Review of Palaeobotany and Palynology 292 (2021) 104457

Contents lists available at ScienceDirect

Review of Palaeobotany and Palynology

journal homepage: www.elsevier.com/locate/revpalbo

Peri-Gondwanan acritarchs, chitinozoans, and miospores from Paleozoic succession in the High Zagros Mountains, southern Iran: Regional stratigraphic significance and paleogeographic implications

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ARTICLE INFO

Article history:
Received 13 December 2020
Received in revised form 19 May 2021
Accepted 23 May 2021
Available online 27 May 2021

Keywords:
Peri-Gondwana
Acritarchs
Chitinozoans
Miospores
Zardkuh mountain
High Zagros Mountains

ABSTRACT

Acritarchs and chitinozoans were documented from Ordovician strata and miospores from Lower Permian beds in the Zardkuh area. Ninety-one palynomorph species, comprising acritarchs (63 species of 31 genera), chitinozoans (16 species of 12 genera), and miospores (12 species of 10 genera) were recognized that form 10 local assemblage zones, comprising Zones A–F= acritarchs, G–I= chitinozoans, and J= miospores. Zone A occurs in the uppermost Ilebeyk Formation, indicating Late Cambrian; Zones B–E are present in the Zardkuh Formation, suggesting Early Ordovician (Tremadocian–Floian)–Middle Ordovician (Dapingian) and Zone F occurs in the Seyahou Formation, presenting Late Ordovician (Hirnantian). Likewise, three Gondwanan chitinozoan Zones G–I were established in this succession. Zones G–H occur in the Upper Shale Member of the Zardkuh Formation, supporting an Early-Middle Ordovician (Floian–Dapingian), and Zone I is restricted to the Seyahou Formation, suggesting Late Ordovician (Hirnantian) age. Finally, Zone J occurs in the Faraghan Formation, confirming Early Permian. Based on palynomorph zones, two hiatuses are present within the Paleozoic sequences of the study area. The first hiatus occurs between the Zardkuh and Seyahou formations, encompassing the Middle Ordovician (Dapingian) and much of the Late Ordovician (Sandbian and Katian). The second hiatus appears between the Seyahou and Faraghan formations, spanning the Silurian, Devonian, Carboniferous, and earliest Permian (Asselian). The palynomorph taxa, including *Arbusculidium, Striatotheca, Coryphidium, Vavrdovella, Eremochitina, Velatachitina,* and miospore taxa, confirm that the study area belongs to peri-Gondwana paleoprovince. Four new species are *Vavrdovella mawlawii* sp.nov., *Vogtlandia zardkuhensis* sp.nov, *Pseudocoryphidium zagrosensis* gen et sp.nov, and *Pterospermella saadii* sp.nov.

1. Introduction

The High Zagros Mountain Belt (HZMB) includes exposures of Lower Paleozoic rocks in the core of several thrusted anticlines developed during the Cenozoic Zagros orogeny (e.g. Kuh-e Faraghan, Kuh-e Gahkum, Kuh-e Surmeh, Kuh-e Dinar, Zardkuh, Kuh-e Sabzu, and Kuh-e Lajin; Setudehnia, 1975). The HZMB belongs to the Zagros Fold-and-Thrust Belt (ZFTB), which extends over about 2000 km from southeast Turkey through southwest Iran down to the Strait of Hormuz (Fig. 1). There is a Paleozoic outcrop at Tang-e Ilebeyk, in the Zardkuh mountain in southwestern Iran. The outcrop is a siliciclastic succession (Fig. 2), which includes the stratotypes of the Ilebeyk and Zardkuh formations (the base of the section at 49°56'10"E and 32°27'34"N and the top of the section at 49°56'55"E and 32°27'52"N), locating immediately southwest of the Zagros Crush Zone, an area of intense faulting and tectonic disturbance (Fig. 1) which has been divided into several structural zones in the past decades (Berberian, 1995; Sherkati et al., 2006; Tavakoli-Shirazi et al., 2012). The area is difficult to access and was first surveyed during early expeditions by J.V. Harrison from 1930 to 1931 (Bakhtiary mountains survey; Harrison et al., 1932; in 1933–34, Kuh-e Galu country survey; Harrison et al., 1935), and later by Setudehnia and Kheradpir in 1971–75 (unpublished company report). These early surveys included geological mapping, lithostratigraphic descriptions, and preliminary low-resolution biostratigraphic dating of the Paleozoic rock units in this area, which are known for their potential as important hydrocarbon reservoirs. The general consensus is that Iran was part of the Gondwanan paleocontinent during the Paleozoic Era (Scotese and McKerrow, 1990; Ghavidel-Syooki, 1997; Molyneux et al., 2013; Harper and Servais, 2013; Torsvik and Cocks, 2017; Ghavidel-Syooki, 2017a; Ghavidel-Syooki, 2019); however, the few and old available reports on Cambrian faunas in the High Zagros Mountains (e.g., King, 1930) refer to a clear non-European faunal affinity, de

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https://doi.org/10.1016/j.revpalbo.2021.104457

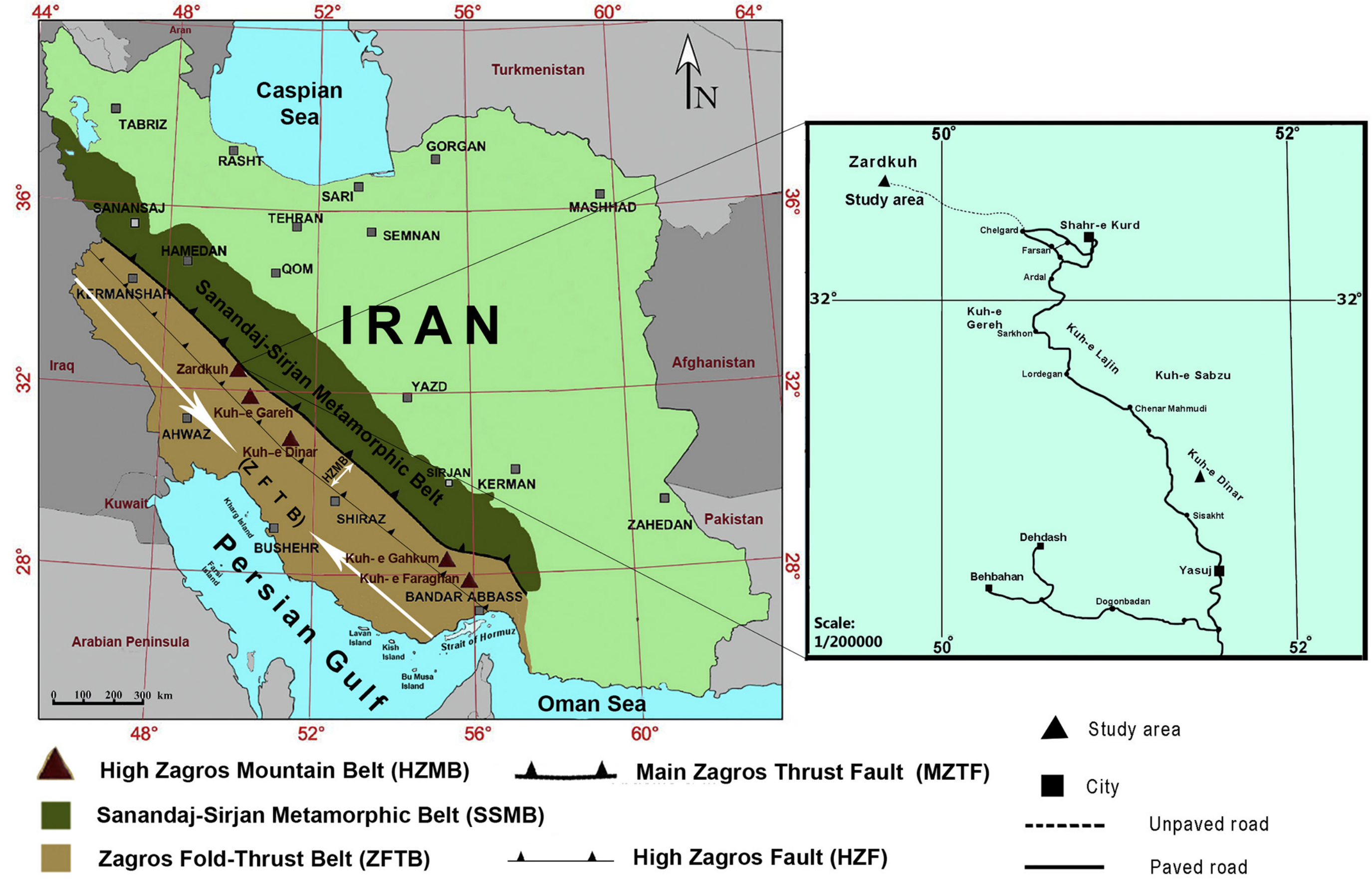


Fig. 1. Major tectonic features of the Zagros Mountains, and adjacent areas; location map of the study area and connection to adjacent cities.

facto excluding a peri-Gondwanan Cambrian paleo-position for the Iranian terrane since the inadequate information on trilobite fauna (e.g. agnostoids). As a result, the correlation of local biostratigraphic units with global Cambrian stages is poorly constrained and the position of the Furongian base has not yet been defined with necessary precision (Alvaro et al., 2013, p. 278). To address this issue, the author of this article carried out a palynological analysis on the collected surface samples from the Paleozoic rock units of Tang-e Ilebeyk to improve the biostratigraphic dating and existing paleogeographic concepts. Since, the biostratigraphy and local palynozonation of the Zardkuh, Seyahou, and Faraghan formations along with the paleogeographic position of the Zardkuh mountain were unclear. These formations contain exceptionally well-preserved palynomorph microfossils, consisting of acritarchs, chitinozoans, and miospores. Acritarchs and chitinozoans are useful complements to trilobites in correlation across Avalonia, Baltica, and Gondwana. They can generally be extracted in large numbers from fine-grained siliciclastic rocks deposited under normal marine conditions, providing a means for detailed sampling and local fossil age

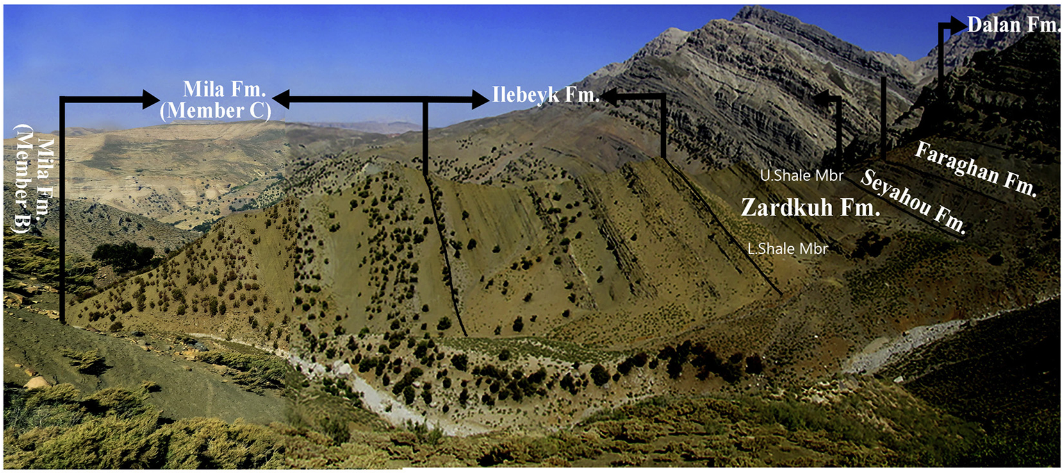


Fig. 2. Outcrop of Paleozoic rock units (Mila, Ilebeyk, Zardkuh, Seyahou, Faraghan, and Dalan formations) in Tang-e Ilebeyk, Zardkuh mountain, the High Zagros Mountains, southern Iran.

constraints. During, the past two decades, several Early–Middle Ordovician acritarch taxa with biostratigraphical or paleogeographical significance have been revised in detail, including *Frankea* (Servais, 1993; Vecoli et al., 1999), *Dicrodiacrodium* (Servais et al., 1996), *Arkonia-Striatotheca* (Servais, 1997), *Aureotesta* (Brocke et al., 1997), *Arbusculidium*, *Veryhachium* (Servais et al., 2007), *Coryphidium* (Servais et al., 2007), *Ampullula* (Yan et al., 2010), *Rhopaliophora* (Li et al., 2014), *Dactylofusa velifera* (Cocchio, 1982) Wang et al., 2015, *Barakella* (Yan et al., 2017), *Orthosphaeridium* (Navidi-Izad et al., 2020), and *Vulcanisphaera* (Kroeck et al., 2020). Other taxa remain imperfectly understood and with a need for detailed revision of their taxonomy, biostratigraphy, paleogeography, and paleoecology. Acritarch zonations have been proposed for Gondwana (Vanguestaine and Van Looy, 1983; Vecoli, 1999; Servais and Mette, 2000; Vecoli and Le Hérissé, 2004; Molyneux et al., 2006; Ghavidel-Syooki and Vecoli, 2008; Casas and Palacios, 2012; Palacios, 2015; Ghavidel-Syooki, 2000, 2001, 2003a, 2006b, 2019; Rubinstein et al., 2019), Avalonia (Martin and Dean, 1981, 1988; Parsons and Anderson, 2000; Vanguestaine and Brück, 2008; Palacios et al., 2009; Potter et al., 2012; Palacios, 2015), Baltica (Volkova, 1990; Volkova and Kirjanov, 1995; Moczydlowska, 2011), and China (Yan et al., 2010; Yan et al., 2013; Liang et al., 2018). These revisions provide detailed biostratigraphic information from strata, which either contain other fossil groups or absent in fossils.

In Iran, a primarily Paleozoic acritarch biozonation has been established for the Mila, Ilebeyk, Zardkuh, Seyahou, Dargaz, Sarchahan, Zakeen, and Faraghan formations of the High Zagros Mountains, southern Iran (Ghavidel-Syooki, 1996), and for the lower Paleozoic succession of the Kuh-e Kharbash in Deh-e Molla area at central Alborz Mountain, northern Iran (Ghavidel-Syooki, 2006a). More recently, acritarch biostratigraphy has been carried out on Cambrian successions (Mila and Ilebeyk formations) of the High Zagros Mountains (Ghavidel-Syooki and Vecoli, 2008; Ghavidel-Syooki et al., 2011a, 2014; Ghavidel-Syooki, 2019; Spina et al., 2020). The aims of this paper are: (1) refine the biostratigraphy of the Zardkuh, Seyahou, and Faraghan formations in the Zardkuh mountain; (2) establish local palynozonation for the identification of Ordovician rock units in the study area, which offers a resource rocks for future oil exploration; (3) confirm the paleobiogeographical affinities of Ordovician acritarchs, chitinozoans and Permian miospores from the High Zagros Mountains (i.e., the Gondwanan vs. the Laurentian paleoprovinces); and calibrate co-occurring acritarch and chitinozoan biozones as well as miospores during the time interval represented by the investigated succession.

2. Geological setting and lithostratigraphy

In the High Zagros Mountains, the Precambrian and Paleozoic deposits are subdivided into the Barut, Zaigun, Lalun, Mila, Ilebeyk, Zardkuh, Seyahou, Dargaz, Sarchahan, Zakeen, Faraghan, and Dalan formations. The present analysis concerns three of those formations (Zardkuh, Seyahou, and Faraghan formations), which are exposed in the Zardkuh area (Fig. 2). The Mila and Ilebeyk formations have already been investigated for palynomorph entities in Tang-e Ilebeyk at the Zardkuh area (Ghavidel-Syooki and Vecoli, 2008; Ghavidel-Syooki, 2019; Spina et al., 2020), but the Zardkuh, Seyahou, and Faraghan formations will be analyzed in this study.

The Ilebeyk Formation is well-exposed in Tang-e Ilebeyk of Zardkuh, Chal-i Sheh, Ghali-Kuh, and Oshtran-Kuh, but it is not present in Kuh-e Gereh and Kuh-e Dinar (Setudehnia, 1975). The formation has a thickness of 273 m and consists of shales and sandstone with scattered limestone intervals that were deposited in a marine environment. Based on trilobites from the uppermost 33.5 m (i.e., *Saukia iranicus*, *Plectotrophia* sp., *Saratoga latefrons, Idahoia* sp., *Calvinella* sp., *Baltagnostus* sp., *Coosia* sp., *Meeria* sp., *Circotheca* sp., *Lotagnostus* sp., *Pseudoagnostus* sp., *Chaungia* sp., and *Labiostria* sp), the Ilebeyk Formation was deposited during the Late Cambrian (Setudehnia, 1975).

In the High Zagros Mountains, Ordovician deposits are subdivided into the Zardkuh, Seyahou, and Dargaz formations. The type section of the Zardkuh Formation is located at Tang-e Ilebeyk in the Zardkuh area (Setudehnia, 1975), whereas the type sections of the Seyahou and Dargaz formations are located at Tang-e Pashagh (Kuh-e Faraghan), on the northern Persian Gulf of southern Iran (Ghavidel-Syooki and Khosravi, 1995; Ghavidel-Syooki et al., 2011b). The Zardkuh Formation is 336 m in its type section at Tang-e Ilebeyk and consists of the Lower Shale Member (L. Shale Mbr) and Upper Shale Member (U. Shale Mbr) (Fig. 3). The Lower Shale Member has a thickness of 93 m and consists of shales and sandstones with a characteristic trilobite-yielding horizon (e.g., *Dikelokephalina* cf. *D. asiatica*) at 12.2 m above the base of the formation that indicates an Early Ordovician age (Kobayashi, 1934; Setudehnia, 1975; Kim and Choi, 2000). The Upper Shale Member is 243 m thick which is dominated by shales, scattered sandstone, and a few meter pisolitic beds, containing graptolites (e.g., *Didymograptus* cf. *D. extensus*, *Temnogratus* sp., and *Schizograptus* sp.) that suggest an Early Ordovician age (Setudehnia, 1975).

In addition to Tang-e Ilebeyk, the Zardkuh Formation has recently been recorded at the Tang-e Pashagh of Kuh-e Faraghan (Ghavidel-Syooki et al., 2014). Here, the Zardkuh Formation has a thickness of 20 m and comprises polymictic conglomerate beds alternating with thin shale intervals containing chitinozoans (e.g., *Euconochitina brevis* Zone) and conodonts (e.g., *Baltoniodus triangularis* Zone) that indicate a late Early Ordovician (late Floian stage) to early Middle Ordovician age (Ghavidel-Syooki et al., 2014). Likewise, a previous palynological study of the Zardkuh Formation reported an age of Tremadocian to Arenigian (assemblages O_1 through O_4 of Ghavidel-Syooki, 1996). The lithology and sedimentary structures of the Zardkuh Formation pointed out to a siliciclastic environment, deposited during sea-level highstand conditions in its type section (Fig. 3 and unpublished company report and this study) and a transition from continental to nearshore environments in the Tang-e Pashagh at Kuh-e Faraghan (Vennin et al., 2015). The Seyahou Formation has a thickness of 850 m at its type locality in Tang-e Pasgagh (Kuh-e Faraghan); it was subdivided into three units that were previously introduced as members of the Seyahou Formation (Ghavidel-Syooki and Khosravi, 1995). (i) The first unit comprises a 20-m thick lower conglomeratic composed of polymictic conglomerate beds alternating with thin shale intervals; this unit was recently redesigned as the upper part of the Zardkuh Formation (Ghavidel-Syooki et al., 2014). (ii) The middle unit, which is heterolithic and 460 m thick and consists of shale and sandstone with interbedded phosphatic and bioclastic carbonate siltstones that yield rich and diversified shelly fauna trilobites, bryozoans, calcitic linguliformean brachiopods, mollusks, and conodonts. (iii) The upper unit is 390 m thick, recognizable by thinly bedded, rhythmic claystone/sandstone couplets that are extremely rich in ichnofossils.

The upper part of Zardkuh Formation and the whole Seyahou Formation range from Floian to Katian in age at the Tang-e Pashagh (Kuh-e Faraghan) based on the occurrence of conodont *Baltoniodus triangularis* (Lindström, 1955) in the lowermost part of the Seyahou Formation and the presence of trilobites (*Dalmanitina*, *Deanaspis, Iberocoryphe*, and *Sardoites*) in the middle part of the formation in the Tang-e Pashagh section (Ghobadi Pour et al., 2015). The trilobite taxa show a strong affinity to mid–high-latitude peri-Gondwanan faunas. Moreover, the Seyahou shale interbeds also yield well-preserved acritarchs and chitinozoans that can be used to identify a biostratigraphical succession ranging from the late Floian (*Euconochitina brevis* Zone) to late Katian (*Ancyrochitina merga* Zone: Ghavidel-Syooki, 2000; Ghavidel-Syooki et al., 2011b). Based on new biostratigraphical data (Ghavidel-Syooki et al., 2014), the first lower conglomerate unit has been proposed as the upper part of the Zardkuh Formation in the Tang-e Pashagh section (Kuh-e Faraghan) and the two latter units are now considered as the Seyahou Formation. Ghavidel-Syooki et al. (2014) identified a considerable hiatus (ranging from the late Dapingian to early Darriwilian) at the top of the late Floian condensed phosphoarenite in Tang-e Pashagh. This phosphorite bed bounds the lower and middle heterolithic unit and is immediately overlain by mid-Darriwilian black shale (Ghavidel-Syooki et al., 2011b). As illustrated in Fig. 3, during the Ordovician period, sedimentation took place in a transgressive-dominated depositional system with common offshore deposits and sandstone substrate and was bracketed by two major regression events; both regressions are topped by: (i) a latest Middle Ordovician (Darriwilian) disconformity related to the progradation of back-shaol; (ii) and latest Late Ordovician (Hirnantian) related to the Foreshore to shoreface, shoal complex.

The Dargaz Formation has a thickness of 10–70 m at its type locality in Tang-e Pashagh in Kuh-e Faraghan (Ghavidel-Syooki et al., 2011b), lying between the Seyahou and Sarchahan formations. This formation consists of lower and upper diamictites and forms massive to crudely stratified, tabular beds up to 6 m thick. Scattered granule to pebble-sized clasts (mainly quartzite lonestones) are either isolated or chaotically clustered and embedded in a greenish, clayey siltstone matrix. The upper Dargaz diamictites are relatively lithologically homogeneous, whereas the thicker, lower Dargaz diamictites are commonly cut by meter-thick, broadly scoured sandstone bodies with pervasive low-angle and trough cross-lamination, and load and flute casts, which indicate a range of north to northeast-directed paleocurrents. In thin-section, the diamictites consist of a mixture of unsorted, fine to medium-grained sandstone with relatively high mud content and occasional preservation of granule-sized quartz and quartzite granules floating within a fine-grained matrix. Outsized clasts embedded in massive

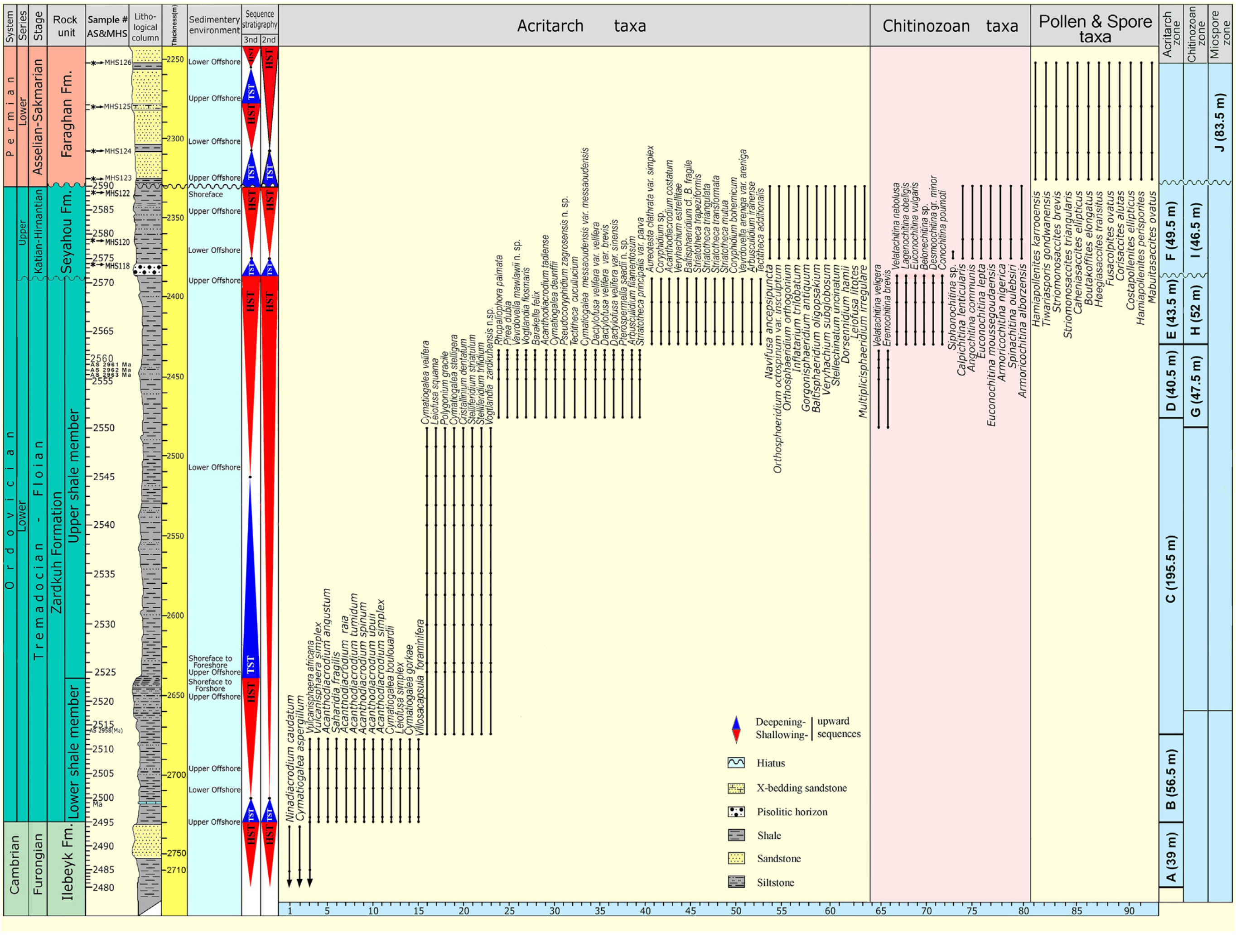


Fig. 3. Stratigraphical distribution of identified palynomorph taxa from the Zardkuh, Seyahou, and Faraghan formations of Zardkuh Mountain, the High Zagros Mountains, southeastern Iran (numbers refer to taxa listed in the caption). 1. *Ninadiacrodium caudatum*; 2. *Cymatiogalea aspergillum*; 3. *Vulcanisphaera africana*; 4. *V. simplex*; 5. *Acanthodiacrodium angustum*; 6. *Saharidia fragilis*; 7. *A. raia*; 8. *A. tumidum*; 9. *A. spinum*; 10; *A. ubuii*; 11. *A. simplex*; 12. *Cymatiogalea boulouardii*; 13. *Leiofusa simplex*; 14. *Cymatiogalea gorkae*; 15. *Villosacapsula foraminifera*; 16. *Cymatiogalea velifera*; 17. *Leiofusa squama*; 18. *Polygonium gracile*; 19. *Cymatiogalea stelligera*; 20. *Cristallinium dentatum*; 21. *Stelliferidium striatulum*; 22. *Stelliferidium trifidum*; 23. *Vogtlandia zardkuhensis* n.sp.; 24. *Rhopaliophora palmata*; 25. *Pirea dubia*; 26. *Vogtlandia flosmaris*; 27. *Barakella felix*; 28. *Acanthodiacrodium tadlense*; 29. *Cymatiogalea deunffii*; 30. *Pseudocoryphidium zagrosensis* n.gen and n.sp.; 31. *Tectitheca cuculluciun*; 32. *Cymatiogalea messaoudensis* var. *messaoudensis*; 33. *Vavrdovella mawlawii* n. sp.; 34. *Dactylofusa velifera* var. *velifera*; 35. *Dactylofusa velifera* var. *brevis*; 36. *Dactylofusa velifera* var. *sinensis*; 37. *Dactylofusa saadii* n. sp.; 38. *Arbusculidium filamentosum*; 39. *Striatotheca principalis* var. *parva*; 40. *Tectitheca additionalis*; 41. *Coryphidium* sp.; 42. *Aureotesta clathrata* var. *simplex*; 43. *Acanthodiacrodium costatum*; 44. *Veryhachium estrellitae*; 45. *Baltisphaeridium* cf. *B. fragile*; 46. *Striatotheca trapeziformis*; 47. *Striatotheca triangulata*; 48. *Striatotheca transformata*; 49. *Striatotheca mutua*; 50. *Coryphidium bohemicum*; 51. *Vavrdovella areniga* var. *areniga*; 52. *Arbusculidium iranense*; 53. *Navifusa ancepsipuncta*; 54. *Orthosphaeridium octospinosum var. insculptum*; 55. *Orthosphaeridium orthogonium*; 56. *Inflatarium trilobatum*; 57. *Gorgonisphaeridium antiquum*; 58. *Baltisphaeridium oligopsakium*; 59. *Veryhachium subglobosum*; 60. *Stellechinatum uncinatum*; 61. *Dorsennidium hamii*; 62. *Leiofusa litotes*; 63. *Multiplicisphaeridium irregulare*; 64. *Velatachitina veligera*; 65. *Eremochitina brevis*; 66. *Velatachitina nebolusa*; 67. *Lagenochitina obeligis*; 68. *Euconochitina vulgaris*; 69. *Belonechitina* sp.; 70. *Desmochitina* gr. *minor*; 71. *Conochitina poumoti*; 72. *Siphonochitina* sp.; 73. *Calpichitina lenticularis*; 74. *Angochitina communis*; 75. *Euconochitina lepta*; 76. *Euconochitina moussegoudaensis*; 77. *Armoricochitina nigerica*; 78. *Spinachitina oulebsiri*; 79. *Armoricochitina alborzensis*; 80. *Hamiapollenites karooensis*; 81. *Tiwariasporis gondwanensis*; 82. *Striomonosaccites brevis*; 83. *Striomonosaccites triangularis*; 84. *Caheniasaccites ellipticus*; 85. *Boutakoffites elongatus*; 86. *Høegiasaccites transitus*; 87. *Fusacolpites ovatus*; 88. *Corisaccites alutas*; 89. *Costapollenites ellipticus*; 90. *Hamiapollenites perisporites*; 91. *Mabuitasaccites ovatus*.

diamictites represent rainout processes formed by the settling of suspended fine material and the release of coarser dropstones from icebergs in the vicinity of a calving front. A weakly developed lamination may record episodic current activity, resulting from the storm, turbidity, or wave-influenced processes. Crosscutting channels from the lower Dargaz diamictite represent high-energy episodes, most likely related to ice proximal outwash deposits, in the form of glaciofluvial or glaciomarine bars. Therefore, the Dargaz Formation is interpreted as a glaciogenic Hirnantian succession (Ghavidel-Syooki et al., 2011b).

The Dargaz Formation is not present at Zardkuh mountain. In this study, the Seyahou Formation is shown to extend into the late Hirnantian (stage slices Hi2), as indicated by chitinozoans of Biozone I.

The Faraghan Formation is widely distributed in the High Zagros Mountains (Szabo and Kheradpir, 1978). The type section is located at Kuh-e Faraghan, approximately 103 km north of Bandar Abbas (Ghavidel-Syooki, 2003b). Its thickness varies from a minimum of a few meters in Kuh-e Dinar to 500 m in the Chal-i-Sheh area. The formation disconformably overlies the Zakeen Formation (Devonian) across most of the Fars and Bandar Abbas provinces, Cambrian to Ordovician deposits in the western High Zagros, and is covered elsewhere by the Middle to Late Permian Dalan Formation (Ghavidel-Syooki, 1997). It consists of shallow marine siliciclastic and foreshore deposits, including tidal flat and tidal-channel, estuarine, sabkha, shoreface, and offshore facies (Zamanzadeh et al., 2009). These deposits are associated with coal layers in the northwestern part of the Zardkuh and Chal-i-Sheh areas (Szabo and Kheradpir, 1978). Palynological data from 500 surface and subsurface samples suggest an Early Permian (Sakmarian–Kungurian) age for the Faraghan Formation (Ghavidel-Syooki, 1997); however, Spina et al. (2018) recently suggested a Late Permian (Guadalupian) age.

3. Materials and methods

One hundred-eighteen surface samples were collected from the Paleozoic succession at Tang-e Ilebeyk in the Zardkuh area. The lithology is dominated by siliciclastic sediments ranging from shales to sandstone (Fig. 2, outcrop section and Fig. 3, in the stratigraphic column). The collected surface samples which were designated by numbers (AS2480–AS2590 and MHS118–MHS126) are preceded by prefixes referring to the collectors (AS, Ataollah Setudehnia; MHS, Mohammad Hossein Saberi). The palynomorphs were extracted from shale, siltstone, and fine-grained sandstone using the standard palynological technique of treatment in HCl and HF to remove carbonates and silicates, respectively, followed by neutralizing the residue in distilled water after each acid treatment. The samples were not oxidized and the resultant residues of each sample were treated with 30 mL saturated zinc bromide with a specific gravity of 1.95. Organic residues were then sieved through 10–20 μm nylon meshes to eliminate the finer debris and facilitate palynological analyses. The palynological residues were mounted on glass slides for optical and scanning electron microscopy examinations. Thirty-seven samples proved to be palyniferous and yielded well-preserved and abundant acritarchs, chitinozoans, miospores, and common graptolite remains (repository code numbers: AS2480, 2485, 2495, 2506, 2510, 2513, 2525, 2526, 2530, 2533, 2535, 2540, 2542, 2545, 2550, 2551, 2555, 2558, 2560, 2562, 2563, 2568, 2570, 2571, 2574, 2575, 2579, 2590 and MHS118, 120, 121, 122, 123, 125, 126) and the remaining 71 samples were either very poor or barren in palynomorphs. The well-preserved organic matter in the palynological residues and the yellow to brown color of the palynomorphs suggest a Thermal Alteration Index of 3–4 (mature), suggesting the generation of hydrocarbon for these Ordovician units.

Genera and species of acritarchs described herein are treated according to the International Code of Nomenclature for algae, fungi, and plants (ICN: McNeil et al., 2011). Most are assigned to the *incertae sedis* group “acritarcha” (Evitt, 1963), and arranged alphabetically by genera. Furthermore, the identified chitinozoan taxa herein are well known elsewhere in the ‘northern’ Gondwana Domain and are listed according to the classification scheme of Paris et al. (1999). The term “miospore” is used as a general term to include all fossil plant spores smaller than 200 μm (Steemans, 2000), including cryptospores, trilete spores, and pollen grains; these are listed according to the classification scheme of Richardson (1996a, 1996b) and Wellman and Richardson (1996). Detailed descriptions are provided only for new and emended taxa. The stratigraphic and numerical distributions of all taxa are shown in Fig. 3 and Table 1.

The measured features included: length of the vesicle (central body; L), width of the vesicle (central body; W), and length of processes (lp) for acritarch taxa. Measurements are given in micrometers (μm) and represent the “minimum (mean) maximum” values of the parameter. All specimens were counted to determine relative abundances for each sample and classified as abundant (‘a’, >50 specimens), common (‘c’, 10–50 specimens), rare (‘r’, rare, < 10 specimens), or very rare (‘vr’, 1–2 specimens).

All hand specimen samples and microscopic slides relating to this study are housed in the paleontological collections of the Exploration Directorate of the National Iranian Oil Company under sample numbers AS2480 to AS2590 and MHS118 to MHS126.

4. Systematics and biostratigraphy of palynomorph taxa

The 6137 palynomorph specimens have been investigated, which consist of 5289 acritarchs, 371 chitinozoans, and 477 miospores (Tables 1). They comprise 63 acritarch species (31 genera),16 chitinozoan species (12 genera), and 12 miospore species (10 genera) were recorded Plates (I–XI) and discussed below.

4.1. List of acritarch species

The acritarch taxa mentioned in the text, in the plates, and the caption are listed below.

Group: Acritarcha Evitt, 1963

Genus: **Acanthodiacrodium** Timofeev, 1958 emend. Deflandre and Deflandre-Rigaud, 1962

Acanthodiacrodium angustum (Downie, 1958) Combaz, 1967 (Plate I, 1, 2)

Acanthodiacrodium costatum Burmann,1968 (Plate III, 1)

Acanthodiacrodium raia (Deunff, 1961) Eisenack et al., 1979 (Plate V, 7)

Acanthodiacrodium simplex Combaz,1967 (Plate III, 3, 20)

Acanthodiacrodium spinum Rasul, 1979 (Plate II, 16)

Acanthodiacrodium tadlense Cramer and Diéz, 1977 (Plate III, 2)

Acanthodiacrodium tumidum (Deunff, 1961) Martin, 1975 (Plate I, 19)

Acanthodiacrodium ubuii Martin, 1969 (Plate II, 7)

Genus: **Arbusculidium** Deunff, 1968

Arbusculidium filamentosum (Vavrdová, 1965) Vavrdová, 1972 emend. (Plate I, 5, 6, 7,8; Plate IV, 15)

Arbusculidium iranense (Ghavidel-Syooki, 1990) emend. Ghavidel-Syooki, 2020 (Plate I, 11; Plate IV, 8)

Genus: **Aureotesta** Vavrdová, 1972

Aureotesta clathrata var. *simplex* (Cramer et al., 1974) emend. Brocke et al., 1998 (Plate II, 8, 12)

Genus: **Baltisphaeridium** Eisenack, 1958 ex Eisenack, 1959 emend. Staplin et al., 1965

Baltisphaeridium cf. *B. fragile* Tongiorgi et al., 1995 (Plate II, 20; Plate III, 4)

Baltisphaeridium oligopsakium Loeblich and Tappan, 1978 (Plate VI, 6)

Genus: **Barakella** Cramer and Diéz, 1977

Barakella felix Cramer and Diéz, 1977 (Plate V, 18, 19, 20)

Genus: **Coryphidium** Vavrdová, 1972 emend. Servais et al., 2008

Table 1
Quantitative distribution of acritarch, chitinozoan, and miospore taxa throughout Paleozoic rock units (Zardkuh, Seyahou, Faraghan formations) of Tang-e Ilebeyk, Zardkuh mountain, the High Zagros Mountains, southeastern Iran.

List of identified species	AS2480	AS2485	AS2494	AS2495	AS2506	AS2510	AS2512	AS2513	AS2525	AS2526	AS2530	AS2533	AS2535	AS2540	AS2542	AS2545	AS2550	AS2551	AS2555	AS2558	AS2560	AS2562	AS2563	AS2568	AS2570	AS2571	AS2574(MHS118)	AS2575	AS2579(MHS120)	AS2590(MHS122)	MHS123	MHS124	MHS125	MHS126	Biozones
Ninadiacrodium caudatum	19	19	5																																A
Cymatiogalea aspergillum	5	15	20																																
Vulcanisphaera africana	19	19	2	1	1	1																													
Vulcanisphaera simplex				2	5	3	36																												B
Acanthodiacrodium angustum				5	20	15	2																												
Saharidia fragilis				35	120	55	30																												
Acanthodiacrodium raia				10	26	23	25																												
Acanthodiacrodium tumidum				32	56	58	68																												
Acanthodiacrodium spinum				145	110	39	53																												
Acanthodiacrodium ubuii				32	38	52	41																												
Acanthodiacrodium simplex				3	6	5	5																												
Cymatiogalea boulouardii				6	9	9	6																												
Leiofusa simplex				8	15	14	12																												
Cymatiogalea gorkae				34	220	95	78																												
Villosacapsula foraminifera				14	12	13	24																												
Cymatiogalea velifera								1	3	4	6	7	9	10	8	5	2																		C
Leiofusa squama								9	12	17	8	2	10	20	40	6	1																		
Polygonium gracile								3	8	6	7	10	30	40	30	6	5																		
Cymatiogalea stelligera								11	25	30	35	40	20	22	10	7	4																		
Cristallinium dentatum								1	2	4	5	2	5	10	9	7	4																		
Stelliferidium striatulum								3	0	5	2	4	6	3	9	10	2																		
Stelliferidium trifidum								1	5	6	7	8	9	12	20	25	4																		
Vogtlandia zardkuhensis n.sp.								3	5	6	10	3	2	1	2	2	1																		
Rhopaliophora palmata																		1	7	9	10	12													D
Pirea dubia																		5	3	2	2	1													
Vavrdovella mawlawii n. sp.																		4	10	15	9	11													
Vogtlandia flosmaris																		1	5	10	5	2													
Barakella felix																		5	9	12	15	20													
Acanthodiacrodium tadlense																		1	15	10	7	2													
Cymatiogalea deunffii																		7	20	25	10	5													
Pseudocoryphidium zagrosensis n.sp.																		5	8	13	15	9													
Tectitheca cucullucium																		5	9	10	15	12													
Cymatiogalea messaoudensis var. messaoudensis																		4	15	25	19	12													
Dactylofusa velifera var. velifera																		19	24	19	14	1													
Dactylofusa velifera var. brevis																		5	5	3	6	6													
Dactylofusa velifera var. sinensis																		4	15	9	4	2													
Pterospermella saadii n. sp.																		6	8	6	3	1													
Arbusculidium filamentosum																		58	105	103	50	2													
Striatotheca principalis var. parva																		16	20	15	33	4													
Aureotesta clathrata var. simplex																							3	6	6	6									E
Coryphidium sp.																							12	14	9	4									
Acanthodiacrodium costatum																							11	13	19	52									
Veryhachium estrellitae																							35	55	40	34									
Baltisphaeridium cf. B . fragile																							17	17	21	11									
Striatotheca trapeziformis																							84	35	30	40									
Striatotheca triangulata																							9	5	10	8									
Striatotheca transformata																							13	20	11	22									
Striatotheca mutua																							30	33	35	41									
Coryphidium bohemicum																							14	20	14	19									
Vavrdovella areniga var. areniga																							13	30	25	42									
Arbusculidium iranense																							22	35	70	85									
Tectitheca additionalis																												21	41	23					F
Navifusa ancepsipuncta																												34	24	11					
Orthosphaeridium octospinosum var. insculptum																												5	7	6					
Stellechinatum uncinatum																												3	17	12					
Orthosphaeridium orthogonium																												10	12	10					
Inflatarium trilobatum																												6	8	5					
Gorgonisphaeridium antiquum																												5	12	10					
Baltisphaeridium oligopsakium																												25	17	16					
Veryhachium subglobosum																												2	1	2					
Dorsennidium hamii																												20	4	6					
Leiofusa litotes																												25	5	4					
Multiplicisphaeridium irregulare																												25	19	11					
Velatachitina veligera																	5	12	32	42	28	27													G
Eremochitina brevis																	2	1	4	2	5	4													
Velatachitina nebulosa																							5	2	4	3	1								H
Lagenochitina obeligis																							2	4	3	2	1								
Euconochitina vulgaris																							6	5	3	2	2								
Belonechitina sp.																							2	3	1	2	3								
Desmochitina gr. minor																							2	3	1	2	3								
Conochitina poumoti																							1	2	4	7	3								
Siphonochitina sp.																												2	3						I
Calpichitina lenticularis																												2	4	1					
Angochitina communis																												2	10	3					
Euconochitina lepta																												10	4	5					
Euconochitina moussegoudaensis																												5	6	8					
Armoricochitina nigerica																												10	15	8					
Spinachitina oulebsiri																												2	3	9					
Armoricochitina alborzensis																												3	2	6					
Hamiapollenites karrooensis																															5	15	10	8	J
Tiwariasporis gondwanensis																															2	5	7	10	
Striomonosaccites brevis																															6	9	5	10	
Striomonosaccites triangularis																															8	12	7	3	
Caheniasaccites ellipticus																															3	11	10	5	
Boutakoffites elongatus																															1	15	10	6	
Hø egiasaccites transitus																															4	15	10	2	
Fusacolpites ovatus																															1	10	13	3	
Corisaccites alutas																															4	20	25	12	
Costapollenites ellipticus																															2	10	15	20	
Hamiapollenites perisporites																															5	15	10	80	
Mabuitasaccites ovatus																															1	4	7	6	
Total number	43	53	27	327	638	382	380	32	60	78	80	76	91	118	128	68	30	159	314	330	250	133	281	302	306	382	186	171	214	156	42	141	129	165	6137

Coryphidium bohemicum Vavrdová, 1972 emend. Servais et al., 2008 (Plate IV, 9-13; Plate V, 17)

Coryphidium sp. A (Plate IV, 1)

Genus: **Cristallinium** Vanguestaine, 1978

Cristallinium dentatum (Vavrdová, 1976) Martin, 1982 (Plate V, 13, 14, 15, 16)

Genus: **Cymatiogalea** Deunff, 1961 emend. Deunff et al., 1974

Cymatiogalea aspergillum Martin *in* Martin and Dean, 1988 (Plate III, 1)

Cymatiogalea boulouardii (Deunff, 1961) Fensome et al., 1990 (Plate III, 16)

Cymatiogalea deunffii Jardiné et al., 1974 (Plate I, 14)

Cymatiogalea gorkae Rauscher, 1974 (Plate II, 17)

Cymatiogalea granulata Vavrdová, 1966 (Plate III, 9)

Cymatiogalea messaoudensis var. *messaoudensis* Servais and Molyneux, 1997 (Plate II, 1; Plate III, 18)

Cymatiogalea stelligera Górka, 1967 (Plate I, 13)

Cymatiogalea velifera (Downie, 1958) Martin, 1968 (Plate V, 6, 8; Plate III, 11)

Genus: **Dactylofusa** Brito and Santos, 1965 emend. Cramer, 1970

(Plate II, 4) *Dactylofusa velifera* var. *velifera* (Cocchio, 1982) Wang et al., 2015

Dactylofusa velifera var. *brevis* (Albani,1989) Wang et al., 2015 (Plate IV, 4, 6, 7; Plate II, 15)

Dactylofusa velifera var. *sinensis* Wang et al., 2015 (Plate IV, 5)

Genus: **Dorsennidium** (Wicander, 1974) Sarjeant and Stancliffe, 1994

Dorsennidium hamii (Loeblich, 1970) Sarjeant and Stancliffe, 1994 (Plate VI, 11

Genus: **Gorgonisphaeridium** Staplin et al., 1965

Gorgonisphaeridium antiquum Loeblich and Tappan, 1978 (Plate VI, 5

Genus: **Inflatarium** Le Hérissé et al., 2015

Inflatarium trilobatum Le Hérissé et al., 2015 (Plate VI, 7)

Genus: **Leiofusa** Eisenack, 1938 emend. Combaz et al., 1967

Leiofusa squama Deunff, 1961 (Plate II, 19)

Leiofusa simplex (Combaz, 1967) Martin, 1975 (Plate I, 20)

Leiofusa litotes Loeblich and Tappan, 1978 (Plate VI, 12)

Genus: **Multiplicisphaeridium** (Staplin) Staplin et al., 1965

Multiplicisphaeridium irregulare Staplin et al., 1965 (Plate VI, 6)

Genus: **Ninadiacrodium** Raevskaya and Servais, 2009

Ninadiacrodium caudatum (Vanguestaine, 1973) Raevskaya and Servais, 2009 (Plate III, 19)

Genus: **Orthosphaeridium** Eisenack, 1968

Orthosphaeridium orthogonium Le Hérissé et al., 2015 (Plate VI, 2)

Orthosphaeridium octospinosum var. *insculptum* Navidi-Izad et al., 2020 (Plate VI, 1)

Genus: **Pirea** Vavrdová, 1972

Pirea dubia Vavrdová, 1972 (Plate II, 3)

Genus: **Polygonium** Vavrdová, 1966 emend. Le Hérissé, 1989

Polygonium gracile Vavrdová, 1966 (Plate II, 18)

Genus: **Pseudocoryphidium** gen. nov.

Pseudocoryphidium zagrosensis gen. nov. and sp. nov. (Plate V, 1-5; Plate II, 2, 5, 10)

Genus: **Pterospermella** Eisenack, 1972

Pterospermella saadii n. sp. (Plate IV, 2, 3)

Genus: **Rhopaliophora** Tappan and Loeblich, 1971 emend. Playford and Martin, 1984

Rhopaliophora palmata (Combaz and Péniguel, 1972) emend. Playford and Martin, 1984 (Plate III, 12)

Genus: **Saharidia** Combaz, 1967

Saharidia fragilis (Downie, 1958) Combaz, 1967 (Plate I, 3, 4)

Genus: **Stellechinatum** Turner, 1984

Stellechinatum uncinatum (Downie, 1958) Molyneux, 1987 (Plate VI, 8)

Genus: **Stelliferidium** Deunff et al., 1974

Stelliferidium striatulum (Vavrdová, 1966) Deunff et al., 1974 (Plate I, 17; Plate III, 7, 8)

Stelliferidium trifidum (Rasul, 1974) Rasul, 1979 (Plate VIII, 13; Plate III, 9)

Genus: **Striatotheca** Burmann, 1970

Striatotheca principalis var. *parva* Burmann, 1970 (Plate II, 9; Plate V, 10)

Striatotheca mutua Burmann, 1970 (Plate IV, 16, 17, 18)

Striatotheca transformata Burmann, 1970 (Plate V, 12)

Striatotheca triangulata (Cramer et al., 1974) Eisenack et al., 1976 (Plate II, 13)

Striatotheca trapeziformis Burmann, 1970 (Plate IV, 14)

Genus: **Tectitheca** Burmann, 1968

Tectitheca additionalis Burmann, 1968 (Plate VI, 3)

Tectitheca cucullucium Cramer and Diéz, 1977 (Plate II, 11)

Genus: **Vavrdovella** Loeblich and Tappan, 1976

Vavrdovella areniga var. *areniga* Molyneux in Molyneux and Rushton, 1988 (Plate III, 5)

Vavrdovella mawlawii n. sp. (Plate I, 12; Plate IV, 18)

Genus: **Veryhachium** Deunff, 1954 emend. Turner, 1984

Veryhachium estrellitae Cramer, 1964 (Plate IV, 19, 20)

Veryhachium subglobosum Jardiné et al., 1974 (Plate VI, 10)

Genus: **Villosacapsula** Loeblich and Tappan, 1976

Villosacapsula foraminifera (Pittau, 1985) emend. Tongiorgi et al., 1994 (Plate

Genus: **Vogtlandia** Burmann, 1970

Vogtlandia flosmaris (Deunff, 1961) Molyneux, 1987 (Plate II, 14)

Vogtlandia zardkuhensis n.sp. (Plate II, 6; Plate III, 14)

Genus: **Vulcanisphaera** Deunff, 1961 emend. Rasul, 1976 emend. Kroeck et al., 2020

Vulcanisphaera africana Deunff, 1961 emend. Kroeck et al., 2020 (Plate I, 15)

Vulcanisphaera simplex (Jardiné et al., 1974) emend. Kroeck et al., 2020 (Plate I, 16)

4.2. Systematic paleontology of the newly identified acritarch taxa

Incertae sedis Group Acritarcha Evitt, 1963.

Genus: **Arbusculidium** Deunff, 1968

Type species: *Arbusculidium destombesii* Deunff, 1968

Arbusculidium iranense Ghavidel-Syooki, 1990 emend. Ghavidel-Syooki, 2020

Plate I, Fig. 11; Plate IV, Fig. 8

Holotype: Plate IV, 8

1990 *Arbusculidium iranica* Ghavidel-Syooki, P. 171, pl. 3, figs. 2, 3, 5,12
1994 *Arbusculidium* sp. Tongiorgi et al., P. 602, pl. I, fig. 7
1999 *Arbusculidium iranica* Fatka and Brocke, P. 171
2006 *Arbusculidium (iranica) iranense* Ghavidel-Syooki, P. 86, pl. II, fig. 2
2019 *Arbusculidium* sp. Kroeck et al., P. 6, pl. 1, figs. 7, 8

Diagnosis: A species of *Arbusculidium* with more than 20 thin processes, numerous striations, and a markedly cylindrical vesicle.

Description: This species is bipolar with a cylindrical outline; one polar cap is covered by filose or very thin processes (>20 in numbers) and another pole is characterized by anastomosing or a net-like structure. The vesicle contains 10–15 ridges that extend from one pole to the other. This species was introduced by Ghavidel-Syooki (1990) as *Arbusculidium iranica*, but as no holotype was designated, it was invalid under the relevant code of nomenclature and has remained so (see ICN: McNeil et al., 2011, Article 40). A holotype is designated here, the species epithet is changed to 'iranense' (meaning 'of Iran'), and other information is given (repository of type material, type-level, and type area).

Dimensions: Vesicle length, 37.1 (40.25) 43.4 μm; process length, 5.5 (5.35) 6.2 μm; the number of processes, 20 at one pole; the net-like

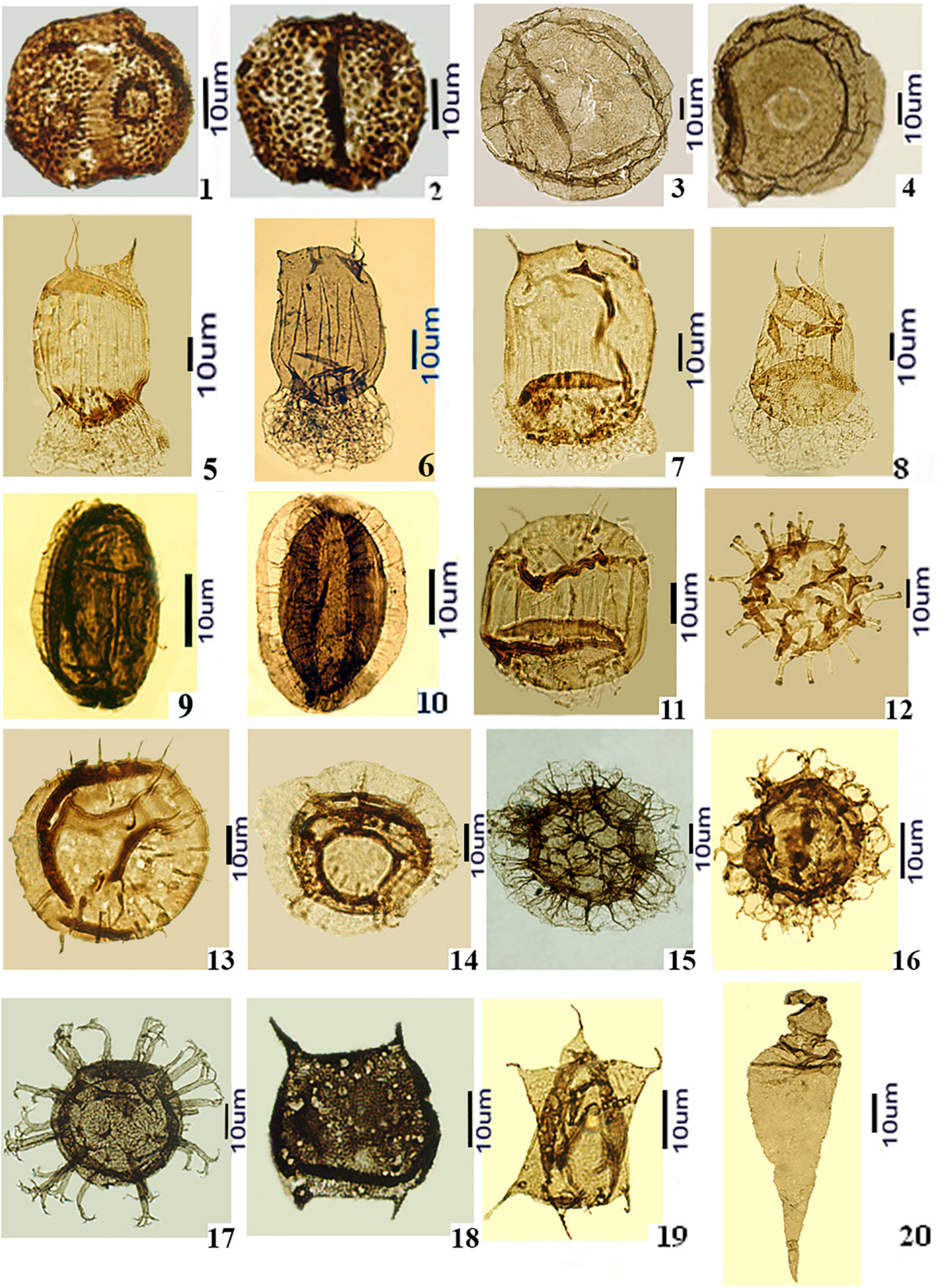


Plate I. 1, 2. *Acanthodiacrodium angustum* (Downie) Combaz, 1967; 3, 4. *Saharidia fragilis* (Downie) Combaz, 1967; 5, 6, 7, 8. *Arbusculidium filamentosum* (Vavrdová, 1965) Vavrdová1972 emend. 9, 10. *Dactylofusa velifera* var. *brevis* (Cocchio, 1982) emend. Wang et al., 2015; 11. *Arbusculidium iranense* (Ghavidel-Syooki, 1990) emend. Ghavidel-Syooki, 2020; 12. *Vavrdovella mawlawii* n. sp.; 13. *Cymatiogalea stelligera* Górka, 1967; 14. *Cymatiogalea deunffii* Jardine et al. 1974; 15. *Vulcanisphaera cirrita* Rasul, 1976; 16. *Vulcanisphaera britanica* Rasul, 1976; 17. *Stelliferidium striatulum* (Vavrdová, 1966) Deunff, Górka, Rauscher, 1976; 18. *Villosacapsula foraminifera* (Pittau) Tongiorgi et al., 1994; 19. *Acanthodiacrodium tumidum* (Deunff, 1961) Martin, 1975; 20. *Leiofusa simplex* (Combaz, 1967) Martin, 1975.

structure, 5 (6) 7 μm at another pole. The size range and morphology of the Zardkuh Formation specimens are like those of *Arbusculidium* sp., from Pakistan (Tongiorgi et al., 1994).

Occurrence: This species is common in the Upper Shale Member of the Zardkuh Formation (samples AS2563–AS2571) of Tang-e Ilebeyk in the Zardkuh area, southeastern Iran (Fig. 3; Table 1). All slides relating to this study are housed in the paleontological collections of the Exploration Directorate of the National Iranian Oil Company under sample numbers AS2563 to AS2572.

Previous records: Until now, this species has indicated the Early Ordovician (Arenigian) in Pakistan (Tongiorgi et al., 1994), southeastern Iran (Zagros Mountains), and northeastern Iran (the Alborz Mountains; Ghavidel-Syooki, 1990, 1996, 2000, 2006a).

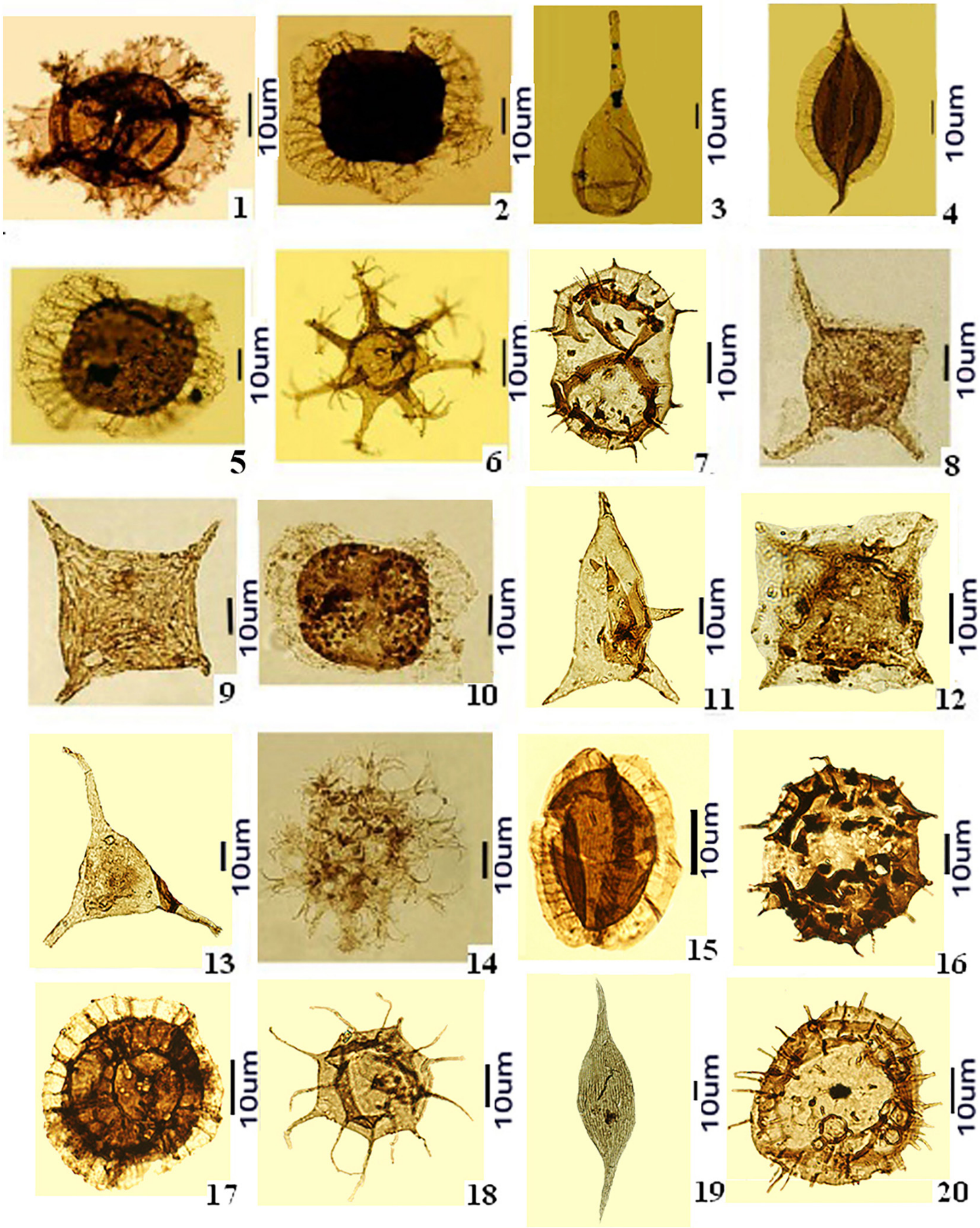


Plate II. 1. *Cymatiogalea messaoudensis* var. *messaoudensis* (Jardiné et al., 1974) Servais and Molyneux, 1997; 2, 5, 10. *Pseudocoryphidium zagrosensis* n gen and n. sp.; 3. *Pirea dubia* Vavrdová, 1972; 4. *Dactylofusa velifera* var. *velifera* (Cocchio, 1982.) Wang et al., 2015; 6. *Vogtlandia zardkuhensis* n. sp.; 7. *Acanthodiacrodium ubui* Martin, 1969; 8, 12. *Aureotesta clathrata* var. *simplex* (Cramer et al., 1974) emend. Brocke et al., 1998; 9. *Striatotheca principalis* var. *parva* Burmann, 1970; 11. *Tectittheca cuculluclum* Cramer and Diéz, 1977; 13. *Striatotheca triangulata* (Cramer et al., 1974) Eisenack et al., 1976; 14. *Vogtlandia flosmaris* (Deunff) Molyneux, 1987; 15. *Dactylofusa velifera* var. *brevis* (Albani, 1989) emend. Wang et al., 2015; 16. *Acanthodiacrodium spinum* Rasul, 1967; 17. *Cymatiogalea gorkae* Rauscher, 1974; 18. *Polygonium gracile* Vavrdová, 1966; 19. *Leiofusa squama* Deunff, 1961; 20. *Baltisphaeridium* cf. *B. fragile* Tongiorgi et al., 1995.

Genus: **Coryphidium** Vavrdová, 1972 emend. Servais et al., 2008

Type species: *Coryphidium bohemicum* Vavrdová, 1972 emend. Servais et al., 2008

Coryphidium sp. A

Plate IV, Fig. 1

Description: This taxon is quadrate with round corners in a vesicle outline. Vesicle walls are single-layered and ornamented by striate ribs approximately parallel to the edges. The processes are homomorphic with a fringe of large, bulbous surface projections, which are proximally opened to the vesicle (processes are cylindrical and range from 6 to 12 in number per corner). The processes appear to be enveloped in a translucent membrane. This taxon is like *Coryphidium bohemicum* in striation of vesicle body and arising and arrangement of processes, but differs in the enveloped translucent membrane that surrounds the processes. On the other hand, *Coryphidium* sp. A., has a close similarity to *Vavrdovella mawlawii* n. sp. in vesicle shape and distribution processes but differs from the latter because of the presence of vesicle striations and translucent membrane. This species is rare in the Upper Shale Member of the Zardkuh Formation (samples AS2563–AS2571). Based on 15 specimens, the biometric data for this taxon are as follows: vesicle length, 27 (30)

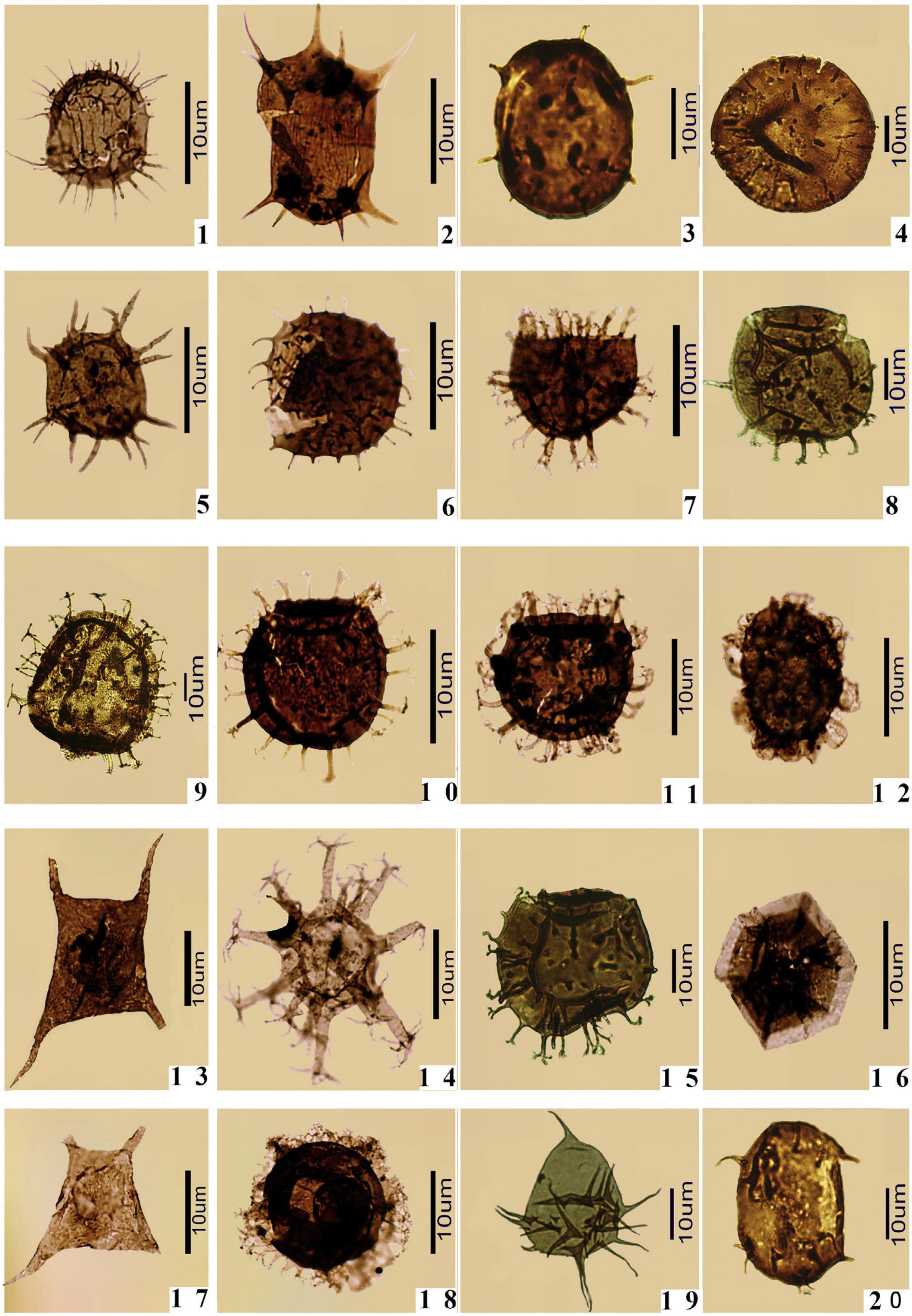


Plate III. 1. *Acanthodiacrodium costatum* Burmann, 1968; 2. *Acanthodiacrodium tadlense* Cramer and Diéz, 1977; 3, 20. *Acanthodiacrodium simplex* Combaz, 1967; 4. *Baltisphaeridium* cf. *B. fragile* Tongiorgi et al., 1995; 5. *Vavrdovella? areniga* (Vavrdová, 1973) emend. Loeblich and Tappan, 1976 areniga Molyneux in Molyneux and Rushton, 1988; 6. *Coryphidium bohemicum* (Vavrdová, 1972) emend. Servais et al., 2008; 7, 8, 10. *Stelliferidium striatulum* (Vavrdova, 1966) emend. Deunff et al., 1974; 9. *Stelliferidium trifidum* (Rasul, 1974) Rasul, 1979; 11. *Cymatiogalea velifera* (Downie, 1958) Martin, 1968; 12. *Rhopaliopora palmata* (Combaz and Péniguel, 1972) emend. Playford and Martin, 1984; 13. *Striatotheca principalis* var. *parva* Burmann, 1970; 14. *Vogtlandia zardkuhensis* n. sp.; 15. *Cymatiogalea aspergillum* Martin in Martin and Dean, 1988; 16. *Cymatiogalea boulouardii* (Deunff, 1961) Fensome et al., 1990; 17. *Striatotheca trapeziformis* Burmann, 1970; 18. *Cymatiogalea messaoudensis* var. *messaoudensis* (Jardine et al., 1974) Servais and Mette, 2000; 19. *Ninadiacrodium caudatum* (Vanguestaine, 1973) Raevskaya and Servais, 2009.

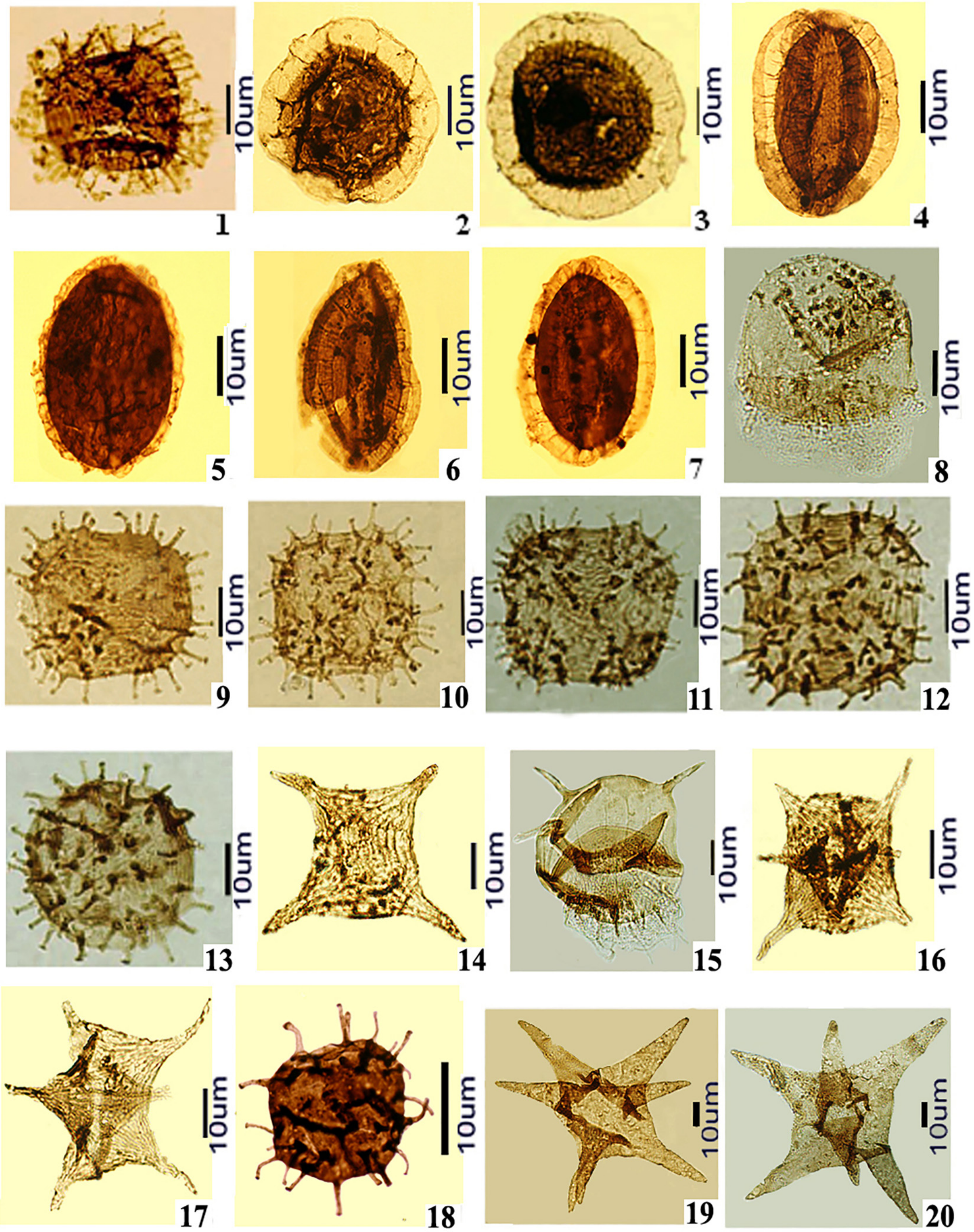


Plate IV. 1. *Coryphidium bohemicum* (Vavrdová, 1972) emend. Servais et al., 2008; 2, 3. *Pterospermella saadii* n. sp.; 4, 6, 7. *Dactylofusa velifera* var. *brevis* (Albani, 1989) Wang et al., 2015; 5. *Dactylofusa velifera* var. *sinensis* Wang et al., 2015; 8. *Arbusculidium iranense* (Ghavidel-Syooki, 1990) emend. Ghavidel-Syooki, 2020; 9-13. *Coryphidium bohemicum* Vavrdová, 1972 emend. Servais et al., 2008; 14. *Striatotheca trapeziformis* Burmann, 1970; 15. *Arbusculidium filamentosum* (Vavrdová, 1965) Vavrdová, 1972 emend. 16, 17. *Striatotheca mutua* Burmann, 1970; 18. *Vavrdovella mawlawii* n. sp.; 19, 20. *Veryhachium estrellitae* Cramer, 1964.

33 μm; process length, 4 (6) 8 μm per corner. Herein, this species was treated using open nomenclature because of insufficient specimens.

Genus: **Pterospermella** Eisenack, 1972

Type species: *Pterospermella aureolata* (Cookson and Eisenack) Eisenack, 1972

Pterospermella saadii n. sp.

Plate IV, 2, 3

Holotype: Plate IV, 3

Type stratum: Upper Shale Member of the Zardkuh Formation, Tang-e Ilebeyk, the Zardkuh mountain, southwestern Iran. Samples AS2551 to AS2562.

Derivation of name: Abū-Muhammad Muslih al-Dīn bin Abdallāh Shīrāzī (known by his pen-name Saadi, or as Saadi of Shīrāzī) was born in 1210 ACE in Shiraz city and died in 1292 in the same city. Saadi is widely recognized as the greatest Persian poet of the classical literary tradition, earning him the nickname "Master of Speech." His major works are called the Gulistan and Bustan books. The following is a Saadi poem translated from Persian into English:

> Human beings are limbs of one body indeed
> For they're created of the same soul and seed
> When one limb is afflicted with pain,

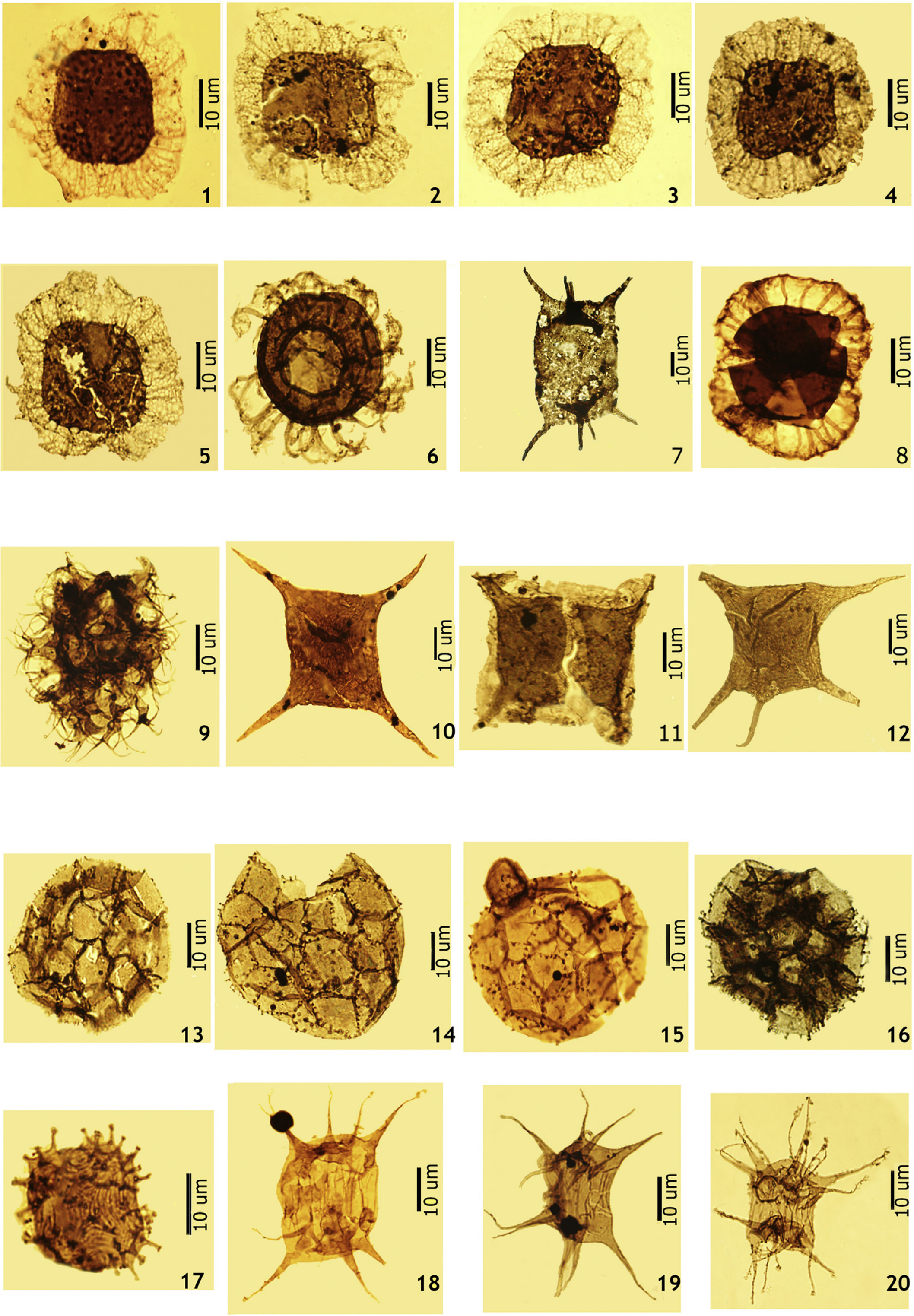


Plate V. 1–5. *Pseudocoryphidium zagrosensis* n. gen and n. sp.; 6, 8. *Cymatiogalea velifera* (Downie, 1958) Martin, 1969; 7. *Acanthodiacrodium raia* (Deunff, 1961) Eisenack et al., 1979; 9. *Vogtlandia flosmaris* (Deunff) Molyneux, 1987; 10. *Striatotheca principalis* var. *parva* Burmann, 1970; 11. *Aureotesta clathrata* var. *simplex* (Cramer et al., 1974) emend. Brocke et al., 1998; 12. *Striatotheca transformata* Burmann, 1970; 13–16. *Cristallinium dentatum* (Vavrdová, 1976) Martin, 1982; 17. *Coryphidium bohemicum* (Vavrdová, 1972) emend. Servais et al., 2008; 18–20. *Barakella felix* Cramer and Diéz, 1977.

Other limbs will feel the bane
He has no sympathy for human suffering,
Is not worthy of being called a human being

Diagnosis: A species of *Pterospermella* with circular to subcircular in outline and a uniform translucent membrane width, but subject to radial folding and numerous filose processal elements; both vesicle and membrane contain finely sculptured with diminutive discrete grana. No excystment is recognizable.

Description: This species is circular to subcircular in outline, consisting of a vesicle body and membrane. The vesicle is surrounded

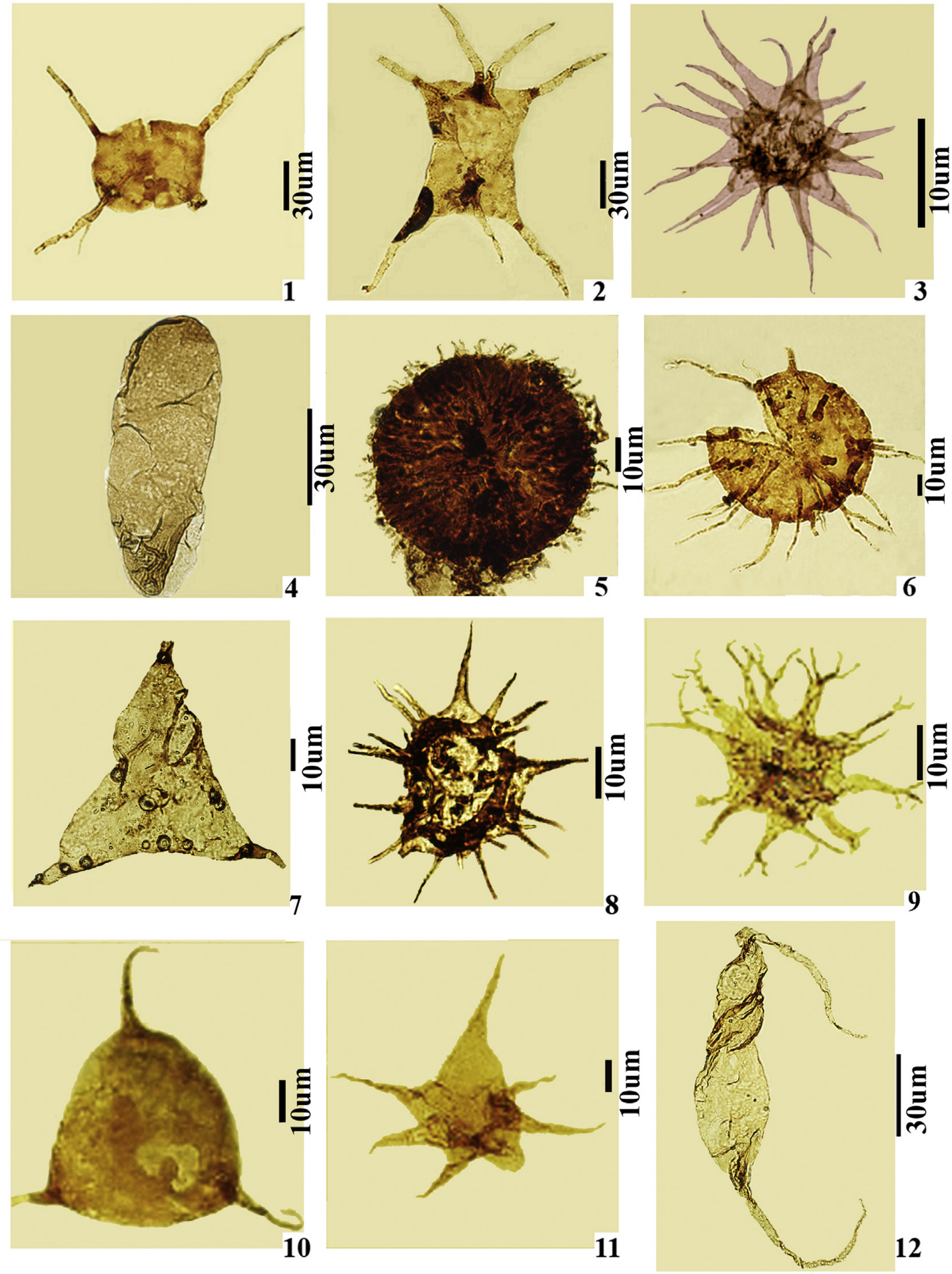


Plate VI. 1. *Orthosphaeridium insculptum* Loeblich, 1970; 2. *Orthosphaeridium orthogonium* Le Hérissé, Molyneux, and Miller, 2015; 3. *Tectitheca additionalis* Burmann, 1968; 4. *Navifusa ancepsipuncta* Loeblich, 1970; 5. *Gorgonisphaeridium antiquum* Loeblich and Tappan, 1978; 6. *Baltisphaeridium oligopsakium* Loeblich and Tappan, 1978; 7. *Inflatarium trilobatum* Le Hérissé et al., 2014; 8. *Stellechinatum uncinatum* (Downie, 1958) Molyneux, 1987; 9. *Multiplicisphaeridium irregulare* Staplin et al., 1965; 10. *Veryhachium subglobosum* Jardine et al., 1974; 11. *Dorsennidium hamii* (Loeblich) Sarjeant and Stancliffe, 1994; 12. *Leiofusa litotes* Loeblich and Tappan, 1978.

by a translucent membrane that is connected to the body by numerous filose processal elements; these elements are slender, solid, and vary from flexible spines to hairs; the numerous filose processal elements; the membrane is subject to radial folding. *Pterospermella saadii* differs from other species of *Pterospermella* in being much smaller in overall size, having fewer folds in the equatorial flange, and numerous filose processal elements, connecting the equatorial flange to the vesicle body. No encystment structure is observed.

Dimensions: Vesical diameter without membrane, 29 (32) 35 μm*;* vesical diameter with a membrane, 30 (38) 46 μm; thickness of the membrane, 5.5 (6.5) 7.5 μm; 20 specimens were measured.

Genus: **Pseudocoryphidium** gen. n.

Diagnosis: Central body is typically quadrate to subquadrate with rounded corners. The vesicle is covered by a translucent membrane. The membrane is square in shape that it is connected to the body by a set of filose processal elements. The filose processal elements are slender, solid, and vary from flexible spines to hairs. This genus is characterized

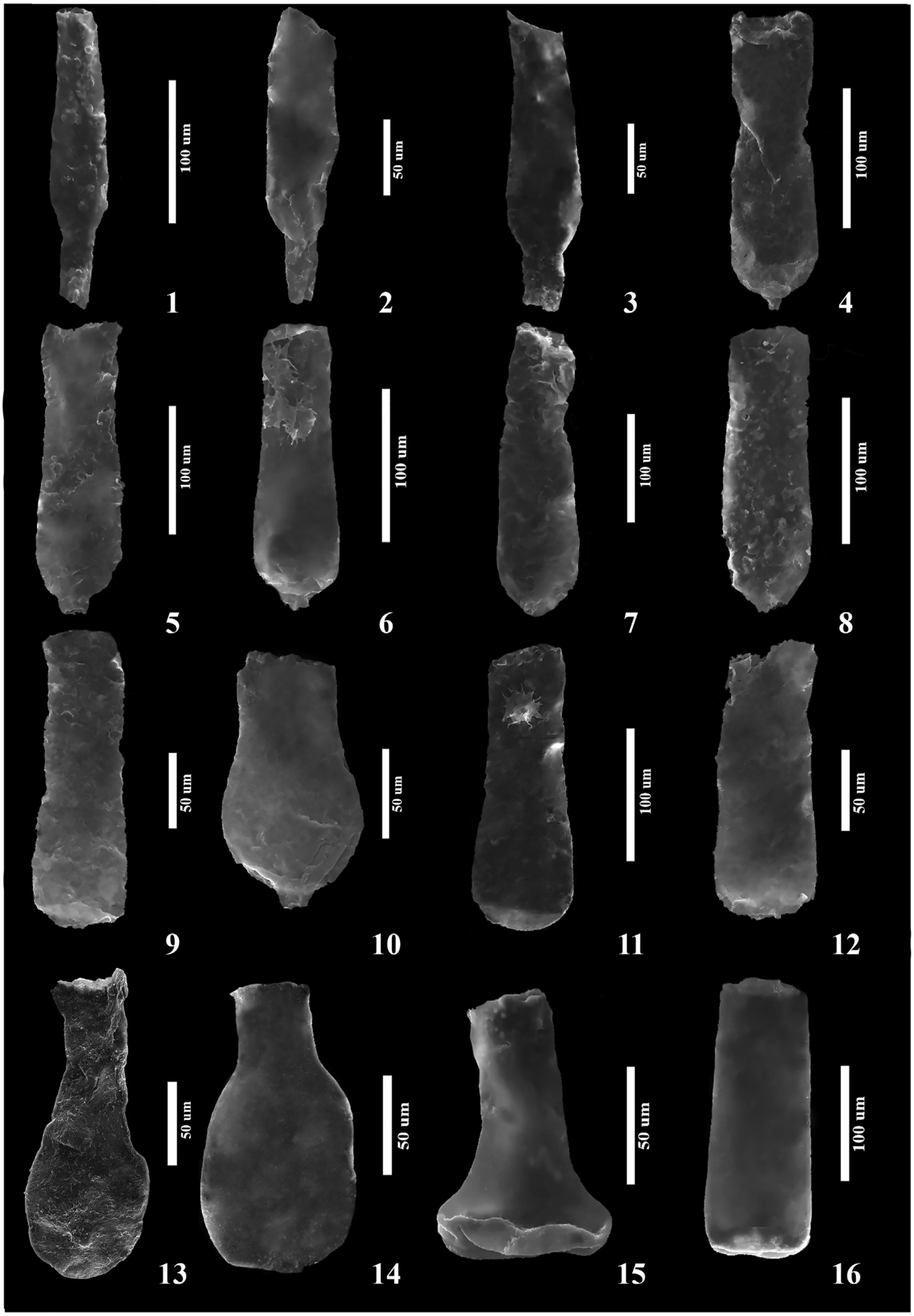


Plate VII. 1–6,10. *Eremochitina brevis* Benoit and Taugourdeau, 1961; 7, 8. *Velatachitina nebulosa* Poumot, 1968; 9, 12. *Conochitina* sp. (with macron in the base); 11. *Conochitina poumoti* Combaz and Péniguel, 1972; 13–14. *Lagenochitina obeligis* Paris, 1981; 15. *Euconochitina vulgaris* (Jenkins, 1967); 16. *Belonechitina* sp.

by lacking ridges in the central body**.** It appears to be a surficial resemblance to the *Coryphidiun* in shape, but the former differs from the latter in presence of a translucent membrane and lacking the ridges. No endodermal structure and no mode of opening are recognizable.

Type species: *Pseudocoryphidium zagrosensis* sp. n.
Pseudocoryphidium zagrosensis sp. n.
Plate V, 1-5; Plate II, 2, 5, 10
Holotype: Plate V, 3

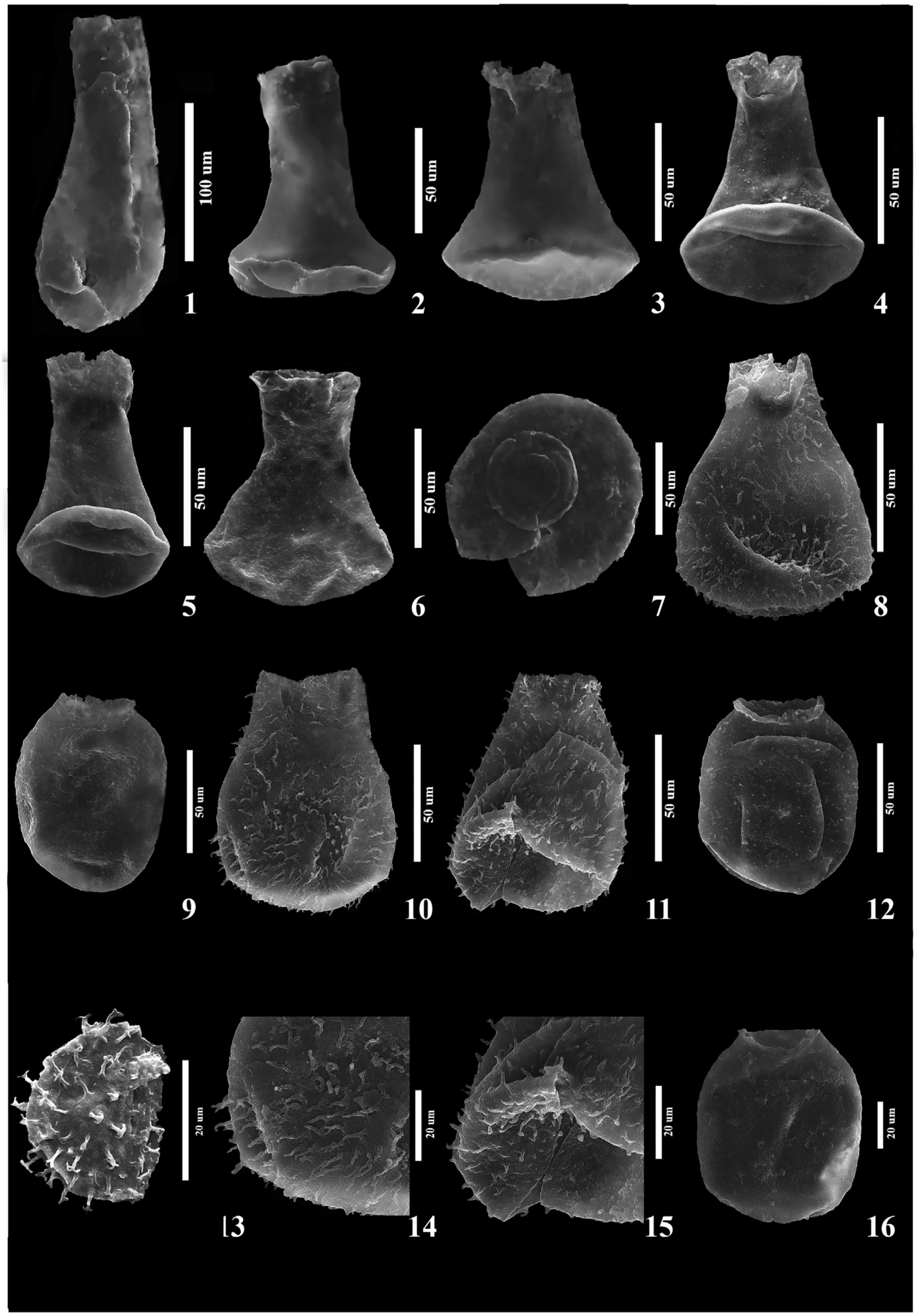


Plate VIII. 1. *Lagenochitina obeligis* Paris, 1981; 2, 3. *Euconochitina vulgaris* (Jenkins, 1967); 4, 5, 6. *Euconochitina lepta* (Jenkins, 1970); 7. *Calpichitina lenticularis* (Bouché, 1965); 13. *Stelliferidium trifidum* (Rasul, 1974) Rasul, 1979; 8, 10, 11, 14, 15. *Angochitina communis* Jenkins, 1967; 9, 12, 16. *Desmochitina* gr. *minor* Paris et al., 2007.

Type stratum: Upper Shale Member of the Zardkuh Formation (samples AS2551–AS2562), southern flank of Zardkuh Mountain, the High Zagros Mountains, southeastern Iran.

Derivation of name: *Pseudocoryphidium* gen. n., refers to the surficial resemblance of its central body to *Coryphidium* from a morphological point of view; *zagrosensis* refers to the Zagros Mountains, where the species was first recorded.

Synonymy:

1990 *Coryphidium persica* Ghavidel-Syooki, p.184, pl. 4, figs. 1–4.
2006a *Coryphidium persianense* Ghavidel-Syooki, pp.13–37, pl. 1V, fig. 3.
2006b *Coryphidium persianense* Ghavidel-Syooki, pp. 81–95, pl. IV, fig. 9

Diagnosis: This species is characterized by quadrate to subquadrate central body with rounded corners. The vesicle is covered by a

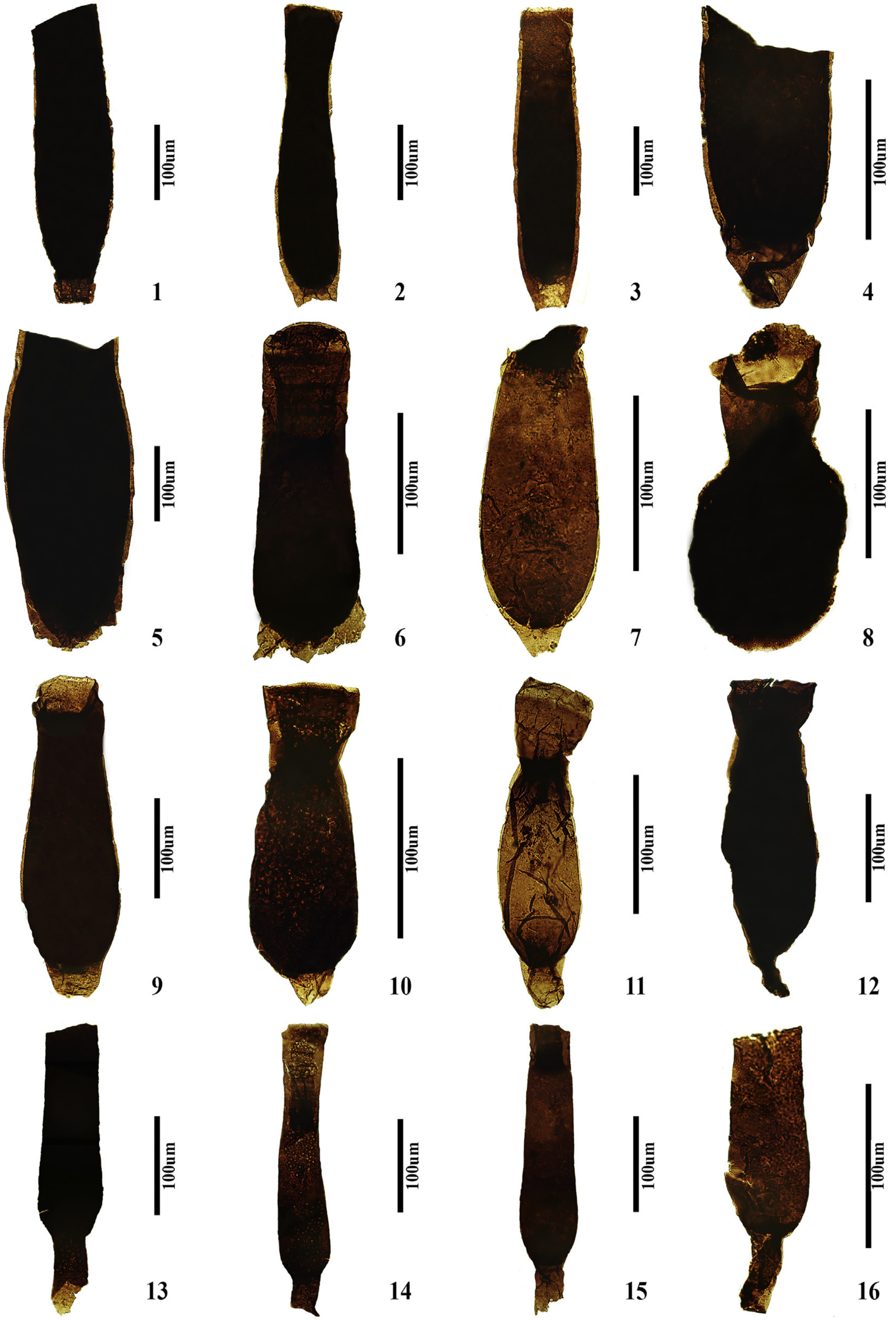


Plate IX. 1–7, 9. *Velatachitina veligera* Poumot, 1968; 10–11. *Velatachitina nebulosa* Poumot, 1968; 8. *Lagenicula obeligis* Paris, 1981; 12. *Siphonochitina* sp.; 13–16. Benoit and Taugourdeau, 1961.

translucent membrane. The membrane is square in shape that it is connected to the body by a set of filose processal elements, which are slender, solid, and vary from flexible spines to hairs. It appears to be a surficial resemblance to the *Coryphidiun* in shape, but the former differs from the latter in presence of a translucent membrane and lacking the ridges. No endodermal structure and no mode of opening are recognizable.

Description: This species has been recorded from both the Zagros and Alborz mountains as *Coryphidium persica* or *Coryphidium persianense* (Ghavidel-Syooki, 1990, 1995, 2006a); it should be mentioned that

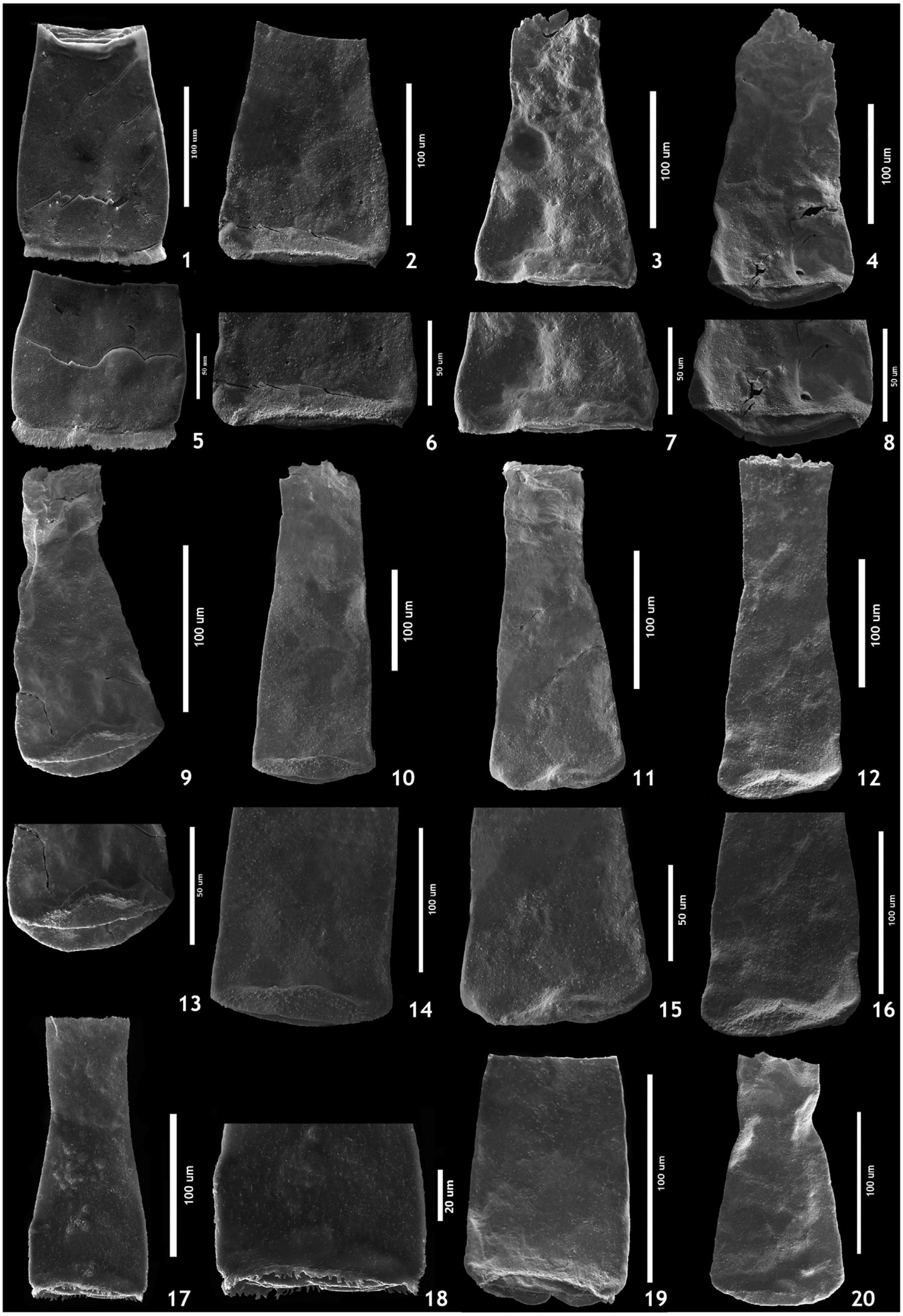


Plate X. 1, 2, 3, 5, 6, 7. *Armoricochitina nigerica* (Bouché, 1965); 4, 8, 19. *Armoricochitina alborzensis* Ghavidel-Syooki and Winchester-Seeto, 2002; 9–16, 20. *Euconochitina moussegoudaensis* Paris, *in* Le Hérissé et al., 2013; 17, 18. *Spinachitina oulebsiri* Paris et al., 2000a.

this species as no holotype had been designated; it was invalid under Article 37 of the version of the I.C.B.N. current at the time of Servais et al. (2008).

Herein, this species was named *Pseudocoryphidium zagrosensis* gen. n and sp. n., and redescripted. *Pseudocoryphidium* and related species have a central body that is quadrate to subquadrate with rounded corners. The vesicle is covered with a translucent membrane, which is quadrate and connected to the body by a set of filose processal elements. The filose processal elements are slender, solid, and vary from flexible spines to hairs. The size range of this taxon varies from 42 to 64 μm (including membrane and body). The size range of the body is 25 to 41 μm and the membrane is 10 to 12 μm. This taxon lacks the ridges that

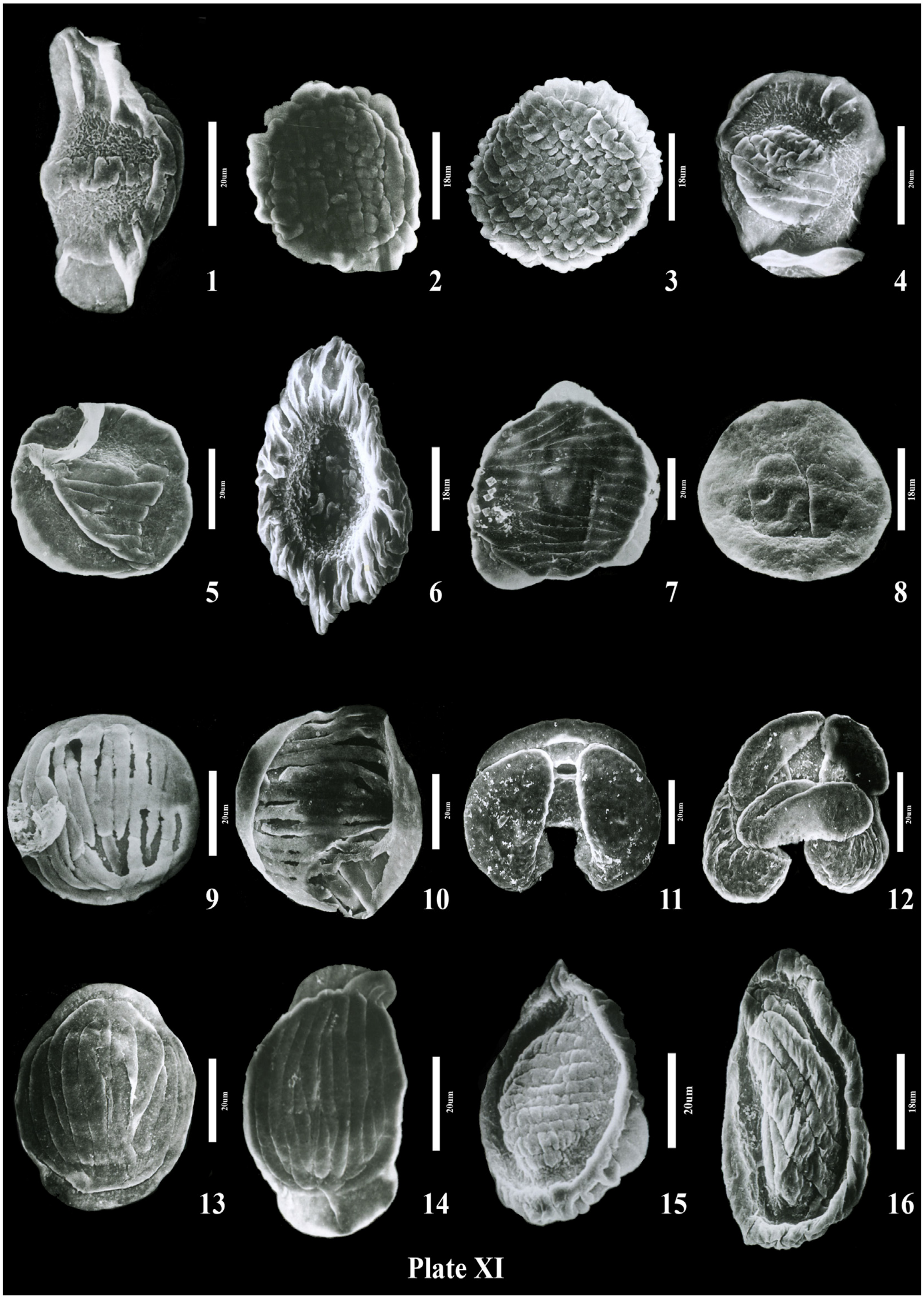


Plate XI. 1. *Hamiapollenites karooensis* (Hart) Hart, 1964; 2, 3. *Tiwariasporis gondwanensis* (Tiwari) Maheshwari and Kar, 1967; 4. *Striomonosaccites triangularis* Maheshwari, 1967; 5. *Striomonosaccites brevis* Bose and Kar, 1966; 6. *Caheniasaccites ellipticus* Bose and Kar, 1966; 7. *Boutakoffites elongatus* Bose and Kar, 1966; 8. *Høegiasaccites transitus* Bose and Kar, 1966; 9, 10. *Fusacolpites ovatus* Bose and Kar, 1966; 11, 12. *Corisaccites alutas* Venkatachala and Kar, 1966; 13. *Costapollenites ellipticus* Tschudy and Kosanke, 1966; 14. *Hamiapollenites perisporites* (Jizba, 1962) Tschudy and Kosanke, 1966; 15, 16. *Maubitasaccites ovatus* Bose and Kar, 1966.

are characteristic of the genus *Coryphidium* in the central body. No endodermal structure and no mode of opening are recognizable.

Dimensions: Based on 20 specimens, the biometric data of this taxon are as follows: total size range of taxon (including membrane and body) 42 (53) 64 μm; size range of central body, 25 (33) 41 μm; size range of membrane 10 (11) 12 μm.

Occurrence: This species is present in abundant frequency in the Upper Member of the Zardkuh Formation (samples AS2551–AS2562) at Tang-e Ilebeyk in the Zardkuh area of the High Zagros Mountains, southeastern Iran (Fig. 3; Table 1).

Previous records: This species has been recorded from Early Ordovician (Floian) strata in the Zardkuh Formation of Zardkuh mountain, southwestern Iran (Ghavidel-Syooki, 1990), and in the Lashkarak Formation in the Alborz Mountains, northeastern Iran (Ghavidel-Syooki, 2006a). In the material study, this taxon is associated with *Arbusculidium filamentosum, Dactylofusa velifera, Barakella felix, Cymatiogalea deunffii*, and *Acanthodiacrodium tadlense.*

Remarks: This species differs from *Coryphidium* and its related species because of the presence of a reticulate membrane around the central body and the absence of ridges in the central body. The membrane is connected to the central body by a set of filose processal elements, which are slender, solid, and vary from flexible spines to hairs.

Genus: **Vavrdovella** Loeblich and Tappan, 1976

Type species: *Vavrdovella areniga* (Vavrdová, 1973) Loeblich and Tappan, 1976

Vavrdovella mawlawii n. sp.

Plate I, Fig. 12; Plate IV, Fig. 18

Holotype: Plate I, Fig. 12

Type stratum: The Upper Shale Member of the Zardkuh Formation (samples AS2551–AS2562), the southern flank of Zardkuh Mountain in the High Zagros Mountains, southeastern Iran.

Derivation of name: Refers to Jalāl ad-Dīn Muhammad Balkhī, a great Iranian poet originally from Greater Khorasan in Greater Iran. His major work is the Masnavi of Mawlawi; his poems have been widely translated and transposed into various languages and formats. Mawlawi has been described as the “most popular poet” and the “best selling poet” in the United States. He was born on September 30, 1207 ACE in Balkh and died on December 17, 1273 ACE in Turkey (Ghunieh or Konya).

For a synonym see *Goniosphaeridium* sp. Ghavidel-Syooki (1990), P. 191, pl. 11, fig. 5

Diagnosis: A species of *Vavrdovella* with quadrate to subquadrate vesicle and rounded corners; processes are homomorphic with bulbous projections at the distal ends and proximally open to the vesicle. The vesicle is smooth without ridges. No excystment is recognizable.

Description: This taxon consists of the vesicle and bulbous surface projections, which are restricted to four corners; processes are homomorphic and bulbous surface projections are proximally opened to the vesicle; the vesicle is quadrate to subquadrate with rounded corners; both processes and vesicle wall are smooth. Excystment opening is not present.

Dimensions: Based on 20 specimens, the biometric data of this taxon are as follows: vesicle length, 32 (40) 48 μm; process length, 10 (12) 14 μm; the number of processes, 28 (34) 40.

Occurrence: This species is present with rare to common frequencies in the Upper Member of the Zardkuh Formation (samples AS2551–AS2562) of Tang-e Ilebeyk in the High Zagros Mountains, southeastern Iran (Fig. 3; Table 1).

Remarks: From a morphological point of view, this taxon resembles *Coryphidium bohemicum* Vavrdová (1972), but it differs in the absence of ridges or striae in its central cavity. *Vavrdovella mawlawii* n. sp. differs from *Vavrdovella areniga* (Vavrdová, 1973) Loeblich and Tappan (1976) in the bulbous distal part of projections.

Genus: **Vogtlandia** Burmann, 1970

Type species: *Vogtlandia ramificata* Burmann, 1970

Vogtlandia zardkuhensis n.sp.

Plate II, Fig. 6; Plate III, Fig. 14

Holotype: Plate II, 3

Type stratum: Zardkuh Formation, Tang-e Ilebeyk, the southern flank of Zardkuh Mountain, the High Zagros Mountains, southeastern Iran.

Diagnosis: A species *of Vogtlandia* with being in polygonal to subcircular outline and much smaller than other species of *Vogtlandia*. The processes are 11–14 in numbers, hollow, cylindrical, homomorphic, and straight. All processes have 8–9 threat-like divisions with a palmate arrangement at their distal ends. The surface of the vesicle wall and the processes are psilate. No excystment is observed.

Derivation of name: Refers to the Zardkuh Formation, where the species was first discovered.

Description: The vesicle is almost subcircular to polygonal in outline. The vesicle wall is single-layered, thin, and bears 11–14 discrete hollow processes. Processes are cylindrical, homomorphic, and straight; they freely communicate with the vesicle cavity. Processes are distal with no branching. All processes have a distal, 8–9 threat-like division with a palmate arrangement. The surface of the vesicle wall and the processes are psilate. No excystment is observed. This species differs from other species of *Vogtlandia* in size, the number of processes, and the type of thread-like division at the distal end of processes.

Dimensions: Based on 15 specimens, the biometric data of this taxon are as follows: vesicle diameter (including processes tip to tip), 24 (35) 46 μm; vesicle length, 14 (15.5) 17 μm; processes length, 9 (12) 15 μm; the number of processes, 11 (13) 15.

Occurrence: This species is present with rare to common frequencies in samples AS2513 to AS2550 of the Lower Shale Member of the Zardkuh Formation, the High Zagros Mountains, southeastern Iran (Fig. 3; Table 1).

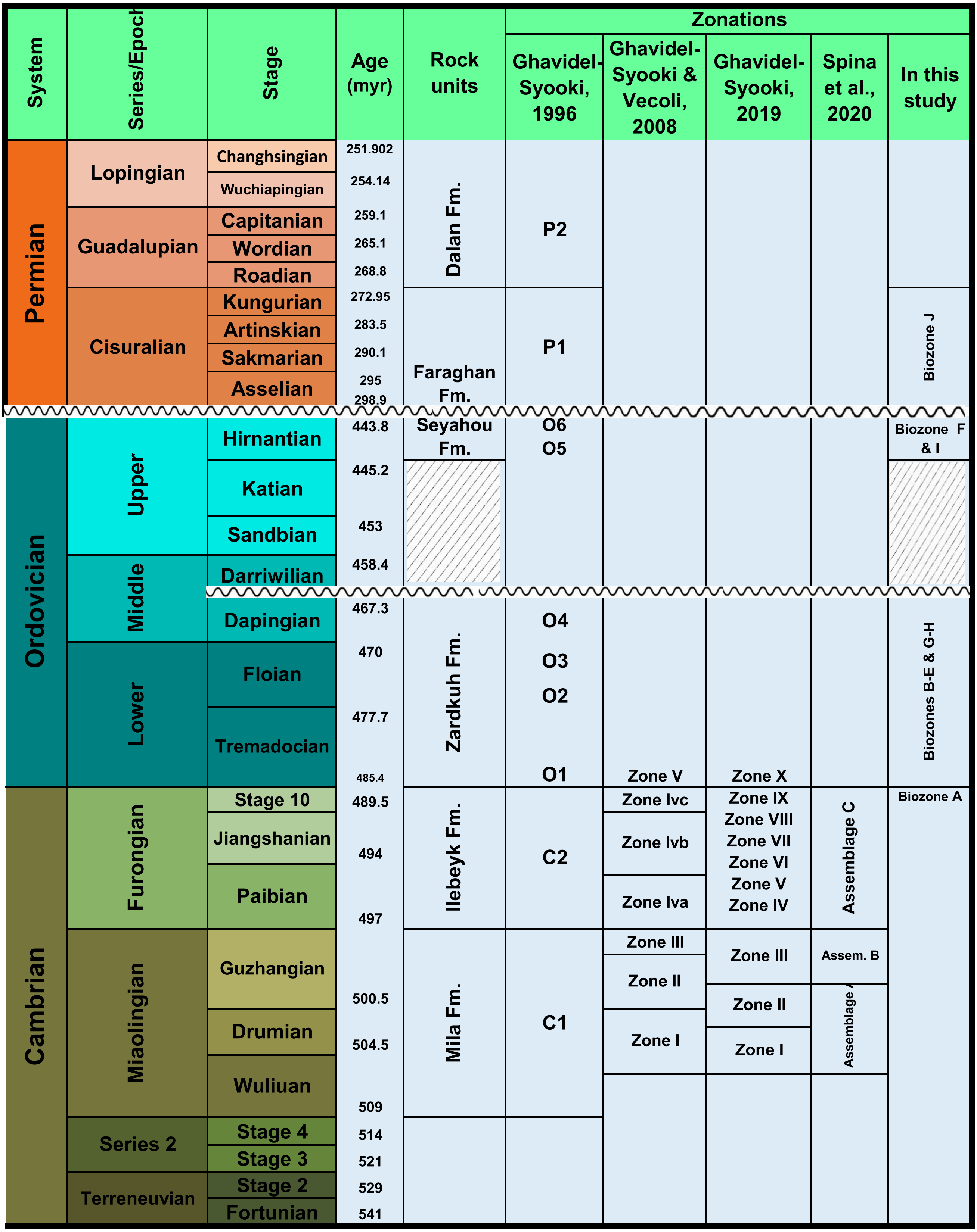
4.3. Acritarch biostratigraphy

The Cambrian rock units (i.e., the Mila and Ilebeyk formations) have been previously investigated (Ghavidel-Syooki, 1990, 1993, 1996; Ghavidel-Syooki and Vecoli, 2008; Ghavidel-Syooki, 2019; Spina et al., 2020) in the High Zagros Mountains (Table 2). In this study, the Ordovician (i.e., the Zardkuh and Seyahou formations) and Permian (i.e., Faraghan and Dalan formations) rock units were sampled in detail to provide data for the First Appearance Datum (FAD) and Last Appearance Datum (LAD) of encountered palynomorph taxa. In total, 63 acritarch species (31 genera) were identified, allowing recognition of six local acritarch assemblage zones.

4.3.1. Acritarch assemblage zone A

This assemblage zone occurs in the uppermost 39 m of the Ilebeyk Formation (samples AS2480–AS2494; See Table 1; Fig. 3). This biozone is characterized by the association of acritarch taxa, such as *Ninadiacrodium caudatum* (Vanguestaine, 1973) Raevskaya and Servais (2009); *Cymatiogalea aspergillum* Martin *in* Martin and Dean, 1988; *Vulcanisphaera africana* Deunff, 1961. The known stratigraphic range of the *Ninadiacrodium caudatum* has up to now been verified within Late Cambrian *Parabolina spinulosa* to *Acerocare* trilobite biozones of elsewhere (Raevskaya and Servais, 2009), and in the Late Cambrian (Furongian) Ilebeyk Formation of the High Zagros Mountains, southwestern Iran (Ghavidel-Syooki and Vecoli, 2008: Ghavidel-Syooki, 2019). Likewise, *Cymatiogalea aspergillum* has been recorded from the Late Cambrian (Furongian) Ilebeyk Formation of the High Zagros Mountains (Ghavidel-Syooki and Vecoli, 2008); the Comley area of Shropshire, England (Potter et al., 2012); eastern Newfoundland, Canada (Martin and Dean, 1988; Parsons and Anderson, 2000); and Öland, Sweden (Di Milia et al., 1989). Another acritarch taxon of this zone is *Vulcanisphaera africana* (Deunff, 1961) which extends into the succeeding assemblage zone (Table 1; Fig. 3). Kroeck et al. (2020) recently carried out a comprehensive revision of the published literature on *Vulcanisphaera* and its related species. They stated that the genus *Vulcanisphaera* Deunff (1961) contains only three species, namely: (1*) V. africana* Deunff, 1961; (2) *V. mougnoana* Martin, 1973; and (3) *V. simplex* Jardiné et al., 1974. Other species are either synonymous with these three species or should be excluded from the genus. Based on their revision, the stratigraphic range of *V. mougnoana* species is from the Miaolingian (Drumian) to the Tremadocian; *V. africana* extends from the Furongian to the Floian, and *V. simplex* is restricted to the Tremadocian. Therefore, based on stratigraphic ranges of *Ninadiacrodium caudatum* and *Cymatiogalea aspergillum,* a Late Cambrian (Furongian) age is suggested for this biozone.

Table 2
Chronostratigraphical correlation of the acritarch assemblages documented in the present study with the palynozones of Ghavidel-Syooki, 1996; Ghavidel-Syooki and Vecoli, 2008; Ghavidel-Syooki, 2019; Spina et al., 2020).



System	Series/Epoch	Stage	Age (myr)	Rock units	Zonations				
					Ghavidel-Syooki, 1996	Ghavidel-Syooki & Vecoli, 2008	Ghavidel-Syooki, 2019	Spina et al., 2020	In this study
Permian	Lopingian	Changhsingian	251.902	Dalan Fm.	P2				
		Wuchiapingian	254.14						
	Guadalupian	Capitanian	259.1						
		Wordian	265.1						
		Roadian	268.8						
	Cisuralian	Kungurian	272.95	Faraghan Fm.	P1				Biozone J
		Artinskian	283.5						
		Sakmarian	290.1						
		Asselian	295 298.9						
Ordovician	Upper	Hirnantian	443.8	Seyahou Fm.	O6 O5				Biozone F & I
		Katian	445.2	▨					▨
		Sandbian	453						
	Middle	Darriwilian	458.4						
		Dapingian	467.3	Zardkuh Fm.	O4				Biozones B-E & G-H
	Lower	Floian	470		O3 O2				
		Tremadocian	477.7 485.4		O1	Zone V	Zone X		
Cambrian	Furongian	Stage 10	489.5	Ilebeyk Fm.	C2	Zone Ivc	Zone IX Zone VIII Zone VII Zone VI Zone V Zone IV	Assemblage C	Biozone A
		Jiangshanian	494			Zone Ivb			
		Paibian	497			Zone Iva			
	Miaolingian	Guzhangian		Mila Fm.	C1	Zone III Zone II	Zone III	Assem. B	
		Drumian	500.5			Zone I	Zone II Zone I	Assemblage	
		Wuliuan	504.5						
	Series 2	Stage 4	509						
		Stage 3	514 521						
	Terreneuvian	Stage 2	529						
		Fortunian	541						

4.3.2. Acritarch assemblage zone B

This assemblage zone occurs in the lowermost 56.5 m (samples AS2495–AS2512) of the Lower Shale Member of the Zardkuh Formation (Table 1; Fig. 3). The biozone is marked by abundant diacromorph taxa such as *Acanthodiacrodium angustum* (Downie, 1958) Combaz, 1967; *Acanthodiacrodium raia* (Deunff, 1961) Eisenack et al., 1979; *Acanthodiacrodium tumidum* (Deunff, 1961) Martin, 1975; *Acanthodiacrodium spinum* (Rasul, 1979); *Acanthodiacrodium ubuii* (Martin, 1968); and *Acanthodiacrodium simplex* (Combaz, 1967). Although diacromorph forms appear in both lower latitude (e.g., Baltica) and high latitude (peri-Gondwana margin) deposits, they are known to be more common at higher latitudes, possibly preferring cold-water environments (Li and Servais, 2002). The other acritarch taxa are *Vulcanisphaera simplex* Jardiné et al., 1974 (=*Vulcanisphaera britannica;* see Kroeck et al., 2019), *Saharidia fragilis* (Downie, 1958) Combaz, 1967; *Cymatiogalea górkae* (Rauscher, 1974); *Cymatiogalea boulouardii* (Deunff, 1961) Fensome et al., 1990; *Leiofusa simplex* (Combaz, 1967) Martin, 1975; and *Villosacapsula foraminifera* (Pittau, 1985; Tongiorgi et al., 1994). Likewise, *Vulcanisphaera africana* from the preceding zone persists in this biozone.

All the aforementioned acritarch taxa have the same FADs and LADs in this part of the Zardkuh Formation (Fig. 3) and have been widely reported in Tremadocian aged strata worldwide, including Iran (Ghavidel-Syooki, 1996, 2016a; Ghavidel-Syooki and Vecoli, 2008); North Africa (Combaz, 1967; Jardiné et al., 1974; Deunff and Massa, 1975; Vecoli, 1999, 2000); England (Rasul and Downie, 1974; Downie, 1984); Belgium and France (Rauscher, 1974; Vanguestaine, 1978); Spain (Wolf, 1980); Czech Republic (Vavrdová, 1989); Newfoundland, Canada (Parsons and Anderson, 2000); the Russian Platform (Volkova, 1990; Paalits, 1995); and Iraq (Baban and Lawa, 2016).

Among the diacromorph species of the genus *Acanthodiacrodium,* the stratigraphic range of *A. angustum* has been verified by independent age control and extends from the early Tremadocian based on samples from the Kallavere Formation of northern Estonia (*Cordylodus proavus* conodont zone; Volkova, 1990) and the Shinetone Shales of Shropshire, England (*Dictyonema flabelliforme* graptolite zone; Rasul and Downie, 1974; Rasul, 1979). Furthermore, other diacromorph taxa, including *Acanthodiacrodium simplex*, *Acanthodiacrodium spinum Acanthodiacrodium tumidum*, *Acanthodiacrodium ubuii*, *Acanthodiacrodium raia, Cymatiogalea boulouardii*, *Cymatiogalea gorkae*, and *Leiofusa simplex* are characteristic components of Tremadocian acritarch suites from several localities worldwide, including North Africa (Combaz, 1967; Jardiné et al., 1974; Deunff and Massa, 1975; Elaouad-Debbaj, 1988; Vecoli, 1999), Italy (Pittau, 1985), Czech Republic (Vavrdová, 1989), France and Belgium (Rauscher, 1974; Martin, 1972, 1977), Newfoundland (Canada; Dean and Martin, 1978; Martin and Dean, 1981; Parsons and Anderson, 2000), Iran (Ghavidel-Syooki, 1995, 1996, 2000, 2001, 2019), Poland (Górka, 1967, 1969), and Russia (Pazio, 2016).

Likewise, *Vulcanisphaera. simplex* is restricted to Tremadocian aged strata (Kroeck et al., 2020) and has been recorded from Iran (Ghavidel-Syooki, 2000, 2006a; Ghavidel-Syooki and Vecoli, 2008), 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., 1993), Spain (Albani et al., 2006; Palacios, 2015), and the Cambrian–Ordovician boundary of Iraq (Baban and Lawa, 2016). Accordingly, there are enough elements for an age assignment of the present zone to the earliest Ordovician (early Tremadocian) for the Lower Shale Member of the Zardkuh Formation.

Based on the *Acanthodiacrodium angustum and Vulcanisphaera simplex,* this biozone corresponds to the Tremadocian acritarch microflora RA10b of Parsons and Anderson (2000), or the Tremadocian of the *Acanthodiacrodium angustum-Vulcanisphaera simplex* (=*V. britannica*) assemblage zone of Vecoli (1999; Fig. 4), as well as to acritarch Zone O_1 of Ghavidel-Syooki (1996), acritarch Zone V of Ghavidel-Syooki and Vecoli (2008), or acritarch Zone X of Ghavidel-Syooki (2019).

4.3.3. Acritarch assemblage zone C

This assemblage zone occurs through a thickness of 195.5 m of the Zardkuh Formation (upper part of the Lower Shale and lower part of the Upper Shale members: samples AS2513–AS2550). The assemblage zone is marked by the disappearance of diacromorph taxa and the appearance of abundant galeate acritarch taxa, consisting of *Stelliferidium trifidum* (Rasul, 1974) Fensome et al., 1990; *Cymatiogalea velifera* (Downie, 1958) Martin, 1968; Cymatiogalea *stelligera* (Górka, 1967); and *Stelliferidium striatulum* (Vavrdová, 1966) Deunff et al., 1974. Likewise, other acritarch groups such as netromorph (e.g., *Leiofusa squama* Deunff, 1961), polygonomorph (e.g., *Cristallinium dentatum* Vavrdová, 1976; Martin, 1982; Polygonium *gracile* Vavrdová, 1966), and acanthomorph acritarch taxa (e.g., *Vogtlandia zardkuhensis* n. sp.) are present at a low frequency (Table 1; Fig. 3).

The galeate acritarch taxa of the Zardkuh Formation have been recorded elsewhere. *Stelliferidium trifidum* was described by Rasul (1974) as *Cymatiogalea trifida* from the Tremadocian Shineton Shales of England and then its stratigraphic range has been verified by *Tetragraptus phyllograptoides* and *Tetragraptus approximatus* graptolites zones as late Tremadoc to early Floian in Norway and Sweden (Molyneux and Rushton, 1988; Fig. 3). This species has also been recorded from the latest Tremadocian to the early Floian deposits at Watch Hill, the Lake District, England (Molyneux and Rushton, 1988), and in the Czech Republic (Fatka, 1992); from the late Tremadocian–early Arenig of Rügen, northeast Germany (Servais and Molyneux, 1997); southwest Spain (Servais and Mette, 2000); and from the late Tremadocian–early Floian deposits of Morocco (Nowak et al., 2015).

Cymatiogalea velifera has been recorded from the Shineton Shale (late Tremadocian) of Shropshire, England (Downie, 1958) and Belgium (Martin, 1968). *Cymatiogalea stelligera* was recorded from late Tremadocian deposits in Poland (Górka, 1967, 1969). *Stelliferidium striatulum* has also been recorded from Tremadocian deposits in Belgium, Algeria (Baudelot and Gery, 1979), Spain (Wolf, 1980), and Iran (Ghavidel-Syooki, 1996). Likewise, this species has been recorded from the Arenig in southern China (Brocke et al., 2000), Czech Republic (Vavrdová, 1966), France (Rauscher, 1973, 1974), Canada (Dean and Martin, 1978), Sardinia (Italy; Albani, 1989), and Pakistan (Tongiorgi et al., 1994); the Arenig–Llanvirn in France (Paris and Deunff, 1970; Rauscher, 1973, 1974), Morocco (Deunff, 1977; Elaouad-Debbaj, 1984), Libya (Deunff and Massa, 1975), Jordan (Keegan et al., 1990), and Tunisia (Vecoli, 1999).

Up to now, *Cristallinium dentatum* has been recorded from the Trémadoc–Arenig in Spain (Servais and Mette, 2000); and the Arenig in southern China (Li, 1987; Yan and Li, 2005; Yan et al., 2013) and Pakistan (Tongiorgi et al., 1994). *Leiofusa squama* has also been recorded from the Tremadocian Algerian Sahara (Deunff, 1961; Combaz, 1967) and Iran (Ghavidel-Syooki, 2016b). *Polygonium gracile* has a long-ranging stratigraphic distribution elsewhere, extending from the Upper Cambrian in England (Downie, 1984) to the Late Ordovician in Iran (Ghavidel-Syooki, 2006a, 2008). No chitinozoan taxa were present in biozones B–C of the Zardkuh Formation; therefore, based on only stratigraphic potentials of acritarch taxa, consisting of *Stelliferidium trifidum, Cymatiogalea velifera*, *Cymatiogalea stelligera*, *Leiofusa squama*, and *Stelliferidium striatulum*, a mid-late Tremadocian age is suggested for acritarch assemblage zone C of the Zardkuh Formation.

4.3.4. Acritarch assemblage zone D

This acritarch assemblage zone is present in a thickness of 40.5 m in the upper part of the Upper Shale Member of the Zardkuh Formation (samples AS2551–AS2562). It is characterized by critical acritarch taxa of Early Ordovician, supplementing those in biozone C, including *Cymatiogalea messaoudensis* var. *messaoudensis*; *Cymatiogalea deunffii* (Jardiné et al., 1974); *Rhopaliophora palmata* (Combaz and Péniguel, 1972) Playford and Martin (1984); *Pirea dubia* (Vavrdová, 1972); *Tectitheca cucullucium* (Cramer and Diéz, 1977); *Vogtlandia flosmaris* (Deunff, 1961) Molyneux (1987); *Barakella felix* (Cramer and Diéz, 1977);

Acanthodiacrodium tadlense (Cramer and Diéz, 1977); *Vavrdovella mawlawii* n. sp., and *Pseudocoryphidium zagrosensis* n. gen., & n.sp., *Arbusculidium filamentosum* (Vavrdová, 1965) and *Striatotheca principalis* var. *parva* (Burmann, 1970). Except for *Vavrdovella mawlawii* n. sp., *Pseudocoryphidium zagrosensis* n. g., and n. sp., and *Pterospermella saadii* n. sp., which are new taxa, the known stratigraphic ranges of the acritarch taxa are as follows.

Cymatiogalea messaoudensis var. *messaoudensis* is recorded for the first time from the Early Ordovician in deposits of the Zardkuh Formation. This taxon has so far been recorded from the Tremadocian in the Algerian Sahara (Jardiné et al., 1974) and Czech Republic (Fatka, 1992); from the late Tremadocian–early Arenig in Rügen, northeast Germany (Servais and Molyneux, 1997), and southwest Spain (Servais and Mette, 2000); and from the late Tremadocian–early Floian in Morocco (Nowak et al., 2015). *Cymatiogalea deunffii* has been recorded from Arenigian in the Algerain Sahara (Jardiné et al., 1974); northeast Iran (Ghavidel-Syooki, 2000, 2001); Chitral, Pakistan (Tongiorgi et al., 1994); England (Molyneux and Rushton, 1988); Spain (Mette, 1989); and Turkey (Dean and Martin, 1992; Martin, 1996).

Rhopaliophora palmata has been recorded from the Tremadocian in England (Cooper and Molyneux, 1990) and in north and south China (Li, 1987; Martin and Yin, 1988; Yin, 1995; Tongiorgi et al., 1995; Brocke et al., 2000; Yan et al., 2013); and from the Arenigian in Argentina (Rubinstein et al., 1999; Rubinstein and Toro, 2001), Iran (Ghavidel-Syooki, 2001), Russia (Raevskaya, 1999; Raevskaya et al., 2004), Australia (Playford and Wicander, 1988), Poland (Raevskaya et al., 2004), and Pakistan (Tongiorgi et al., 1994). In the present study, it is associated with the Biozone G in the Upper Shale Member, which is equivalent to the late Floian (upper stage slices Fl2 to Fl3 and upper time slice 2b to 2c; Videt et al., 2010). The genus *Rhopaliophora* is most common in low latitude (warm water) taxa, but it has also been recorded in high latitude localities, such as northern England (Cooper and Molyneux, 1990), Argentina (Rubinstein et al., 1999; Rubinstein and Toro, 2001; Rubinstein et al., 2011), southern China (Yan et al., 2013) and Iran (Ghavidel-Syooki, 2001, 2003a; this study). As such, the genus *Rhopaliophora* seems to be a eurythemic taxon (Wicander, 2004). Therefore, it can not be restricted to low latitude anymore.

Pirea dubia has been recorded from Klabava Shales (Arenigian), Bohemia (Vavrdová, 1972); Arenigian, Iran (Ghavidel-Syooki, 1990, 2000, 2001); Upper Arenigian–lower Llanvirnian (Dapingian), Tadla Basin, Morocco (Cramer et al., 1974); and Late Arenigian, Cis-Sahara, Morocco (Cramer and Diéz, 1977).

Barakella felix has been recorded from the Floian-Dapingian of southern China (Lu, 1987; Tongiorgi et al., 1995, 2003; Brocke, 1997, 1998; Brocke et al., 2000; Yan et al., 2010; Li et al., 2014; Yan et al., 2015) and Argentina (Rubinstein et al., 1999, 2011; Rubinstein and Toro, 2001; Aráoz, 2009); from the Floian deposits of Iran (Ghavidel-Syooki, 2003a, 2006a, 2006b; Ghavidel-Syooki et al., 2014 and this study); from the late Arenig of Pakistan (Quintavalle et al., 2000; Tongiorgi et al., 1994); from the Middle Ordovician (Dapingian–Darriwilian) in Tunisia (Vecoli, 1999), Morocco (Cramer and Diéz, 1977), Algeria (Vecoli, 1999; Vecoli and Le Hérissé, 2004), and the Arabian Peninsula (Jachowicz, 1995; Le Hérissé et al., 2007). The FAD of *Barakella felix* is the early Floian in southern China, but outside of China, it has not been recorded older than middle Floian (Yan et al., 2017). In the present study, *Barakella felix* is in the Biozone G of the Upper Shale Member, which represents the late Floian (upper stage slices Fl2 to Fl3 and the upper time slices 2b to 2c of Videt et al., 2010). Except for a doubtful record from Sweden, all records of *Barakella* are from the peri-Gondwana margin, making it an indicator of the peri-Gondwana paleoprovince (Yan et al., 2017). This taxon has been recorded from the Early Ordovician (late Floian), Kasba Tadla Basin, Cis-Saharan Morocco (Cramer and Diéz, 1977).

Vogtlandia flosmaris has so far been recorded from the Arenig in South Wales (Molyneux, 1987), Chitral (Pakistan; Tongiorgi et al., 1994) and southeastern Iran (Ghavidel-Syooki, 1990); from the Middle Ordovician (Llanvirnian) in the Saih Nihayda Formation of Oman (Molyneux et al., 2006) and Morocco (Deunff, 1961; Molyneux, 1987).

Dactylofusa velifera has a characteristic membrane that is easily differentiated from other fusiform Ordovician acritarch species. The taxonomy was revised based on morphological and biometric studies by Wang et al. (2015), who introduced three subspecies: *Dactylofusa velifera* var. *brevis*, *Dactylofusa velifera* var. *velifera*, and *Dactylofusa velifera* var. *sinensis*. Likewise, they stated that stratigraphical and paleogeographical occurrences of *Dactylofusa velifera* indicate that this taxon was widely distributed around the peri-Gondwanan margin during the Early Ordovician and early Middle Ordovician. *Dactylofusa velifera* is biostratigraphically important because its FAD can be used to indicate the late Tremadocian (Wang et al., 2015). Up to now, *Dactylofusa velifera* has been recorded from the Tremadocian Mabrouk Member of the Andam Formation, Oman (Molyneux et al., 2006); from the Early Ordovician–early Middle Ordovician (Dapingian) in southern China (Wang et al., 2015); from the Early Ordovician in Iran (Ghavidel-Syooki, 1990); from the Late Arenig in Pakistan (Tongiorgi et al., 1994) and Sardinia (Italy; Albani, 1989); and the Early–Middle Ordovician in Argentina (Rubinstein et al., 2019). The taxonomy, biostratigraphy, and palaeobiogeography of *D. velifera* were revised by Wang et al., 2015. Likewise, Servais et al., 2018 reviewed occurrences, particularly the first occurrences of the species, who suggested that its FAD was in the upper Tremadocian (stage slice Tr3 and time slice 1d) in Avalonia, southern Gondwana, and slightly earlier at the base of stage slice Tr3 and time slice 1c in southern China. In the present study, this species occurs in the Biozone G, corresponding to the late Floian (upper stage slices Fl2 to Fl3 and upper time slices 2b to 2c; Videt et al., 2010).

Arbusculidium filamentosum has so far been recorded from Arenigian strata of the Zagros and Alborz Mountains (Ghavidel-Syooki, 1990, 1995, 1996, 2006b), Pakistan (Tongiorgi et al., 1994), Morocco (Cramer et al., 1974), and Argentina (Rubinstein and Toro, 2001; Rubinstein et al., 2019); and from the Arenig-Llanvirnian in China (Li, 1987; Yin, 1995; Tongiorgi et al., 2003; Yan et al., 2013). The stratigraphic occurrence of this species was verified by independent age control: early Arenigian (*Didymograptus extensus* graptolite zone) Wabana Group in Bell Island, eastern Newfoundland, Canada (Martin in Dean and Martin, 1978); the highest record is late Arenigian (*Tetragraptus reclinatus abbreviatus* graptolite zone) Klabava Formation of the Prague Basin, Czech Republic (Vavrdová, 1990). Based on a revision of Servais et al. (2018), the FAD of *Arbusculidium filamentosum* is in stage slices Fl1–Fl2 of (time slice 2b) in both Avalonia and southern Gondwana, but its FAD is in stage slice Fl2 (upper part of time slice 2b) in both southern China and Argentina.

Striatotheca has been recorded from the late Tremadocian in Belgium (Martin, 1969), Algeria (Baudelot and Gery, 1979), and Spain (Wolf, 1980); the Arenig in southern China (Li, 1987; Brocke et al., 2000), Czech Republic (Vavrdová, 1966), France (Rauscher, 1973, 1974), Canada (Dean and Martin, 1978), Sardinia (Italy; Albani, 1989), Pakistan (Tongiorgi et al., 1994); northeast Iran (Ghavidel-Syooki, 1990, 2001, 2003a, 2006a), and Colombia (Rubinstein et al., 2019); from the Arenig-Llanvirn in France (Rauscher, 1974) and Morocco (Deunff, 1977; Elaouad-Debbaj, 1984; Fournier-Vinas, 1985); from the Floian-Dapingian in southern China (Yan et al., 2013); from the Middle Ordovician of France (Paris and Deunff, 1970), Libya (Deunff and Massa, 1975), Jordan (Keegan et al., 1990), South Wales (Turner, 1984), and Tunisia (Vecoli, 1999); In the present material, both *Striatotheca principalis* and *Arbusculidium filamentosum* are present in the Biozone G in the Upper Shale Member, which is equivalent to the late Floian (stage slices Fl2 to Fl3 with upper time slices 2b to 2c; Videt et al., 2010). In terms of paleobiogeography, *Striatotheca* is a characteristic component of the peri-Gondwana paleoprovince (Servais et al., 2018; Kroeck et al., 2019).

The acritarch assemblage zone D corresponds to the Biozone G, which restricts all acritarch taxa to the late Floian (upper stage slices

Fl2 to Fl3 and upper time slices 2b to 2c; Videt et al., 2010). On the other hand, from a paleobiogeographical point of view, both chitinozoan and acritarch elements indicate the peri-Gondwana paleoprovince (Webby et al., 2004; Paris, 2006; Videt et al., 2010; Servais et al., 2018; Kroeck et al., 2019).

4.3.5. Acritarch assemblage zone E

This acritarch assemblage zone is characterized by the co-occurrence of several acritarch taxa between samples AS2563 to AS2571; it has a thickness of 43.5 m in the upper part of the Upper Shale Member. The zone is marked by Early Ordovician index acritarch taxa that supplement those reported in zone D, consisting of *Aureotesta clathrata* var. *simplex* (Cramer et al., 1974) Brocke et al. (1998); *Coryphidium* sp., *Acanthodiacrodium costatum* (Burmann, 1968); *Baltisphaeridium* cf. *B. fragile* (Tongiorgi et al., 1995); *Veryhachium estrellitae* Cramer (1964); *Coryphidium bohemicum* (Vavrdová, 1972) Servais et al. (2008); *Striatotheca mutua* (Burmann, 1970); *Striatotheca transformata* (Burmann, 1970); *Striatotheca triangulata* (Cramer et al., 1974) Eisenack et al. (1976); *Striatotheca trapeziformis* (Burmann, 1970); *Tectitheca additionalis* (Burmann, 1968); *Vavrdovella areniga* (Vavrdová, 1973) *areniga* Molyneux in Molyneux and Rushton, 1988; and *Arbusculidium iranense* (Ghavidel-Syooki, 1990). The acritarch assemblage zone E corresponds to the Biozone H. The known stratigraphic ranges of the acritarch taxa are discussed below.

Aureotesta clathrata var. *simplex* has up to now been recorded from the Arenigian of England (Molyneux, 1990), Newfoundland (Canada; Dean and Martin, 1978), southern China (Brocke et al., 2000), Argentina (Rubinstein and Toro, 2001), Bohemia (Vavrdová, 1979, 1990), Pakistan (Quintavalle et al., 2000), Sardinia (Italy; Albani, 1989), and Iran (Ghavidel-Syooki, 1990, 1996, 2000, 2006a); from the Arenig-Llanvirn of Morocco (Cramer et al., 1974), Bohemia (Vavrdová, 1977, 1986), Belgium (Servais, 1991), Argentina (Rubinstein et al., 2019), and Llanvirn (Belgium; Servais and Maletz, 1992). The FAD of *Aureotesta clathrata* var. *simplex* has recently been revised by Servais et al. (2018), who suggested the early Floian (stage slice Fl1 and time slice 2a) in both Avalonia and southern China; in contrast, in southern Gondwana, its FAD in stage slice Fl2 with a lower level of time slice 2b, and in eastern Gondwana its stage slice is Fl2 with an upper level of time slice 2b. This species has not been reported from Baltica and so remains an indicator of the Peri-Gondwanan acritarch province (Li, 1987; Servais et al., 2003; Molyneux et al., 2013).

Acanthodiacrodium costatum has recorded from the Floian of Pakistan (Tongiorgi et al., 1994), Iran (Ghavidel-Syooki, 2003a, 2006a); eastern Newfoundland (Canada; Martin in Dean and Martin, 1978), Italy (Tongiorgi et al., 1984; Albani, 1989), Czech Republic (Vavrdová, 1990), Morocco (Cramer and Diéz, 1977), England (Molyneux, 1979), and southwest China (Brocke, 1996). The stratigraphic occurrences of *Acanthodiacrodium costatum* were verified by independent age control: lower Floian *Didymograptus extensus* graptolite zone of Bell island, eastern Newfoundland, Canada (Martin in Dean and Martin, 1978); the highest record is from the Dapingian (*Didymograptus* graptolite zone) of the Prague Basin, Czech Republic (Vavrdová, 1977).

Baltisphaeridium cf. *B. fragile* has been recorded from the Arenigian of southern China (Tongiorgi et al., 1995; Yan et al., 2013). *Veryhachium estrellitae* was recorded from the Arenigian of Poland (Górka, 1969), China (Wang et al., 2013), and Iran (Ghavidel-Syooki, 1990).

The genus *Coryphidium* is a common component of the peri-Gondwanan acritarch paleoprovince (Li, 1987; Servais et al., 2003; Molyneux et al., 2013); its FAD is in the uppermost Tremadocian (Servais et al., 2008). Up to now, this taxon has not been recorded from the Baltic or Laurentia (Servais and Fatka, 1997). In Avalonia, the first occurrence of *Coryphidium* in northwest England is in the upper part of sub-assemblage 3 of the *messaoudensis-trifidum* assemblage, corresponding to the uppermost Tremadocian (upper part of stage slice Tr3 and time slice 1d of Molyneux et al., 2007). Servais et al. (2018) recently revised the FAD of *Coryphidium* elsewhere, presenting the uppermost Tremadocian (stage slice Tr3 and time slice 1d) in Avalonia, southern Gondwana, and eastern Gondwana, and the late Tremadocian (stage slice Tr3 and time slice 1c) in southern China. In the present material, the FAD of *Coryphidium bohemicum* is in the Floian Stage. *Coryphidium bohemicum* is the type species of the genus *Coryphidium* and has been reported from many localities around the margin of Gondwanan, including the Arenig of France (Rauscher, 1974; Fournier-Vinas and Donnot, 1977), Ireland (Connery and Higgs, 1999), Sardinia (Italy; Albani, 1989), Argentina (Rubinstein and Toro, 2001), Pakistan (Tongiorgi et al., 1994; Quintavalle et al., 2000), and Iran (Ghavidel-Syooki, 1990, 2006a; Ghavidel-Syooki et al., 2014); the Arenig–Llanvirn of England (Turner and Wadge, 1979; Cooper et al., 1995; Molyneux and Leader, 1997), southern 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); the Llanvirn of Tunisia (Vecoli, 1999), Germany (Maletz and Servais, 1993), and Colombia (Rubinstein et al., 2019). The FAD of *Coryphidium bohemicum* has recently been revised by Servais et al. (2018), who suggested the early Floian (stage slice Fl1 and lower level of time slice 2b) in Avalonia, southern Gondwana, and southern China; in eastern Gondwana, its FAD is in the Middle Floian (stage slice Fl2 and upper level of time slice 2b).

Striatotheca was revised by Servais (1997), who suggested it as a characteristic genus of the peri-Gondwanan paleoprovince. The FAD of *Striatotheca* is at the late Tremadocian (base of stage slice Tr3 and time lice 1c of Servais et al., 2018) in both Avalonia and southern Gondwana, whereas its FAD in southern China is the early Floian (stage slice Fl1 and time slice 2a of Servais et al., 2018) and Middle Floian (stage slice Fl2 and upper level of time slice 2b of Servais et al., 2018). In the present study, some species of genus *Striatotheca* (e.g., *Striatotheca mutua, Striatotheca transformata, Striatotheca triangulata,* and *Striatotheca trapeziformis*) were identified from the uppermost part of the Upper Shale Member.

Striatotheca transformata has been recorded from the Arenigian of southwest China (Li, 1987), Vogtland (eastern Germany; Burmann, 1970; Servais, 1997), Iran (Ghavidel-Syooki, 1990, 2001, 2003a, 2006a; Ghavidel-Syooki et al., 2014), and the Llanos Basin, Colombia (Rubinstein et al., 2019). *Striatotheca triangulata* has also been recorded from the Arenigian in France (Rauscher, 1974) and southeastern Iran (Ghavidel-Syooki, 1990, 2001); and from the late Arenigian–Llanvirnian in the Tadla Basin, Morocco (Cramer et al., 1974). *Striatotheca trapeziformis* has been recorded from the late Arenigian or early Llanvirnian in eastern Germany (Burmann, 1970). *Tectitheca additionalis* has been recorded from the late Floian of southern China, (Yan and Li, 2005); the late Arenigian–early Llanvirnian of eastern Germany (Burmann, 1968); the late Floian–early Middle Ordovician (Dapingian) of southeastern Iran (Ghavidel-Syooki et al., 2014); and the Lower Darriwilian of Argentina (Rubinstein et al., 2011). *Vavrdovella areniga var. areniga* (Molyneux in Molyneux and Rushton, 1988) has been recorded from the early Arenigian in the Czech Republic (Vavrdová, 1973, 1976; Fatka, 1992), southeastern Iran (Ghavidel-Syooki, 1990), and Pakistan (Tongiorgi et al., 1994); the late Tremadocian–early Arenigian in southern China (Wang et al., 2013), southwest Spain (Servais and Mette, 2000), northern England (Molyneux and Rushton, 1988), and the northern Gondwana margin (Vecoli and Le Hérissé, 2004).

Based on the FADs of the majority of acritarch genera and species of this biozone and the absence of typical taxa of younger strata (e.g., *Frankea*, *Arkonia,* and *Orthosphaeridium*), the studied materials of acritarch assemblage zone E are assigned to the latest Floian.

4.3.6. Acritarch assemblage zone F

This acritarch assemblage zone is marked by the disappearance of Early Ordovician (Tremadocian-Floian) acritarchs and the appearance of Late Ordovician acritarch taxa in 49.5 m of the Seyahou Formation

(Fig. 3, AS2575–AS2590 and AS2575–MHS122). This assemblage is characterized by critical acritarch taxa consisting of *Navifusa ancepsipuncta* (Loeblich, 1970); *Orthosphaeridium octospinosum* var. *insculptum* (Navidi-Izad et al., 2020); *Stellechinatum uncinatum* (Downie, 1958) Molyneux, 1987; *Orthosphaeridium orthogonium* (Le Hérissé et al., 2015); *Inflatarium trilobatum* (Le Hérissé et al., 2015); *Gorgonisphaeridium antiquum* (Loeblich and Tappan, 1978); *Baltisphaeridium oligopsakium* (Loeblich and Tappan, 1978); *Veryhachium subglobosum* (Jardiné et al., 1974); *Dorsennidium hamii* (Loeblich, 1970) Sarjeant and Stancliffe, 1994; *Leiofusa litotes* (Loeblich and Tappan, 1978); and *Multiplicisphaeridium irregulare* (Staplin et al., 1965).

Among these taxa, *Stellechinatum uncinatum* is a long-ranging taxon that is recorded from the Late Cambrian in Canada (Martin, 1988); Estonia (Volkova, 1993); the Tremadocian in Estonia (Volkova, 1989) and Belgium (Vanguestaine and Brück, 2008); the early Arenig of Czech Republic (Vavrdová, 1993); and the late Arenig of England (Molyneux, 1987, 1990), Pakistan (Tongiorgi et al., 1994), Italy (Albani, 1989). The remaining are typical acritarch species of the Late Ordovician, as discussed below.

Navifusa ancepsipuncta is a typical species of the Upper Ordovician sediments of North America (Jacobson and Achab, 1985; Wicander et al., 1999), Portugal (Elaouad-Debbaj, 1984; Playford and Wicander, 2006), Morocco (Elaouad-Debbaj, 1988), Iran (Ghavidel-Syooki, 2008, 2016b, 2017a; Ghavidel-Syooki and Borji, 2018; Ghavidel-Syooki and Piri-Kangarshahi, 2021), and the Arabian Peninsula (Jachowicz, 1995; Le Hérissé et al., 2015).

Orthosphaeridium insculptum has been recorded from the Late Ordovician (Katian) Sylvan Shale in the USA (Loeblich, 1970; Wicander et al., 1999; Playford and Wicander, 2006); and from the Late Ordovician (late Katian–early Hirnantian) of Iran (Ghavidel-Syooki et al., 2011a; Ghobadi Pour et al., 2015; Ghavidel-Syooki, 2003a, 2008, 2016b, 2017a, 2017b; Ghavidel-Syooki and Piri-Kangarshahi, 2021), Portugal, Canada (Martin, 1980; Jacobson and Achab, 1985), the Arabian Peninsula (Jachowicz, 1995; Le Hérissé et al., 2015), and Libya (Abuhmida, 2013).

Orthosphaeridium orthogonium Le Hérissé et al. (2015) has been recorded from the Quwarah member of the Qasim Formation (late Katian–early Hirnantian), the Arabian Peninsula.

Inflatarium trilobatum has been recorded from the Quwarah member of the Qasim Formation (late Katian–early Hirnantian), the Arabian Peninsula (Le Hérissé et al., 2015); the Ghelli Formation (Katian–Hirnantian), northeast Alborz Mountain, Iran (Ghavidel-Syooki et al., 2011a; Ghavidel-Syooki, 2016a; Ghavidel-Syooki and Borji, 2018; Ghavidel-Syooki and Piri-Kangarshahi, 2021); the Late Ordovician (Katian–Hirnantian) Gorgan Schists in the southern Caspian Sea (Ghavidel-Syooki, 2008); and the Late Ordovician (Katian–Hirnantian) Seyahou Formation, the High Zagros Mountain (Ghavidel-Syooki, 1990).

Gorgonisphaeridium antiquum has been recorded from the Late Ordovician (Sandbian) in the United States (Loeblich and Tappan, 1978) and the Late Ordovician (Katian) of the Alborz and the Zagros Mountains, Iran (Ghavidel-Syooki et al., 2011a, 2011b; Ghavidel-Syooki, 2008, 2016a).

Baltisphaeridium oligopsakium has been recorded from the Sylvan Shale (Katian) of the United States (Loeblich and Tappan, 1978; Miller, 1991; Wicander et al., 1999; Playford and Wicander, 2006) and the Ghelli Formation, northeast Alborz Mountain, Iran (Ghavidel-Syooki et al., 2011a; Ghavidel-Syooki, 2008, 2016a, 2017a).

Veryhachium subglobosum has been recorded from the Late Ordovician of Algeria (Jardiné et al., 1974; Vecoli, 1999, 2000), Libya (Molyneux and Paris, 1985; Vecoli, 1999, 2000), Tunisia (Vecoli, 1999, 2000), Iran (Ghavidel-Syooki, 1996, 2008, 2016b: Ghavidel-Syooki and Borji, 2018), and the Arabian Peninsula (Jachowicz, 1995; Molyneux and Al-Hajri, 2000).

Dorsennidium hamii has been recorded from the Sylvan Shale (Katian) of the United States (Wicander et al., 1999; Playford and Wicander, 2006) and the Late Ordovician (Katian–Hirnantian) Ghelli and Seyahou formations, Iran (Ghavidel-Syooki et al., 2011a, 2011b; Ghavidel-Syooki, 2016a; Ghavidel-Syooki and Piri-Kangarshahi, 2021).

Leiofusa litotes has been recorded from the Late Ordovician (Katian) Sylvan Shale in the USA (Loeblich and Tappan, 1978), and the Late Ordovician (Katian) Ghelli Formation, Iran (Ghavidel-Syooki, 2000, 2016a, 2017b; Ghavidel-Syooki and Borji, 2018; Ghavidel-Syooki and Piri-Kangarshahi, 2021).

Multiplicisphaeridium irregulare has been recorded from the Caradoc–Ashgill of Gaspe Québec, Canada (Staplin et al., 1965; Martin, 1980); from the Upper Ordovician of the United States (Wright and Meyer, 1981; Wicander et al., 1999; Playford and Wicander, 2006), Belgium (Martin, 1974), and the Ashgill of Iran (Ghavidel-Syooki et al., 2011b; Ghavidel-Syooki, 2006b, 2008, 2016b; Ghavidel-Syooki and Borji, 2018; Ghavidel-Syooki and Piri-Kangarshahi, 2021).

In fact, many acritarch species recorded from several localities in Laurentia are also found elsewhere in the world, making them useful for global correlation. These include *Dorsennidium hamii, Navifusa ancepsipuncta, Multiplicisphaeridium irregulare, Gorgonisphaeridium antiquum, Orthosphaeridium orthogonium, Orthosphaeridium insculptum, Veryhachium subglobosum, Baltisphaeridium oligopsakium*, and *Leiofusa litotes.* This acritarch assemblage zone coincides with the Biozone I in the Hirnantian (stage slice Hi2), which is consistent with the samples of AS2575 to AS2590, or MHS118 to MHS122 (Fig. 3).

5. Chitinozoan systematics

5.1. List of chitinozoan fauna

The following chitinozoan taxa were identified (Plates VII–X):

Order: Operculatifera Eisenack, 1931

Family: Desmochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily: Desmochitininae Paris, 1981

Genus: **Calpichitina** Wilson and Hedlund, 1964

Calpichitina lenticularis (Bouché, 1965) (Plate VIII, 7)

Genus: **Desmochitina** Eisenack, 1931

Desmochitina gr. *minor* Eisenack, 1931 (Plate VIII, 9, 12, 13, 16)

Subfamily: Pterochitininae Paris, 1981

Genus: **Armoricochitina** Paris, 1981

Armoricochitina alborzensis Ghavidel-Syooki and Winchester-Seeto, 2002 (Plate X, 4, 8, 19)

Armoricochitina nigerica (Bouché, 1965) (Plate X, 1, 2, 3, 5, 6, 7)

Order: Prosomatifera Eisenack, 1972

Family: Conochitinidae Eisenack, 1931, emend. Paris, 1981

Subfamily: Conochitininae Paris, 1981

Genus: **Conochitina** Eisenack, 1931, emend. Paris et al., 1999

Conochitina sp (Plate VIII, 9, 12)

Genus: **Euconochitina** Taugourdeau, 1966 emend. Paris et al., 1999

Euconochitina lepta (Jenkins, 1970) emend. Paris et al., 1999 (Plate VIII, 4, 5, 6)

Euconochitina moussegoudaensis Paris *in* Le Hérissé et al., 2013 (Plate X, 9, 10, 11, 12, 13, 14, 15, 16, 20)

Euconochitina vulgaris (Jenkins, 1967) (Plate VII, 15; Plate VIII, 2, 3)

Subfamily: Belonechitininae Paris, 1981

Genus: **Belonechitina** Jansonius, 1964

Belonechitina sp. (Plate VII, 16)

Subfamily: Spinachitininae Paris, 1981

Genus: **Spinachitina** Schallreuter, 1963, emend. Paris et al., 1999

Spinachitina oulebsiri Paris et al., 2000a (Plate X, 17, 18)

Subfamily: Velatachitininae Achab et al., 1993

Genus: **Velatachitina** Poumot, 1968

Velatachitina veligera Poumot, 1968 (Plate IX, 1, 2, 3, 4, 5, 6, 7, 9)

Velatachitina nebulosa Poumot, 1968 (Plate IX, 10, 11)

Subfamily: Eremochitininae Paris, 1981

Genus: **Eremochitina** Taugourdeau and Jekhowsky, 1960

Eremochitina brevis Benoit and Taugourdeau, 1961(Plate VII, 1, 2, 3, 4, 5, 6,10)

Genus: **Siphonochitina** Jenkins, 1967

Siphonochitina sp. (Plate IX, 12)

Family: Lagenochitinidae Eisenack, 1931, emend. Paris, 1981

Subfamily: Lagenochitininae Eisenack, 1931, emend. Paris et al., 1999

Genus: **Lagenochitina** Eisenack, 1931

Lagenochitina obeligis Paris, 1981 (Plate VIII, 1; Plate VII, 13, 14; Plate IX, 8).

Subfamily: Angochitininae Paris, 1981

Genus: **Angochitina** Eisenack, 1931

Angochitina communis Jenkins, 1967 (Plate VIII, 8, 10, 11, 14, 15)

5.2. Biostratigraphy of chitinozoan fauna

Chitinozoans constitute an extinct group of mysterious organic-walled microfossils, which are exclusive marine origin (Southerland, 1994; Paris, 1981, 2006). They are characteristic of the Ordovician–Late Devonian (~488–359 Myr). Chitinozoans have been successfully used to establish the paleogeographical affinities of different terranes from different continents (Cocks and Verniers, 1998). Moreover, they are extensively used in high-resolution biostratigraphy as most of them have a short range and they allow to establish global biozonations (Paris et al., 2000a). Their biozonations based on the index species are defined on two important criteria short-ranging and their identification in surface and subsurface sequences free from breaks in sedimentation. In the present study, the identified chitinozoan fauna from the Zardkuh and Seyahou formations in Tang-e Ilebeyk, at the Zardkuh area permitted recognition of three biozones in the marine siliciclastic succession of the Ordovician rock units, which verify the First Appearance Datum (FAD) of several chitinozoan taxa, which are all well known in the peri-Gondwana Domain. These chitinozoan biozones and their biostratigraphic attribution ages are discussed below in ascending stratigraphic order (Fig. 3).

5.2.1. Biozone G

This biozone is characterized by the co-occurrence of two diagnostic chitinozoan species consisting of *Eremochitina brevis* (Benoit and Taugourdeau, 1961) and *Velatachitina veligera* (Poumot, 1968) in the Upper Shale Member of the Zardkuh Formation and extend through a thickness of 47.5 m (Fig. 3, AS2550–AS2562).

Eremochitina brevis is a diagnostic species of the Gondwanan paleocontinent that has been recorded from the Middle Floian (Whitlandian) of southwest Europe (Paris, 1981, 2006), Turkey (Paris et al., 2007), southeastern Iran (Ghavidel-Syooki et al., 2014), northwest Argentina (Achab et al., 2006), China (Chen et al., 2009), and Morocco (Elaouad-Debbaj, 1984); from late Tremadocian–middle Floian in Colombia (Rubinstein et al., 2019); from the Early Ordovician (earliest Floian) of southern China (Liang et al., 2018); and from the middle Floian–Dapingian of northwest Argentina (Achab et al., 2006), Libya (Abuhmida and Wellman, 2017). This species corresponds to the total range of the *Eremochitina brevis* biozone of Paris (1981) or the stage slice Fl3 (time slice 2c of Webby et al., 2004) in the northern Gondwana Domain.

Velatachitina veligera was recorded from the Middle Arenig of Europe (Paris, 1981), and from the late Tremadocian–middle Floian in Colombia (Rubinstein et al., 2019). It should be noted that *V. veligera* was introduced by Al-Hajri (1995) as a biozone in the upper part of the Saq Formation in the KAHF-1 well of the Arabian Peninsula. Al-Hajri (1995) stated that the *Velatachitina veligera* zone appears to be equivalent to the *Desmochitina ornensis* of Paris (1981), suggesting late Arenig or early Middle Ordovician (Dapingian) age. Based on the absence of *destombesi-baculata* chitinozoan biozones and comparison to global chronostratigraphic charts (Webby et al., 2004; Paris, 2006; Videt et al., 2010), this part of the Upper Shale Member of the Zardkuh Formation is assigned to the late Floian (stage slice Fl3 and time slice 2c of Webby et al., 2004).

5.2.2. Biozone H

This biozone is characterized by the co-occurrence of several chitinozoan species in the uppermost part of the Upper Shale Member and extends through a thickness of 52 m (sample AS2563–AS2574 or AS2563–MHS118). The chitinozoan biozone consists of *Velatachitina nebolusa* Poumot (1968); *Lagenochitina obeligis* (Paris, 1981); *Belonechitina* sp.; *Euconochitina vulgaris* (Jenkins, 1967) Paris, 1981; *Conochitina poumoti* (Combaz and Péniguel, 1972); and *Desmochitina* gr. *minor* (Paris et al., 2007). The known stratigraphic ranges of the chitinozoan taxa of this biozone are discussed below.

Lagenochitina obeligis is a long-ranging taxon that appears in the upper part of the *Eremochitina brevis* biozone and ranges up to the Darriwilian (e.g., Paris, 1981, Table 1; Samuelsson and Vernier, 2000, figs. 4 and 5). It is used as the index species of the *Lagenochitina obeligis* zone in the Lower–Middle Ordovician sequence of the South American segment of Gondwana (Grahn, 2006). The morphology of Iranian specimens shows close similarity to the type species, which was described and illustrated by Paris (1981). This taxon has been recorded from the Early Ordovician (Floian) Zardkuh Formation in Kuh-e Faraghan, northern Persian Gulf (Ghavidel-Syooki et al., 2014), and from the Early Ordovician (Floian) in southern China (Liang et al., 2018).

Euconochitina vulgaris has been recorded from the middle Floian Massif Armoricain (Paris, 1981); the middle Floian–Dapingian basal part of the Pissot Formation (Paris, 1981); the Darriwilian (artus Graptolite Biozone) Hope Shales, Shropshire, England (Jenkins, 1967); the middle Floian–Dapingian Brabant Massif, Belgium (Samuelsson and Vernier, 2000); and from the late Floian–Darriwilian Tachilla Formation, Morocco (Elaouad-Debbaj, 1984).

Conochitina poumoti was described in the “late Arenig and Llanvirn” of the Canning basin of Australia (Combaz and Péniguel, 1972). It has up to now been reported from the basal part of Lower Fezouata Formation (late Tremadocian) in the Anti-Atlas area, Morocco (Elaouad-Debbaj, 1988); the late Arenig of the Granby crater in Sweden (Grahn et al., 1996); the late Floian–Dapingian in China (Chen et al., 2009); and the Early Ordovician (late Floian) Zardkuh Formation, Kuh-e Faraghan, in the northern Persian Gulf, southern Iran (Ghavidel-Syooki et al., 2014). In brief, this species is restricted to the North African segment of Gondwana, where it ranges from Floian to Darriwilian (Benoit and Taugourdeau, 1961; Taugourdeau et al., 1967).

Velatachitina nebolusa has been recorded from the early Middle Ordovician in North Africa (Cramer, 1964; Poumot, 1968); the middle Darriwilian strata in Algeria (Paris, unpublished); the Middle Ordovician Hanadir Shale Member, northwestern Arabian Peninsula (Al-Hajri, 1995); and from the lower part of the Saih Nihayda Formation (early middle Darriwilian), Oman (Richards et al., 2010).

Desmochitina gr. *minor* is a very long-ranging and cosmopolitan species that is claimed to be found in strata ranging from the Floian to the Katian (e.g., Grahn, 1984; Paris et al., 2007; Ghavidel-Syooki, 2008). Based on comparison to global chronostratigraphic charts (Webby et al., 2004; Paris, 2006; Videt et al., 2010), and Servais et al. (2018), this part of the Upper Shale Member of the Zardkuh Formation is assigned to the late Floian (stage slice Fl3 and time slice 2c)–Dapingian (stage slice Dp1 and time slice 3a). The top of this chitinozoan biozone is marked by the pisolitic horizon that suggests a hiatus from the upper Dapingian (Dp2)–lower Hirnantian (stage slice Hi1). This pisolitic horizon is associated with starvation, reworking, sedimentation, and the onset of a distinct stratigraphic gap which is a complex process, recorded in Iran (Zardkuh/ Seyahou formations in Kuh-e Faraghan; Ghavidel-Syooki et al., 2014).

5.2.3. Biozone I

This biozone is marked by the co-occurrence of several chitinozoan species in the uppermost part of the "Paleozoic undifferentiated strata," which is now called the Seyahou Formation, and extends through a thickness of 46.5 m (Fig. 3; samples AS2575–AS2590). The Seyahou Formation reduces from 850 m in its type section (Kuh-e Faraghan) to 48 m at Tang-e Ilebeyk in the Zardkuh area. The biozone is characterized by the co-occurrence of Late Ordovician chitinozoan taxa, including *Calpichitina lenticularis* (Bouché, 1965); *Angochitina communis* Jenkins (1967); *Euconochitina lepta* (Jenkins, 1970) Paris et al., 1999; *Euconochitina moussegoudaensis* Paris in Le Hérissé et al. (2013); *Armoricochitina nigerica* (Bouché, 1965); *Armoricochitina alborzensis* Ghavidel-Syooki and Winchester-Seeto (2002); *Spinachitina oulebsiri* Paris et al. (2000a); and one chitinozoan taxon from the Middle Ordovician, namely *Siphonochitina* sp., (at the inception of this biozone). The known stratigraphic ranges of the chitinozoan taxa are discussed below.

Armoricochitina nigerica has so far been recorded from the Late Ordovician of Nigeria (Bouché, 1965); the late Caradocian–Ashgillian in northeast Libya (Molyneux and Paris, 1985; Hill and Molyneux, 1988; Grignani et al., 1991), Algeria (Oulebsir and Paris, 1995), the northern Gondwana Domain (Paris, 1990), the Arabian Peninsula (Al-Hajri, 1995; Paris et al., 2000b), and England (Van Nieuwenhove et al., 2006); the Late Ordovician (Caradocian–Ashgillian) of Morocco (Bourahrouh et al., 2004; Le Heron et al., 2008); the Late Ordovician (Katian-Hirnantian) in Turkey (Paris et al., 2007); the Ashgillian (Katian–Hirnantian) in Iran (Ghavidel-Syooki, 2008; Ghavidel-Syooki et al., 2011a; Ghavidel-Syooki et al., 2011b; Ghavidel-Syooki, 2016b, 2017a, 2017b; Ghavidel-Syooki and Borji, 2018; Ghavidel-Syooki and Piri-Kangarshahi, 2021); and the Late Ordovician (Hirnantian) in northern Chad and southeastern Libya (Le Hérissé et al., 2013; Thusu et al., 2013).

Calpichitina lenticularis has up to now been recorded from the Llandeilo–Ashgillian in Morocco (Elaouad-Debbaj, 1984; Soufiane and Achab, 1993; Bourahrouh et al., 2004; Le Heron et al., 2008); the Late Ordovician (Caradocian–Ashgillian) in the Arabian Peninsula (Al-Hajri, 1995; Paris et al., 2015; Al-Shawareb et al., 2017) and Turkey (Paris et al., 2007); the Late Ordovician (Caradocian–Ashgillian) in Algeria (Oulebsir and Paris, 1995), Libya (Molyneux and Paris, 1985), Iran (Ghavidel-Syooki and Winchester-Seeto, 2002; Ghavidel-Syooki, 2008; Ghavidel-Syooki et al., 2011a, 2011b; Ghavidel-Syooki, 2016a, 2017a, 2017b; Ghavidel-Syooki and Borji, 2018; Ghavidel-Syooki and Piri-Kangarshahi, 2021), and England (Van Nieuwenhove et al., 2006); and the Caradocian in Scandinavia (Grahn and Nõlvak, 2007).

Armoricochitina alborzensis was originally been recorded from Late Ordovician Iran (Ghavidel-Syooki and Winchester-Seeto, 2002; Ghavidel-Syooki, 2016a, 2016b, 2017a; Ghavidel-Syooki and Piri-Kangarshahi, 2021), and from Ashgillian (Katian–Hirnantian) Libya (Abuhmida, 2013).

Angochitina communis has so far been recorded from the Caradocian of Shropshire, England (Jenkins, 1967); and from the Late Ordovician (Ashgill) of England (Vandenbroucke, 2008) and Iranian Platform (Ghavidel-Syooki, 2008, 2016a, 2017a, 2017b; Ghavidel-Syooki and Piri-Kangarshahi, 2021).

Euconochitina lepta has up to now been recorded from Ashgillian of the United States (Jenkins, 1970) and Morocco (Elaouad-Debbaj, 1984; Bourahrouh et al., 2004; Le Heron et al., 2008); the Ashgillian (late Katian) in southwest Libya (Abuhmida, 2013), Algeria (Oulebsir and Paris, 1995), the Arabian Peninsula (Al-Hajri, 1995), Turkey (Steemans et al., 1996), and Iranian Platform (Ghavidel-Syooki and Winchester-Seeto, 2002; Ghavidel-Syooki, 2008, 2016a, 2017a, 2017b; Ghavidel-Syooki and Piri-Kangarshahi, 2021); and from the Late Ordovician (Hirnantian) of southeastern Turkey (Paris et al., 2007).

Euconochitina moussegoudaensis has so far been recorded from the late Hirnantian or the early Rhuddanian in northern Chad and southeast Libya (Le Hérissé et al., 2013; Thusu et al., 2013); and from the Late Ordovician (Hirnantian) in Iran (Ghavidel-Syooki, 2008, 2016a, 2017a); Ghavidel-Syooki and Borji, 2018; Ghavidel-Syooki and Piri-Kangarshahi, 2021).

Spinachitina oulebsiri forms a well known chitinozoan biozone of the northern Gondwana Doman and was originally established in the Upper Member of the M' Kratta Formation, northeast Algerian Sahara, Bordj Nili area (Paris et al., 2000a). *Spinachitina oulebsiri* is indirectly correlatable with the *persculptus* graptolite zone, indicating a late Hirnantian age (Webby et al., 2004). Accordingly, the *oulebsiri* chitinozoan biozone is of interest in the correlation of Late Ordovician strata and for the identification of the Ordovician Silurian boundary. This species has up to now been recorded from the Hirnantian in Algeria (Paris et al., 2000a); Morocco (Le Heron et al., 2008); the Ashgillian (Katian–Hirnantian) of Iran (Ghavidel-Syooki, 2008; Ghavidel-Syooki et al., 2011a, 2011b; Ghavidel-Syooki, 2016a, 2017a, 2017b; Ghavidel-Syooki and Borji, 2018; Ghavidel-Syooki and Piri-Kangarshahi, 2021); the Late Ordovician (late Hirnantian)–Early Silurian (Rhuddanian) in northern Chad and southeastern Libya (Le Hérissé et al., 2013); and the Ashgillian (early–late Katian) of southwest Libya (Abuhmida, 2013). Based on comparison to the global chronostratigraphic chart of Videt et al. (2010), this chitinozoan biozone corresponds to the total range of *Spinachitina oulebsiri* (time slice Hi2), which suggests that the Seyahou Formation of Zardkuh Mountain is Hirnantian and is equivalent to the Dargaz Formation in age (Ghavidel-Syooki et al., 2014). Herein, it should be mentioned that *Spinachitina oulebsiri* is accompanied by reworked chitinozoan taxa from older Ordovician strata (e.g., *Siphonochitina* sp., *Armoricochitina nigerica*, and *Ancyrochitina merga*, *Calpichitina lenticularis, and Angochitina communis*), corresponding to a considerable hiatus that spans from the Darriwilian to the upper Katian.

6. Miospore systematics

6.1. List of miospore taxa

The following miospore taxa were identified (Plate XI)
Anteturma: POLLENITES Potonié, 1931
Turma: SACCITES Erdtman, 1947
Subturma: MONOSACCITES (Chitaley) Potonié and Kremp, 1954
Subinferaturma: Caheniasaccites Bose and Kar, 1966
Genus: **Caheniasaccites** Bose and Kar, 1966
Caheniasaccites ellipticus Bose and Maheshwari, 1968 (Plate XI, 6)
Genus: **Boutakoffites** Bose and Kar, 1966
Boutakoffites elongatus Bose and Kar, 1966 (Plate XI, 7)
Genus: **Costapollenites** Tschudy and Kosanke, 1966
Costapollenites ellipticus Tschudy and Kosanke, 1966 (Plate XI, 13
Genus: **Fusacolpites** Bose and Kar, 1966
Fusacolpites ovatus Bose and Kar, 1966 (Plate XI, 9, 10)
Genus: **Mabuitasaccites** Bose and Kar, 1966
Mabuitasaccites ovatus Bose and Kar, 1966 (Plate XI, 15, 16)
Genus: **Striomonosaccites** Bharadwaj, 1962
Striomonosaccites brevis Bose and Kar, 1966 (Plate XI, 5)
Striomonosaccites triangularis Bose and Kar, 1966 (Plate XI, 4)
Genus: **Høegiasaccites** Bose and Kar, 1966
Høegiasaccites transitus Bose and Kar, 1966 (Plate XI, 8)
Subturma: DISACCITES Cookson, 1947
Genus: **Corisaccites** Venkatachala and Kar, 1966
Corisaccites alutas Venkatachala and Kar, 1966 (Plate XI, 11, 12)
Infraturma: Striatiti Pant, 1954
Genus: **Hamiapollenites** (Wilson, 1962) Tschudy and Kosanke, 1966
Hamiapollenites perisporites (Jizba, 1962) Tschudy and Kosanke, 1966 (Plate X, 14)
Hamiapollenites karooensis (Samolovich) Hart, 1964 (Plate XI, 1)
Anteturma: SPORITES Potonié, 1893
Infraturma: ORNATI Potonie, 1956
Genus: **Tiwariasporis** Maheshwari and Kar, 1967

Tiwariasporis gondwanensis (Tiwari) Maheshwari and Kar, 1967 (Plate XI, 2, 3)

6.2. Biostratigraphy miospore taxa Biozone J

This assemblage biozone is characterized by the disappearance of Lower Paleozoic acritarch and chitinozoan taxa and the appearance of Upper Paleozoic miospore taxa. The biozone extends through a thickness of 83.5 m (samples MHS123–MHS126) of the Faraghan Formation (Fig. 3; Table 1). The assemblage zone is marked by critical miospore taxa of the Upper Paleozoic miospore species, consisting of *Caheniasaccites ellipticus* (Bose and Maheshwari, 1968); *Boutakoffites elongatus* (Bose and Kar, 1966); *Costapollenites ellipticus* (Tschudy and Kosanke, 1966); *Fusacolpites ovatus* (Bose and Kar, 1966); *Mabuitasaccites ovatus* (Bose and Kar, 1966); *Striomonosaccites brevis* (Bose and Kar, 1966); *Striomonosaccites triangularis* (Bose and Kar, 1966); *Høegiasaccites transitus* (Bose and Kar, 1966); *Corisaccites alutas* (Venkatachala and Kar, 1966); *Hamiapollenites perisporites* (Jizba, 1962) Tschudy and Kosanke, 1966; *Hamiapollenites karooensis* (Samolovich) Hart, 1964; and *Tiwariasporis gondwanensis* (Tiwari) Maheshwari and Kar, 1967. The known stratigraphic ranges of the miospore taxa are discussed below.

Caheniasaccites ellipticus has up to now been recorded from the Lower Permian of the Congo (Bose and Kar, 1966; Bose and Maheshwari, 1968; Maheshwari and Bose, 1969) and Gabon (Jardiné et al., 1974); and the Lower Permian Faraghan Formation of Kuh-e Faraghan, the High Zagros Mountains, northern Persian Gulf (Ghavidel-Syooki, 1988, 1997).

Boutakoffites elongatus has so far been reported from Lower Permian of the Congo (Bose and Kar, 1966; Bose and Maheshwari, 1968) and the Faraghan Formation at Kuh-e Faraghan, the High Zagros Mountains, northern Persian Gulf (Ghavidel-Syooki, 1988, 1997).

Costapollenites ellipticus has hitherto been recorded from the Early Permian (Wolfcampian) of Texas, U.S.A. (Tschudy and Kosanke, 1966), Gabon (JJardiné et al., 1974), and the Faraghan Formation at Kuh-e Faraghan, the High Zagros Mountains, southern Iran (Ghavidel-Syooki, 1988, 1997).

Fusacolpites ovatus has so far been recorded from the Early Permian of the Congo (Bose and Kar, 1966, 1967), the Angoula Series of the Bekang and Koumiki Members in Gabon (Jardiné et al., 1974), and the Faraghan Formation of Kuh-e Faraghan, the High Zagros Mountains, southern Iran (Ghavidel-Syooki, 1988, 1997).

Mabuitasaccites ovatus has up to now been recoded from the Early Permian of the Congo (Bose and Kar, 1966, 1967), the Angoula Series of the Bekang Member in Gabon (Jardiné et al., 1974), and Iran (Ghavidel-Syooki, 1988, 1997).

Striomonosaccites brevis has hitherto been recorded from the Early Permian of the Congo (Bose and Kar, 1966; Maheshwari, 1969), Gabon (Jardiné et al., 1974), and Iran (Ghavidel-Syooki, 1988, 1997). *Striomonosaccites triangularis* has so far been recorded from the Early Permian of the Congo (Bose and Kar, 1966; Maheshwari, 1969), Gabon (Jardiné et al., 1974), and Iran (Ghavidel-Syooki, 1988, 1997).

Høegiasaccites transitus has been so far recorded from the Early Permian of the Congo (Bose and Kar, 1966), the Angoula Series of Bekang Member in Gabon (Jardiné et al., 1974), and the lower Faraghan Formation at Kuh-e Faraghan, southeastern Iran (Ghavidel-Syooki, 1988, 1997).

Corisaccites alutas has hitherto been recorded from the Early Permian of the Amb Formation in the Salt Range of western Pakistan (Venkatachala and Kar, 1966; Balme, 1970), India (Lele and Chandra, 1969), Australia (Segroves, 1969), Rhodesia (Chandra and Surange, 1977), the Faraghan Formation of southeastern Iran (Ghavidel-Syooki, 1988, 1997), and the Dorud Formation in central Alborz Mountains of Iran (Ghavidel-Syooki, 1995; Angiolini and Stephenson, 2008).

Hamiapollenites perisporites has so far been recorded from the Early Permian of the United States (Jizba, 1962; Tschudy and Kosanke, 1966), the Faraghan Formation at Kuh-e Faraghan in the Zagros Mountains (Ghavidel-Syooki, 1988, 1997; Spina et al., 2018), and the Dorud Formation in central Alborz Mountains of Iran (Ghavidel-Syooki, 1995). *Hamiapollenites karooensis* has so far been recorded from the Lower Permian of the Koumiki member of Agoula Series in Gabon (Jardiné et al., 1974), Tanzania (Hart, 1964), and the Faraghan Formation of Kuh-e Faraghan in the High Zagros Mountains (Ghavidel-Syooki, 1988, 1997; Spina et al., 2018).

Tiwariasporis gondwanensis has hitherto been recorded from the Lower Permian of the Barakar Formation in India (Tiwari, 1968), the Congo (Maheshwari and Kar, 1967), and the Faraghan Formation of southern Iran (Ghavidel-Syooki, 1988, 1997).

Based on the stratigraphic ranges of the above-mentioned miospore taxa, an Early Permian (Sakmarian to Kungurian) age was attributed to the Faraghan Formation at Tang-e Ilebeyk in the Zardkuh Mountain, southern Iran.

7. Paleobiogeography

On a global scale, Lower–Middle Ordovician acritarch and chitinozoan taxa show marked provincialism with two major different microflora and microfauna, consisting of the peri-Gondwanan and Baltic paleoprovinces (Molyneux et al., 2013). This provincialism was likely controlled by several paleoenvironmental factors, such as water temperature and oceanic currents (Tongiorgi et al., 1995; Molyneux et al., 2013; Servais et al., 2014). Here, the chronostratigraphic divisions adopted for the Mediterranean and “north Gondwana” are from Bergström et al. (2009). “Servais et al. (2018) pointed out that the term "north Gondwana" had been used to refer to those parts of the Paleozoic continent of Gondwana that are in the most northerly present-day positions, but that these areas had been located at high southern paleolatitudes and along the margin of southwestern Gondwana during the early Palaeozoic. Following the reconstructions of Ordovician paleogeography by Torsvik and Cocks (2017) and usage by Servais et al. (2018), the term southern Gondwana is applied here to regions between a paleolatitude of about 60°S and the Ordovician South Pole (principally North Africa but also some components of the Armorican Terrane Assemblage such as Bohemia, Saxothuringia and Iberia); western Gondwana is used for the Arabian Peninsula, Pakistan, and Western Australia; and eastern Gondwana comprises regions on the opposite margin of the paleocontinent, but data are essentially restricted to those from northwestern Argentina and Colombia. South China is treated as a separate entity situated adjacent to the western margin of Gondwana during the Early and Middle Ordovician (Torsvik and Cocks, 2017, fig. 6.1)."

Herein, the author investigated Ordovician (Zardkuh and Seyahou formations) and Permian (Faraghan Formation) rock units in the High Zagros Mountains; this resulted in 63 acritarch species (31 genera), 16 chitinozoan species (12 genera), and 12 miospore species (10 genera) that were applied to verify the paleobiogeographic position of the Zagros Mountains (i.e., Gondwanan vs. Laurentia paleoprovince). Among the identified acritarchs of the Zardkuh Formation, several morphotype taxa are important not only for biostratigraphy but also for paleobiogeography, including *Arbusculidium*, *Aureotesta*, *Barakella, Coryphidium, Dactylofusa*, *Striatotheca*, *Vavrdovella*, *Vulcanisphaera,* and *Orthosphaeridium.*

Arbusculidium was originally described by Deunff (1968) from the Tremadocian of Morocco and the species of genus were recorded subsequently from Estonia (Paalits, 1995). At the genus level, it is mainly characteristic of the Ordovician in southern Scandinavia, South America, North Africa, eastern Newfoundland, southern China, and Europe. One of the important species of this genus is *Arbusculidium filamentosum,* which is a characteristic component of the peri-Gondwanan acritarch province*;* its FAD is Fl1 in Avalonia and Gondwanan high paleolatitude (Servais et al., 2018).

Coryphidium Vavrdová (1972) is a common component of acritarch assemblages from the Floian to Darriwilian in the peri-Gondwana paleocontinent. One of the important species of this genus is *Coryphidium bohemicum,* which is a characteristic component of the peri-Gondwanan acritarch province (Vavrdová, 1972; Molyneux et al., 2013; Servais et al., 2018). This genus and its species have not been recorded from Baltica or Laurentia (Servais and Fatka, 1997).

Striatotheca Burmann (1970) is another characteristic taxon of the peri-Gondwanan acritarch province (Li, 1987; Servais, 1997; Servais et al., 2003). The most common species is *Striatotheca principalis* var. *parva,* for which the first occurrence is in basal assemblages of the *messaoudensis–trifidum* microflora in the English Lake District (Molyneux et al., 2007); that is, the uppermost Tremadocian. *Striatotheca principalis* var. *parva* has up to now been recorded from many localities of the Gondwanan margin.

Aureotesta Vavrdová (1972) and *Marrocanium* (Cramer et al., 1974) were regarded as synonyms for the reason of their morphological continuum (Brocke et al., 1997). The most common species is *Aureotesta clathrata* var. *simplex* (Brocke et al., 1998) that it has not been reported from Baltica and Laurentia. Therefore, it remains an indicator for the peri-Gondwanan acritarch assemblages (Li, 1987; Servais et al., 2003; Molyneux et al., 2013; Servais et al., 2018; Kroeck et al., 2019).

Barakella Cramer and Diéz (1977) and its two species, *Barakella felix* and *Barakella fortunata* were from the Kasba Tadla Basin, Morocco. *Barakella* is a useful taxon for biostratigraphical applications and has been widely been recorded around the Gondwana margin from high to low latitudes. *Dactylofusa* (Brito and Santos, 1965) emend. Cramer, 1970 is a morphotype that is easily recognizable from other Ordovician acritarch taxa owing to a characteristic membrane. The most common species of this genus is *Dactylofusa velifera* Cocchio (1982) that indicates a wide distribution around the peri-Gondwanan margin during the Early-early Middle Ordovician (Servais et al., 2018; Kroeck et al., 2019).

Vulcanisphaera was first erected by Deunff (1961) in Cambrian–Ordovician boundary strata of the Algerian Sahara, with a description of its type species *V. africana* Deunff (1961); it was found subsequently on most other paleocontinents, with a total of 32 species assigned to this genus. Kroeck et al. (2019) recently carried out a comprehensive revision of the published literature and suggested that *Vulcanisphaera* has three easily differentiable species: (1) *V. africana* Deunff, 1961; (2) *V. mougnoana* Martin, 1973; and (3) *V. simplex* Jardiné et al., 1974. Other species are either synonymous with these three or must be excluded from the genus. The stratigraphic ranges of the species have been determined. *V. mougnoana* ranges from the Miaolingian (Vuliuan–Guzhangian) to the Early Ordovician (Tremadocian), *V. africana* is found with certainty from the Late Cambrian (Furongian) to the Floian, and *V. simplex* is restricted to the Tremadocian. The genus *Vulcanisphaera* is very widespread, with a cosmopolitan distribution from the Late Cambrian to Early Ordovician, recording the margin of Gondwana, Avalonia, Baltica, Russia, and Laurentia (Kroeck et al., 2019).

Orthosphaeridium Eisenack (1968) is a common acritarch in the Ordovician. It was erected by Eisenack, 1968 from erratic boulders derived from the Ordovician of Baltica and subsequently from many other localities. *Orthosphaeridium* first appeared in southern China in the *Expansograptus hirundo* graptolite biozone of the early Dapingian (stage slice Dp1 and time slice 3a of the Middle Ordovician) and reached a global distribution during the Middle and Late Ordovician (Navidi-Izad et al., 2020).

Vavrdovella and *Vavrdovella areniga* were erected by Loeblich and Tappan (1976) and described as *Vavrdovella? areniga* (Vavrdová, 1973) *areniga* by Molyneux in Molyneux and Rushton (1988). *Vavrdovella* and related species have been recorded from several peri-Gondwana localities during the late Tremadocian-late Floian (Kroeck et al., 2019).

Cymatiogalea Deunff, 1961 emend. Deunff et al. (1974) and other galeate acritarch taxa are present in the Zardkuh Formation. In the present study, C*ymatiogalea messaoudensis* Jardiné et al. (1974), and *Stelliferidium trifidum* (Rasul, 1974) Rasul, 1979 were recorded for the first time from the study area. These two species and associated

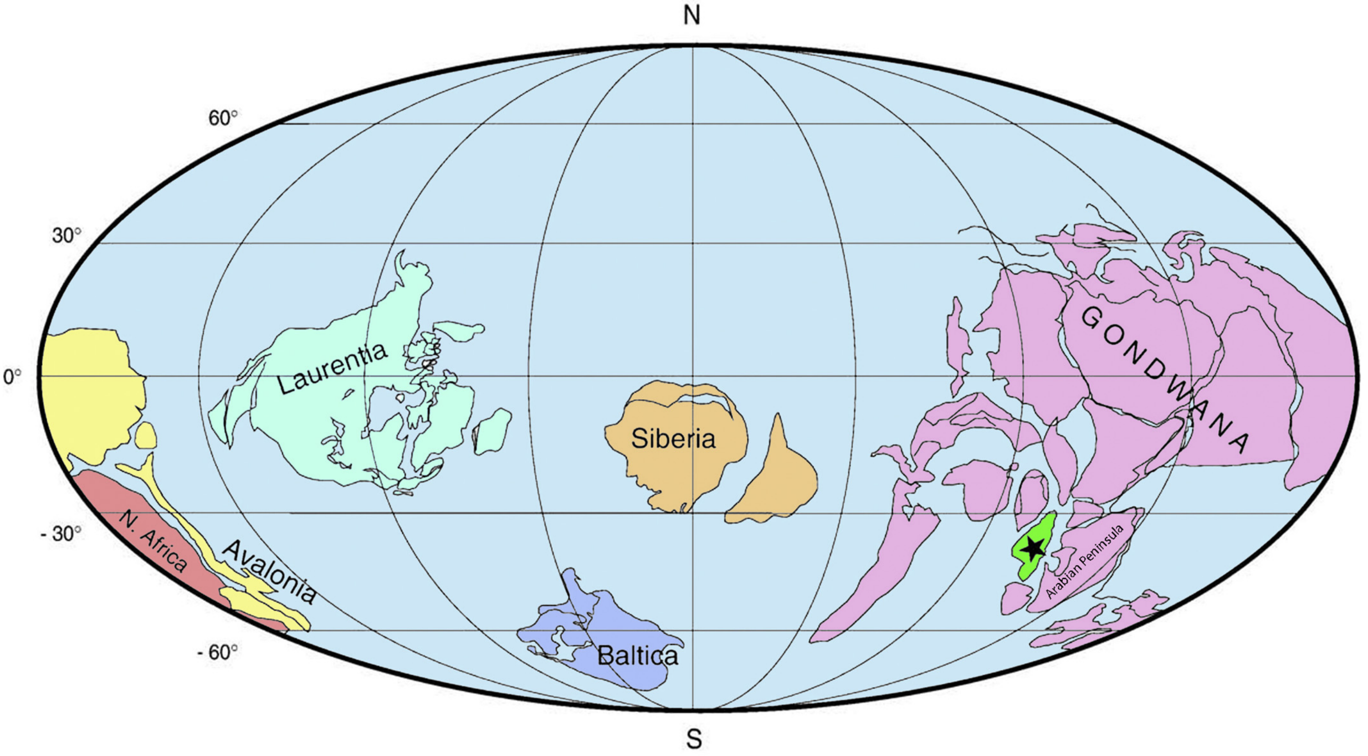


Fig. 4. Paleogeographical model of continental mass distribution during Ordovician times; figure modified from Scotese and McKerrow (1990) according to further data from Torsvik and Cocks, 2017. The star denotes the study area (star).

acritarch taxa have been introduced as the "*messaoudensis–trifidum* assemblage" from England by Servais and Molyneux (1997). Based on the literature review, there is no doubt that all localities from which this characteristic assemblage has been described are from high southern latitudes (>60°) of the Early Ordovician and were part of the northern margin of the Gondwanan continent (Servais and Mette, 2000; Molyneux et al., 2007; Servais et al., 2003). The *messaoudensis–trifidum* assemblage has never been recorded from warm-water environments, locating close to the equator (e.g., Laurentia, Australia), nor from localities in intermediate latitudes, at about 20–40 ° (e.g., South China and Baltica). It is possible to attribute this assemblage to the cold or cold-temperate area, in the southern hemisphere around the northern rim of the peri-Gondwanan continent (Servais and Mette, 2000), while the *Aryballomorpha-Athabascaella-Lua* (AAL) assemblage is regarded as a typical warm-water province at low paleolatitudes (Wicander, 2004; Servais et al., 2003). However, the distinction between these two assemblages might not be so straightforward, as some elements of the AAL assemblage also occur in high latitudes (Vecoli, 2004; Breuer and Vanguestaine, 2004); since significant "mixing" of typical elements of the two assemblages have been reported from South China and Baltica (Wang et al., 2013). Based on the above-mentioned data, there is a high similarity between the palynozones of the Zagros Mountains with peri-Gondwana acritarch assemblages that indicate Iran was located further south along with the North Africa–Gondwanan margin (Fig. 4) that was present in the paleogeographical reconstruction maps of the Ordovician period (Molyneux et al., 2013; Alvaro et al., 2013; Harper and Servais, 2013; Torsvik and Cocks, 2017; Servais et al., 2018).

8. Conclusions

Palynological analysis of the Zardkuh, Seyahou, and Faraghan formations at Tang-e Ilebeyk, in the Zardkuh area of the High Zagros Mountains yielded well-preserved, diverse, and abundant acritarch, chitinozoan, and miospore taxa that allowed for precise age dating of the investigated Paleozoic rock units. A total of 91 morphotype taxa was identified, consisting of 63 acritarch species (31 genera), 16 chitinozoans species (12 genera), and 12 miospore species (10 genera). Ten palynomorph local assemblage biozones were established within the Paleozoic succession, including six acritarch, three chitinozoan, and one miospore biozones. Acritarch assemblages A occurs in the uppermost part of the Ilebeyk Formation, indicating Late Cambrian; Assemblages B–E are present in the Zardkuh Formation, suggesting Early Ordovician (Tremadocian–Floian); and assemblage F occurs in the Seyahou Formation, indicating Late Ordovician (Hirnantian). Likewise, three well known chitinozoan biozones numbered G to I were introduced. Biozones G–H occur in the Upper Shale Member of Zardkuh Formation, supporting a late Early Ordovician (Floian) age, while Biozone I is restricted to the Seyahou Formation and suggests a Late Ordovician (Hirnantian) age. Finally, miospore assemblage J is present in the Faraghan Formation, substantiating an Early Permian age.

Five acritarch taxa were erected as new species, namely *Vogtlandia zardkuhensis* n. sp., *Pseudocoryphidium zagrosensis* n. gen. & n. sp., *Vavrdovella mawlawii* n. sp., *Pterospermella saadii* n. sp., and *Coryphidium* sp. It should be mentioned that *Coryphidium* sp., was left in open nomenclature because of insufficient specimens. Likewise, *Arbusculidium iranica* was emended and introduced as *Arbusculidium iranense* n. sp.

Several easily recognizable acritarch taxa were identified in the Zardkuh Formation, including *Arbusculidium filamentosum, Barakella felix*, *Coryphidium bohemicum*, *Dactylofusa velifera*, *Striatotheca* spp., *Cymatiogalea messaoudensis* var. *messaoudensis*, *Aureotesta clathrata* var. *simplex, Rhopaliophora palmata*, and *Vavrdovella areniga* var. *areniga*. Among these acritarch taxa, some, such as *Arbusculidium*, *Striatotheca*, and *Coryphidium*, are relatively more important since they belong to the peri-Gondwanan acritarch province, suggesting that the Zagros terrane was part of the peri-Gondwanan paleoprovince during the Lower Ordovician. Moreover, three diagnostic taxa (*Coryphidium*, *Striatotheca*, and *Arbusculidium)* are also present in the Lower and Middle Ordovician of the Alborz Mountains and east-central Iran, suggesting that all parts of Iran were included in the peri-Gondwanan paleoprovince, within a colder-water depositional environment. Furthermore, paleogeographic reconstruction maps of Torsvik and Cocks (2017) have placed the Zagros region at mid to high southern paleolatitudes at about 50°S to 60°S during the Ordovician. *Rhopaliophora* is the most common taxon at low latitudes, but has also been found in higher latitude localities such as northern England (Cooper and Molyneux, 1990), Argentina (Rubinstein et al., 1999), Iran (Ghavidel-Syooki, 2001), and China (Yan et al., 2013). Based on the FADs of the identified genera and their species and the absence of typical taxa of younger strata, such as *Frankea, Arkonia*, and *Orthosphaeridium*, the studied material of the Zardkuh Formation is probably late Floian in age; however, the presence of *Velatachitina nebulosa* and *Belonechitina* sp., could be suggestive of early Middle Ordovician (Dapingian) for the uppermost part of the formation.

Based on the potential and presence of palynological assemblage zones, two hiatuses are present within the Paleozoic sequence at Tang-e Ilebeyk. The first hiatus appears between the Zardkuh and Seyahou formations, spanning the late Middle Ordovician (stage slice Dp 2) to Late Ordovician (stage slice Hi2). The second is present between the Seyahou and Faraghan formations, encompassing the whole Silurian (Sarchahan Fm.), Devonian (Zakeen Fm.), and Carboniferous.

In terms of paleobiogeography, the presence of the three diagnostic acritarch genera (*Arbusculidium*, *Coryphidium*, and *Striatotheca*) indicate that not only the Zagros terrane but also the Alborz and central-eastern terranes were included in the peri-Gondwanan acritarch province. Furthermore, the "*messaoudensis–trifidum* acritarch assemblage" is regarded as representing a typical cold-water province, at middle to high paleolatitudes while the AAL assemblage is regarded as a typical warm-water province at low paleolatitudes. However, the distinction between these two assemblages might not be so straightforward, as some elements of the AAL assemblage also occur in high latitudes; since significant "mixing" of typical elements of the two assemblages have recently been reported from South China and Baltica. The presence of these taxa in the Zardkuh Formation reveals that the study area was located at a high southern latitude (50°–60°S). This acritarch assemblage is characteristic of high southern latitude cold-water environments on the periphery of Gondwana and it has never been recorded from a warm-water environment close to the equator (e.g., Laurentia, Australia).

In this study, the encountered chitinozoan fauna have resulted in three chitinozoan biozones, consisting of *Eremochitina brevis*, *Lagenochitina obeligis*, and *Spinachitina oulebsiri.* The *Eremochitina brevis* Biozone is present in the Upper Shale Member of the Zardkuh Formation, where it is associated with *Velatachitina veligera.* These two chitinozoan species are characteristic elements of the southern Gondwanan paleoprovince during the Early Ordovician (Floian). The *Lagenochitina obeligis* biozone also appears in the uppermost part of the Lower Shale Member of the Zardkuh Formation. The accompanying species include *Velatachitina nebolusa*, *Euconochitina vulgaris*, *Conochitina poumoti*, *Belonechitina* sp., and *Desmochitina* gr. *minor*. Except for *Desmochitina* gr. *minor*, which is a long-ranging and cosmopolitan taxon, the rest are Gondwanic elements of the late Early Ordovician (Floian) to early Middle Ordovician (Dapingian). The *Spinachitina oulebsiri* Biozone is present in the Seyahou Formation and is associated with other classical components of the Late Ordovician, such as *Calpichitina lenticularis*, *Angochitina communis*, *Euconochitina lepta*, *Euconochitina moussegoudaensis*, *Armoricochitina nigerica*, and *Armoricochitina alborzensis.* The *Spinachitina oulebsiri* biozone is also well known in the northern Gondwana paleoprovince during the Late Ordovician (late Hirnantian).

Over the past 20 years, chitinozoan research has resulted in three major and well-documented paleogeographic provinces (e.g., Laurentia, Baltica, and northern Gondwana). Despite an increasing number of studies, fundamental differences have not been revealed in the composition of chitinozoan assemblages between major paleogeographic domains. To date, five genera, appear to be restricted to the northern Gondwana realm during the Ordovician, which was located at a relatively high latitude (e.g., *Armoricochitina*, *Eremochitina*, *Velatachitina*, *Sagenochitina*, and *Siphonochitina*). In contrast, many cosmopolitan species are known from both equatorial and circum-polar paleolatitudes (e.g., *Acanthochitina symmetrica*, *Cyathochitina campanulaeformis*, *Desmochitina minor*, *Lagenochitina baltica*, *Plectochitina sylvanica*). The chitinozoan biozonations of the Baltica, Gondwana, and Laurentia domains highlight differences at the species level between the three major paleogeographic realms. All of the chitinozoan species found in the Ordovician of the Zardkuh Mountain have been recorded from the northern Gondwana Domain, which includes North Africa (Morocco, Algeria, Tunisia, Libya, and Nigeria), the Middle East (the Arabian Peninsula, Syria, Jordan, Iran), southwestern Europe (Italy, France, Spain, and Portugal), and Central Europe (Czech Republic). In particular, *Eremochitina brevis*, *Armoricochitina nigerica*, *Ancyrochitina merga*, and *Spinachitina oulebsiri* have never been recorded outside of northern Gondwana. In conclusion, evidence from acritarch and chitinozoan biogeographic affinities indicate that the study locality belongs to a peri-Gondwanan paleogeographical domain; this is consistent with recent paleogeographic reconstruction maps that place Iran at the high latitudes on the periphery of the Gondwanan supercontinent, paleogeographically separated from the Laurentian and Baltican paleocontinents by a large ocean (Iapetus).

The identified miospore taxa from the Faraghan Formation of Tang-e Ilebeyk consist of *Caheniasaccites ellipticus*, *Boutakoffites elongatus*, *Costapollenites ellipticus*, *Fusacolpites ovatus*, *Mabuitasaccites ovatus*, *Striomonosaccites brevis*, *Striomonosaccites triangularis*, *Høegiasaccites transitus*, *Corisaccites alutas*, *Hamiapollenites perisporites*, *Hamiapollenites karooensis*, and *Tiwariasporis gondwanensis*. Among the miospore taxa, except for *Hamiapollenites perisporites* and *Costapollenites ellipticus*, which have a global distribution during the Early Permian, the rest has been recorded from different parts of the Gondwanan paleoprovince (e.g., Australia, Angola, Congo, India, Pakistan, and Iran).

Declaration of Competing Interest

I wish to submit an original research article for publication in Review of Palaeobotany and Palynology, titled “Peri-Gondwanan acritarchs, chitinozoans, and miospores from Paleozoic succession in the High Zagros Mountains, southern Iran: Regional stratigraphic significance and paleogeographic implications.” This manuscript has not been published or presented elsewhere in part or in its entirety and is not under consideration by any other journal. I have read and understood your journal's policies, and I believe that neither the manuscript nor the study violates any of these. There are no conflicts of interest to declare.

Acknowledgments

The author wishes to acknowledge two anonymous referees for their valuable suggestions that greatly improved the manuscript. Likewise, the author would like to thank Zahra Orak for the palynological analysis of samples and M.H. Piri-Kangarshahi for drafting tables and figures. The author specially thanks his wife and his daughters, Hedieh Ghavidel-Syooki and Mona Ghavidel-Syooki, for their encouragement to finalize this contribution. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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