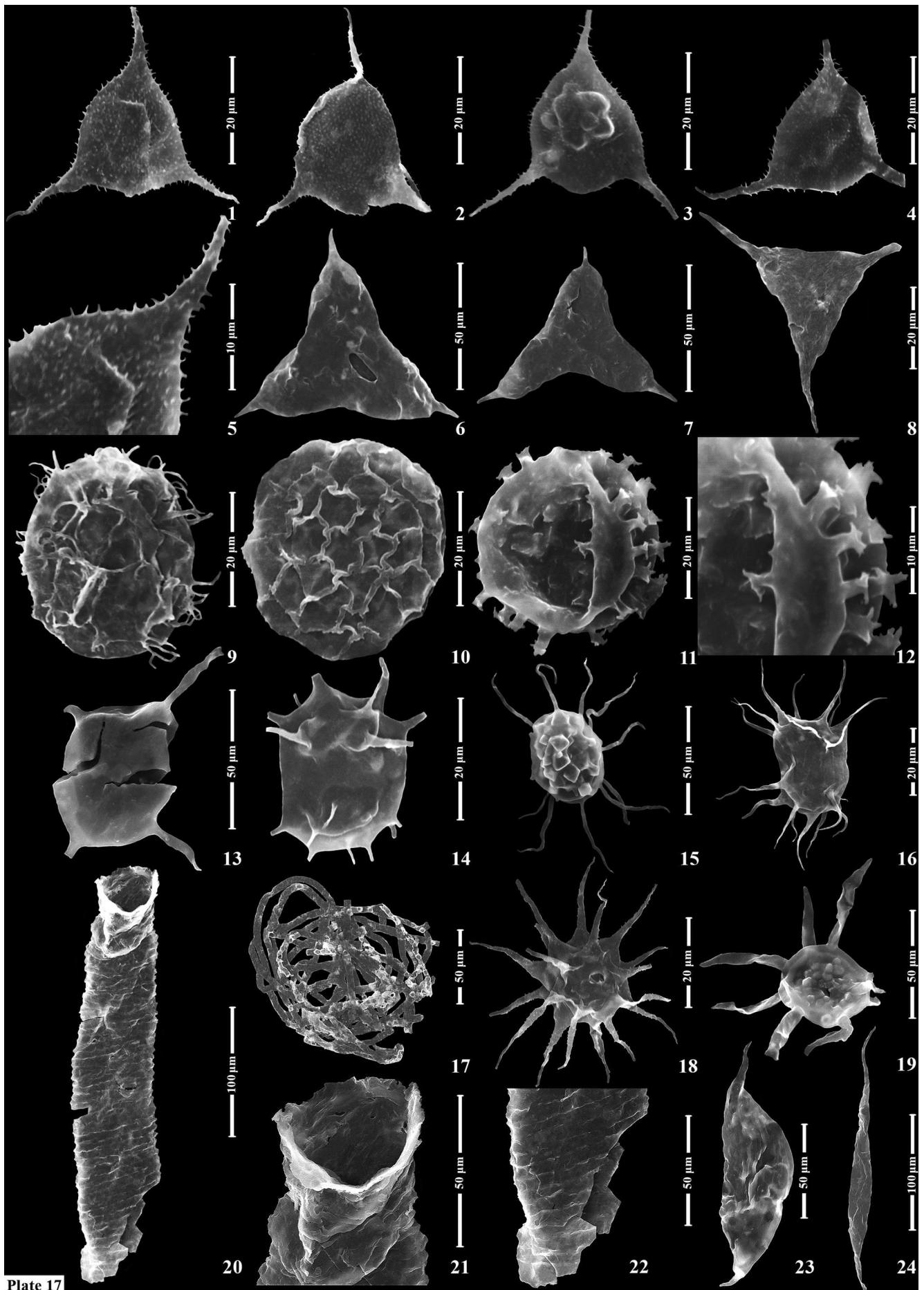


Plate 17

Plate 17. Figures 1, 5; 2, 3, 4. *Villo sacapsula setosapellucula* (Loeblich 1970) Loeblich and Tappan 1976; figures 6, 7. *Inflatarium alborzensis* sp. nov. (holotype: Plate 17, figure 6); figure 8. *Veryhachium* cf. *scabratum* Cramer 1964; figure 9. *Vulcanisphaera mougoana* (Martin 1973) emend. Kroeck et al. 2020; figure 10. *Cristallinium cambriense* (Slovikova, 1968) Vanguestaine 1978; figures 11, 12. *Tylotopalla caelamenicetus* Loeblich 1970; figure 13. *Orthosphaeridium rectangulare* (Eisenack 1963) Eisenack 1968a; figure 14. *Dasydiacrodium obsonum* Martin in Martin and Dean 1988; figure 15. *Baltisphaeridium fragile* Tongiorgi et al. 1995; figure 16. *Acanthodiacrodium crassus* (Loeblich and Tappan 1978) Vecoli 1999; figure 17. *Siphonophycus typicum* (Hermann 1974), Butterfield 1994; figure 18. *Stellechinatum celestum* (Martin) Turner 1984; figure 19. *Baltisphaeridium perclarum* Loeblich and Tappan 1978; figures 20–22. Chitinous graptolite cyst; figure 23. *Dactylofusa platynetrella* (Loeblich and Tappan 1978) Fensome et al. 1990; figure 24. *Leiofusa litotes* Loeblich and Tappan 1976.

epochs (e.g. see Martin and Dean 1988; Vecoli 1996, 1999; Moczydłowska 1998; Vanguestaine 2002). This biozone is equivalent temporally to the Acritarch Assemblage Zone III of Ghavidel-Syooki and Vecoli (2008) and Assemblage B of Spina et al. (2021), both observed in the High Zagros Mountains, thus attributing it to the early Furongian Global Stage. Notably, no macrofauna has been documented within this interval of the Lashkarak Formation at the Simeh-Kuh. Therefore, relying on the biostratigraphically significant acritarch taxa, this thickness of the Lashkarak Formation is assigned to the early Furongian stage.

4.2.2. *Ninadiacrodium caudatum*-*Dasydiacrodium obsonum* assemblage biozone (B)

This acritarch assemblage biozone is distinguished by the concurrent presence of *Ninadiacrodium caudatum* (Vanguestaine) Raevskaya and Servais (2009), and *Dasydiacrodium obsonum* Martin in Martin and Dean (1988) within the siliciclastic sediments located at the lowest stratum of the Lashkarak Formation. This particular biozone comprises a thickness of 19 m within the study section at the Simeh-Kuh locality, with its upper boundary aligning with the base of the subsequent assemblage biozone (C). The genus *Ninadiacrodium* is characteristic of the Late Cambrian epoch and is typically found in cold- to temperate-water phytoplankton assemblages in the Southern Hemisphere (Raevskaya and Servais 2009). This genus and its species are primarily confined to the Upper Cambrian strata of Gondwana, Avalonia, and Baltica. *Ninadiacrodium caudatum* has been documented in Furongian-aged deposits from various regions, including the Kara Plate in the Yaroslavl region of Russia (Volkova 1990, 1999); Estonia (Volkova 1990; Paalits 1992; Mens et al. 1993); Shropshire, England (Potter et al. 2012); eastern Newfoundland, Canada (Martin and Dean 1988; Parsons and Anderson 2000); North Africa and adjacent areas (Ribecai and Vanguestaine 1993); Spain (Albani et al. 2006); Algeria (Vecoli 1996, 1999; Vecoli et al. 1999); and southern Iran (Ghavidel-Syooki and Vecoli 2008; Ghavidel-Syooki 2019; Spina et al. 2021). In the current dataset, *N. caudatum* (Plate 12, figures 13, 14) and *N. dumontii* (Plate 13, figures 13, 17; 14, 18) were identified in samples MG-MHP 122 to 125 of the Lashkarak Formation, including a thickness of 19 m within the study section (Figure 5 and Table 1a–c). It is noteworthy that according to the literature, the genus *Ninadiacrodium* and its species have not been documented in China (Raevskaya and Servais 2009). Another significant acritarch species within this biozone is *Dasydiacrodium obsonum* Martin in Martin and Dean 1988 (Plate 13, figures 9, 10; Plate 17, figure 14), which is typically found within the Furongian *Parabolina spinulosa*-*Acerocare* trilobite biozones. This taxon has been documented in Furongian-aged strata across various regions, including eastern Newfoundland, Canada (Martin and Dean 1988); Estonia (Paalits 1992); England (Potter et al. 2012); Belgium and France (Ribecai and Vanguestaine 1993); north-eastern China (Martin 1993); Algeria (Vecoli 1996); Arctic Russia (Moczydłowska and Stockfors 2004); northern Spain (Albani et al. 2006); and southern Iran (Ghavidel-Syooki and Vecoli

2008; Ghavidel-Syooki 2019). Furthermore, many associated acritarch taxa from the preceding biozone persist into this assemblage biozone (Figure 5 and Table 1a–c). Notably, macrofauna has not been observed within this interval of the Lashkarak Formation at Simeh-Kuh. Therefore, this thickness of the Lashkarak Formation in the Alborz Mountains, north of Iran, is assigned to the middle–late Furongian based on well-known acritarch taxa.

4.2.3. *Vulcanisphaera simplex*-*Saharidina fragilis* assemblage biozone (C)

This acritarch assemblage biozone is distinguished by the simultaneous presence of *Vulcanisphaera simplex* Jardiné et al. 1974 and *Saharidina fragilis* (Downie) Combaz 1967, immediately succeeding the assemblage biozone (B) within the Lashkarak Formation (Figure 5 and Table 1a–c). This particular biozone includes the samples MG-MHP 126 to 130, encompassing a thickness of 23 m within the study section at the Simeh-Kuh locality. According to Kroeck et al. (2020), *Vulcanisphaera simplex* is an excellent index microfossil for the Tremadocian Tr1–Tr3 (time slices 1a–1d). *Vulcanisphaera simplex* (Plate 15, figure 6) was observed in samples MG-MHP 126 to 130 of the Lashkarak Formation. To date, this taxon has been documented in Tremadocian-aged strata in various regions, including Iran (Ghavidel-Syooki 2000, 2006, 2021; Ghavidel-Syooki and Vecoli 2008; Ghavidel-Syooki and Piri-Kangarshahi 2023), Tunisia (Vecoli et al. 1999), Algeria (Jardiné et al. 1974; Vecoli et al. 1995, 1999; Vecoli 1996), Morocco (Elaouad-Debbaj 1988), France (Cocchio 1982), Italy (Pittau 1985; Di Milia et al. 2022), Spain (Albani et al. 2006; Palacios 2015), and Iraq (Baban and Lawa 2016). Hence, the presence of *V. simplex* confirms the Early Ordovician (Tremadocian) age for this assemblage. Another notable acritarch species within this biozone is *Saharidina fragilis*, originally documented from the Tremadocian-age Shineton Shales of England (Downie 1958). *Saharidina fragilis* (Plate 12, figure 15) was identified in samples MG-MHP 126 to 130 of the Lashkarak Formation at the Simeh-Kuh locality. This species has been reported from numerous localities in Tremadocian Tr1–Tr3 (time slices 1a–1d), including France (Martin 1973); the Lower Shale Member of the Zardkuh Formation in the High Zagros Mountains, southern Iran (Ghavidel-Syooki and Vecoli 2008; Ghavidel-Syooki 2021); the lower Tremadocian Tr1 (time slice 1a) of the Lashkarak Formation in northern Iran (Ghavidel-Syooki 1995, 2001a, 2003); the lower Tremadocian Tr1 (time slices 1a–1b), Algeria (Combaz 1967); the upper Tremadocian Tr3 (time slice 1d) in the Shineton Shales of England (Downie 1958); and the Floian Fl1 (time slice 2a) in the Klabava Formation, Bohemia (Vavrlová 1972). Additionally, neither trilobites nor brachiopods have been documented within this interval of the Lashkarak Formation at Simeh-Kuh (Popov and Cocks 2017, fig. 2, L1–L15). Therefore, considering the presence of these index acritarch taxa, it is suggested that this 23 m part of the Lashkarak Formation corresponds to an Early Ordovician (Tremadocian) age.

4.2.4. *Arbusculidium filamentosum-Vavrdovella mawlawii assemblage biozone (D)*

The co-occurrence of *Arbusculidium filamentosum* Vavrdová 1972 and *Vavrdovella mawlawii* Ghavidel-Syooki 2021 delineates this acritarch assemblage biozone, which directly succeeds the assemblage biozone (C) within the Lashkarak Formation at the Simeh-Kuh locality (Figure 5 and Table 1a–c). This particular assemblage biozone includes samples MG-MHP 131 to 142, covering a thickness of 58 m within the measured section. *Arbusculidium filamentosum* (Plate 16, figures 3, 4) is recognised as a prominent index species for the Peri-Gondwanan acritarch palaeoprovince, typically found along the subpolar margin of Gondwana. This taxon has been documented in numerous regions, including Floian-aged strata in southern and northern Iran (Ghavidel-Syooki 1990, 1995, 1996, 2006, 2021), Pakistan (Tongiorgi et al. 1994), Morocco (Cramer et al. 1974), and Argentina (Rubinstein et al. 2001; 2019), and in Floian–Darriwilian-aged strata in China (Li 1987; Yin 1995; Tongiorgi et al. 2003; Yan et al. 2013). The stratigraphical occurrence of this species is corroborated by independent age control: its FAD is identified in the early Floian (*Didymograptus extensus* graptolite zone) within the Wabana Group of Bell Island, eastern Newfoundland, Canada (Martin in Dean and Martin 1978), while its LAD is situated in the late Floian (*Tetragraptus reclinatus abbreviatus* graptolite zone) within the Klabava Formation of the Prague Basin, Czech Republic (Vavrdová 1990). Furthermore, as indicated by Servais et al. (2018), the FAD of *A. filamentosum* corresponds to the upper Floian Fl3 (time slice 2c) in Avalonia and southern Gondwana and to the middle Floian Fl2 (time slice 2b) in South China and East Gondwana (Argentina). *Vavrdovella mawlawii* is another acritarch species confined to this particular assemblage. *Vavrdovella mawlawii* (Plate 16, figure 16) was initially described from the late Floian Fl3 (time slice 2c) in the Upper Shale Member of the Zardkuh Formation, the High Zagros Mountains of southern Iran (Ghavidel-Syooki 2021). The associated acritarchs within this assemblage biozone consist of *Arbusculidium iranense* (Plate 16, figures 1, 2), *Baltisphaeridium fragile* (Plate 15, figure 24; Plate 17, figure 15), *Veryhachium estrellitae* (Plate 16, figure 21), *Veryhachium lairdii* group (Plate 15, figure 18), and *Veryhachium trispinosum* group (Plate 16, figure 23). Among these associated acritarchs, *V. lairdii* and *V. trispinosum* display a broad temporal range, spanning the Early to Late Ordovician (Servais et al. 2007) and persist into the subsequent assemblage biozones (Figure 5 and Table 1a–c). In contrast, *A. iranense*, *B. fragile*, and *V. estrellitae* have been documented in limited localities, primarily from rocks of the late Floian Fl3 (time slice 2c), specifically within the Upper Shale Member of the Zardkuh Formation in the High Zagros Mountains of southern Iran (Ghavidel-Syooki 2021); in the early Floian Fl1 (time slice 2a), within the Lashkarak Formation in the Gerdkuh locality within the Alborz Mountains, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023); and in South China (Tongiorgi et al. 1995, 2003). Additionally, the presence of the brachiopod species *Thysanotos multispinulosus* Popov et al. (2008) within this interval of the Lashkarak Formation suggests a

Floian age (Popov and Cocks 2017, fig. 2, L17). Therefore, the combination of acritarch and brachiopod species supports the age of a Floian Global Stage for samples MG-MHP 131 to 142 of the Lashkarak Formation at the Simeh-Kuh.

4.2.5. *Coryphidium bohemicum-Striatotheca principalis assemblage biozone (E)*

This particular assemblage biozone is distinguished by the concurrent presence of *Coryphidium bohemicum* Vavrdová 1972, and *Striatotheca principalis* Burmann 1970, immediately succeeding the assemblage biozone (D) in this context. In the current dataset, this acritarch assemblage is observed in samples MG-MHP 143 to 146, including a thickness of 22 m within the Lashkarak Formation (Figure 5 and Table 1a–c). The FAD of *Coryphidium* is situated in the uppermost Tremadocian (Servais et al. 2008) and represents a common component of the Peri-Gondwanan acritarch palaeoprovince (Vavrdová 1972; Li 1987; Servais et al. 2003; Molyneux et al. 2013). Thus far, this taxon has not been documented in the Baltic or Laurentian palaeoprovinces (Servais and Fatka 1997). In Avalonia (north-west England), the initial occurrence of *Coryphidium* is noted in the upper part of sub-assemblage 3 of the *messoudensis-trifidum* assemblage, corresponding to the late Tremadocian Tr3 (time slice 1d). Servais et al. (2018) revised the FAD of *Coryphidium* elsewhere, indicating its presence in the late Tremadocian Tr3 (time slice 1d) in Avalonia, southern Gondwana, eastern Gondwana, and South China. In our dataset, the FAD of *Coryphidium bohemicum* (Plate 16, figures 13, 14, 15) is situated within the Floian Fl1–Fl3 (time slices 2a–2c). *Coryphidium bohemicum*, the type species of the genus, is a characteristic biostratigraphical marker for the margin of Gondwana. It has been identified in strata assigned to the Floian in various regions including France (Rauscher 1973), Italy (Albani 1989), Pakistan (Tongiorgi et al. 1994; Quintavalle et al. 2000), Iran (Ghavidel-Syooki 1990, 2006, 2021; Ghavidel-Syooki et al. 2014), and Argentina (Rubinstein et al. 2001). Additionally, it has been documented in the Floian–Darriwilian of England (Turner and Wadge 1979; Cooper et al. 1995; Molyneux and Leader 1997), South China (Li 1987; Yin 1995; Brocke et al. 2000; Tongiorgi et al. 2003), Morocco (Cramer et al. 1974), and Czech Republic (Vavrdová 1972, 1976, 1977, 1993). It has also been noted in Middle Ordovician (Darriwilian) strata in Tunisia (Vecoli 1999), Germany (Maletz and Servais 1993), and Colombia (Rubinstein et al. 2019). The FAD of *C. bohemicum* has been recently reevaluated by Servais et al. (2018), who proposed its occurrence in the early Floian Fl1, corresponding to the lower level of time slice 2b as defined by Webby et al. (2004), in Avalonia, southern Gondwana, and South China. In eastern Gondwana, the FAD of this species is positioned within the middle Floian Fl2, corresponding to the upper level of time slice 2b. The genus *Striatotheca* Burmann 1970, encountered in the assemblage biozone (E), is another characteristic taxon of Peri-Gondwana (Li 1987; Servais 1997; Servais et al. 2003). The most commonly encountered representative of this genus is *Striatotheca* sp., which initially appeared in basal assemblages of the *messoudensis-trifidum* assemblage in England (Molyneux et al.

2007), specifically within the uppermost Tremadocian. According to Servais et al. (2018), the FAD of this taxon is present in the late Tremadocian Tr3 (time slice 1c) in both Avalonia and southern Gondwana. In contrast, the FAD of this species is positioned in the early Floian Fl1 (time slice 2a) in South China and the middle Floian Fl2 (upper level of time slice 2b) in eastern Gondwana. In the current dataset, *Striatotheca principalis* var. *parva* and *S. mutua* are present within the Lashkarak Formation at the Simeh-Kuh locality. Up to now, *S. principalis* var. *parva* (Plate 16, figures 17–20) has been documented from the late Floian–early Darriwilian Fl3–Dw1 (time slices 2c–4a) in Germany (Burmann 1970) and from the uppermost Floian Fl3 (time slice 2c) of the Upper Shale Member of the Zardkuh Formation in the High Zagros Mountains, southern Iran (Ghavidel-Syooki 2021). The associated acritarch taxa of this assemblage consist of *Baltisphaeridium klabavense* (Vavrdová 1965) Kjellström 1971, *Coryphidium almohadillum* (Cramer & Díez 1976) Servais et al. 2008, *Pachysphaeridium sidereum* Ribecai & Tongiorgi 1999, *Peteinosphaeridium angustilaminae* Playford et al. 1995, *P. coronula* Yin et al. 1998, *P. dissimile* (Górka) Yin 1995, *P. eximum* Playford et al. 1995, *P. exornatum* Tongiorgi et al. 1995, *Striatotheca mutua* Burmann 1970, and *Tectitheca additionalis* Burmann 1968. Among these acritarch taxa, *C. almohadillum* (Plate 16, figures 17, 18, 19; 20) has been documented from the late Floian Fl3 (time slice 2c) in Cis-Saharan, Morocco (Cramer and Díez 1976); from the mid-late Floian Fl2–Fl3 (time slices 2b–2c) within the Lashkarak Formation at Gerdkuh, located in the Alborz Mountains, north of Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023); and at the Tremadocian–Floian boundary in Ireland (Connery and Higgs 1999). *Striatotheca mutua* (Plate 14, figures 13–15) has been observed from late Floian–early Darriwilian Fl3–Dw1 (time slices 2c–4a), Germany (Burmann 1970); late Floian Fl3 (time slice 2c) within the Upper Shale Member of the Zardkuh Formation, the High Zagros Mountains, southern Iran (Ghavidel-Syooki 2021); and the middle–upper Floian Fl2–Fl3 (time slices 2b–2c) of the Lashkarak Formation, Gerdkuh locality, Alborz Mountains, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023). *Tectitheca additionalis* (Plate 16, figures 7, 11; 22) has been recorded from the mid-late Floian Fl2–Fl3 (time slices 2b–2c) within the Lashkarak Formation at the Gerdkuh locality, Alborz Mountains, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023); late Floian–early Darriwilian Fl3–Dw1 (time slices 2c–4c), Germany (Burmann 1968) and Cis-Saharan Morocco (Cramer and Díez 1977); and the Upper Shale Member of the Zardkuh Formation in the High Zagros Mountains (Kuh-e Faraghan), southern Iran (Ghavidel-Syooki et al. 2011b). Further, this biozone contains *Baltisphaeridium klabavense* (Plate 13, figures 1, 2, 3; Plate 15, figures 19, 20), which has been documented from numerous localities, including early Floian Fl1 (time slice 2a) in South China (Brocke et al. 2000) and France (Rauscher 1973); mid-late Floian Fl2–Fl3 (time slices 2b–2c) within the Lashkarak Formation at the Gerdkuh locality, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023), and South China (Tongiorgi et al. 2003); Floian Fl1–Fl3 (time slices 2a–2c), central Bohemia (Vavrdová 1965); Floian–

Darriwilian Fl1–Dw3 (time slices 2a–4c), central Bohemia (Vavrdová 1977); Dapingian Dp1–Dp3 (time slices 3a–3b), Turkey (Paris et al. 2007) and Jordan (Keegan et al. 1990); Dapingian–Darriwilian Dp1–Dw3 (time slices 3a–4b), the Arabian Peninsula (Le Hérissé et al. 2017); and early Darriwilian Dw1 (time slice 4a), the Algerian Sahara (Vecoli 1999), Tunisia (Vecoli 1999), and Libya (Deunff and Massa 1975). *Pachysphaeridium sidereum* (Plate 14, figures 4, 8; 12) has been documented from the late Floian Fl3 (time slice 2c) in Öland (Ribecai and Tongiorgi 1999); early Darriwilian Dw1 (time slice 4a) in Estonia (Eisenhardt, 1989; referred to as *Goniosphaeridium connectum*); and Darriwilian Dw1–Dw3 (time slices 4a–4c) within the upper member of the Dawan Formation, South China (Tongiorgi et al. 2003). The genus *Peteinosphaeridium* and its species, including *P. angustilaminae* (Plate 13, figures 21, 22), *P. coronula* (Plate 13, figures 15, 19; 16, 20; 23, 24), *P. eximum* (Plate 14, figure 21), *P. exornatum* (Plate 14, figures 3, 7), and *P. dissimile* (Plate 13, figures 8, 12; Plate 14, figures 1, 5; 2, 6), are present in this assemblage biozone, ranging from the mid to late Floian Fl2–Fl3 (time slices 2b–2c). Furthermore, this interval of the Lashkarak Formation at Simeh-Kuh contains conodonts (*Gothodus costulatus* and *Trapezognathus diprion*) (Lindström 1955), which are indicative of the upper *Oepikodus evae* Conodont Zone in the lowermost part and the *Baltoniodus navis* Conodont Zone in the lower to middle parts of the Dapingian Global Stage (Popov and Cocks 2017, fig. 2, L17). Therefore, while the encountered acritarchs indicate the late Floian–early Dapingian Fl3–Dp1 (time slice 2c–lower–middle level of the time slice 3a), the conodont zones suggest the Dapingian Global Stage for samples MG-MHP 143 to 146 from the Lashkarak Formation at the Simeh-Kuh locality.

4.2.6. *Arkonia virgata*-*Orthosphaeridium quadrinatum* assemblage biozone (F)

This particular acritarch assemblage biozone is marked by the simultaneous occurrence of *Arkonia virgata* Burmann 1970 and *Orthosphaeridium quadrinatum* (Burmann 1970) Eisenack et al. 1976, directly succeeding the previous assemblage biozone (E). This acritarch assemblage is identified within samples MG-MHP 147 to 172, including a thickness of 127 m within the Lashkarak Formation (Figure 5 and Table 1a–c). *Arkonia virgata* (Plate 13, figures 5, 6, 7; Plate 14, figures 17, 18, 19) is a valuable indicator of the Middle Ordovician within the Peri-Gondwanan palaeoprovince. Its earliest occurrence is noted in the early Darriwilian Dw1. It corresponds to time slice 4a (Servais and Maletz 1992), with its latest occurrence observed in the upper Darriwilian Dw3 and time slice 4c (Trythall et al. 1987). Servais et al. (2018) provided a revised stratigraphical distribution of the genus *Arkonia*, proposing its FAD in the late Floian Fl3 (time slice 2c) in South China; lower Dapingian Dp1 (time slice 3a) in South Gondwana; lower Darriwilian Dw1 (time slice 4a) in East Gondwana; and middle Darriwilian Dw2 (time slice 4b) in Avalonia. *Orthosphaeridium quadrinatum* (Plate 15, figures 15, 16) is another significant microfossil in this assemblage biozone. Initially reported from late Darriwilian Dw3 (time slice 4c) in Germany (Burmann 1970), it has subsequently

been recorded from various localities. These include Floian–Dapingian Fl1–Dp3 (time slices 2a–3b), China (Yin 1995); early Darriwilian Dw1 (time slice 4a), Germany (Heuse et al. 1994); late Darriwilian Dw3 (time slice 4c), the Lashkarak Formation at the Gerdkuh locality, Alborz Mountains, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023); mid–late Darriwilian Dw2–Dw3 (time slices 4b–4c), Germany (Burmann 1970, 1976); early Sandbian Sa1 (time slice 5a), the Arabian Peninsula (Jachowicz 1995); Sandbian–early Katian Sa1–Ka1 (time slices 5a–Vla of Videt et al. 2010) of England (Downie 1984; Turner 1984), Czech Republic (Vavrdová 1974), western Iraq (Al-Ameri 2010), and northern Iran (Ghavidel-Syooki 2017c); and Katian–Hirnantian Ka1–Hi2 (time slices Vla–VII of Videt et al. 2010), Jordan (Keegan et al. 1990). The associated acritarch taxa in this assemblage biozone include *Baltisphaeridium llanvirnianum* Deunff 1977, *Goniosphaeridium splendens* (Eisenack 1931) Turner 1984, *Orthosphaeridium ternatum* (Burmann 1970) Eisenack et al. 1976, *Peteinosphaeridium velatum* (Kjellström 1971) Playford et al. 1995, and *Stellechinatum celestum* (Martin 1969) Turner 1984. *Baltisphaeridium llanvirnianum* has been recorded from a few localities, including Darriwilian Dw1–Dw3 (time slices 4a–4c) in Morocco (Deunff 1977) and North Africa (Vecoli 1999). It is recorded for the first time in the Alborz Mountains, northern Iran. *Goniosphaeridium splendens* (Plate 15, figure 21) has been recorded from various localities, including Darriwilian Dw1–Dw3 (time slices 4a–4c), France (Deunff and Paris 1970); Late Darriwilian Dw3 (time slice 4c), the Lashkarak Formation at the Gerdkuh locality, Alborz Mountains, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023); and Late Sandbian–early Katian Sa2–Ka1 (time slices 5b–Vla of Videt et al. 2010), Shropshire, England (Turner 1984). *Orthosphaeridium ternatum* (Plate 15, figure 12) has been recorded in various localities, including Darriwilian Dw1–Dw3 (time slices 4a–4c), France (Rauscher 1973); Darriwilian Dw1–Dw3 (time slices 4a–4c), England (Booth 1979); Late Darriwilian Dw3 (time slice 4c), Germany (Burmann 1970); Dapingian Dp1–Dp3 (time slices 3a–3b), Turkey (Paris et al. 2007) and Iraq (Al-Ameri 2010); and Sandbian–Katian Sa1–Ka4 (time slices 5a–Vld of Videt et al. 2010), Iran (Ghavidel-Syooki et al. 2014; Ghavidel-Syooki 2016).

Peteinosphaeridium velatum (Plate 14, figures 9, 10; 11, 22) has been documented in several regions, including Floian Fl1–Fl3 (time slices 2a–2c), Öland, Sweden (Playford et al. 1995; Ribecai and Tongiorgi 1995), and South China (Tongiorgi et al. 1995; 2003); Floian–Dapingian Fl1–Dp3 (time slices 2a–3b), the Lashkarak Formation in the Gerdkuh locality at the Alborz Mountains, north of Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023); Dapingian–Darriwilian Dp1–Dw3 (time slices 3a–4c), the Hanadir Shale Member of the Qasim Formation, the Arabian Peninsula (Le Hérissé et al. 2017); and early Darriwilian Dw1 (time slice 4a), Gotland, Sweden (Kjellström 1971), South China (Tongiorgi et al. 1998), Algerian Sahara (Vecoli et al. 1999), and Tunisia (Vecoli 1999; Vecoli et al. 1999). *Stellechinatum celestum* (Plate 15, figures 22, 23; Plate 17, figure 18) has been documented in various locations, including Floian Fl1–Fl3 (time slices 2a–2c),

Belgium (Martin and Richards 1979), and Algerian Sahara (Jardiné et al. 1974); Floian–Darriwilian Fl1–Dw3 (time slices 2a–4c), France (Martin 1973); early Darriwilian Dw1 (time slice 4a), Belgium (Servais and Maletz 1992); late Darriwilian Dw3 (time slice 4c), South Wales, England (Turner 1985); Darriwilian Dw1–Dw3 (time slices 4a–4c), Czech Republic (Vavrdová 1977), and the Arabian Peninsula (Jachowicz 1995); late Darriwilian–early Katian Dw3–Ka1 (time slices 4c–Vla), North Wales, England (Trythall et al. 1987); and Sandbian–early Katian Sa1–Ka1 (time slices 5a–Vla), type area, Shropshire, England (Turner 1984). Further, the presence of trilobite species like *Neseuretus* aff. *tristani* and brachiopod species such as *Bastamorthis multicostata* in the remaining stratigraphical section of Simeh-Kuh suggests a late Middle Ordovician (Darriwilian) age (Popov and Cocks 2017; see Figure 2, L18–L24). Consequently, the *Arkonia virgata*–*Orthosphaeridium quadrinatum* assemblage biozone and its associated acritarch taxa support a middle Dapingian–late Darriwilian Dp2–Dw3 (time slices 3b–4c) age, which is closely equivalent to the age indicated by the trilobite and brachiopod species for samples MG-MHP 147 to 172 of the Lashkarak Formation in Simeh-Kuh.

4.2.7. *Orthosphaeridium bispinosum*–*Ordovicidium elegantulum* assemblage biozone (G)

This acritarch assemblage biozone was characterised by the simultaneous presence of *Orthosphaeridium bispinosum* Turner 1984 and *Ordovicidium elegantulum* Tappan and Loeblich 1971. This biozone occurs immediately after biozone (F) within the Lashkarak Formation at the Simeh-Kuh locality. This assemblage zone occurs in samples MG-MHP 173 to 180, covering a thickness of 58 m within the study section. *Orthosphaeridium bispinosum* (Plate 15, figures 10, 11) has been documented in various regions, including the late Darriwilian to early Katian Dw3–Ka1 (time slices 4c–Vla of Videt et al. 2010) in Portugal (Henry and Thadeau 1971); Sandbian Stage slice Sa1 (time slice 5a), France (Henry 1969); Sandbian–Katian Sa1–Ka3 (time slices 5a–Vlb), Jordan (Keegan et al. 1990); Sandbian–Katian Sa1–Ka4 (time slices 5a–Vld), northern Gondwana (Vecoli and Le Hérissé 2004); Sandbian–Hirnantian Sa1–Hi2 (time slices 5a–VII), Iraq (Al-Ameri 2010); early Katian Ka1 (time slice Vla) in Shropshire, England (Turner 1984), and the Arabian Peninsula (Jachowicz 1995); and Katian Stage slices Ka1–Ka4 (time slices Vla–Vld) in the Seyahou Formation of the High Zagros Mountains, southern Iran (Ghavidel-Syooki et al. 2014). Similarly, *Ordovicidium elegantulum* (Plate 15, figures 1, 2) is present in samples MG-MHP 173 to 180 from the Simeh-Kuh locality. *Ordovicidium elegantulum* has been documented in various localities, including the late Darriwilian to early Katian Dw3–Ka1 (time slices 4c–Vla), Oklahoma, USA (Tappan and Loeblich 1971); Sandbian–early Katian Sa1–Ka1 (time slices 5a–Vla of Videt et al. 2010), Shropshire, England (Turner 1984), and the Eden Formation in Indiana, USA (Colbath 1979), China (Li and Wang 1997), the Arabian Peninsula (Jachowicz 1995), and Iraq (Al-Ameri 2010); Katian Stage slices Ka1–Ka4 (time slices Vla–Vld) in Iran (Ghavidel-Syooki 2008, 2016; Ghavidel-Syooki et al. 2011a; 2014; Ghavidel-

Syooki and Piri-Kangarshahi 2021); Katian–Hirnantian Ka1–Hi2 (time slice Vla–VII of Videt et al. 2010), Sweden (Eiserhardt 1992); Katian–Hirnantian Ka2–Hi2 (time slices Vlb–VII) in the Prague Basin, Czech Republic (Vavrdová 1988, 1989), Morocco (Elaouad-Debbaj 1988), Algeria, Tunisia, and northwest Libya (Vecoli 1999, 2000); and Hirnantian Stage slices Hi1–Hi2 (time slice VII of Videt et al. 2010) in northern Chad and south-eastern Libya (Le Hérissé et al. 2013). The associated acritarch taxa of this assemblage biozone include *Acanthodiacerdium crassus* (Loeblich and Tappan) Vecoli 1999, *Baltisphaeridium razii* Ghavidel-Syooki and Piri-Kangarshahi 2023, and *Villosacapsula setosapellicula* (Loeblich) Loeblich & Tappan 1976. *Acanthodiacerdium crassus* (Plate 15, figure 14; Plate 17, figure 16) first appeared in sample MG-MHP 173 and persisted into the succeeding assemblage biozone. This species has been documented in various regions, including Sandbian–Katian Sa1–Ka1 (time slices 5a–Vla), Eden Formation, Indiana, USA (Loeblich and Tappan 1978); and Katian Stage slices Ka2–Ka4 (time slices Vlb–Vld), Missouri, USA (Miller 1991), Anticosti Island, Canada (Jacobson and Achab 1985), Algerian Sahara (Vecoli 1999), Jordan (Keegan et al. 1990), the Arabian Peninsula (Jachowicz 1995), and Iran (Ghavidel-Syooki 1996, 2001a, 2008, 2016, 2017a, 2017b, 2017c; Ghavidel-Syooki and Piri-Kangarshahi 2021). *Baltisphaeridium razii* (Plate 14, figures 16, 20; Plate 16, figure 24) also appeared in sample MG-MHP 173. This species was previously recorded from the late Middle Ordovician in the Lashkar Formation in the Gerdkuh area in the Alborz Mountains, north of Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023). *Villosacapsula setosapellicula* (Plate 17, figures 1–5) occurred at the onset of this assemblage and continued into the succeeding assemblage biozone. This species has been recorded from various regions, including Katian Stage slices Ka1–Ka4 (time slices Vla–Vld of Videt et al. 2010), Oklahoma and Missouri, USA (Loeblich 1970; Wicander et al. 1999; Playford and Wicander 2006), Algerian Sahara (Jardiné et al. 1974), Libya (Molyneux and Paris 1985; Hill and Molyneux 1988), Canada (Jacobson and Achab 1985), Morocco (Elaouad-Debbaj 1988), Jordan (Keegan et al. 1990), and Iran (Ghavidel-Syooki 2008, 2016, 2017a, 2017b, 2017c, 2021; Ghavidel-Syooki et al. 2011a, 2011b; 2014; Ghavidel-Syooki and Borji 2018; Ghavidel-Syooki and Piri-Kangarshahi 2021). As a result, the *Orthosphaeridium bispinosum-Ordovicidium elegantulum* assemblage biozone and the associated acritarch taxa suggest the Sandbian–early Katian Sa1–Ka1 (time slices 5a–Vla) for samples MG-MHP 173 to 180 of the Upper Ordovician deposits in the Simeh-Kuh locality, northern Iran. However, it is important to note that strata younger than the Lower–Middle Ordovician were not reported from the Simeh-Kuh locality; the Upper Ordovician sediments are recorded for the first time in the study section.

4.2.8. *Baltisphaeridium perclarum-Inflatarium trilobatum* assemblage biozone (H)

The assemblage biozone delineated here is distinguished by the simultaneous presence of *Baltisphaeridium perclarum* Loeblich and Tappan 1978 and *Inflatarium trilobatum* Le

Hérissé et al. 2015 within samples MG-MHP 188 to 208, comprising 188 m. This biozone immediately follows the assemblage biozone (G) in the study section at the Simeh-Kuh locality (Figure 5 and Table 1a–c). *Baltisphaeridium perclarum* (Plate 15, figure 9; Plate 17, figure 19) is a significant microfossil in the Late Ordovician. This acritarch species has been documented in various regions, including the Sandbian–Katian Sa1–Ka4 (time slices 3a–Vld) strata in Kansas, USA (Wright and Meyers 1981); Gaspé, Québec, Canada (Martin 1980); northeast Libya (Hill and Molyneux 1988); and Estonia (Uutela and Tynni 1991). Additionally, it has been observed in middle Katian–Hirnantian Ka2–Hi2 (time slices Vlb–VII) sediments in Oklahoma and Missouri, USA (Loeblich and Tappan 1978; Robertson 1997), as well as in Iran (Ghavidel-Syooki 2008, 2016; Ghavidel-Syooki and Piri-Kangarshahi 2021).

Inflatarium trilobatum (Plate 15, figure 5; Plate 17, figures 6, 7) represents another significant index microfossil of the Late Ordovician age. This species was initially documented in the late Katian–early Hirnantian Ka4–Hi1 (time slices Vld—the lower level of time slice VII of Videt et al. 2010), specifically within the Quwarah Member of the Qasim Formation in the Arabian Peninsula (Le Hérissé et al. 2015). Furthermore, it has been identified in Katian–Hirnantian Ka1–Hi2 (time slices Vla–VII) strata in Iran (Ghavidel-Syooki et al. 2011b as *Veryhachium* sp. cf. *V. triangulatum*; Ghavidel-Syooki and Borji 2018; Ghavidel-Syooki and Piri-Kangarshahi 2021; this study). The associated acritarch taxa within this assemblage biozone include *Dactylofusa platynetrella* (Plate 17, figure 23), *Inflatarium alborzensis* sp. nov. (Plate 17, figures 6, 7), *Leiofusa litotes* (Plate 17, figure 24), *Multiplicisphaeridium irregularare* (Plate 15, figures 3, 4), *Navifusa ancepsipuncta* (Plate 15, figure 13), *Orthosphaeridium insculptum* (Plate 15, figure 17), *Orthosphaeridium rectangulare* (Plate 17, figure 13), *Tylotopalla caelamenicuttis* (Plate 17, figures 11, 12), and *Veryhachium* cf. *scabratum* (Plate 17, figure 8). Among these associated acritarch taxa, *Veryhachium* cf. *scabratum* Cramer 1964 has been documented from the Silurian strata in Spain (Cramer 1964, 1969), Belgium (Martin 1966), and the Algerian Sahara (Magloire 1967), while the remaining taxa have an Upper Caradoc–Ashgill stratigraphical range in North America (Jacobson and Achab 1985; Miller 1991; Wicander et al. 1999; Playford and Wicander 2006), Portugal (Elaouad-Debbaj 1978), and Morocco (Elaouad-Debbaj 1988). Consequently, the presence of this acritarch assemblage biozone suggests the Katian Stage slices Ka2–Ka4 (time slices Vla–Vld) for samples MG-MHP 181 to 208 within the stratigraphical study section at the Simeh-Kuh locality.

4.3. Systematics of new chitinozoan species

Almost all discussed chitinozoan taxa are assigned to well-known species. Therefore, their formal systematic treatment is not given here, and detailed descriptions are provided only for new taxa. Measurements are given in micrometres (μm), and their values are expressed as minimum (mean) maximum.

Incertae sedis Group Chitinozoa Eisenack 1931
Order PROSOMATIFERA Eisenack, 1972

Family CONOCHITINIDAE Eisenack 1931 emend. Paris 1981
Subfamily TANUCHITININAE Paris 1981

Genus *Tanuchitina* Jansonius 1964 emend. Paris et al. 1999

Type species. *Tanuchitina ontariensis* Jansonius 1964

Tanuchitina hosseini-nezhadi sp. nov.

Plate 8, figures 2, 6; 3, 7; 4, 8; Plate 10, figures 11, 15; 19, 23

Holotype. Plate 8, figure 2.

Type locality. The Simeh-Kuh locality, 13 km north-western Damghan city in the Alborz Mountains, north of Iran.

Type stratum. Upper Ordovician, Ghelli Formation, samples DOEStubMG-MHP-182 to DOEStubMG-MHP-205.

Derivation of the name. This species is dedicated to Dr Mahmoud Hoseini-Nezhad for his help in preparing samples for this research work.

Dimensions. Total vesicle length (L) = 214 (243.5) 273 μm ; Maximum chamber diameter (D_p) = 58 (60) 62 μm ; Collarette diameter (d_{coll}) = 46.4 (51) 55.6 μm ; width of carina 2.6 (3.9) 5.2 μm ; $n=10$.

Description. This species has an elongated, narrow, cylindrical vesicle with straight flanks, which gently tapers towards the aperture. *Tanuchitina hosseini-nezhadi* sp. nov. has a short membranous carina below the basal margin, which surrounds a concave to slightly convex base. The vesicle surface is smooth.

Remarks: *Tanuchitina hosseini-nezhadi* sp. nov. is distinguished by its elongated, narrow, and cylindrical vesicle with straight flanks. This species exhibits a short membranous basal carina and a concave to slightly convex bottom. While bearing a resemblance to *Tanuchitina achabae* Paris 1981 and *Tanuchitina domfrontensis* Paris 1981, from the Bohemian Terrane, the Iranian specimens deviate from those described in Paris 1981 by featuring a simple cylindrical chamber, in contrast to the subcylindrical and fusiform chambers found in the Bohemian region. Conversely, similarities exist between the new specimens and *Tanuchitina huanghuaensis* of China (Chen et al. 2009), albeit the Iranian specimens are notably smaller than their Chinese counterparts.

Family LAGENOCHEITINIDAE Eisenack 1931 emend. Paris 1981
Subfamily CYATHOCHEITININAE Paris 1981

Genus *Cyathochitina* Eisenack 1955 emend. Paris et al. 1999

Type species. *Cyathochitina campanulaeformis* (Eisenack 1931)

Cyathochitina sp. A

Plate 11, figures 1, 5, 9

Type locality. The Simeh-Kuh locality, 13 km north-west of Damghan city in the Alborz Mountains, north of Iran.

Type stratum. Upper Ordovician, at the basal part of the Ghelli Formation, sample DOEStubMG-MHP-174.

Dimensions. $L=261$ (266) 271 μm ; $D_p=110.5$ (119) 127.5 μm ; oral tube length (ln) = 61 (66) 77 μm ; $d_{coll}=58.5$ (60) 61.5 μm ; width of the carina = 9.5 (10) 10.5 μm ; $n=10$.

Description. The species exhibits a subconical body and a cylindrical neck with a straight aperture. Notably, the body is ornamented with 40 longitudinal ribs. Its flexure is rounded, while the flanks present a convex profile. The base is flat, featuring a short carina along the basal edge. Furthermore, the vesicle wall is characterised by long, distinct ridges extending from the aperture to the basal edge.

Remarks. *Cyathochitina* sp. A exhibits similarity in shape and size with *Cyathochitina reticulifera* Grahn 1981, and *Cyathochitina costata* Grahn 1982. However, it differs from these Swedish species in ornamentation, notably lacking concentric ridges on its flat base. Similarly, the Iranian species resembles *Cyathochitina stentor* Eisenack 1937, due to its longitudinal ribs, although it is smaller in size. *Cyathochitina* sp. A was left in open nomenclature since there were not enough specimens to observe concentric ridges on the flat base of this species, if it is a new species.

4.4. Chitinozoan biostratigraphy

The chitinozoan microfauna comprises a group of marine microfossils characterised by organic-walled structures, existing from the Ordovician to Late Devonian (~488–359 Ma). These microfossils play a vital role in elucidating the palaeogeographical connections among different terranes across continents. Moreover, they are extensively employed in high-resolution biostratigraphy due to their narrow temporal distribution, facilitating the establishment of biozones. The present study identified 58 chitinozoan species (22 genera) from the Lashkarak and Ghelli formations at the Simeh-Kuh locality. This identification led to the recognition of 14 chitinozoan biozones, which are discussed in ascending stratigraphical order. The terminology adopted for the global time scale in this chitinozoan biostratigraphy adheres to the format established by Bergström et al. (2009) for stages and stage slices and for time slices by Paris (1990) as outlined in Webby et al. (2004) and Videt et al. (2010).

4.4.1. *Eremochitina brevis* Biozone (1)

This biozone encompasses the total range of *Eremochitina brevis* Benoit & Taugourdeau 1961. This index species was initially identified in the Quartzites de Hamra within well AMg-1, located in the western Algerian Sahara. According to the lithostratigraphical classification by Legrand (1985), this formation is correlatable with the upper part of the Oued Rharbi Member of the El Arich el Mega Formation (Paris 1990). *Eremochitina brevis* is a prominent microfossil indicative of the late Early Ordovician (Floian) subpolar margin within the Peri-Gondwana region, including southern Europe and northern Africa (Paris 1990, 1999; Webby et al. 2004; Videt et al. 2010; Gutiérrez-Marco et al. 2013). In the present study, *E. brevis* (Plate 9, figures 1, 5; 20, 22) is observed within samples MG-MHP 143 to 145, encompassing 11 m thickness of the Lashkarak Formation (Figure 6 and Table 2a–c).

According to the literature, *E. brevis* has been documented in various time intervals and geographical locations.

It has been recorded from the late Tremadocian–middle Floian Tr3–Fl2 (time slices 1d–2b), Colombia (Rubinstein et al. 2019); Floian Fl1–Fl3 (time slices 2a–2c), the Algerian Sahara (Paris 1990), Anti-Atlas, Morocco (Elaouad-Debbaj 1984, 1986), Libya (Paris 1990), France and Portugal (Rauscher 1968; Paris 1981), Pakistan (Tongiorgi et al. 1994), South China (Chen et al. 2009; Liang et al. 2018), and Turkey (Paris et al. 2007); late Floian Fl3 (time slice 2c), Iran (Ghavidel-Syooki 2021, 2023; Ghavidel-Syooki and Piri-Kangarshahi 2023); Floian–Dapingian Fl1–Dp3 (time slices 2a–3b), north-western Argentina (Achab et al. 2006), Libya (Abuhmida and Wellman 2017), Peri-Gondwanan southern Europe, and northern Africa (Gutiérrez-Marco et al. 2013); and early Darriwilian Dw1 (time slice 4a), Portugal (Vaz 2014). *Eremochitina brevis* is found in the current dataset with *Cyathochitina campanulaeformis* Eisenack 1931, *Cyathochitina varenensis* Paris 1981, and *Desmochitina minor* Eisenack 1931. Among these taxa, *C. campanulaeformis* (Plate 6, figure 12) and *D. minor* (Plate 1, figures 1–3; 6, 7) have extensive ranges during the Ordovician (Paris 1990; Butcher 2009), while *C. varenensis* is a diagnostic species in the late Floian–early Darriwilian Stage slices Fl3–Dw1 (time slices 2c–4a) within the Armorican Massif of France (Paris 1981) and the Lashkarak Formation of northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023). Following the chronostratigraphical calibration proposed for chitinozoan biozones, the *Eremochitina brevis* Biozone is assigned to the late Floian Fl3 (time slice 2c) within the North Gondwana Domain (Paris 1990; Videt et al. 2010; Gutiérrez-Marco et al. 2013).

4.4.2. *Desmochitina ornensis* Biozone (2)

This biozone includes the full range of *Desmochitina ornensis* Paris 1981. Initially, it was identified in the lowest strata of the Pissot Formation within the Domfront Syncline and the basal layers of the Postolonnec Formation in France. *Desmochitina ornensis* characterises the early Middle Ordovician (Dapingian) within the North Gondwana Domain (Paris 1990; Videt et al. 2010; Gutiérrez-Marco et al. 2013). In the current study, specimens of *D. ornensis* (Plate 1, figure 4; Plate 9, figure 3) are present in the sampling interval MG-MHP 146 to 147, including 6 m thickness of the Lashkarak Formation, immediately succeeding the *Eremochitina brevis* Biozone (Figure 6 and Table 2a–c) at the Simeh-Kuh locality. This species has been documented in numerous regions, including Dapingian Dp1–Dp3 (time slices 3a–3b) in the basal sections of the Pissot and Postolonnec formations in France (Paris 1981), the lower part of the Caceres Group (base of the Brejo Fundeiro Formation) in central Portugal (Young 1988), Algerian Sahara, and Libyan subsurface materials (Paris 1981), the lower strata of the Edjeleh Formation in the Illizi Basin, and the Kasbah Leguiné Formation in north-western Libya (Paris 1990), Peri-Gondwanan terranes of southern Europe and northern Africa (Gutiérrez-Marco et al. 2013), the Upper Shale Member of the Zardkuh Formation in the High Zagros Mountains, southern Iran (Ghavidel-Syooki 2021, 2023), and the Lashkarak Formation in the Gerdkuh locality within the Alborz Mountains, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023); and the early Darriwilian

Dw1 (time slice 4a) in Portugal (Vaz 2014). The associated chitinozoa in this biozone include *C. campanulaeformis*, *C. varenensis*, and *D. minor*, all of which persist from the preceding biozone into subsequent biozones (Figure 6 and Table 2a–c). According to the chronostratigraphical calibration proposed for the chitinozoan biozones, this biozone encompasses the entire range of *Desmochitina ornensis*, indicating the upper level of Dp2 to the lower level of upper Dp3 (the upper level of time slices 3a to the middle level of time slice 3b).

4.4.3. *Belonechitina henryi* Biozone (3)

This biozone marks the complete range of *Belonechitina henryi* Paris 1981 within the North Gondwana Domain (Paris 1990). Initially, it was identified in the lower part of the Pissot Formation with an age of middle Floian–lower Darriwilian Fl2–Dw1 (time slices 2b–3a) in the Domfront Syncline, north-western France (Paris 1981). In the current study, *B. henryi* (Plate 9, figure 6) is observed within the sampling range MG-MHP 148 to 150, comprising 20 m of the Lashkarak Formation, immediately succeeding the *Desmochitina ornensis* Biozone (Figure 6 and Table 2a–c). This species is a reliable microfossil marker for the upper Dapingian Stage slice Dp3 (time slice 3b) within the North Gondwana Terrane (Paris 1990; Videt et al. 2010; Gutiérrez-Marco et al. 2013). This taxon has been documented in various regions, including the Dapingian type section (Dawan Formation) in the Yichang area, China (Chen et al. 2009); Dapingian Dp1–Dp3 (time slices 3a–3b), Argentina (Rubinstein et al. 2019), southern Europe and northern Africa (Gutiérrez-Marco et al. 2013), as well as Iran (Ghavidel-Syooki 2023; Ghavidel-Syooki and Piri-Kangarshahi 2023). The associated chitinozoan species within this biozone consist of *C. campanulaeformis*, *C. varenensis*, and *D. minor*, which persist from the preceding biozone into the succeeding biozones (Figure 6 and Table 2a–c). According to the chronostratigraphical calibration proposed for the chitinozoan biozones (Webby et al. 2004; Videt et al. 2010; Gutiérrez-Marco et al. 2013), the *B. henryi* Biozone indicates the late Dapingian to early Darriwilian Stage slices Dp3–Dw1 (time slices 3b–4a) for the samples MG-MHP 148 to 150 of the Lashkarak Formation at the Simeh-Kuh locality within the Alborz Mountains, northern Iran.

4.4.4. *Cyathochitina protocalix* Biozone (4)

This biozone encompasses the range of *Cyathochitina protocalix* Paris 1981 within the North Gondwana Domain (Paris 1990; Videt et al. 2010; Gutiérrez-Marco et al. 2013). This diagnostic species was initially identified within the lower portion of the Pissot Formation in the Domfront Syncline, north-western France (Paris 1981). In the current study, *Cyathochitina protocalix* (Plate 6, figures 4, 8) is observed in the study section (samples MG-MHP 151 to 152), covering 6 m of the Lashkarak Formation, immediately succeeding the *Belonechitina henryi* Biozone (Figure 6 and Table 2a–c). This taxon is a reliable index fossil for the earliest late Middle Ordovician (early Darriwilian) within the North Gondwana

Domain. *Cyathochitina protocalix* has been documented in various localities, including the lower part of the Pissot Formation during the late Floian to early Darriwilian Stage slices Fl3–Dw1 (time slices 2c–4a) in the Armorican Massif, France (Paris 1981); lower Darriwilian Stage slice Dw1 (time slice 4a), Portugal (Vaz 2014); and Darriwilian Stage slices Dw1–Dw2 (time slices 4a–4b) in the Peri-Gondwanan southern Europe and northern Africa (Gutiérrez-Marco et al. 2013); and the early Darriwilian (upper Dw1 and lower Dw2 and time slice upper 4a and lower 4b), the Lashkarak Formation, in the Gerdkuh locality, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023). The associated chitinozoan taxa within this biozone include *C. campanulaeformis* and *D. minor*, which persist from the preceding biozones into this biozone (Figure 6 and Table 2a–c). According to the chronostratigraphical calibration proposed for the chitinozoan biozones (Paris 1990 in Webby et al. 2004; Videt et al. 2010; Gutiérrez-Marco et al. 2013, fig. 1), the *Cyathochitina protocalix* Biozone is attributed to the Darriwilian Stage slices Dw1–lower Dw2 (the upper level of time slice 4a and the lower level of time slice 4b) for the sampling interval MG-MHP 151 to 152 of the Lashkarak Formation in the Simeh-Kuh locality within the Alborz Mountains.

4.4.5. *Cyathochitina calix* Biozone (5)

This biozone corresponds to the complete range of *Cyathochitina calix* (Eisenack 1931) sensu Paris 1981 within the North Gondwana Domain. Due to taxonomic challenges associated with the type specimen raised by Eisenack, as discussed in Paris (1981, p. 289), the identification of *C. calix* here is confined to the morphotypes illustrated by Paris (1981) and Grahn (1980). Despite this limitation, *C. calix* is designated as the index species for the biozone owing to its morphological continuity within an evolutionary lineage that starts with *C. protocalix* and concludes with *C. kuckersiana* (see discussion in Paris 1981, p. 102, 103). In this study, *Cyathochitina calix* (Plate 5, figures 18, 22) is found in the study section (samples MG-MHP 153 to 155), covering 10 m of the Lashkarak Formation (Figure 6 and Table 2a–c), immediately succeeding the *Cyathochitina protocalix* Biozone, which was recently documented in the Lashkarak Formation at the Gerdkuh locality in the Alborz Mountains, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023). This taxon has been observed in various regions, including the upper Floian to upper Darriwilian Stage slices Fl3–Dw3 (time slices 2c–4c), Sweden (Grahn 1980, 1981), and Estonia (Eisenack 1958, 1968c); early Darriwilian Stage slice Dw1 (time slice 4a), the Hope Shales, Welsh Borderland, England (Jenkins 1967); Darriwilian Stage slices Dw1–Dw3 (time slices 4a–4c), South China (Liang et al. 2018), Peri-Gondwanan southern Europe and northern Africa (Gutiérrez-Marco et al. 2013), Portugal (Vaz 2014), and north of Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023). This species is also an excellent index microfossil in the Middle Ordovician (middle Darriwilian), the North Gondwana Domain. Utilising the chronostratigraphical calibration proposed for the chitinozoan biozones (Paris 1990; Webby et al. 2004; Videt et al. 2010), the *Cyathochitina calix* Biozone validates the early middle Darriwilian Stage

slice Dw2 (lower level of time slice 4b) for the sampling interval MG-MHP 153 to 155 of the Lashkarak Formation at the Simeh-Kuh locality in the Alborz Mountains, northern Iran.

4.4.6. *Siphonochitina formosa* Biozone (6)

The complete range of *Siphonochitina formosa* Jenkins 1967 delineates this biozone. Due to its distinct morphology and extensive geographical distribution, *S. formosa* is an index fossil for the Darriwilian stage. In the current dataset, *S. formosa* (Plate 9, figures 21, 23, 24) is present in samples MG-MHP 156 to 160, comprising 17 m of the Lashkarak Formation, immediately succeeding the *Cyathochitina calix* Biozone (Figure 6 and Table 2a–c). This taxon has been documented in numerous regions, including the early Darriwilian Dw1 (time slice 4a), the Hope Shales in England (Jenkins 1967), Florida in the USA (Andress et al. 1969), and France (Paris 1981, 1990); late Darriwilian Dw3 (time slice 4c), the Hanadir Shale Member of the Qasim Formation, the Arabian Peninsula (McClure 1988; Al-Hajri 1995; Le Hérisse et al. 2007), Turkey (Paris et al. 2007), and Libya (Combaz and Poumot 1962; Abuhmida and Wellman 2017); Darriwilian late Dw2–early Dw3 (upper level of time slice 4b to the lower level of time slice 4c), the Upper Shale Member of the Zardkuh Formation in the High Zagros Mountains, southern Iran (Ghavidel-Syooki et al. 2011b; Ghavidel-Syooki 2021, 2023), and the Lashkarak Formation at the Gerdkuh locality within the Alborz Mountains, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023). The associated chitinozoan taxa within this biozone include *C. campanulaeformis*, *D. minor*, and *Conochitina chydaea* (Jenkins 1967). Notably, *C. chydaea* has been documented in various locations, including early Darriwilian Dw1 (time slice 4a) in the lower Hope Shales, Shropshire, England (Jenkins 1967); mid-Darriwilian Dw2 (time slice 4b), within the Cape Cormorant Formation (*Pterograptus elegans* Zone, or *Cyathochitina jenkinsi* Zone) in western Newfoundland, Canada (Albani et al. 2001); and mid-Darriwilian Dw2 (time slice 4b) in southern Europe and northern Africa (Gutiérrez-Marco et al. 2013; Vaz 2014). Following the chronostratigraphical calibration proposed for chitinozoan biozones (Paris 1990, 1996; Webby et al. 2004; Videt et al. 2010), the presence of *Siphonochitina formosa* and *Conochitina chydaea* confirms the Darriwilian upper Dw2–lower Dw3 (from the upper level of time slice 4b to the lower level of time slice 4c) for the sampling interval MG-MHP 156 to 160 of the Lashkarak Formation at the Simeh-Kuh locality in north of Iran.

4.4.7. *Cyathochitina jenkinsi* Biozone (7)

This biozone encompasses the entire *Cyathochitina jenkinsi* Neville 1974 range within the North Gondwana Terrane (Videt et al. 2010; Gutiérrez-Marco et al. 2013). In the current dataset, *Cyathochitina jenkinsi* (Plate 6, figures 1, 5; 2, 6; 3, 7) is observed in 14 m of the upper part of the Lashkarak Formation (samples MG-MHP 163 to 165), directly succeeding the *S. formosa* biozone (Figure 6 and Table 2a–c). Initially, this taxon was recorded from the Darriwilian–Sandbian Dw1–

Sa2 (time slices 4a–5b) in western Newfoundland, Canada (Neville 1974). This species has been documented in other regions, including the Darriwilian (*Pterograptus elegans* Zone = *Didymograptus artus*) within the upper part of the Cape Cormorant Formation (*Pterograptus elegans* Zone = *Didymograptus artus*) in western Newfoundland, Canada (Albani et al. 2001), and the mid-Darriwilian Dw2 (time slice 4b) in southern Europe and northern Africa (Gutiérrez-Marco et al. 2013; Sale 2015). The associated chitinozoan species within this biozone include *C. campanulaeformis*, *D. minor*, and *C. chydaea*, which persist from the preceding chitinozoan biozones. Thus, following the chronostratigraphical calibration proposed for chitinozoan biozones (Videt et al. 2010), the late Darriwilian Dw3 (time slice 4c) is attributed to samples MG-MHP 161 to 165 of the Lashkarak Formation at the Simeh-Kuh locality, the Alborz Mountains, northern Iran.

4.4.8. *Armoricochitina armoricana* Biozone (8)

This biozone represents the complete range of *Armoricochitina armoricana* (Rauscher and Doubinger 1967) within the North Gondwana Domain (Paris 1990; Videt et al. 2010; Gutiérrez-Marco et al. 2013). Initially, it was described from the Armorican Massif, both in the Urville Formation (Schistes à Calyménés in Rauscher and Doubinger 1967) and the Andouillé Formation in the Bois de Gondin section, eastern Brittany, France (Paris 1981). This index species was identified in the middle section of the Andouillé Formation and was designated as the type locality for this biozone, which is associated with *Didymograptus artus* and *Pterograptus cf. elegans*, indicating the early to middle Darriwilian Dw1–Dw2 (time slices 4c–4b). In the current material, *Armoricochitina armoricana* (Plate 2, figures 16, 24) is observed in samples MG-MHP 166 to 169, covering 15 m of the Lashkarak Formation, immediately following the *Cyathochitina jenkinsi* Biozone (Figure 6 and Table 2a–c) at the Simeh-Kuh locality. Furthermore, *Armoricochitina armoricana* has been documented in the Darriwilian Dw3 (time slice 4c) in other regions, such as southern Europe and northern Africa (Gutiérrez-Marco et al. 2013; Sale 2015). The associated chitinozoan taxa within this biozone include *C. campanulaeformis*, *D. minor*, and *C. chydaea*, which persist from the preceding chitinozoan biozones (Figure 6 and Table 2a–c). According to the chronostratigraphical calibration proposed for chitinozoan biozones (Videt et al. 2010), the late Darriwilian Dw3 (lower–middle levels of time slice 4c; *Didymograptus murchisoni* Zone) is attributed to the sampling interval MG-MHP 166 to 169 of the Lashkarak Formation at the Simeh-Kuh locality in north of Iran. Consequently, the *Cyathochitina jenkinsi* and *Armoricochitina armoricana* biozones manifest distinct positions within the late Darriwilian Global Stage slice Dw3.

4.4.9. *Laufeldochitina clavata* Biozone (9)

This biozone represents the partial range of *Laufeldochitina clavata* (Jenkins 1967), from its FAD up to the FAD of *Linochitina pissotensis* (Paris 1981), which is the index species for the succeeding biozone. *Laufeldochitina clavata* is notably

abundant in the Ferruginous Sandstone Member of the May Formation, which constitutes the type stratum of this biozone, located near Caen in Normandy, France (Paris 1990). Within the current study material, *Laufeldochitina cf. clavata* (Plate 6, figure 24) is observed in the interval MG-MHP 170 to 171 of the Lashkarak Formation, comprising 5 m of the study section. This interval immediately succeeds the LAD of *Armoricochitina armoricana* Biozone. The associated chitinozoan taxa within this biozone include *C. campanulaeformis*, *D. minor*, and *C. chydaea*. *Laufeldochitina clavata* was described initially from uppermost Middle–lowermost Upper Ordovician strata, such as the Betton and Glenburrell Beds in Shropshire, England (Jenkins 1967). *Laufeldochitina clavata* has been documented in other regions, including the late Darriwilian of North Spain (Gutiérrez-Marco et al. 1996), the Algerian Sahara (Oulebsir and Paris 1995), the Hanadir Member of the Qasim Formation in the Arabian Peninsula (Al-Hajri 1995; Paris et al. 2000a; Cesari et al. 2018), the Gerdkuh locality within the Lashkarak Formation in the Alborz Mountains, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023), and the Gondwanan region (Sale 2015, see fig. 6). *Laufeldochitina clavata* is an excellent index fossil for the middle to late Darriwilian Dw2–Dw3 (time slices 4b–4c) within the North Gondwana Domain (Paris 1981; Achab 1988). Consequently, based on the chronostratigraphical calibration proposed for the chitinozoan biozones (Paris 1990; Webby et al. 2004; Videt et al. 2010), the uppermost Darriwilian Dw3 (time slice 4c) is suggested for the sampling interval MG-MHP 170 to 171 of the Lashkarak Formation in the Simeh-Kuh site.

4.4.10. *Linochitina pissotensis* Biozone (10)

This biozone includes the entire range of *Linochitina pissotensis* Paris 1981 from its first appearance to the first appearance of *Lagenochitina ponctei* Rauscher 1973, which is the index species for the succeeding biozone in the North Gondwanan region. Among the most well-documented successions for this taxon are the Cacemes and Vale Saido sections in central Portugal (Young 1988). *Linochitina pissotensis* is commonly associated with trilobites, brachiopods, ostracods, and graptolites, including *Gymnograptus linnarsoni*, *Orthograptus propinguus*, *Glyptograptus cf. cernus*, and *G. teretiusculus* in the Fonte da Horta Formation (Henry et al. 1977). This graptolite fauna suggests an early Llandeilo age, at least if the *teretiusculus* graptolite Biozone does not slightly overlap the upper Darriwilian (Bergström 1973). *Linochitina pissotensis* has been documented in numerous regions, including the late Darriwilian in the Cacemes Formation of central Portugal (Young 1988), the lower Member of the May Formation in France (Rauscher 1973), the Azel Shale Member of the Hassi Touarej Formation in north-eastern Algerian Sahara (Combaz and Poumot 1962), the Bir Ben Tartar Formation in western Libya (Paris in Massa 1988), the Hanadir Shale Member of the Qasim Formation in the Arabian Peninsula (Al-Hajri 1995), and Anticosti Island, Canada (Achab 1984). In the current dataset, *Linochitina pissotensis* (Plate 9, figures 17, 18, 19) is observed in samples MG-MHP 172 to 173, comprising 7 m of the Lashkarak

Formation, immediately following the *Laufeldochitina* cf. *clavata* Biozone (Figure 6 and Table 2a–c). This marks the first recorded occurrence of this species in the Lashkarak Formation within the Alborz Mountains, northern Iran. The associated chitinozoan taxa within this biozone include *C. campanulaeformis*, *D. minor*, and *C. chydaea*, which persist from the preceding biozones. Based on the chronostratigraphical calibration proposed for chitinozoan biozones (Paris 1990; Webby et al. 2004; Videt et al. 2010; Sale 2015), the latest Darriwilian Global Stage slice Dw3 (uppermost level of time slice 4c of Webby et al. 2004) is suggested for the interval MG-MHP 172 to 173 of the Lashkarak Formation in the Simeh-Kuh locality within the Alborz Mountains, north of Iran.

4.4.11. *Belonechitina robusta* Biozone (11)

This biozone corresponds to the interval between the FAD of *Belonechitina robusta* Eisenack 1959 and the FAD of *Tanuchitina fistulosa* (Taugourdeau & de Jekhowsky 1960) Paris et al. 2000. *Belonechitina robusta* was documented in the Upper Ordovician strata in Europe (Caradocian), including Portugal, France, Spain, and Bohemia (Paris 1990, p. 199). It was identified within the Balclatchie Group in Scotland during the early Caradoc (Jansonius 1964). Its presence in Baltoscandinavia (Grahn 1981, 1982; Nölvak and Grahn 1993) and Shropshire suggests an occurrence ranging from at least the Cheneyan–Streffordian (early Katian Stage slice and time slice Vla; Paris 1979). This species has a restricted range in the Viola Springs Formation in Oklahoma, and it supports either Late Sandbian–lower middle Katian Sa2–Ka2 (time slices 5b–lower level of Vlb of Videt et al. 2010) or Late Soudleyan–Marshbrookian age (*Climacograptus wilsoni*–*Dicranograptus clingani* zones; Ross 1982). *Belonechitina robusta* is associated with the *Nemagraptus gracilis* Zone in this formation, suggesting a Sandbian Sa1–Sa2 and time slices 5a–5b age (Achab 1986). In the Trenton Group, *B. robusta* correlates with Sandbian Sa2 (time slice 5b) or Harnagian–Soudleyan age (Barnes et al. 1981). *Belonechitina robusta* has been recorded in the Sandbian–early Katian in Iran (Ghavidel-Syooki 2008, 2023; Ghavidel-Syooki and Piri-Kangarshahi 2023) and the early Katian in Estonia. The ages provided by various researchers indicate the presence of *Belonechitina robusta* in different geological formations and epochs, ranging from the late Sandbian to the early Katian, including North America, Iran, and Estonia. These findings suggest that the species had a wide distribution and persisted through different geological intervals. *Belonechitina robusta* appears in the study section immediately following the LAD of *Linochitina pissotensis* Biozone. It comprises 15 m of the lowermost part of the Upper Ordovician Ghelli Formation. The *robusta* Biozone is poorly dated and, together with the underlying *tanvillensis* Biozone, suggests late Sandbian–early Katian Sa2–Ka1 (time slices 5b–Vla) or post-early Harnagian–pre-Onnian (Paris 1990). *Belonechitina robusta* is noted for its distinctive morphology and widespread geographical distribution in various regions and geological stages. In the current study, the striking feature of this biozone is the presence of *Belonechitina capitata*

Eisenack 1962, *Calpichitina lenticularis* (Bouché 1965), *Cyathochitina kuckersiana* (Eisenack 1934), *Cyathochitina* sp. A, *Desmochitina amphorea* Eisenack 1931, *Desmochitina erinacea* Eisenack 1931, *Desmochitina elongata* Eisenack 1958, *Desmochitina nodosa* Eisenack 1931, *Desmochitina minor typica* Eisenack 1931, *Desmochitina juglandiformis* Laufeld 1967, *Eisenackitina rhenana* (Eisenack 1939), *Eisenackitina* cf. *oelandica* (Eisenack 1955), *Lagenochitina prussica* Eisenack 1931, *Pistillachitina pistillifrons* (Eisenack 1939), *Rhabdochitina magna* Eisenack 1931, *Rhabdochitina usitata* Jenkins 1967, and *Spinachitina multiradiata* (Eisenack 1959).

Belonechitina capitata (Plate 5, figures 1, 5, 9; 2, 6; 11, 15) appeared at the base of the *robusta* Biozone (samples MG-MHP 176) and continued into succeeding biozones. *Belonechitina capitata* is recorded for the first time in the Upper Ordovician Ghelli Formation of the Simeh-Kuh locality in the Alborz Mountains, northern Iran. This taxon has been recorded elsewhere from the Darriwilian Dw1–Dw3 (time slices 4a–4c), Estonia (Tammekänd et al. 2010); Darriwilian–late Sandbian Dw1–Sa2 (time slices 4a–5b), the Baltic (Eisenack 1962, 1968b); Darriwilian–early Sandbian Dw1–Sa1 (time slices 4a–5a), the Arabian Peninsula (Al-Hajri 1995), and Canada (Achab and Asselin 1995); early Sandbian Stage slice Sa1 (time slice 5a), Sweden (Laufeld 1967); middle Sandbian–early Katian Sa2–Ka1 (time slices 5b–Vla), Öland, Sweden (Grahn 1981); early Sandbian–middle Katian Sa1–Ka3 (time slices 5a–Vlb), Gotland, Sweden (Grahn 1982), and north-east Libya (Molyneux and Paris 1985); Sandbian–early Katian Sa1–Ka1 (time slices 5a–Vla), Scandinavia (Grahn and Nölvak 2007), and Sweden Vandenbroucke 2004; Grahn 1997); Katian Ka1–Ka3 (time slices Vla–Vlb), England (Vandenbroucke et al. 2008); and middle Katian Ka2–Ka3 (time slices Vlb–Vld) in Libya (Abuhmida 2013).

Calpichitina lenticularis (Plate 3, figures 13–16; Plate 11, figures 19, 20) is observed at the base of the *robusta* Biozone (Figure 6 and Table 2a–c). This taxon has been documented in several localities, including the Sandbian Sa1–Sa2 (time slices 5a–5b) in the Louredo Formation, Portugal (Paris 1979); Sandbian–Katian Sa1–Ka4 (time slices 5a–Vld), Morocco (Elaouad-Debbaj 1984; Bourahrouh et al. 2004), and Algeria (Oulebsir and Paris 1995); early Katian Ka1 (time slice Vla) in the Seyahou Formation, the High Zagros Mountains, southern Iran (Ghavidel-Syooki 2000, 2021, 2023), and Ghelli Formation, the Alborz Mountains, north of Iran (Ghavidel-Syooki and Winchester-Seeto 2002; Ghavidel-Syooki 2008, 2016, 2017a, 2017b, 2017c; Ghavidel-Syooki and Borji 2018); Katian Ka1–Ka4 (time slices Vla–Vld) in the Ghelli Formation, Kuh-e Boghou, central Iran (Ghavidel-Syooki and Piri-Kangarshahi 2021), the Quwarah Member of the Qasim Formation, the Arabian Peninsula in the southern Persian Gulf (Al-Hajri 1995; Al-Shawareb et al. 2017), Turkey (Paris et al. 2007); latest Katian–Hirnantian Ka4–Hi2 (time slices Vld–VII), Libya (Abuhmida 2013); and Sandbian–early Katian Sa1–Ka1 (time slices 5a–Vla), Scandinavia (Grahn and Nölvak 2007), and Greenscoe section, Southern Lake District, UK (Van Nieuwenhove et al. 2006). In the Arabian Peninsula, this species defines the *Calpichitina lenticularis* Biozone (Al-Hajri 1995), corresponding to the total range of this taxon from its

FAD to the FAD of *Tanuchitina fistulosa*. The associated chitinozoan taxa of this biozone in the Arabian Peninsula include *Angochitina communis*, *Belonechitina robusta*, *B. micracantha*, *D. juglandiformis*, *Euconochitina tanvillensis*, and *Tanuchitina ontariensis*. The *Calpichitina lenticularis* Biozone is equivalent to the *Euconochitina tanvillensis* Biozone in the North Gondwana Domain, encompassing the late Sandbian–early Katian Stage slices Sa2–Ka1 (time slices 5b–Vla). *Cyathochitina kuckersiana* (Plate 6, figures 10, 11) was identified in sample MG-MHP 176 at the base of the *robusta* Biozone and persisted into the succeeding biozones (Figure 6 and Table 2a–c). This species exhibits an extended range from the Early Ordovician (Floian) to the Early Silurian (Telychian) and is considered cosmopolitan. It has been documented in various regions, including the late Floian–late Darriwilian Fl3–Dw3 (time slices 2c–4c) in the USA (Grahn and Bergström 1984), and Estonia (Tammekänd et al. 2010); late Darriwilian Dw3 (time slice 4c), Sweden (Laufeld 1967; Grahn 1981); late Darriwilian–late Katian Dw3–Ka4 (time slices 4c–Vld), Morocco (Soufiane and Achab 1993); Sandbian–early Katian Sa1–Ka1 (time slices 5a–Vla), the USA (Siesser et al. 1998); Katian Ka2–Ka3 (time slice Vlb), Sweden (Grahn 1981), and Estonia (Eisenack 1962); Katian Ka1–Ka3 (time slices Vla–Vlb), Russia (Laufeld 1971); Middle–Late Ordovician, South China (Liang et al. 2023); Katian Ka4 (time slice Vld), Morocco (Le Héron et al. 2008), and Argentina (De la Puente and Rubinstein 2013); late Hirnantian Hi2 (time slice VII) to the Early Silurian (Rhuddanian) in northern Chad and south-eastern Libya (Le Hérisse et al. 2013); Llandovery (Rhuddanian–Telychian), north-east Libya (Hill et al. 1985); Silurian in Canada (Soufiane and Achab 2000); Llandovery (Rhuddanian–Telychian) in Wales (Mullins and Loydell 2002); and Rhuddanian in Latvia (Loydell et al. 2003), Jordan (Butcher 2009), and South China.

Cyathochitina sp. A (Plate 11, figures 1, 5, 9) appeared only in the sample MG-MHP 176 at the base of the *robusta* Biozone in the study section (Figure 6 and Table 2a–c), and it was recorded for the first time in the Alborz Mountains.

Desmochitina amphorea (Plate 1, figures 8, 9) was also identified in the study section (sample MG-MHP 176) of Simeh-Kuh. This taxon has been documented in various localities, including Baltic undifferentiated erratic boulders of late Darriwilian Dw3 (time slice 4c) (Eisenack 1959); late Darriwilian–early Katian Dw3–Ka1 (time slices 4c–Vla of Videt et al. 2010), Estonia (Eisenack 1962, 1965); early Sandbian Sa1 (time slice 5a), Estonia (Hints and Nölvak 2023); early Katian Ka1 (time slice Vla), Acton Scott Beds, Welsh Borderland, England (Jenkins 1967); early Sandbian Sa1 (time slice 5a), Dalby Limestone, Dalarna, Sweden (Laufeld 1967); Sandbian Sa1–Sa2 (time slices 5a–5b), Louredo Formation, Portugal (Henry et al. 1974).

Desmochitina erinacea (Plate 11, figure 3) was observed at the base of the *robusta* Biozone and continued into the succeeding biozone (Figure 6 and Table 2a–c). *Desmochitina erinacea* is considered a cosmopolitan species and has been documented in various regions, including the latest Darriwilian–late Sandbian Dw3–Sa2 (time slices 4c–5b) in South China (Liang et al. 2017); Darriwilian–late Sandbian

Dw1–Sa2 (time slices 4a–5b) in Baltoscandia (Nölvak and Grahn 1993; Nölvak et al. 2019, 2022); early Sandbian–late Katian Sa1–Ka4 (time slices 5a–Vld) in England (Vandenbroucke 2008); and latest Darriwilian Dw3 (time slice 4c) in Iran (Ghavidel-Syooki and Piri-Kangarshahi 2021). In Baltoscandia, *D. erinacea* does not extend beyond Sandbian Sa2 (time slice 5b) (Nölvak and Grahn 1993).

Desmochitina elongata (Plate 11, figure 16) was identified at the base of the *robusta* Biozone (MG-MHP 176) and persisted into the succeeding biozones. *Desmochitina elongata* was recorded in England from late early Sandbian Sa1 (middle level of time slice 5a) (Vandenbroucke 2008).

Desmochitina nodosa (Plate 1, figures 5, 10, 21) was found in samples MG-MHP 176 to 193 of the Simeh-Kuh section, marking its first identification in the Alborz Mountains, northern Iran. *Desmochitina nodosa* has previously been documented from the Darriwilian Dw1–Dw3 (time slices 4a–4c) in Baltic erratics in Poland (Kozłowski 1963); late Sandbian Sa2 (time slice 5b) in Estonia (Eisenack 1962), Sweden (Bergström et al. 1967; Grahn 1981, 1982), and Belgium (Vanmeirhaeghe 2006); early Katian Ka1 (time slice Vla) in England (Vandenbroucke 2008), and Sweden (*Diplograptus multidens* Zone; Bergström et al. 1967).

Desmochitina minor typica (Plate 1, figures 11–15, 24; Plate 11, figure 15) was identified in the study section (samples MG-MHP 176 to 197) of the Simeh-Kuh locality. This taxon has been documented in various regions, including the Sandbian–Katian Sa1–Ka4 (time slices 5a1–Vld) in the UK (Vandenbroucke 2008); Katian Ka1–Ka4 (time slices Vla–Vld) in the Quwarah Member of the Qasim Formation, the Arabian Peninsula (Paris et al. 2015), and Iran (Ghavidel-Syooki et al. 2011a, 2011b; Ghavidel-Syooki and Piri-Kangarshahi 2021; Ghavidel-Syooki 2023).

Desmochitina juglandiformis (Plate 1, figures 16–20; 22, 23; Plate 11, figures 7, 13, 14) appeared at the base of the *robusta* Biozone and persisted into the succeeding biozones (samples MG-MHP 176 to 203). According to a literature review, *Desmochitina juglandiformis* has been recorded in numerous localities, including Sandbian Sa1–Sa2 (time slices 5a–5b of Videt et al. 2010) in Sweden (Laufeld 1967) and Belgium (Vanmeirhaeghe 2006). *Desmochitina juglandiformis* is also found in the *robusta* Biozone in northern Gondwana (southern Spain, Vanmeirhaeghe 2006) and Iran (Ghavidel-Syooki 2017b, 2017c). *Desmochitina juglandiformis* was recovered from the *wilsoni* to the *clingani* graptolite biozones (Verschaeve 2004; Zalasiewicz et al. 2004).

Eisenackitina rhenana (Plate 4, figures 16, 20) was discovered in samples MG-MHP 176 to 177 within the Upper Ordovician deposits at the Simeh-Kuh locality, marking its first recorded occurrence in the Alborz Mountains, northern Iran. This species has been documented in various localities, including the early Sandbian Sa1 (time slice 5a of Videt et al. 2010) in the Louredo Formation, Synclinal de Buçaco, Portugal (Paris 1981), and the lower Wood Brook and Spy Wood Brook sections, Shelve Inlier, Welsh Borderland, England (Vandenbroucke 2008). *Eisenackitina cf. oelandica* (Plate 9, figure 14) was exclusively found in sample MG-MHP 174 within the study section of the Simeh-Kuh area (Figure 6

and **Table 2a–c**). This taxon has been recorded in a few localities, including Darriwilian Dw1–Dw3 (time slices 4a–4c) in the *Calymene* Shale to *Marrolithus* Shale, Normandy, France (Rauscher and Doubinger 1967; Rauscher 1970); late Darriwilian–early Sandbian Dw3–Sa1 (time slices 4c–5a) in Dalby, Öland, Sweden (Grahn 1981).

Lagenochitina prussica (Plate 6, **figures 22, 23**) was observed at the base of the *robusta* Biozone and persisted into the succeeding biozones. This taxon has been documented in numerous regions, including the Sandbian–Hirnantian Sa1–Hi2 (time slices Sa1–VII) in Gotland, Sweden (Grahn 1982), and Russia (Laufeld 1971); early Katian Ka1 (time slice Vla), Sweden (Laufeld 1967); early–mid Katian Ka1–Ka3 (time slices Vla–Vlb), the UK (Vandenbroucke et al. 2005); late Katian Ka4 (time slices Vlc–Vld), Belgium (Vanmeirhaeghe 2006), and Morocco (Le Héron et al. 2008); late Katian–Hirnantian Ka4–Hi2 (time slices Vld–VII), Turkey (Paris et al. 2007), and north-east Libya (Paris 1988); Katian–Hirnantian Stage slices Ka1–Hi2 (time slices Vla–VII), Iran (Ghavidel-Syooki 2008, 2017b; Ghavidel-Syooki and Piri-Kangarshahi 2021), and Baltic (Nölvak 1980), and Morocco (Elaouad-Debbaj 1984); mid Katian–late Hirnantian Ka2–Hi2 (time slices Vlb–VII) in the North Gondwana Domain (Paris 1990); late Katian–Hirnantian Ka4–Hi2 (time slice Vld–VII), north-east Libya (Paris 1988); and late Hirnantian Hi2 (time slice VII), Morocco (Bourahrouh et al. 2004), Algeria (Paris et al. 2000b), and Libya (Abuhmida 2013).

Pistillachitina pistillifrons (Plate 5, **figures 13; 17, 21; 19, 23; Plate 11, figure 6**) was observed at the base of the *robusta* Biozone in the study section (samples MG-MHP 176 to 208) of the Simeh-Kuh locality, persisting through the succeeding biozones. Thus far, *P. pistillifrons* has been documented in the Sandbian Sa1 (time slice 5a) in the Cardigan area, England (Vandenbroucke 2008); late Katian Ka4 (time slice Vld) in the Ghelli Formation, northern Iran (Ghavidel-Syooki and Winchester-Seeto 2002), and Seyahou Formation, the High Zagros Mountains, southern Iran (Ghavidel-Syooki 2023); Katian Ka2–Ka4 (time slices Vlb–Vld) in the Upper Ktaoua Formation, Morocco (Elaouad-Debbaj 1984, pl. 2, fig. 26 as *Belonechitina pistillifrons*). Paris (1990) noted that *P. pistillifrons* ranges from *Lagenochitina deunffii* to *Lagenochitina dalbyensis* biozones in the Sandbian Global Stage slices Sa1–Sa2 (time slices 5a–5b of Webby et al. 2004). Based on the age adopted for both the *Belonechitina robusta* Biozone and associated chitinozoan taxa, 15 m of the basal part of the Upper Ordovician deposits at the Simeh-Kuh locality is assigned to the Caradocian age (Aurelucian to early Streffordian) or Sandbian–lower-middle Katian Stage slices Sa1–Ka2 (time slices 5a–Vlb).

Rhabdochitina usitata (Plate 4, **figures 23, 24**) is present in samples MG-MHP 176 to 200 of the Simeh-Kuh section. This taxon has been documented in various locations, including the Darriwilian Dw1–Dw3 (time slices 4a–4c), western Newfoundland, Canada (Albani et al. 2001); late Darriwilian Dw3 (time slice 4c) in the Lashkarak Formation at the GerdKuh locality, northern Iran (Ghavidel-Syooki and Piri-Kangarshahi 2023); Darriwilian–Sandbian Dw1–Sa2 (time slices 4a–5b), Shropshire, England (Jenkins 1967); Sandbian

Sa1–Sa2 (time slices 5a–5b), the Anticosti Islands (Achab 1984); late Sandbian Sa2 (time slice 5b), England (Vandenbroucke 2008); Sandbian Sa1–Sa2 (time slices 5a–5b), the Viola limestones, Arbuckle Mountains of Oklahoma (Jenkins 1969); Sandbian–Katian Sa1–Ka4 (time slices 5a1–Vld) in Iran (Ghavidel-Syooki 2001b); and Katian Ka1–Ka4 (time slices Vla–Vld) in the Gorgan Schists, south-eastern Caspian Sea, Alborz Mountains, northern Iran (Ghavidel-Syooki 2008).

Rhabdochitina magna (Plate 9, **figure 2**; Plate 11, **figure 24**) emerged at the base of the *robusta* Biozone and extended into the succeeding biozone (**Figure 6** and **Table 2a–c**). This species has been documented in numerous localities, including late Floian–early Darriwilian Fl3–Dw1 (time slices 2c–4a) in Öland, Sweden (Grahn 1980, 1981); early Darriwilian–middle Katian Dw1–Ka3 (time slice 4a–Vlb), Estonia (Eisenack 1962, 1965, 1968a, 1968b); and late Darriwilian Dw3 (upper level of time slice 4c) in the Meadowtown Beds, Welsh Borderland, England (Jenkins 1967).

Spinachitina multiradiata (Plate 3, **figure 24**; Plate 8, **figures 23, 24**; Plate 9, **figures 7, 8; 9, 10; 11, 12; 16**; Plate 10, **figures 10, 14**) appeared at the base of the *robusta* Biozone and persisted into the succeeding chitinozoan biozone. This species is documented for the first time in the Alborz Mountains, northern Iran. *Spinachitina multiradiata* has been recorded from various regions, including early Sandbian–early Katian Stage slices Sa1–Ka1 (time slices 5a–Vla), Sweden (Grahn 1982); late Sandbian Sa2 (time slice 5b), Estonia (Eisenack 1959); Sandbian Sa1–Sa2 (time slices 5a–5b), Estonia (Hints and Nölvak 2023); and late Sandbian–early Katian Sa2–Ka1 (time slices 5b–Vla) in Shropshire, England (Jenkins 1967; Vandenbroucke 2008). Consequently, all the Caradocian strata are in the study section, following the *Linachitina pis-sotensis* Biozone of the Middle Ordovician chitinozoan biozone. As a result, this biozone correlates to the *ponctidalyensis* biozones (Paris 1990).

4.4.12. *Tanuchitina fistulosa* Biozone (12)

This biozone corresponds to the partial range of *Tanuchitina fistulosa* (Taugourdeau & de Jekhowsky 1960) Paris et al. 2000, from its FAD to the FAD of *Acanthochitina barbata* Eisenack 1931. *Tanuchitina fistulosa* has been documented in the upper Caradoc (early Katian) of the Algerian Sahara (Taugourdeau and de Jekhowsky 1960), Morocco (Bourahrouh et al. 2004), the Arabian Peninsula (Al-Hajri 1995; Paris et al. 2000a; Al-Shawareb et al. 2017), Turkey (Paris et al. 2007), and Iran (Ghavidel-Syooki 2001a, 2017b, 2017c, 2023; Ghavidel-Syooki and Winchester-Seeto 2002; Ghavidel-Syooki and Piri-Kangarshahi 2021). Furthermore, it is present in the Hirnantian Hi1–Hi 2 (time slice VII), the Baq'a Shale Member of the Sarah Formation in the Arabian Peninsula (Paris et al. 2015). In the present dataset, *T. fistulosa* (Plate 8, **figures 1, 5**; Plate 11, **figures 4, 8**) was observed in the study section (samples MG-MHP 178 to 181), which comprises 21 m of alternating mottled dark shales and micaeuous grey sandstones within the Upper Ordovician strata (**Figure 6** and **Table 2a–c**) at the Simeh-Kuh section. The

striking features of this biozone include the presence of *Ancyrochitina onniensis* Jenkins 1967, *Angochitina communis* Jenkins 1967, *Angochitina cf. dicranum* Jenkins 1967, *Belonechitina micracantha* (Eisenack 1931), *Cyathochitina latipatagium* (Jenkins 1969), *Fungochitina spinifera* (Eisenack 1962), *Hyalochitina jajarmensis* Ghavidel-Syooki 2017c, *Lagenochitina baltica* Eisenack (1931), and *Spinachitina bulmani* (Jansonius 1964) Jenkins 1967.

In the present material, *Ancyrochitina onniensis* (Plate 4, figures 4, 8; 9; 10, 11) was observed at the base of the *fistulosa* Biozone (MG-MHP 178 to 183) and extended into the basal part of the succeeding biozone. This marks its first recorded occurrence in the Alborz Mountains. Previously, this taxon has been documented in various regions, including the early Katian Ka1 (time slice Vla), Onnia Beds in Shropshire, England (Jenkins 1967; Vandenbroucke 2008); and the late Katian Ka4 (time slices Vlc–Vld), the Upper Ktaoua Formation, Anti-Atlas, Morocco (Elaouad-Debbaj 1984). *Angochitina communis* (Plate 3, figures 17, 18; 19, 20; 21) was identified at the base of the *fistulosa* Biozone within the stratigraphical study section of the Simeh-Kuh locality (Figure 6 and Table 2a–c). This taxon has been documented in various locations, including the late Sandbian Sa2 (time slice 5b of Videt et al. 2010), the upper Dalby limestone, Sweden (Grahn 1981); Katian Ka1–Ka3 (time slices Vla–Vlb), the Onnia beds, Welsh Borderland, England (Jenkins 1967; Vandenbroucke 2008); Katian Ka1–Ka4 (time slices Vla–Vld), the Quwarah Member of the Qasim Formation in the Arabian Peninsula (Paris et al. 2015); and Katian Ka1–Ka4 (time slices Vla–Vld) in the Seyahou Formation, the Zardkuh mountain, the High Zagros Mountains, southern Iran (Ghavidel-Syooki 2021). *Angochitina cf. dicranum* (Plate 11, figure 2) is likewise restricted to the *fistulosa* Biozone within the Simeh-Kuh locality. This taxon was previously documented in the early Katian Ka1 (time slice Vla) within the Onnia beds in the Welsh Borderland, England (Jenkins 1967).

Belonechitina micracantha (Plate 5, figures 3, 7; 4, 8; 10, 14; 11, 15; 12, 16) was observed at the base of the *fistulosa* Biozone and extended into the succeeding biozone. *Belonechitina micracantha* exhibits a wide distribution and has been documented in various regions, including Darriwilian–Dapingian Dp1–Dw3 (time slices 3a–4c), Sweden (Vandenbroucke 2004); Dapingian–early Katian Dp1–Ka1 (time slice 3a–Vla of Videt et al. 2010), the Arabian Peninsula (Al-Hajri 1995; Al-Shawareb et al. 2017); Darriwilian Dw1–Dw3 (time slices 4a–4c), Turkey (Paris et al. 2007), UK (Vanmeirhaeghe 2006), Australia (Winchester-Seeto et al. 2000); Darriwilian–early Katian Dw1–Ka1 (time slices 4a–Vla), Canada (Achab and Asselin 1995), and Scandinavia (Grahn and Nölvak 2007); Sandbian–Katian Sa1–Ka4 (time slices 5a–Vld), Libya (Molyneux and Paris 1985; Abuhmida 2013); middle Katian Ka2–Ka4 (time slices Vlb–Vld), Anti-Atlas, Morocco (Elaouad-Debbaj 1984; Bourahrouh et al. 2004; Le Héron et al. 2008), and UK (Van Nieuwenhove et al. 2006); Sandbian–middle Katian Sa1–Ka3 (time slices 5a–Vlb), UK (Vandenbroucke et al. 2008); and Darriwilian–Hirnantian Dw1–Hi2 (time slices 4a–VII), China (Xiaofeng and Xiaohong 2004).

In Iran, *B. micracantha* has been documented in the Sandbian–Katian Sa1–Ka4 (time slices 5a–Vld), specifically within the Gorgan Schists, Deraznow area, southern Caspian Sea, in northern Iran (Ghavidel-Syooki 2008). Further, it has been recorded in the Katian–Hirnantian Ka1–Hi2 (time slices Vla–VII), the Ghelli Formation within the Alborz Mountains, northern Iran (Ghavidel-Syooki and Borji 2018; Ghavidel-Syooki and Piri-Kangarshahi 2021), and the Sandbian–Hirnantian Sa1–Hi2 (time slices 5a–VII) in the Seyahou Formation, within the High Zagros Mountains, southern Iran (Ghavidel-Syooki 2023).

Cyathochitina latipatagium (Plate 11, figure 12) is present in the *fistulosa* Biozone and persists into the succeeding biozone (Figure 6 and Table 2a–c). This species has been documented in numerous locations, including Darriwilian Dw1–Dw3 (time slices 4a–4c), Calymene Shale, France (Rauscher and Doubinger 1967); Darriwilian Dw2–Dw3 (time slices 4b–4c), Folkeslunda and Dalby Limestone, Öland, Sweden (Grahn 1981); Sandbian–early Katian Sa1–Ka1 (time slices 5a–Vla), Coston Beds to Onnia Beds in Welsh Borderland, UK (Jenkins 1967), Louredo Formation, Serra de Bucaco, Portugal (Paris 1979), Viola limestone, Oklahoma, USA (Jenkins 1969), Trenton Group to Utica Formation, Canada (Martin 1975); late Sandbian Sa2 (time slice 5b), Estonia (Eisenack 1962); and Sandbian–Hirnantian Sa1–Hi2 (time slices 5a–VII), Macasty Formation to Ellis Bay Formation, Canada (Achab 1978).

Fungochitina spinifera (Plate 4, figures 12; 13, 17; 14, 18; 15, 19) was identified at the base of the *fistulosa* Biozone and persisted into the succeeding biozones (Figure 6 and Table 2a–c). To date, this taxon has been documented in various geological stages and regions, including late Sandbian–early Katian Sa2–Ka1 (time slices 5b–Vla), Greenscoe section southern Lake District, and the British historical type areas and adjacent key sections (Van Nieuwenhove et al. 2006; Vandenbroucke 2008); Hirnantian Global Stage slices Hi1–Hi2 (time slice VII), the Arabian Peninsula (Paris et al. 2015; Al-Shawareb et al. 2017); Katian Stage slices Ka1–Ka4 (time slices Vla–Vld of Videt et al. 2010), Iran (Ghavidel-Syooki 2017c, 2023; Ghavidel-Syooki and Borji 2018; Ghavidel-Syooki and Piri-Kangarshahi 2021); and Late Hirnantian Hi2 (time slice VII), Bir Tlacsin Formation, Libya (Abuhmida 2013). In England, *Fungochitina spinifera* is restricted to the Katian Ka1–Ka4 (time slices Vla–Vld) (Vandenbroucke 2008). However, Van Nieuwenhove et al. (2006) proposed that the *Fungochitina spinifera* biozone is equivalent to the upper part of *Euconochitina tanvillensis*, *Belonechitina robusta*, *Tanuchitina fistulosa*, and the lower part of *Acanthochitina barbata* biozones.

Hyalochitina jajarmensis (Plate 4, figures 1, 5; 2, 6; 3, 7) was initially described from the early Katian Ka1 (time slice Vla) in the Ghelli Formation within the Alborz Mountains, northern Iran (Ghavidel-Syooki 2017c). Subsequently, this species was also documented in the same formation in central Iran (Ghavidel-Syooki and Piri-Kangarshahi 2021).

Lagenochitina baltica (Plate 8, figures 19, 20; Plate 9, figure 13) was found at the base of the *fistulosa* Biozone in the study section (samples MG-MHP 178 to 208) of Simeh-Kuh in

the Alborz Mountains, northern Iran. This taxon has been documented in numerous regions, including Darriwilian–Hirnantian Dw1–Hi2 (time slices 4a–VII), China (Wang and Chen 2004); Sandbian–early Katian Sa1–Ka1 (time slices 5a–Vla), Shropshire (Coston–Alternata and Onnia Beds), England (Jenkins 1967; Vandenbroucke et al. 2003, 2005, 2008), Portugal (Paris 1979); Sandbian–Hirnantian Sa1–Hi2 (time slices 5a–VII), the Northern Gondwanan Domain (Paris 1990), Scandinavia (Grahn and Nölvak 2007), Belgium (Vanmeirhaeghe 2006), and Morocco (Bourahrouh et al. 2004); early–middle Katian Ka1–Ka3 (time slices Vla–Vlb of Videt et al. 2010), north-east Libya (Molyneux and Paris 1985); Katian–Hirnantian Ka1–Hi2 (time slices Vla–VII), Iran (Ghavidel-Syooki 2008; Ghavidel-Syooki et al. 2011b; Ghavidel-Syooki 2017b, 2017c; Ghavidel-Syooki and Piri Kangarshahi, 2021), Belgium, and North England (Vanmeirhaeghe et al. 2005); late Katian Ka4 (time slice Vld), Estonia (Eisenack 1959, 1965; Nölvak 1980); Katian–Hirnantian Ka1–Hi2 (time slices Vla–VII), Turkey (Paris et al. 2007); middle Katian Ka2–Ka3 (time slice Vlb of Videt et al. 2010), Vauréal Formation, Anticosti Island, Canada (Achab 1977); Katian–Hirnantian Ka1–Hi2 (time slices Vla–VII), Estonia (Hints et al. 2007); middle Katian–Hirnantian Ka2–Hi2 (time slices Vlb–VII), UK (Van Nieuwenhove et al. 2006); and Hirnantian Hi1–Hi2 (time slice VII), Morocco (Le Héron et al. 2008).

Spinachitina bulmani (Plate 8, figures 17, 21; 18, 22; Plate 10, figures 9, 13; 20, 24) is observed at the basal part of the *fistulosa* Biozone and extends into the succeeding biozones (Figure 6 and Table 2a–c). This species has been documented in various locations, including late Sandbian Sa2 (time slice 5b of Videt et al. 2010), Scotland, and Shropshire, UK (Jansonius 1964; Jenkins 1967); Sandbian–Katian Sa1–Ka4 (time slices 5a–Vld), Belgium (Vanmeirhaeghe 2007); Katian Ka1–Ka4 (time slices Vla–Vld), Morocco (Elaouad-Debbaj 1984), Anticosti Island, Canada (Achab 1978), Norway (Grahn et al. 1994), Libya (Molyneux and Paris 1985), UK (Vandenbroucke 2005), and Iran (Ghavidel-Syooki and Winchester-Seeto 2002); Katian–Hirnantian Ka1–Hi2 (time slices Vla–VII), Iran (Ghavidel-Syooki 2008, 2017b, 2017c, 2023; Ghavidel-Syooki et al. 2011a, Ghavidel-Syooki and Borji 2018; Ghavidel-Syooki and Piri-Kangarshahi 2021); and early Hirnantian Hi1 (lower level of time slice VII), Memouniat Formation (Abuhmida 2013). *Spinachitina bulmani* has also been recorded in the Sandbian–Katian Sa1–Ka4 (time slices 5a–Vld of Videt et al. 2010) in Avalonia, Laurentian, Gondwanan palaeocontinents, and South China (Liang et al. 2023). The age for both the *Tanuchitina fistulosa* Biozone and the associated chitinozoan taxa in the sampling interval MG–MHP 178 to 181 within the Ordovician sediments of Simeh-Kuh indicate the upper Caradoc (upper Streffordian) or the early Katian Ka1 (the upper level of time slice Vla).

4.4.13. *Acanthochitina barbata* Biozone (13)

This biozone spans the entire range of *Acanthochitina barbata* Eisenack 1931 from its FAD up to the FAD of *Armoricochitina nigerica* (Bouché 1965). *Acanthochitina barbata* is an excellent microfossil marker for the early Ashgill (Pusgillian = the middle Katian Stage slices Ka2–Ka3 and time

slice of Vlb of Videt et al. 2010) in the North Gondwana Domain, succeeding the *Tanuchitina fistulosa* Biozone (Paris 1999; Paris et al. 2000b; Webby et al. 2004; Videt et al. 2010). In the current study, *Acanthochitina barbata* (Plate 3, figures 1, 5; 2, 6; 3, 7; 4, 8) was observed within samples MG–MHP 182 to 185 of the study section, covering 19 m of alternating black micaceous shales and grey sandstones of the Upper Ordovician Ghelli Formation (Figure 6 and Table 2a–c) at the Simeh-Kuh locality. The striking feature of this biozone is the presence of *Acanthochitina latebrosa* Vandenbroucke 2008, *Acanthochitina cf. pudica* Vandenbroucke 2008, *Cyathochitina costata* Grahn 1982, *Euconochitina lepta* (Jenkins 1970) Paris et al. 1999, *Spinachitina coronata* (Eisenack 1931), *Tanuchitina hosseini-nezhadi* sp. nov., and *Tanuchitina ontariensis* Jansonius 1964.

Acanthochitina latebrosa (Plate 10, figures 1–4; 5–7; 8; 18, 22) has previously been documented in the early Katian Ka1 (time slice Vla) of the Onny Formation, Shropshire, UK (Vandenbroucke 2008). Its occurrence in the Alborz Mountains in northern Iran is reported here for the first time. *Acanthochitina cf. pudica* (Plate 3, figures 9, 10; 11, 12) was observed in the study section (samples MG–MHP 182 to 185) of the Upper Ordovician deposits at the Simeh-Kuh locality. This taxon has previously been identified in the late Sandbian Sa2 (time slice 5b of Webby et al. 2004) in England (Vandenbroucke 2008), as well as in the High Zagros Mountains, southern Iran (Ghavidel-Syooki 2023).

Cyathochitina costata (Plate 11, figures 10, 11) was found in samples MG–MHP 182 to 185 of the study section at the Simeh-Kuh locality. This taxon has been documented in various regions, including the Katian Ka1–K3 (time slices Vla–Vlb), Götland, Sweden (Grahn 1982); early Katian Ka1 (time slice Vla), Estonia (Nölvak 1980); Katian Ka2–Ka3 (time slice Vlb), the Ghelli Formation, Alborz Mountains, northern Iran (Ghavidel-Syooki and Winchester-Seeto 2002); late Hirnantian Hi2 (the upper level of time slice VII), Latvia (Hints et al. 2010) and the Bir Tlacsin Formation in Libya (Abuhmida 2013).

Euconochitina lepta (Plate 6, figures 15, 16; 17–21; Plate 9, figure 15) was present in the *barbata* Biozone (samples MG–MHP 182 to 200) and extended into the succeeding biozone within the stratigraphical study section at the Simeh-Kuh locality. This taxon has been documented in numerous locations, including the Katian Ka1–Ka4 (time slices Vla–Vld), the Sylvan Shale, Oklahoma, USA (Jenkins 1970); late Katian Ka4 (time slices Vlc–Vld), UK (Vandenbroucke 2008); mid-late Katian Ka2–Ka4 (time slices Vlb–Vld), Morocco (Elaouad-Debbaj 1984), and Algeria (Oulebsir and Paris 1995; Paris et al. 2000b); and Katian Ka1–Ka4 (time slices Vla–Vld), the Arabian Peninsula (Al-Shawareb et al. 2017), south-eastern Turkey (Paris et al. 2007), and Iran (Ghavidel-Syooki and Winchester-Seeto 2002; Ghavidel-Syooki 2008, 2016, 2017a, 2017b, 2017c, 2021, 2023; Ghavidel-Syooki and Borji 2018; Ghavidel-Syooki and Piri-Kangarshahi 2021).

Spinachitina coronata (Plate 5, figures 20, 24) occurred in the *barbata* Biozone in the study section (samples MG–MHP 182 to 185) in the Upper Ordovician deposits of the Simeh-Kuh locality. Up to now, this species has been recorded from

the late Sandbian–middle Katian Sa2–Ka3 (time slices 5b–Vlb), Götland, Sweden (Grahn 1982); early Katian Ka1 (time slice Vla), England (Vandenbroucke 2008).

Tanuchitina hosseini-nezhadi sp. nov. (Plate 8, figures 2, 6; 3, 7; 4, 8; Plate 10, figures 11, 15; 19, 23) appeared at the base of the *barbata* Biozone and persisted into the succeeding biozone of the study section at the Simeh-Kuh locality.

Tanuchitina ontariensis (Plate 7, figures 4, 8; 10, 14; 11, 15; 12, 16; 17, 21; 18, 22; 19, 23; 13, 20, 24; Plate 8, figures 9, 13; 10, 14; 11, 15; 12, 16) was present at the base of the *barbata* Biozone and persisted into the succeeding biozone. *Tanuchitina ontariensis* is a distinctive species of the Late Ordovician age. To date, it has been documented in various regions, including the Katian Ka1–Ka4 (time slices Vla–Vld), Sylvan Shale of Oklahoma, USA (Jenkins 1970), Vaureal Formation, Canada (Achab 1983), the Arabian Peninsula (Al-Hajri 1995), Turkey (Paris et al. 2007), and the Upper Ordovician Ghelli and Seyahou formations in Iran (Ghavidel-Syooki 2017b, 2017c, 2023; Ghavidel-Syooki and Borji 2018; Ghavidel-Syooki and Piri-Kangarshahi 2021). All the aforementioned chitinozoan species are characteristic of the Katian stage (Jenkins 1969; Elaouad-Debbaj 1984, 1990; Ghavidel-Syooki and Winchester-Seeto 2002; Van Nieuwenhove et al. 2006; Ghavidel-Syooki 2008, 2016, 2017a, 2017b, 2017c, 2023; Vandenbroucke et al. 2009; Abuhmida 2013; Ghavidel-Syooki and Piri-Kangarshahi 2021). Based on a comparison with the chronostratigraphical charts of Paris et al. (2000b), Bergström et al. (2009), Webby et al. (2004), and Videt et al. (2010), the sampling interval from MG-MHP 182 to 185 of the stratigraphical study section at the Simeh-Kuh locality is assigned to the middle Katian Ka2–Ka3 (time slice Vlb).

4.4.14. *Armoricochitina nigerica* Biozone (14)

This biozone corresponds to the partial-range biozone of *Armoricochitina nigerica* (Bouché 1965), extending from its FAD to the FAD of *Ancyrochitina merga*, the succeeding index species biozone in the North Gondwana Domain. In the current dataset, *Armoricochitina nigerica* (see Plate 2, figures 17, 21; 20; 18, 22; and Plate 11, figures 17, 21; 18, 22) is observed within the Upper Ordovician strata of the study section (samples MG-MHP 186 to 208), comprising 151 m of alternating calcareous black shale and mottled grey sandstone beds at the Simeh-Kuh locality (Figure 6 and Table 2a–c) in the Alborz Mountains, north of Iran. Until now, this species has been documented in the Late Ordovician (Ashgill) within the North Gondwana Domain (Bouché 1965; Molyneux and Paris 1985; Al-Hajri 1995; Oulebsir and Paris 1995; Paris et al. 2000b; Ghavidel-Syooki and Winchester-Seeto 2002; Bourahrouh et al. 2004; Paris et al. 2007; Ghavidel-Syooki 2008, 2016, 2017a, 2017b, 2017c, 2021, 2023; Le Héron and Craig 2008; Ghavidel-Syooki et al. 2011a, 2011b; Abuhmida 2013; Le Hérissé et al. 2013; Paris et al. 2015; Al-Shawareb et al. 2017; Oktay and Wellman 2019; Ghavidel-Syooki and Piri-Kangarshahi 2021). *Armoricochitina nigerica* is a pivotal chitinozoan species, delineating the northern Gondwanan high palaeoplate during the Late Ordovician. Its absence from records in the United Kingdom

and Belgium suggests that it did not spread to the north of the margin of the Rheic Ocean (Paris et al. 2015). The notable characteristic of this biozone is the presence of several key species, including *Armoricochitina alborzensis* Ghavidel-Syooki & Winchester-Seeto 2002, *Armoricochitina iranica* Ghavidel-Syooki & Winchester-Seeto 2002, *Rhabdochitina curvata* Al-Shawareb et al. 2017, *Tanuchitina alborzensis* Ghavidel-Syooki 2017b, 2017c, *Tanuchitina anticostiensis* Achab 1977, *Tanuchitina bergstroemi* Laufeld 1967, and *Tanuchitina densimura* Al-Shawareb et al. 2017.

Armoricochitina alborzensis (Plate 2, figures 1, 5; 2, 6; 3, 7; 19, 23), and *Armoricochitina iranica* (Plate 2, figures 4, 8, 12; 9, 13; 10, 14; 11, 15) were initially described by Ghavidel-Syooki and Winchester-Seeto 2002 within the Upper Ordovician type section of the Ghelli Formation in the Alborz Mountains. These species, along with *A. nigerica*, have been identified from the uppermost level of Katian Ka3 to the lower-middle levels of Katian Ka4 (time slices Vlb–Vlc) within the Ghelli Formation at Kuh-e Saluk, in the Alborz Mountains northern Iran (Ghavidel-Syooki and Winchester-Seeto 2002; Ghavidel-Syooki et al. 2011a; Ghavidel-Syooki 2016, 2017b, 2017c; Ghavidel-Syooki and Borji 2018), as well as at Kuh-e Boghou, central Iran (Ghavidel-Syooki and Piri-Kangarshahi 2021), within the Seyahou Formation in the High Zagros Mountains, southern Iran (Ghavidel-Syooki 2023), and in Libya (Abuhmida 2013). Similarly, *Tanuchitina alborzensis* (Plate 7, figures 1, 5, 9) is observed at the base of the *nigerica* Biozone, extending from sample MG-MHP 186 to 191 with infrequent occurrence in the study section of the Simeh-Kuh area. This species was initially documented within the Katian Ka1–Ka4 (time slices Vla–Vld) of the Ghelli Formation in the Alborz Mountains, northern Iran (Ghavidel-Syooki 2017b, 2017c).

Tanuchitina anticostiensis (Plate 7, figures 2, 6) is a significant species within the Upper Ordovician strata, including from the Caradocian to Ashgillian stages. This taxon has been documented in various regions, including the Sandbian to Hirnantian Sa1–Hi2 (time slices 5a1–VII), Canada (Achab 1977) and north-eastern Libya (Molyneux and Paris 1985); late Katian–early Hirnantian Ka4–Hi1 (time slices Vld–VII), Libya (Abuhmida 2013); and Katian Ka1–Ka4 (time slices Vla–Vld), Iran (Ghavidel-Syooki 2017c, 2023; Ghavidel-Syooki and Borji 2018). *Tanuchitina bergstroemi* (Plate 7, figures 3, 7) first appeared at the onset of the *nigerica* Biozone and persisted through samples MG-MHP 186 to 191 in the Simeh-Kuh locality in the study section. Thus far, this species has been documented in the Katian Stage slice Ka1 (time slice Vla) within the Fajacka shale of Dalarna, Sweden (Laufeld 1967); Katian Ka1–Ka3 (time slice Vla to the lower level of Vlc) in the Central Condroz Inlier, Belgium (Vanmeirhaeghe 2006); and England (Vandenbroucke 2008). The current study identified *Tanuchitina densimura* (Plate 10, figures 12, 16) and *Rhabdochitina curvata* (Plate 9, figure 4) within the *nigerica* Biozone. Their presence extended throughout samples MG-MHP 186 to 191 in the study section at the Simeh-Kuh locality within the Alborz Mountains, northern Iran. These taxa were initially described within the middle–late Katian to early Hirnantian Ka2–Hi1 (time slices Vlb–VII of Videt et al. 2010),

specifically in the Quwarah Member of the Qasim Formation in the Arabian Peninsula (Al-Shawareb et al. 2017).

All the aforementioned chitinozoan taxa are indicative of the Katian Stage (Jenkins 1969; Elaouad-Debbaj 1984; Paris 1990; Ghavidel-Syooki and Winchester-Seeto 2002; Van Nieuwenhove et al. 2006; Ghavidel-Syooki 2008, 2016, 2017a, 2017b, 2017c, 2023; Vandebroucke et al. 2009; Abuhmida 2013; Ghavidel-Syooki and Piri-Kangarshahi 2021). Following comparison with the chronostratigraphical charts of Paris et al. 2000b, Bergström et al. 2009, Webby et al. 2004, and Videt et al. 2010), the sample interval MG-MHP 186 to 208 in the study section at Simeh-Kuh locality is assigned to late middle Katian Ka3–early Ka4 (time slices Vlb–Vlc). Consequently, a significant hiatus is noted between the Ghelli and Geirud formations, covering the late Ashgillian (latest Katian–Hirnantian), Silurian, and lower–middle Devonian in the Simeh-Kuh section of the Alborz Mountains, northern Iran.

5. Palaeobiogeography

Globally, Early–Late Ordovician acritarch and chitinozoan taxa exhibit distinct provincialism, characterised by two major microfloral and microfaunal realms, comprising the Peri-Gondwana (Peri-Antarctica) and Baltic palaeoprovinces (Vavrdová 1974; Colbath 1990; Molyneux et al. 2013). This provincialism is thought to be influenced by various palaeoenvironmental factors, such as water temperature and oceanic currents (Tongiorgi et al. 1995; Molyneux et al. 2013; Servais et al. 2014). Because of this provincialism, the chronostratigraphical divisions adopted for the Mediterranean and ‘North Gondwana’ regions are based on the framework presented by Bergström et al. (2009). It is noteworthy that Servais et al. (2018) clarified that the term ‘North Gondwana’ refers to parts of the Palaeozoic continent of Gondwana that presently occupy the most northerly positions. However, during the early Palaeozoic, these areas were situated at high southern palaeolatitudes along the subpolar margin of Gondwana.

Following the reconstructions of Ordovician palaeogeography presented by Torsvik and Cocks (2016) and the terminology employed by Servais et al. (2018), the term ‘southern Gondwana’ is utilised here to refer to regions situated between a palaeolatitude of approximately 60°S and the Ordovician South Pole. This primarily includes North Africa and specific components of the Armorican Terrane Assemblage, such as Bohemia, Saxothuringia, and Iberia. In contrast, ‘western Gondwana’ is applied to the Arabian Peninsula, Iran, Pakistan, and Western Australia (see Figure 7). ‘Eastern Gondwana’, in turn, encompasses regions located on the opposite margin of the palaeocontinent, with available data primarily limited to north-western Argentina and Colombia. It is important to note that during the Early and Middle Ordovician, South China was a distinct entity positioned adjacent to the western margin of Gondwana, as illustrated by the reconstructions provided by Torsvik and Cocks (2016, fig. 6.1). Within the stratigraphical study section encompassing the Lashkarak and Ghelli formations,

numerous acritarchs have been identified, and several morphotype taxa stand out as significant for chronostratigraphy and palaeobiogeography, including *Arbusculidium filamentosum*, *Arkonia virgata*, *Baltisphaeridium llanvirnianum*, *Coryphidium bohemicum*, *Cymatiogalea aspergillum*, *Dasydiacrodium obsonum*, *Inflatarium trilobatum*, *Leiofusa stoumonensis*, *Ninadiacrodium caudatum*, *N. dumontti*, *Orthosphaeridium bispinosum*, *O. insculptum*, *O. quadrinatum*, *O. rectangulare*, *O. ternatum*, *Peteinosphaeridium* spp., *Stellechinatum celestum*, *Striatotheca principalis*, *Timofeevia phosphoritica*, *Vulcanisphaera africana*, *V. mougnoana*, and *V. simplex*.

The genus *Arbusculidium* is a distinctive element in the late Early–Middle Ordovician. It is found in Gondwana, Avalonia, southern Scandinavia, and South China (Figure 7). Notably, *Arbusculidium filamentosum*, a key species, is an excellent index for the Peri-Gondwanan palaeoprovince. It is documented in the Floian age strata in various regions, including Iran, Pakistan, Morocco, Argentina, and the Floian–Darriwilian strata in South China. The stratigraphical occurrence of *Arbusculidium filamentosum* is supported by independent age control. Its FAD is confirmed in the early Floian (*Didymograptus extensus* graptolite zone) in the Wabana Group, Bell Island, eastern Newfoundland, Canada. At the same time, the LAD is established in the late Floian (*Tetrograptus reclinatus abbreviatus* graptolite zone) in the Klabava Formation of the Prague Basin, Czech Republic. This study identifies *Arbusculidium filamentosum* in samples MG-MHP 131 to 142 of the Lashkarak Formation at the Simeh-Kuh section, indicating its presence during the Floian Global Stage.

Arkonia virgata was described by Burmann in 1970. This species holds significance as an index species in the late Early–Middle Ordovician in Gondwana, Avalonia, and South China (Figure 7). Its documented occurrences encompass various regions and temporal ranges, including the middle Darriwilian Dw2 in Belgium, Czech Republic, Germany, and Portugal, as well as the late Darriwilian Dw3 in North Wales, England (time slice 4c; *Hustedograptus teretiusculus* graptolite Zone). In the present study, *Arkonia virgata* is identified in the samples MG-MHS 147–172, ranging from middle Dapingian to late Darriwilian Dp2–Dw3 (time slices 4b–4c), the Lashkarak Formation at the Simeh-Kuh locality within the Alborz Mountains, northern Iran. According to Servais et al. (2018), the FAD of *Arkonia* is observed in the late Floian Fl3 (time slice 2c), South China; Dapingian Dp1 (time slice 3a), southern Gondwana; middle Darriwilian Dw2 (time slice 1c), Avalonia; and Darriwilian Dw1 (time slice 4a) in eastern Gondwana. The presence of *Arkonia virgata* in the Lashkarak Formation confirms the inclusion of the Alborz Mountains in the Peri-Gondwana palaeocontinent during the late Early–Middle Ordovician.

Baltisphaeridium llanvirnianum was described by Deunff in 1977. This species was found for the first time in the study section (samples MG-MHP 147 to 172) in the Lashkarak Formation at the Simeh-Kuh locality within the Alborz Mountains of northern Iran. Previously, this taxon had only

been identified in Llanvirnian strata in North Africa (Deunff 1977; Vecoli 1999).

Coryphidium was identified by Vavrdová in 1972. This morphotype is a common in acritarch assemblages from the late Tremadocian to the Darriwilian in Peri-Gondwana, Avalonia, and South China. *Coryphidium bohemicum*, a significant species within this genus, is crucial in the Peri-Gondwanan acritarch palaeoprovince. It has been documented in Floian age strata in various regions, including France, Italy, Pakistan, Iran, Argentina, England, South China, Morocco, and the Czech Republic; and in the Middle Ordovician (Darriwilian) in Tunisia, Germany, and Colombia. The current study identifies the FAD of *Coryphidium bohemicum* within the upper Floian FI3 (time slice 2c), associated with the *Eremochitina brevis* Biozone. Notably, *Coryphidium* and its species have not been documented in the regions of Baltica or Laurentia.

Cymatiogalea aspergillum is restricted to the Upper Cambrian deposits and has been documented in Avalonia, Baltica, and Gondwana (Figure 7). This taxon has been recorded in Furongian age strata in various regions, including eastern Newfoundland, Canada; Oland, Sweden; Belgium; St Tudwal's Peninsula, North Wales, England; Comley area, Shropshire, England; and southern Iran.

Dasydiacodium obsonum, an index fossil for the Late Cambrian, is found in Gondwana, Avalonia, Baltica, and South China (Figure 7). This species has been identified in Furongian age strata in various regions, including eastern Newfoundland, Canada; North Estonia; Belgium and France; north-east China; Algeria; Arctic Russia; northern Spain; and the High Zagros Mountains, southern Iran.

Inflatarium trilobatum is a notable marker for the Late Ordovician of western Gondwana. It has been documented in late Katian age strata within the Quwarah Member of the Qasim Formation in the Arabian Peninsula. Additionally, its occurrences have been noted in the Ghelli Formation in both northern and central Iran (Figure 7).

Leiofusa stoumonensis is exclusively found in the Upper Cambrian strata of Gondwana, Avalonia, and Baltica (Figure 7). It has been documented in Furongian age strata in various regions, including Stavelot, Belgium; eastern Newfoundland, Canada; central Sardinia, Italy; the East European Platform; St Tudwal's Peninsula, north-western Wales, England; and the High Zagros Mountains, southern Iran.

Ninadiacodium and its species are confined to Upper Cambrian deposits and identified in Gondwana, Avalonia, and Baltica (Figure 7). Its species have been documented in Furongian age strata in various regions, including Russia, Estonia, Sweden, Spain, eastern Newfoundland, Canada, Belgium, northern France, North Africa, and the High Zagros Mountains, southern Iran. *Ninadiacodium* is recognised in the Southern Hemisphere in cold- to temperate-water phytoplankton assemblages. In the current material, *Ninadiacodium caudatum* and *Ninadiacodium dumontii* are observed in the basal part of the Lashkarak Formation at the Simeh-Kuh section, marking their first occurrence in the Alborz Mountains, north of Iran.

Orthosphaeridium is a prominent acritarch morphotype in Middle–Upper Ordovician strata in Baltica, Gondwana, Laurentia, and South China (Figure 7). It disappeared at the end of the Ordovician and has never been recorded from the Silurian. In South China, *Orthosphaeridium* first appeared in the *Expansograptus hirundo* graptolite zone of the early Dapingian Dp1 (time slice 3a) and later achieved a global distribution during the Middle and Late Ordovician. This genus and its species have been documented in various regions, including Portugal, France, Jordan, northern Gondwana, Iraq, Shropshire in England, the Arabian Peninsula, Iran, and North America. *Orthosphaeridium bispinosum* and *O. ternatum* have not been recorded from the Laurentian palaeocontinent among the species of this genus.

Peteinosphaeridium spans from the Early to Late Ordovician (uppermost Tremadoc–upper Ashgill) and has been identified in Laurentia, Gondwana, Baltica, and South China (Figure 7). In the current dataset, *P. angustilaminae*, *P. eximium*, *P. exornatum*, *P. dissimile*, *P. coronula*, and *P. velatum* were found in samples MG-MHP 143 to 146 within the Lashkarak Formation at the Simeh-Kuh. These occurrences coincide with the *Coryphidium bohemicum*–*Striatotheca principalis* assemblage biozone. Notably, *P. exornatum* is confined to the Mediterranean sector of the Peri-Gondwanan, while *P. dissimile* is restricted to the Baltic palaeoprovince. The remaining taxa, however, are present in both palaeoprovinces.

Stellechinatum celestum is a distinctive acritarch species indicative of the late Early–Middle Ordovician in Gondwana and Avalonia. This taxon has been documented in various regions, including the Floian FI1–FI3 (time slices 2a–2c) in France and the Algerian Sahara. Furthermore, it has been identified in the middle Darriwilian Dw2 (time slice 4b), Belgium; mid-late Darriwilian Dw2–Dw3 (time slices 4b–4c) in the Czech Republic and North Africa; late Darriwilian Dw3 (time slice 4c) in South Wales, England, and late Darriwilian–early Katian Dw3–Ka1 (time slices 4c–Vla) in North Wales; and Sandbian–early Katian Sa1–Ka1 (time slices 5a–Vla), Shropshire in England.

Timofeevia phosphoritica is a distinctive component of Middle–Late Cambrian acritarch assemblages found in Gondwana, Avalonia, Baltica, Laurentia, and South China (Figure 7). This species has been identified in various locations, including Belgium and France, the East European Platform, Morocco, Libya, eastern Newfoundland, Upper Cambrian strata in Wales, stratal sequences in western Missouri, and Iran. In the present study, *T. phosphoritica* is identified in the Furongian acritarch assemblages A–B of the Lashkarak Formation at the Simeh-Kuh locality.

Vulcanisphaera is a significant indicator for the Late Cambrian to Early Ordovician epochs along the margins of Gondwana, Avalonia, Baltica, Laurentia, and South China (Figure 7). This genus, along with its species such as *Vulcanisphaera africana*, *V. mouguoana*, and *V. simplex*, is identified in the basal acritarch assemblage biozones within the Lashkarak Formation at the Simeh-Kuh section. Specifically, *V. africana* has been documented in the

Furongian–Tremadocian of Iran, Iraq, Tunisia, Italy, Algeria, Morocco, and Argentina.

Vulcanisphaera mougnoana was initially described in the Miaolingian and identified in Spain, Algeria, and Iran. This species gained a broader distribution during the Furongian, with occurrences documented in Iran, Iraq, Libya, Tunisia, Algeria, Italy, and Spain.

Vulcanisphaera simplex is an excellent index microfossil for the Tremadocian Tr1–Tr3 (time slices 1a–1d) within Peri-Gondwana. Its presence has been documented in various regions, including Iraq, Spain, Iran, Tunisia, Algeria, France, Italy, and Argentina. Therefore, identifying *Vulcanisphaera simplex* provides evidence for Peri-Gondwanan affinities in the Early Ordovician (Tremadocian), the Lashkarak Formation at Simeh-Kuh within the Alborz Mountains, north of Iran.

Likewise, in this study, the identified chitinozoan taxa have contributed to the delineation of 14 chitinozoan biozones, encompassing species such as *Eremochitina brevis*, *Desmochitina ornensis*, *Belonechitina henryi*, *Cyathochitina protocalix*, *C. calix*, *Siphonochitina formosa*, *C. jenkinsi*, *Aremoricochitina armoricana*, *Laufeldochitina cf. clavata*, *Linochitina pissotensis*, *Belonechitina robusta*, *Tanuchitina fistulosa*, *Acanthochitina barbata*, and *Armoricochitina nigerica*.

Eremochitina brevis comprises the oldest chitinozoan biozone identified in the Simeh-Kuh locality. This taxon is accompanied by *C. campanulaeformis*, *C. varennensis*, and *D. minor* within the Lashkarak Formation. The biozone includes the complete range of *E. brevis* (Floian Stage slice of Fl3 and time slice 2c) in the North Gondwana Domain (Videt et al. 2010). *Desmochitina ornensis* directly follows the *E. brevis* Biozone within the Lashkarak Formation. *Desmochitina ornensis* is a distinctive taxon characteristic of the early Middle Ordovician, particularly the Dapingian Stage slice Dp2 (time slice 3a) within the North Gondwana Terrane. *Belonechitina henryi* follows the *D. ornensis* Biozone within the Lashkarak Formation. This taxon is a reliable index fossil for the Dapingian Stage slice Dp3 (time slice 3b) in the North Gondwana Domain (Paris 1990; Webby et al. 2004; Videt et al. 2010).

Cyathochitina protocalix indicates the earliest late Middle Ordovician (early Darriwilian) age within the North Gondwana Domain (Gutierrez-Marco et al. 2013). We identified this species in the Lashkarak Formation within the Alborz Mountains. According to the chronostratigraphical calibration proposed for the chitinozoan biozones, its biozone encompasses the total range of *C. protocalix*, suggesting the lowermost Darriwilian Stage slice Dw1 and lower Dw2 (time slices upper 4a and lower 4b). *Cyathochitina calix* (Eisenack 1931) sensu Paris 1981, was first recorded within the Lashkarak Formation in the Simeh-Kuh locality in the Alborz Mountains. As an excellent index fossil, *C. calix* indicates the Middle Ordovician (Darriwilian Stage slice of the lower Dw2 and time slice lower 4b) in the North Gondwana Terrane.

After *C. calix* in the Lashkarak Formation, *Siphonochitina formosa* appears. This species is a prominent index fossil within the middle Darriwilian Stage slices of the upper Dw2 and lower Dw3 (time slices of upper 4b and lower 4c) in the North Gondwana Domain (Videt et al. 2010; Gutierrez-Marco

et al. 2013). Following *S. formosa* in the Lashkarak Formation, *Cyathochitina jenkinsi* emerges. This taxon is an index fossil within the middle–late Darriwilian Stage slices Dw2–Dw3 (time slices 4b–4c) in the North Gondwana Terrane.

After *C. jenkinsi* in the Lashkarak Formation, *Armoricochitina armoricana* emerges. This species is an excellent microfossil indicator within the late Darriwilian Stage slice Dw3 (time slice 4c) in the Gondwana regions (Paris 1990; Videt et al. 2010; Gutierrez-Marco et al. 2013). Following *A. armoricana* in the Lashkarak Formation within the Alborz Mountains, *Laufeldochitina cf. clavata* appears. This taxon is an excellent index species for the uppermost part of the Middle Ordovician, particularly the middle–late Darriwilian Stage slices Dw2–Dw3 (time slices 4b–4c) in the North Gondwana Domain, after *L. cf. clavata* in the Lashkarak Formation at the Simeh-Kuh, *Linochitina pissotensis* Paris (1981) emerges. This species is regarded as an excellent fossil indicator for the latest Darriwilian Global Stage slice Dw3 (the uppermost level of time slice 4c) in the North Gondwana Domain.

Belonechitina robusta appears in the Gelli Formation of the study section after the LAD of *L. pissotensis*. The *B. robusta* Biozone corresponds to the interval range of this species from its FAD to the FAD of *Tanuchitina fistulosa*. The *robusta* and underlying *tanvillensis* biozones indicate the Sandbian–early Katian Sa1–Ka1 (time slices 5a–Vla) in the North Gondwana Terrane. Following *B. robusta* in the Ghelli Formation at the Simeh-Kuh locality, *Tanuchitina fistulosa* emerges. This biozone corresponds to the partial range of *Tanuchitina fistulosa*, spanning from its FAD to the FAD of *Acanthochitina barbata*. *Tanuchitina fistulosa* has been documented in the late early Katian Ka1 (the upper time slice Vla). After *T. fistulosa* in the Ghelli Formation at the Simeh-Kuh locality, *Acanthochitina barbata* appears. This species spans from its FAD to the FAD of *Armoricochitina nigerica* (Bouché 1965). *Acanthochitina barbata* is an index microfossil for the early Ashgill (Pusgillian) or the middle Katian Stage slices Ka2–Ka3 (time slice of Vlb), succeeding the *Tanuchitina fistulosa* Biozone (Paris 1999; Paris et al. 2000b; Webby et al. 2004; Videt et al. 2010) in the North Gondwana Domain. Following *A. barbata* in the Ghelli Formation at the Simeh-Kuh site, *Armoricochitina nigerica* emerges. This biozone corresponds to the partial-range biozone of *Armoricochitina nigerica*, extending from its FAD to the FAD of *Ancyrochitina merga*, the succeeding index species biozone in the North Gondwana Domain. This species has been documented within the middle–upper Katian Ka3–Ka4 (time slices upper Vlb–Vlc). *Armoricochitina nigerica* is a pivotal chitinozoan species, delineating the northern Gondwanan high palaeoplate during the Late Ordovician. Its absence from records in the United Kingdom and Belgium suggests that it did not spread to the north of the margin of the Rheic Ocean (Paris et al. 2015).

6. Conclusions

The palynological analysis of the Lashkarak and Ghelli formations at the Simeh-Kuh locality in the Alborz Mountains

provided valuable insights into the geological and palaeontological characteristics of the study section. The analysis focused on acritarchs, chitinozoans, scolecodonts, and graptolite remains. One hundred and seventeen morphotypes were recognised, including 59 acritarch species from 33 genera and 58 chitinozoan species from 22 genera. Scolecodonts and graptolite remains were observed, although they were not studied in detail. The precise dating of the study section was achieved through the analysis of acritarchs and chitinozoans. Eight acritarch assemblage biozones and 14 chitinozoan biozones were established. Acritarch biozones A–B were identified in the lower part of the Lashkarak Formation at the Simeh-Kuh locality, suggesting a Late Cambrian (Furongian) age for this rock sequence. The acritarch assemblage biozone C comes immediately after assemblage biozone B, indicating the Tremadocian Tr1–Tr3 (time slices 1a–1d). Following this sequence, the acritarch biozone D is present in the Lashkarak Formation immediately after assemblage biozone C, supporting the Floian Fl1–Fl3 (time slices 2a–2c). Subsequently, acritarch biozone E emerges in the middle part of the Lashkarak Formation, marking the late Floian–early Dapingian Fl3–Dp1 (time slices 2c–3a). Moving forward, acritarch biozone F appears in the upper part of the Lashkarak Formation, suggesting the middle Dapingian–late Darriwilian Dp2–Dw3 (time slices 3b–4c). The acritarch biozones G and H are identified in the Upper Ordovician Ghelli Formation, immediately succeeding the previous acritarch assemblage biozone F. This implies for the first time the presence of Upper Ordovician strata, Sandbian–Katian Sa1–Ka4 (time slices 5a–Vld) in the Simeh-Kuh locality. In the study section, these acritarch assemblage biozones signify continuous sedimentation from the Late Cambrian (Furongian) to the Late Ordovician (Sandbian–Katian). Similarly, the Simeh-Kuh locality reveals 14 well-established chitinozoan biozones: the *Eremochitina brevis*, *Desmochitina ornensis*, *Belonechitina henryi*, *Cyathochitina protocalix*, *Cyathochitina calix*, *Siphonochitina formosa*, *Cyathochitina jenkinsi*, *Armoricochitina armoricana*, *Laufeldochitina cf. clavata*, *Linochitina pissotensis*, *Belonechitina robusta*, *Tanuchitina fistulosa*, *Acanthochitina barbata*, and *Armoricochitina nigerica* biozones, all of which are classical components of the Northern Gondwana Domain/Peri-Gondwana palaeoprovince. These biozones have been previously identified in the North Gondwana Domain.

The *E. brevis* Biozone is in the middle of the Lashkarak Formation, indicating a late Early Ordovician age (late Floian) on the Global Stage slice Fl3 (time slice 2c). The *D. ornensis* and *B. henryi* biozones follow the preceding biozone, suggesting the Dapingian Dp1–Dp3 (time slices 3a to 3b). Moving further, the *C. protocalix*, *C. calix*, *S. formosa*, *C. jenkinsi*, *A. armoricana*, *L. cf. clavata*, and *L. pissotensis* biozones are present in the upper part of the Lashkarak Formation, supporting the Darriwilian Dw1–Dw3 (time slices 4a–4c). Similarly, the *Belonechitina robusta*, *Tanuchitina fistulosa*, *Acanthochitina barbata*, and *Armoricochitina nigerica* biozones are identified in the Upper Ordovician Ghelli Formation, confirming the Sandbian–Katian Sa1–Ka4 (time slices 5a–Vlc). Consequently, a significant hiatus is evident between the Ghelli and Geirud formations, encompassing the latest Ordovician (latest Katian–Hirnantian), Silurian, and Early-

Middle Devonian. This hiatus is characterised by the absence of the *A. merga*–*T. elongata* chitinozoan biozones, and it corresponds to the 2 m of red beds between the Ghelli and Geirud formations.

In terms of palaeobiogeography, the Lashkarak Formation reveals four diagnostic acritarch genera – *Arbusculidium*, *Coryphidium*, *Striatotheca*, and *Arkonia* – which hold particular significance as they belong to the Peri-Gondwanan palaeoprovince. The presence of this marine microflora in the Lashkarak Formation suggests the inclusion of the Alborz Mountains in the Peri-Gondwanan palaeoprovince, which was situated at high southern palaeolatitudes (50–60°S) during the Early–Middle Ordovician. Similarly, identifying a well-known chitinozoan marine microfauna in the Lashkarak and Ghelli formations leads to the establishment of 14 chitinozoan biozones. These are the *Eremochitina brevis*, *Desmochitina ornensis*, *Belonechitina henryi*, *Cyathochitina protocalix*, *Cyathochitina calix*, *Siphonochitina formosa*, *Cyathochitina jenkinsi*, *Armoricochitina armoricana*, *Laufeldochitina cf. clavata*, *Linochitina pissotensis*, *Belonechitina robusta*, *Tanuchitina fistulosa*, *Acanthochitina barbata*, and *Armoricochitina nigerica* biozones, all of which are classical components of the Northern Gondwana Domain/Peri-Gondwana palaeoprovince. The presence of these chitinozoan biozones in the Lashkarak and Ghelli formations indicates that the study area was located at a high southern latitude (50–60°S), attributed to the subpolar margin of the Northern Gondwana Domain.

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- Appendix 1** The acritarch species from the Simeh-Kuh locality, as referenced in the text, **Figure 5**, Plates 12–17, and **Table 1a–c**, are documented and treated by the International Code of Botanical Nomenclature (ICBN: McNeill et al. 2012). The genera and species are presented below in alphabetical order, along with their respective author names:
- Genus *Acanthodiacrodium* Timofeev 1958 emend. Deflandre & Deflandre-Rigaud 1962
 - A. crassus* (Loeblich & Tappan 1978) comb. nov. Vecoli 1999 (Plate 15, figure 14; Plate 17, figure 16)
 - Genus *Arbusculidium* Deunff 1968
 - A. filamentosum* (Vavrdová 1965) Vavrdová 1972 (Plate 16, figures 3, 4)
 - A. iranense* (Ghavidel-Syooki 1990) emend. Ghavidel-Syooki 2021 (Plate 16, figures 1, 2)
 - Genus *Arkonia* Burmann 1970
 - A. virgata* Burmann 1970 (Plate 13, figures 5, 6, 7; Plate 14, figures 17, 18, 19)
 - Genus *Baltisphaeridium* Eisenack 1958 ex Eisenack 1959 emend. Staplin et al. 1965
 - B. fragile* Tongiorgi et al. 1995 (Plate 15, figure 24; Plate 17, figure 15)
 - B. klabavense* (Vavrdová 1965) Kjellström 1971 (Plate 13, figures 1, 2, 3; Plate 15, figures 19, 20)
 - B. llanvirnianum* Deunff 1977 (Plate 15, figures 7, 8)
 - B. perclarum* Loeblich & Tappan 1978 (Plate 15, figure 9; Plate 17, figure 19)
 - B. razi* Ghavidel-Syooki & Piri-Kangarshahi 2023 (Plate 14, figures 16, 20; Plate 16, figure 24)
 - Genus *Coryphidium* Vavrdová 1972 emend. Servais et al. 2008
 - C. almohadillum* (Cramer & Díez 1976) Servais et al. 2008 (Plate 16, figures 8, 12)
 - C. bohemicum* (Vavrdová 1972) Servais et al. 2008 (Plate 16, figures 13, 14, 15)
 - Genus *Cristallinum* Vanguastaine 1978
 - C. cambriense* (Slaviskoya, 1968) Vanguastaine 1978 (Plate 12, figure 12; Plate 16, figure 5; Plate 17, figure 10)
 - C. ovillense* (Cramer & Díez 1972) Martin in Martin & Dean 1981 (Plate 12, figure 11)
 - Genus *Cymatiogalea* Deunff 1961 emend. Deunff et al. 1974
 - C. aspergillum* Martin in Martin & Dean 1988 (Plate 13, figure 11; Plate 16, figures 6, 10)
 - Genus *Dactylofusa* Brito & Santos 1965 emend. Cramer 1970
 - D. kazzazii* sp. nov. (Plate 12, figures 1, 5; 2, 6; 3, 4, 9)
 - D. platynetrella* (Loeblich & Tappan) Fensome et al. 1990 (Plate 17, figure 23)
 - Genus *Dasydiacrodium* Timofeev 1959 ex and emend. Deflandre & Deflandre-Rigaud, 1962 emend. Moczydlowska & Stockforts, 2004.
 - D. obsonum* Martin in Martin & Dean 1988 (Plate 13, figures 9, 10; Plate 17, figure 14)
 - Genus *Eliasum* Fombella 1977
 - E. cf. llaniscum* Fombella 1977 (Plate 12, figure 10)
 - Genus *Goniophaeridium* (Staplin et al. 1965) emend. Kiryanov 1978
 - G. splendens* (Eisenack 1931) Turner 1984 (Plate 15, figure 21)
 - Genus *Inflatarium* Le Hérisse et al. 2015
 - I. trilobatum* Le Hérisse et al. 2015 (Plate 15, figure 5)
 - I. alborense* sp. nov. (Plate 17, figures 6, 7; holotype, plate 17, figure 6)
 - Genus *Leiofusa* (Eisenack 1938) Combaz et al. 1967
 - L. litotes* Loeblich & Tappan 1976 (Plate 17, figure 24)
 - L. stoumonensis* Vanguastaine 1973 (Plate 13, figure 4)
 - Genus *Leiosphaeridia* (Eisenack 1958) Downie & Sarjeant 1963 emend.
 - Leiosphaeridia* sp. (Plate 12, figure 7)
 - Genus *Lophosphaeridium* Timofeev 1959 ex Downie 1963, emend. Lister 1970
 - L. variable* Volkova 1974 (Plate 12, figure 8)
 - Genus *Multiplicisphaeridium* Staplin 1961 emend. Lister 1970
 - M. irregularare* Staplin et al. 1965 (Plate 15, figures 3, 4)
 - Genus *Navifusa* Combaz et al. 1967 ex Eisenack 1976
 - N. ancepsipuncta* Loeblich 1970 (Plate 15, figure 13)
 - Genus *Ninadiacrodium* Raevskaya & Servais 2009
 - N. caudatum* (Vanguastaine 1973) Raevskaya & Servais 2009 (Plate 12, figures 13, 14)
 - N. dumontii* (Vanguastaine 1973) Raevskaya & Servais 2009 (Plate 13, figures 13, 17; 14, 18)
 - Genus *Ordovicidium* Tappan & Loeblich 1971
 - O. elegantulum* Tappan & Loeblich 1971 (Plate 15, figures 1, 2)
 - Genus *Orthosphaeridium* Eisenack, 1968 emend. Navidi-Izad et al. 2020
 - O. bispinosum* Turner 1984 (Plate 15, figures 10, 11)
 - O. insculptum* Loeblich 1970 (Plate 15, figure 17)
 - O. quadrinatum* (Burmann 1970) Eisenack et al. 1976 (Plate 15, figures 15, 16)
 - O. rectangulare* (Eisenack 1963) Eisenack, 1968 (Plate 17, figure 13)
 - O. ternatum* (Burmann 1970) Eisenack et al. 1976 (Plate 15, figure 12)
 - Genus *Pachysphaeridium* Burmann 1970 emend. Ribecai & Tongiorgi 1999
 - P. sidereum* Ribecai & Tongiorgi 1999 (Plate 14, figures 4, 8; 12)

- Genus **Peteinosphaeridium** Staplin et al. 1965 emend. Playford et al. 1995
- P. angustilaminae** Playford et al. 1995 (Plate 13, figures 21, 22)
 - P. coronula** Yin et al. 1998 (Plate 13, figures 15, 19; 16, 20; 23, 24)
 - P. dissimile** (Górká 1969) Yin 1995 (Plate 13, figures 8, 12; Plate 14, figures 1, 5; 2, 6)
 - P. eximum** Playford et al. 1995 (Plate 14, figure 21)
 - P. exornatum** Tongiorgi et al. 1995 (Plate 14, figures 3, 7)
 - P. velatum** Kjellström 1971 emend. Playford et al. 1995 (Plate 14, figures 9, 10; 11, 22)
 - Genus **Saharidia** Combaz 1967
 - S. fragilis** (Downie 1958) Combaz 1967 (Plate 12, figure 15)
 - Genus **Siphonophycus** Knoll et al. 1991
 - S. typicum** (Hermann 1974) Butterfield 1994 (Plate 17, figure 17)
 - Genus **Stellechinatum** Turner 1984
 - S. celestum** (Martin 1969) Turner 1984 (Plate 15, figures 22, 23; Plate 17, figure 18)
 - Genus **Striatotheca** Burmann 1970
 - S. mutua** Burmann 1970 (Plate 14, figures 13, 14, 15)
 - S. principalis** var. **parva** Burmann 1970 (Plate 16, figures 17, 18, 19; 20)
 - Genus **Tectitheca** Burmann 1968
 - T. additionalis** Burmann 1968 (Plate 16, figures 7, 11; 22)
 - Genus **Timofeevia** Vanguestaine 1978
 - T. lancarea** (Cramer & Díez 1972) Vanguestaine 1978 (Plate 12, figures 17, 21; 18, 22; Plate 14, figures 23, 24)
 - T. phosphoritica** Vanguestaine 1978 (Plate 12, figure 16)
 - Genus **Tylotopalla** Loeblich 1970
 - T. caelamenicutis** Loeblich 1970 (Plate 17, figures 11, 12)
 - Genus **Vavrdovella** Loeblich & Tappan 1976
 - V. mawlawii** Ghavidel-Syooki 2021 (Plate 16, figure 16)
 - Genus **Veryhachium** Deunff 1954 emend. Turner 1984
 - V. estrellitae** Cramer 1964 (Plate 16, figure 21)
 - V. lairdii** group (Servais et al. 2007) (Plate 15, figure 18)
 - V. trispinosum** group (Servais et al. 2007) (Plate 16, figure 23)
 - V. cf. scabratum** Cramer 1964 (Plate 17, figure 8)
 - Genus **Villosacapsula** Loeblich & Tappan 1976
 - V. setosapellicula** (Loeblich 1970) Loeblich & Tappan 1976 (Plate 17, figures 1, 5; 2, 3, 4)
 - Genus **Vulcanisphaera** Deunff 1961 emend. Rasul 1976 emend. Kroek et al. 2020
 - V. africana** Deunff 1961 (Plate 12, figures 19, 23)
 - V. mougnoana** (Martin 1973) emend. Kroek et al. 2020 (Plate 12, figures 20, 24; Plate 16, figure 9; Plate 17, figure 9)
 - V. simplex** (Jardiné et al. 1974) emend. Kroek et al. 2020 (Plate 15, figure 6)

Appendix 2 The chitinozoan species from the Simeh-Kuh locality, as mentioned in the text, Figure 6, Plates 1–11, and Table 2a–c, are documented and classified below based on the suprageneric classification of Paris et al. (1999):

- Order **OPERCULATIFERA** Eisenack 1931
- Family **DESMOCHITINIDAE** Eisenack 1931 emend. Paris 1981
- Subfamily **DESMOCHITININAE** Paris 1981
- Genus **Calpichitina** Wilson & Hedlund 1964
- C. lenticularis** (Bouché 1965) (Plate 3, figures 13–16; Plate 11, figures 19, 20)
- Genus **Desmochitina** Eisenack 1931
- D. amphorea** Eisenack 1931 (Plate 1, figures 8, 9)
- D. elongata** Eisenack 1958 (Plate 11, figure 16)
- D. erinacea** Eisenack 1931 (Plate 11, figure 3)
- D. juglandiformis** Laufeld 1967 (Plate 1, figures 16–20; 22, 23; Plate 11, figures 7, 13, 14)
- D. minor** Eisenack 1931 (Plate 1, figures 1–3; 6, 7)
- D. nodosa** Eisenack 1931 (Plate 1, figures 5, 10, 21)
- D. ornensis** Paris 1981 (Plate 1, figure 4; Plate 9, figure 3)
- D. minor typica** Eisenack 1931 (Plate 1, figures 11–15, 24; Plate 11, figure 15)
- Subfamily **EISENACKITININAE** Paris 1981
- Genus **Eisenackitina** (Jansonius 1964) Paris 1981
- E. cf. oelandica** (Eisenack 1955) (Plate 9, figure 14)
- E. rhenana** (Eisenack 1939) Plate 4, figures 16, 20
- Subfamily **Margachitininae** Paris 1981
- Genus **Linochitina** (Eisenack 1968b) Paris 1981
- L. pissotensis** Paris 1981 (Plate 9, figures 17, 18, 19)
- Subfamily **PTEROCHITININAE** Paris 1981
- Genus **Armoricochitina** Paris 1981
- A. alborzensis** Ghavidel-Syooki & Winchester-Seeto 2002 (Plate 2, figures 1, 5; 2, 6; 3, 7; 19, 23)
- A. armoricana** (Rauscher & Doubinger 1967) (Plate 2, figures 16, 24)
- A. iranica** Ghavidel-Syooki & Winchester-Seeto 2002 (Plate 2, figures 4, 8, 12; 9, 13; 10, 14; 11, 15)
- A. nigerica** (Bouché 1965) (Plate 2, figures 17, 21; 20; 18, 22; Plate 11, figures 17, 21; 18, 22)
- Order **PROSOMATIFERA** Eisenack, 1972
- Family **CONOCHEITINIDAE** Eisenack 1931, emend. Paris 1981
- Subfamily **CONOCHEITININAE** Paris 1981
- Genus **Conochitina** Eisenack 1931, emend. Paris et al. 1999
- C. chydaea** Jenkins 1967 (Plate 4, figures 21, 22)
- Genus **Euconochitina** Taugourdeau 1966 emend. Paris et al. 1999
- E. lepta** (Jenkins 1970) emend. Paris et al. 1999 (Plate 6, figures 15, 16; 17–21; Plate 9, figure 15)
- Genus **Pistillachitina** Taugourdeau 1966
- P. pistillifrons** (Eisenack 1939) (Plate 5, figures 13; 17, 21; 19, 23; Plate 11, figure 6)
- Genus **Rhabdochitina** Eisenack 1931
- R. usitata** Jenkins 1967 (Plate 4, figures 23–24)
- R. curvata** Al-Shawareb et al. 2017 (Plate 9, figure 4)
- R. magna** Eisenack 1931 (Plate 9, figure 2; Plate 11, figure 24)
- Subfamily **BELONECHITININAE** Paris 1981
- Genus **Belonechitina** Jansonius 1964
- B. capitata** (Eisenack 1962) (Plate 5, figures 1, 5, 9; 2, 6)
- B. henryi** Paris 1981 (Plate 9, figure 6)
- B. micracantha** (Eisenack 1931) (Plate 5, figures 3, 7; 4, 8; 10, 14; 11, 15; 12, 16)
- B. robusta** (Eisenack 1959) Paris 1981 (Plate 10, figures 17, 21)
- Genus **Acanthochitina** Eisenack 1931 emend. Jenkins 1967
- A. barbata** Eisenack 1931 (Plate 3, figures 1, 5; 2, 6; 3, 7; 4, 8)
- A. cf. pudica** Vandenbroucke 2008 (Plate 3, figures 9, 10; 11, 12)
- A. latebrosa** Vandenbroucke 2008 (Plate 10, figures 1–4; 5–7; 8; 18, 22)
- Subfamily **EREMOCHITININAE** Paris 1981
- Genus **Eremochitina** Taugourdeau & Jekhowsky 1960
- E. brevis** Benoit & Taugourdeau 1961 (Plate 9, figures 1, 5; 20, 22)
- Genus **Siphonochitina** Jenkins 1967
- S. formosa** Jenkins 1967 (Plate 9, figures 21, 23, 24)
- Subfamily **TANUCHITININAE** Paris 1981
- Genus **Hyalochitina** Paris et al. 1999
- H. jajarmensis** Ghavidel-Syooki 2017c (Plate 4, figures 1, 5; 2, 6; 3, 7)
- Genus **Tanuchitina** Jansonius 1964 emend. Paris et al. 1999
- T. alborzensis** Ghavidel-Syooki 2017c (Plate 7, figures 1, 5, 9)
- T. anticostiensis** (Achab 1977) (Plate 7, figures 2, 6)
- T. bergstroemi** Laufeld 1967 (Plate 7, figures 3, 7)
- T. densimura** Al-Shawareb et al. 2017 (Plate 10, figures 12, 16)
- T. fistulosa** (Taugourdeau & de Jekhowsky 1960) (Plate 8, figures 1, 5; Plate 11, figures 4, 8)
- T. ontariensis** Jansonius 1964 (Plate 7, figures 4, 8; 10, 14; 11, 15; 12, 16; 17, 21; 18, 22; 13; 19, 23; 13, 20, 24; Plate 8, figures 10, 14; 11, 15; 12, 16)
- T. hosseini-nezhadi** sp. nov. (Plate 8, figures 2, 6; 3, 7; 4, 8; 9, 13; Plate 10, figures 11, 15; 19, 23)
- Genus **Laufeldochitina** Paris 1981
- Laufeldochitina** cf. **clavata** Jenkins 1967 (Plate 6, figure 24)
- Subfamily **SPINACHITININAE** Paris 1981
- Genus **Spinachitina** Schallreuter 1963, emend. Paris et al. 1999
- S. bulmani** (Jansonius 1964) Jenkins 1967 (Plate 8, figures 17, 21; 18, 22; Plate 10, figures 9, 13; 20, 24)
- S. coronata** (Eisenack 1931) (Plate 5, figures 20, 24)
- S. multiradiata** (Eisenack 1959) (Plate 3, figure 24; Plate 8, figures 23, 24; Plate 9, figures 7, 8; 9, 10; 11, 12; 16; Plate 10, figures 10, 14)
- Family **LAGENOCHITINIDAE** Eisenack 1931 emend. Paris 1981

Subfamily **LAGENOCHITININAE** Paris 1981

Genus **Lagenochitina** Eisenack 1931

L. baltica Eisenack 1931 (Plate 8, figures 19, 20; Plate 9, figure 13)

L. prussica Eisenack 1931 (Plate 6, figures 22, 23)

Subfamily **CYATHOCHITININAE** Paris 1981

Genus **Cyathochitina** Eisenack 1955 emend. Paris et.al. 1999

C. campanulaeformis (Eisenack 1931) (Plate 6, figure 12)

C. calix (Eisenack 1931) (Plate 5, figures 18, 22)

C. costata Grahn 1982 (Plate 11, figures 10, 11)

C. jenkinsi Neville 1974 (Plate 6, figures 1, 5; 2, 6; 3, 7)

C. kuckersiana (Eisenack 1934) (Plate 6, figures 10, 11)

C. latipatagium (Jenkins 1969) (Plate 11, figure 12)

C. protocalix Paris 1981 (Plate 6, figures 4, 8)

C. sp. A (holotype; Plate 11, figures 1)

C. varenensis Paris 1981 (Plate 6, figures 9, 13, 14)

Subfamily **ANGOCHITININAE** Paris 1981

Genus **Angochitina** Eisenack 1931

A. communis Jenkins 1967 (Plate 3, figures 17, 18; 19, 20; 21)

Angochitina cf. *dicranum* Jenkins 1967 (Plate 11, figure 2)

Genus **Fungochitina** Taugourdeau 1966 restrict. Paris et al. 1999

F. spinifera (Eisenack 1962) (Plate 4, figures 12; 13, 17; 14, 18; 15, 19)

Subfamily **ANCYROCHITININAE** Paris 1981

Genus **Ancyrochitina** Eisenack 1955

A. onniensis Jenkins 1967 (Plate 4, figures 4, 8; 9; 10, 11)