Journal of Sciences, Islamic Republic of Iran 29(1): 35 - 51 (2018) http://jsciences.ut.ac.ir
University of Tehran, ISSN 1016-1104

Chronostratigrahy of Acritarchs and Chitinozoans from upper Ordovician Strata from the Robat-e Gharabil Area, NE Alborz Mountains, Northern Khorassan Province: Stratigraphic and Paleogeographic Implications

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Received: 5 September 2016 / Revised: 14 January 2017 / Accepted: 13 February 2017

Abstract

The Palaeozoic rock units mainly, Ghelli, Niur, Padeha, Khoshyeilagh and Mobark formations are well-exposed in the north of Robat-e Gharabil village. 116 out of 157 surface samples were analyzed to determine aged relationships of Ghelli Formation. The samples of Ghelli Formation are dominated by acritarchs (42 species belonging to 23 genera) and chitinozoans (26 species distributing among 15 genera). Two new acritarch species are introduced, consisting of *Goniosphaeridium iranense* n.sp., and *Goniosphaeridium persianense* n. sp. Based on the restricted stratigraphic range of chitinozoan species, Late Ordovician (Ashgill) age is assigned to the Ghelli Formation. On the other hand, the presence of diagnostic chitinozoan taxa in the Ghelli Formation consisting of *Armoricochitina nigerica*, *Ancyrochitina merga*, and *Spinachitina oulebsiri* chitinozoan biozones, suggest a clear palaeobiogeographic affinity between NE Alborz Mountain and North Gondwana Domain. The presence of some chitinozoan and acritarch taxa from the Baltic and Laurentia in Gondwanan chitinozoan biozones of the Robat-e Gharabil area suggests the existence of counter-clockwise marine currents that resulted in bringing planktonic organisms (acritarchs and chitinozoans) from lower latitudes (Baltica) to higher latitudes (Northern Gondwanan Domain) settings.

Keywords: Acritarchs; Chitinozoans; Biostratigraphy; NE Alborz Mountain; Northeastern Iran.

Introduction

The Palaeozoic strata are well exposed in 4km of the north of Robat-e Gharabil village. The road from Gorgan to Robat-e Gharabil or Shahrud - Jajarm cities and Robate-e Gharabil are the principal links to the study area (Fig. 1). Herein, the Palaeozoic succession crops out in Kuh-e- Kurkhud, nothern Robat-e Gharabil village and divides, in ascending stratigraphic order, into the Barut (Upper Precambrian), Ghelli

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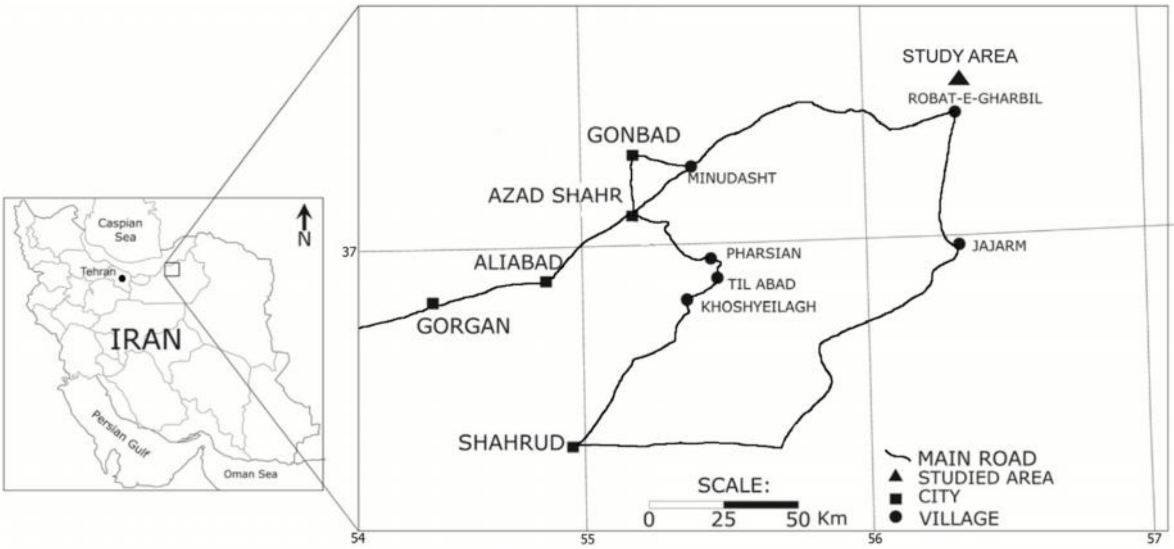

Figure 1. Geographic setting and location of study section (after Ghavidel-Syooki et al. 2011).

(Ordovician), Niur (Silurian), Padeha, Khoshyeilagh (Upper Devonian) and Mobarak Formation (Lower Carboniferous). Due to lack of diagnostic fossils, the precise age of the Ghelli Formation has not been determined in Kuh-e-Kurkhurd, northern Robate Gharabil village. Hence, based on stratigraphic position, this formation has been assigned to the Ordovician? or Silurian? This paper is concerned with age determination of the Ghelli Formation in the Kuh-e-Kurkhurd, northern Robat-e-Gharabil village. Therefore, a stratigraphical column was measured and sampled in order to determine not only the age relationship of this Palaeozoic rock unit, but also the palaeogeographic position of this part of the Alborz Mountains by using acritarchs and chitinozoans. The encountered fauna and flora will also clarify their affiliations to the Gondwanan and/or Laurentia palaeo-provinces.

1- Regional stratigraphic setting

The Ghelli Formation is well-developed at its stratotype in the Kuh-e-Saluk, northern Ghelli village, approximately, 55km southwest of Bojnourd city, in the NE Alborz Mountain Range.

In the Robat-e-Gharabil village, the Palaeozoic succession has a thickness of 465m and in ascending stratigraphic order; it has been divided into the Ghelli (183m), Padeha (159m) and Khoshyeilagh formations (123m) [3]. The thickness of the formations substantially reduces from Kuh-e-Saluk in northern Ghelli village toward the Kuh-e-Kurkhurd, northern Robat-e- Gharabil village. The distance of the studied stratigraphic section is approximately, 4 km north of the Robat-e Gharabil village with geographical coordination's of basal part section 56 °, 19', 50.01″E longitude and 37,° 21′, 16.16" N latitude. The base of the Ghelli strata is traversed by the Almeh fault. Therefore, the Ghelli Formation rests on the Barut Formation in the lower contact whereas its upper contact with a disconformity is covered by the Padeha Formation. Hence, there is a hiatus between the Ghelli and Padeha formations, encompassing the Silurian period. The Palaeozoic succession of northern Robat-e-Gharabil village in the Kuh-Kurkhurd in ascending stratigraphic order, is as below:

Ghelli Formation: This formation was named and introduced for the Ordovician deposits in the northeastern Alborz Mountain Ranges (Kopeh Dagh Region) for the first time by [3]. The Ghelli Formation was named after Ghelli village where locates in the southern flank of Kuh- e –Saluk (Saluk Mountain), 55km southwest Bojnourd city. The Ghelli Formation has a thickness more than 900m [3, 14].This formation has been divided into three members in the stratotype which are discussed from base to top as the followings:

A - Volcanic Member

This member consists of pyroclastic elements, lava flow and sedimentary strata which is overlain by the Shale and Sandstone Member of the Ghelli Formation with the Katian age. This member has a thickness of 262m and from base to top comprises 20m light gray agglomerate, 121m basic volcanic rock, 1m light brown limestone and gray shale, 20m basic volcanic rock, 20m biosparite, dark gray, sandy limestone with thin layers of calcareous shale, 30m dark brown and green in part sandstone, coarse-grained poor to medium sorted and cross-bedded in the lower part and graded in the top, 50m dark green basic volcanic rock, 0.2m red-brown highly fossiliferous shale and o.3m light buff fossiliferous limestone [3] . Based on marine palynomorph (acritarchs) and brachiopod fauna, this interval of the Ghelli Formation has been assigned to the Middle – early Late Ordovician [14].This member of Ghelli Formation is not present the Kuh-e-Kurkhurd in the northern of Robat-e Gharabil village.

B - Shale and Sandstone Member

This member has a thickness 412m and rests on the volcanic Member. The Shale and Sandstone Member of Ghelli Formation from base to top consists of 2m reddish brown, unsorted bioclast wackstone/packstone and non-calcareous siliciclastic sediments (e.g. shale, siltstone, and sandstone) upward. 40m out of 412m mostly composes of sandstone with interbedded sandy shales. It should be mentioned that there are sedimentary textures such as coarsening-upward in this sandstone unit. This member of Ghelli Formation has assigned to the Katian by using chitinozoan biozones in the Ghelli area [14, 16].This Member is not present in Kuh-e Kurkhurd, in northern of Robat-e- Gharabil village.

C - Mélange Member

This member is 224 m thick and consists of syndeposite mélange of greenish gray silty shale, siltstone and sandstone, grading near to the top to a normal shale sequence [3], Afshar-Harb, in his first geological investigation has stated that only lower member of the Ghelli Formation contains brachiopod fauna (Volcanic Member). Therefore, based on stratigraphic position, he assigned Ordovician age to the Ghelli Formation. Later on, one sample from the top of Ghelli Formation (Mélange Member) was studied for palynomorphs by J.J. Chateauneuf and a few samples from the Niur Formation for brachiopods by J.G.Jenny [3 see reference therein]. Hence based on paleontological data, he assigned the Upper Ordovician for the Ghelli Formation and the Lower Silurian for the Niur Formation. In this study, observation of field works and palaeontological data revealed that he Volcanic, Shale and Sandstone as well mélange members of the Ghelli Formation are not present because of the major fault of Robat-e –Gharabil village at the base of Ghelli Formation. The lower Palaeozoic succession is183 m thick in Kuh-Kurkhurd in north of the Robat-e-Gharabil village. The reduced thickness of the Ghelli Formation is either related to the major fault at the base lower Palaeozoic succession or disconformity between the Ghelli and Padeha formations. As a result of this study, we suggest that only uppermost Shale and Sandstone member of the Ghelli Formation and the Shale member of the Niur Formation have outcrop in the Kuh-e-Kurkhurd in the northern of the Robat-e-Gharabil village.

Materials and Methods

One hundred and sixteen surface samples were collected for palynological study from the Lower Palaeozoic succession near north of the Robat-e-Gharabil village in the Kuh-e- Kurkhurd area. The field and laboratory descriptions of samples are shown on the stratigraphic column (Fig. 2). Each sample is designated with the National Iranian Oil Company Code number with the prefix MG-SB the samples include MG-SB-02 to MG-SB-157 and deposited in the Natural History Museum Department Organization Environment (DOE). Palynomorph entities were extracted from shale, siltstone and fine grained sandstone samples by using the standard palynological technique of treatment in HCl and HF to remove carbonate and silicate, respectively, followed by neutralizing the residue in distilled water after each acid treatment. Samples were not oxidized, and the resultant residues of each sample were treated with 30ml of saturated zinc bromide with a specific gravity of 1.95. The remaining organic residue was then sieved through a 15μm nylon mesh sieve in order to eliminate the finer debris and facilitate palynological analyses. Palynological preparations were then studied by using transmitted light and scanning electron microscopy. The miospores and acritarchs range in color from yellow to orange-brown, indicating an intermediate degree of thermal maturity (Plates I-II). All slides used in this study are housed in the Palaeontological Collections in the Natural History Museum Department Organization Environment (DOE) including, the sample MG-SB-02 to MG-SB-157.

2-Palynostratigraphy

Most of the studied samples contained well-preserved and abundant palynomorphs (e. g. acritarchs, chitinozoans, scolecodonts and graptolite remains) with the exception of those collected from the Padeha Formation, which are barren, consisting of a succession of evaporate and dolomite . In general, the acritarchs are more abundant than other palynomorphs in the Lower Palaeozoic succession of Kuh-e-Kukhurd in north of Robat-e-Gharabil village.

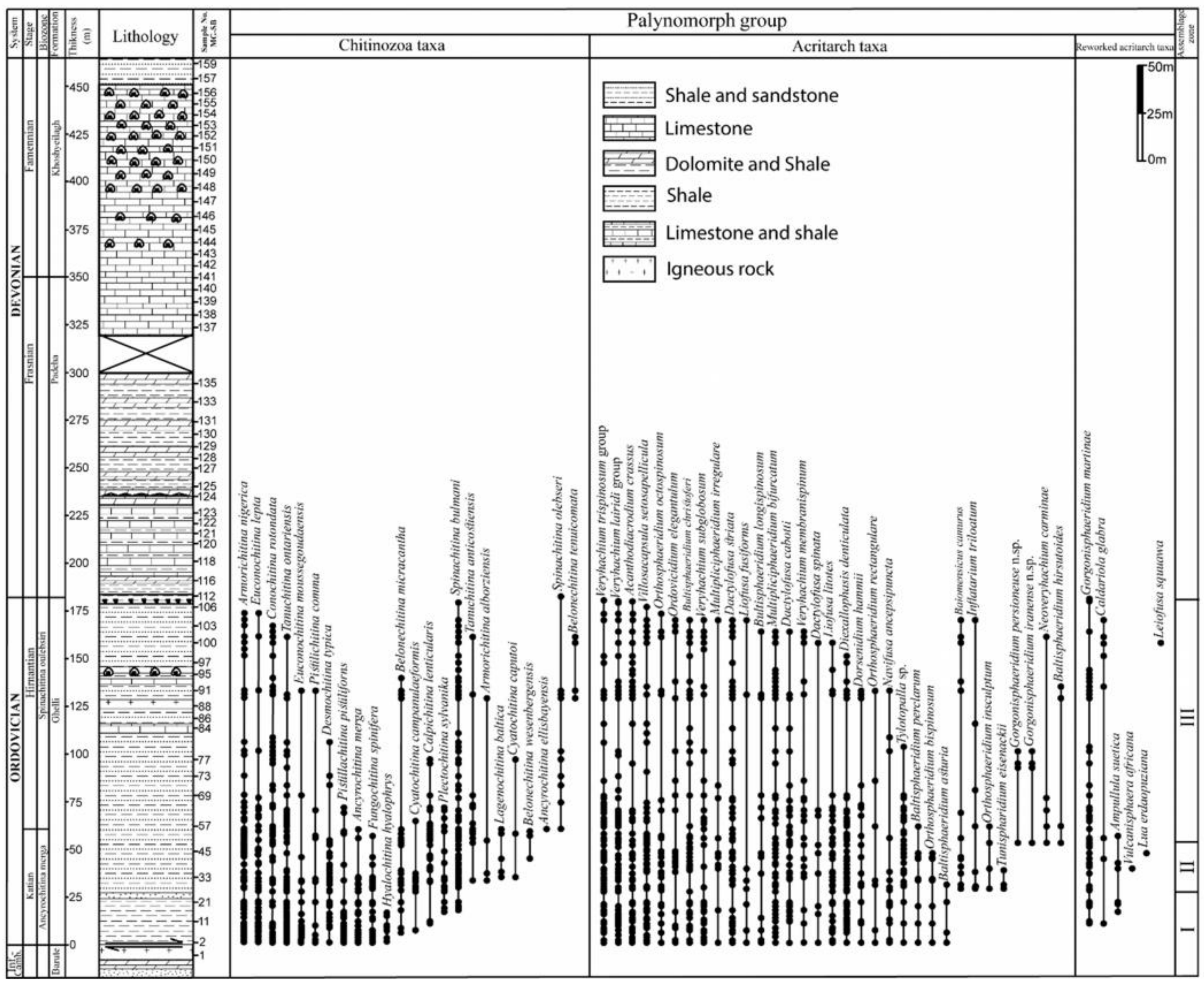

Figure 2. Lithostratigraphy, stratigraphic distribution of palynomorphs, biozonations, and chronostratigraphic attribution of the study section.

The palynomorph entities and organic debris are dark yellow to orange-brown in color, which indicates a fairly high thermal maturity for the organic materials of Lower Palaeozoic strata (Thermal Alteration Index = 3. 5 -4.0) in this part of the Alborz Mountain Ranges. In this study, 42 acritarch species (23 genera) and 27 chitinozoan species (15 genera) were recognized. In addition, rare graptolite remains and common scolecodonts were also encountered, which have not been described in the present study. The chitinozoans permit the recognition of two biozones in the Lower Palaeozoic succession of study area, which are well known in the so-called "North Gondwana Domain"[39]. The chitinozoan biozones are discussed below in ascending stratigraphical order along with biostratigraphic age [36]. The identified chitinozoan taxa discussed herein are well known elsewhere [15, 16, and 39]; therefore, they are listed below according to the grouping of the classification scheme of [38]. Likewise, the acritarch taxa discussed and illustrated herein are followed as form species and form genera under provisions of the International Code of Botanical Nomenclature (I. C. B. N) and are arranged alphabetically by genera under the informal *incertae sedis* "acritarch" group.

2. 1. Acritarchs

The following acritarch taxa were identified (Plates I-III):

Group Acritarcha Evitt, 1963
Genus *Acanthodiacrodium* [52].
Acanthodiacrodium crassus [52] [Plate II, 1, 11]
Genus *Ampullula* [7]
Ampullula suetica [7] [Plate II, 2]
Genus *Baltisphaeridium* [11]
Baltisphaeridium asturiae [7] [Plate II, 14].
Baltisphaeridium longispinosum [47] [Plate II, 5]
Baltisphaeridium hirsutoides [9] [PlateII, 15].
Baltisphaeridium christoferi [9] [Plate I, 20; Plate III, 9]
Baltisphaeridium perclarum [32] [Plate II, 4]
Genus *Baiomeniscus* [32]
Baiomeniscus camurus [32] [Plate II, 8]
Genus *Caldariola* [33]
Caldariola glabra [33] [Plate I, 13].
Genus *Dactylofusa* [7]
Dactylofusa striata [13] [Plate II, 6].
Dactylofusa [13] [Plate I, 19].
Dactylofusa cabottii [13] [Plate II, 19].
Dactylofusa spinata [7] [Plate I, 19].
Genus *Diexallophasis* [7]
Diexallophasis denticulata [13] [Plate II, 13].
Genus *Dorsennidium* [7].
Dorsennidium hamii [7] [Plate I, 5].
Genus Goniosphaeridium [7]
Goniosphaeridium martinae [12] [Plate III, 11, 12]
Goniosphaeridium iranense n. sp. [Plate III, 1, 2, 4, 5]
Goniosphaeridium persianense n. sp. [Plate III, 3, 6, 7, 10]
Genus *Inflatarium* [28].
Inflatarium trilobatum [28] [Plate I, 18]
Genus *Leiofusa* [29]
Leiofusa fusiformis [29] [Plate II, 9].
Leiofusa squama [7] [Plate II, 7].
Leiofusa litotes [32] [Plate II, 10].
Genus *Lua* [33]
Lua erdaopuziana [33] [Plate II, 3].
Genus *Multiplicisphaeridium* [7]
Multiplicisphaeridium bifurcatum [45] [Plate II, 17].
Multiplicisphaeridium irregulare [45] [Plate II, 18].
Genus *Navifusa* [29]
Navifusa ancepsipuncta [29] [Plate II, 20]
Genus Neoveryhachium [7]
Neoveryhachium carminae [7] [Plate I, 1]
Genus *Ninadiacrodium* [42]
Ninadiacrodium caudatum [42] [Plate I, 15].
Genus *Ordovicidium* [45]
Ordovicidium elegantulum [45] [Plate II, 16].
Genus *Orthosphaeridium* [27]
Orthosphaeridium bispinosum [7] [Plate I, 3].
Orthosphaeridium rectangulare [11] [Plate I, 11].
Orthosphaeridium insculptum [31] [Plate I, 12].
Orthosphaeridium octospinosum [11] [Plate I, 2].
Genus *Tunisphaeridium* [32]
Tunisphaeridium eisenackii [32] [Plate I, 16].
Genus *Tylotopalla* [31]
Tylotopalla sp.cf. *T. caelamenicutis* [31] [Plate I, 17].
Genus *Veryhachium* [43]
Veryhachium lairdii group [Plate I, 4]
Veryhachium trispinosum group [Plate I, 9]
Veryhachium membranispinum [14] [Plate I, 6].
Veryhachium europium group [Plate II, 12]
Veryhachium subglobosum [22] [Plate I, 8].
Veryhachium reductum [23] [Plate I, 10].
Genus *Villosacapsula* [32]
Villosacapsula setosapellicula [32] [Plate I, 7].
Genus *Vulcanisphaera* [43]
Vulcanisphaera africana [43] [Plate I, 14].

Systematic descriptions of new acritarch species

In this study, acritarch taxa from the Lower Palaeozoic succession (Ghelli Formation) were illustrated on plates I through III. Detailed descriptions were provided only for new taxa (Plate III). The picked specimens and the individuals observed under Scanning

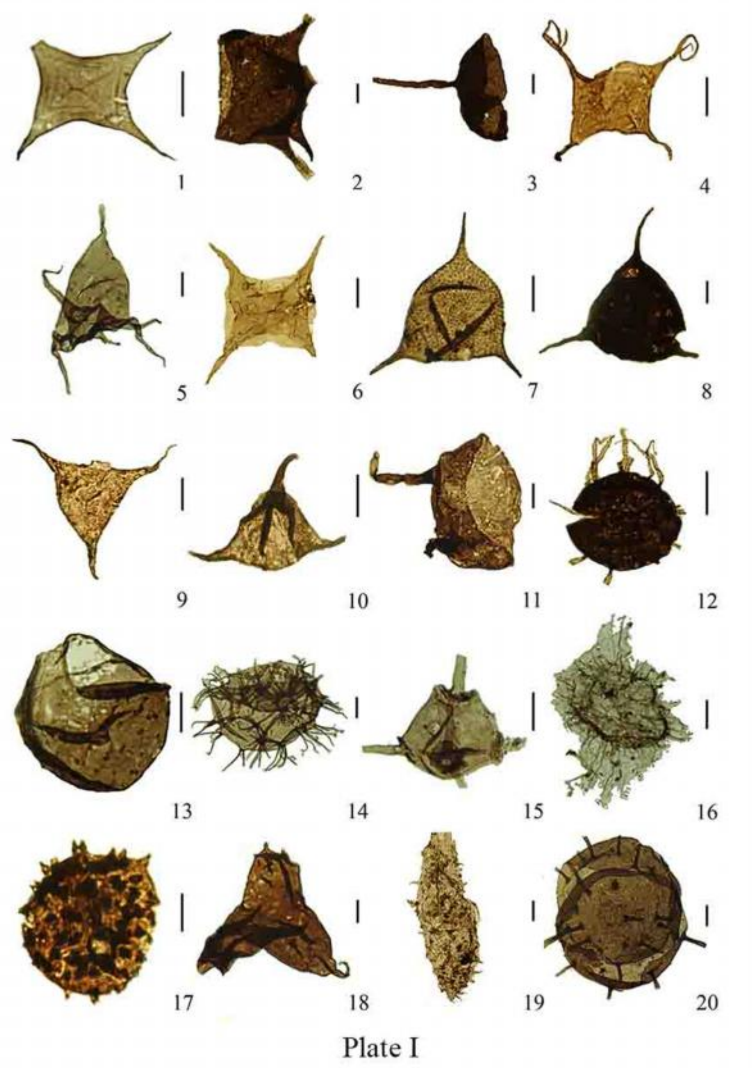

Plate I (Scale bars represent 10 um)
Fig.1. *Neoveryhachium carminae* [7].
Fig.2. Orthosphaeridium octospinosum [11].
Fig.3. *Orthosphaeridium bispinosum* [7].
Fig.4. *Veryhachium lairdii* group
Fig.5. *Dorsennidium hamii* [7].
Fig.6. *Veryhachium membranispinum* [14].
Fig.7. *Villosacapsula setosapellicula* [33].
Fig.8. *Veryhachium subglobosum* [22].
Fig.9. *Dactylofusa spinata* [13].
Fig.10.*Veryhachium reductum* [24].
Fig.11. *Orthosphaeridium rectangulare* [11].
Fig.12. *Orthosphaeridium insculptum* [11].
Fig.13. *Caldariola glabra* [33].
Fig.14. *Vulcanisphaera africana* [43].
Fig.15. *Ninadiacrodium caudatum* [42].
Fig.16. *Tunisphaeridium eisenackii* [32].
Fig.17. *Tylotopalla* sp.cf. *T. caelamenicutis* [32].
Fig.18. *Inflatarium trilobatum* [29].
Fig.19. *Dactylofusa spinata* [33].
Fig.20. *Baltisphaeridium christoferi* [9].

Electron Microscope (SEM) are housed in the palynological collections of the National Historical Museum of Department Origination Environment (DOE) of Iran under samples number of MG-SB-02 to

MG-SB-157.

Genus *Goniosphaeridium* Eisenack, 1969

Type species: *Goniosphaeridium polygonale* ex *Ovum hispidium polygonale* Eisenack, 1931

Goniosphaeridium persianense n.sp. (Plate III, 3, 6, 7, 10)

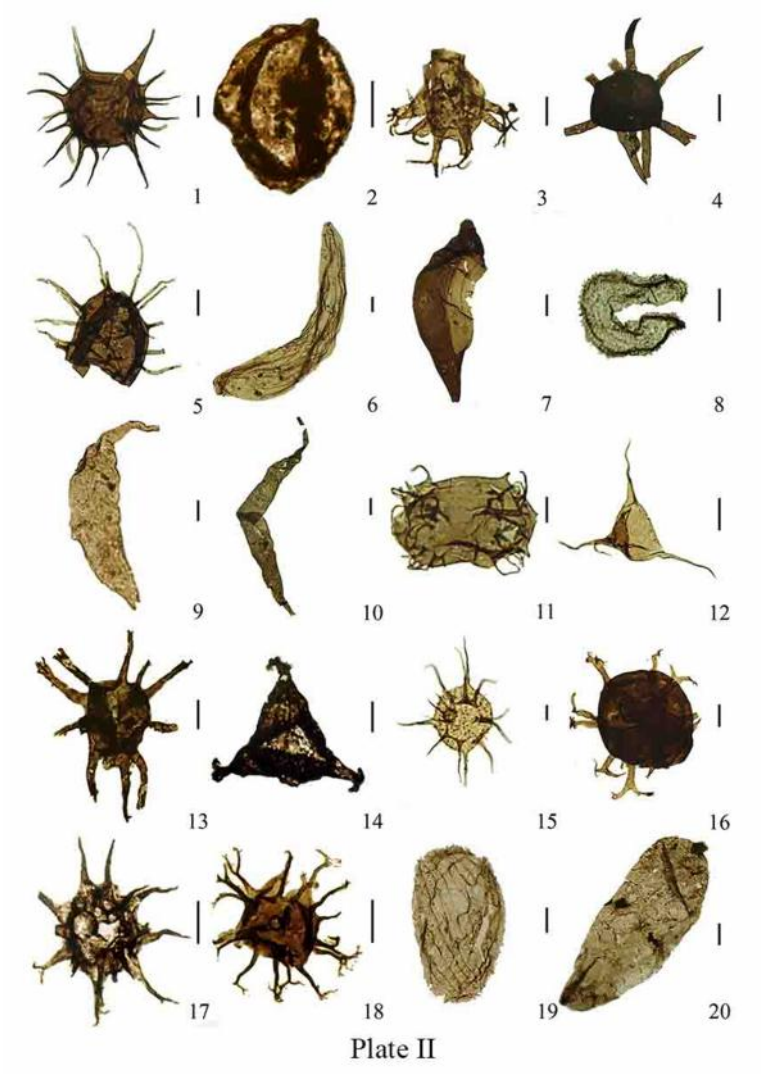

Plate II (Scale bars represent 10 um)
Figs.1, 11. *Acanthodiacrodium crassus* [52].
Fig.2. *Ampullula suetica* [7].
Fig.3. *Lua erdaopuziana* [7].
Fig.4. *Baltisphaeridium perclarum* [33].
Fig.5. *Baltisphaeridium longispinosum* [47].
Fig.6. *Dactylofusa striata* [13].
Fig.7. *Leiofusa squama* [7].
Fig.8. *Baiomeniscus camurus* [32].
Fig.9. *Leiofusa fusiformis* [30].
Fig.10. *Leiofusa litotes* [33].
Fig.12. *Veryhachium europium* group.
Fig.13. *Diexallophasis denticulata* [13].
Fig.14. *Baltisphaeridium asturiae* [7].
Fig.15. *Baltisphaeridium hirsutoides* [9].
Fig.16. *Ordovicidium elegantulum* [45].
Fig.17. *Multiplicisphaeridium bifurcatum* [45].
Fig.18. *Multiplicisphaeridium irregulare* [45].
Fig.19. *Dactylofusa cabottii* [13].
Fig.20. *Navifusa ancepsipuncta* [30].

Holotype: Plate III, 7.

Paratype: Plate III, 3.

Type stratum: Ghelli Formation, sample number MG-SB, 4km, north of Robat-e Gharabil village, southern flank of Kuh-e-Kurkhud, NE Alborz Mountain Range.

Derivation of name: From the Latin word Persia, which refers to the ancient name of Iran.

Dimensions: 47(48.5)50µm; specimens were measured. Length of process: 5 (6) 7um.

Occurrences: In the Ghelli Formation from the sample of MG-SB-50 to MG-SB-78, in *Spinachitina*

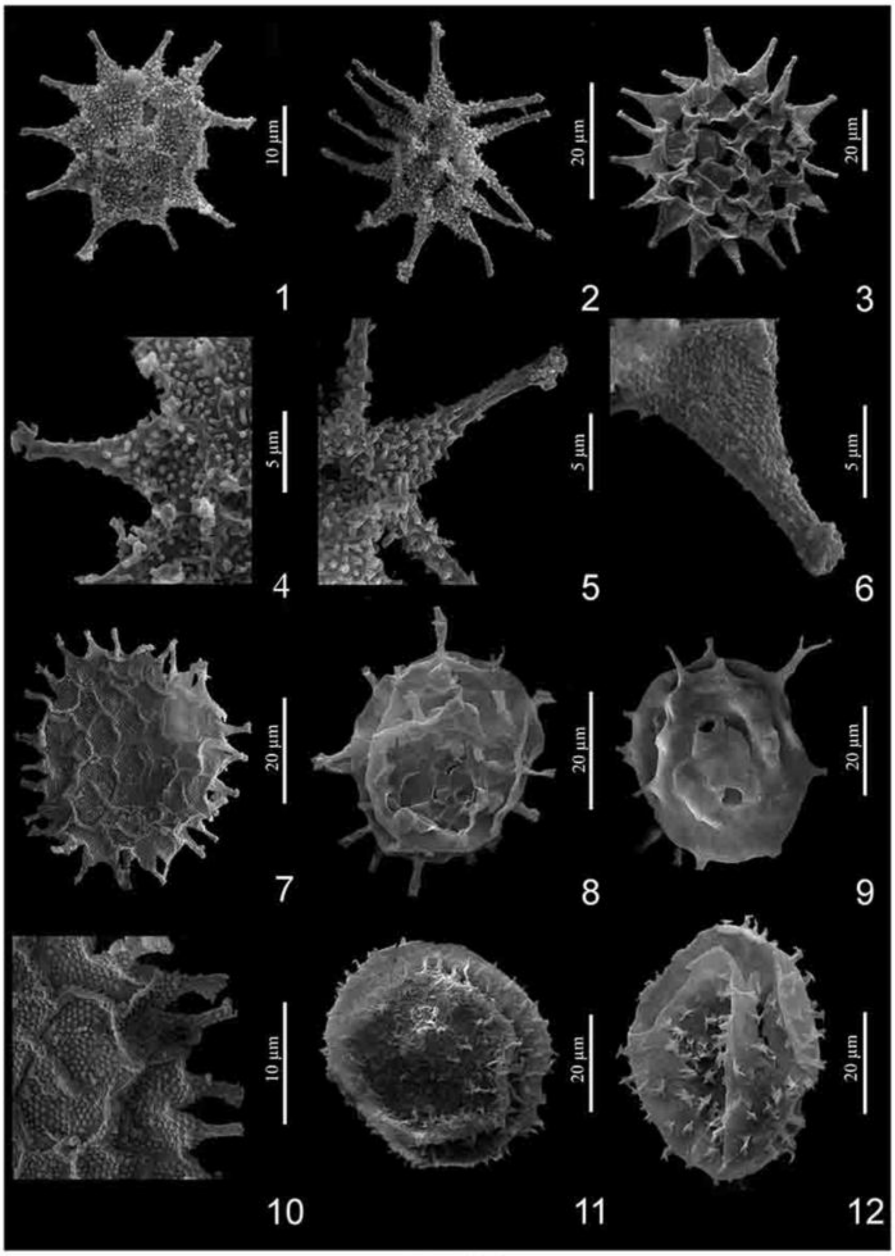

plate III

Plate III (Scale bars represent with um for each photos)
Figs. 1, 2, 4, 5. *Goniosphaeridium iranense* n. sp.
Figs. 3, 6, 7, 10. *Goniosphaeridium persianense* n. sp.
Figs. 8, 11, 12. *Goniosphaeridium martinae* [12].
Fig.9. *Baltisphaeridium christoferi* [9].

oulebsiri Zone with Hirnantian age

Description: Vesicle is fine granular and polygonale in outline. It bears uniform number of short simple conical processes. Processes change from 17 to 30 in number. The base of processes are wide and distal termination acuminate, or bulbous. Processes are ornamented by granulate.

Remarks: This species differs from other species of *Goniosphaeridium* in polygonal structure vesicle and densely granulate ornamentation on both vesicle and processes as well the conical processes with distal termination acuminate, or bulbous.

Goniosphaeridium iranense n. sp. (Plate III, 1, 2, 4, 5)

Holotype: Plate III, 1.

Paratype: Plate III, 2.

Type stratum: Ghelli Formation, sample number MG-SB, 4km, north of Robat-e Gharabil village, southern flank of Kuh-e-Kurkhud, NE Alborz Mountain Range.

Derivation of name: Derivation of name: Refers to Iran, the country in which the species was first recorded.

Dimensions**:** 33 (35)37 µm; specimens were measured. Length of processes: 6 (7) 8um.

Occurrences: In the Ghelli Formation from the sample of MG-SB-50 to MG-SB-78, in *Spinachitina oulebsiri* Zone with Hirnantian age

Description: Vesicle is granulate and polygonale in outline. It bears uniform number of short conical processes, changing from 10 to 12 in number. The base of processes are wide and distal termination acuminate, or bulbous. Processes are ornamented by granulate, verrucate.

Remarks: This species differs from other species of *Goniosphaeridium* in polygonal structure vesicle (inside and outside) and densely granulate ornamentation on vesicle and processes. The processes are conical with distal termination acuminate, or bulbous.

2 2. Acritarch biostratigraphy

The encountered acritarch taxa in the Lower Palaeozoic succession (Ghelli Formation) consist of 42 acritarch species (23 genera). In this study, three local acritarch assemblage zones were recognized which are discussed in ascending stratigraphical order in below (Fig. 2):

2. 2. 1 Acritarch assemblage Zone I

This acritarch assemblage zone is marked by the first appearance datum (FAD) of several acritarch taxa in the sample MG-SB-2 and extends within the succeeding biozones (Fig. 2). This assemblage is well defined by appearance of the Upper Ordovician acritarch taxa, consisting of *Navifusa ancepsipuncta* [32], *Acanthodiacrodium crassus* [32]., *Villosacapsula setosapellicula* [32], *Multiplicisphaeridium irregulare* [45], *Orthosphaeridium bispinosum* [7] *Orthosphaeridium rectangulare* [11], *Orthosphaeridium octospinosum* [11], *Ordovicidium elegantulum* [45] , *Dactylofusa spinata* [13], *Dactylofusa striata* [13], *Dactylofusa cabottii* [13], *Dorsennidium hamii* [7] *Tylotopalla* sp. cf. *T. caelamenicutis* [31], *Baltisphaeridium perclarum*[32], *Baltisphaeridium asturiae* [7], *Baltisphaeridium longispinosum*[47], *Baltisphaeridium hirsutoides* [9], *Baltisphaeridium christoferi* [7], *Diexapllophasis denticulata* [13], *Neoveryhachium* sp. cf. *N. carminae* [7], *Veryhachium lairdii* group, *Veryhachium trispinosum* group, *Veryhachium subglobosum* [21], *Veryhachium membranispinum* [14], *Leiofusa litotes* [31] and *Leiofusa fusiformis* [29]. These taxa are associated with reworked Lower Ordovician (Tremadocian - Floian) acritarch taxa (e. g. *Ampullula* suetica, *Vulcanisphaera africana*, *Lua erdaopuziana*, *Caldariola glabra* and *Ninadiacrodium caudatum*), which probably originated from neighboring areas with short transport distance since they have good preservation. Amongst the aforementioned taxa, the Upper Ordovician acritarch species of this zone, *Baltisphaeridium perclarum* and *Villosacapsula setosapellicula* have been recorded from the Richmondian (Katian) of Oklahoma [18], Missouri [47], Algerian Sahara [5], Libya [1]; the Katian of Canada [24]; the Upper Ordovician of Morocco [8] and Jordan [27] and Iran [15, 17, 18]. Likewise, the acritarch species *Veryhacium subglobosum* has previously been recorded from the Upper Ordovician of Algeria [1, 5]; Libya [1]; Iran [15, 16.17, 18]; Jordan [27] and Saudi Arabia [23]. The acritarch species of *Orthosphaeridium rectangulare* , *Dactylofusa spinata*, *Navifusa ancepsipuncta*, *Acanthodiacrodium crassus*, *Multiplicisphaeridium irregulare*, *Multiplicisphaeridium bifurcatum*, *Ordovicidium elegantulum* and *Dorsennidium hamii* are typical acritarch taxa which have been recorded from the Upper Ordovician of Czech Republic [51], North America [47, 24] and North Africa [8, 5], Iran [15, 16] and Iraq [4]. Furthermore, some of the acritarch species of this zone, such as *Veryhachium lairdii* group, *Veryhachium trispinosum* group, *Orthosphaeridium bispinosum* and *Dactylofusa cabottii* have been recorded from the Middle-Upper Ordovician strata of Sweden [20], England [45], the United States [32], Czech Republic [51], Saudi Arabia [23], China [29] and Iran [15, 16]. It worth mentioning here that *Dactylofusa cabottii* [13], is a common palynomorph in the Ordovician – Silurian shallow-water, nearshore, marine strata [20]. On the other hand, based upon acritarch biostratigraphy of the *Dicellogratus complanatus* graptolite Zone from the Vaureal Formation (Katian) of Anticosti Island, Québec, Canada [24] and the Katian Maquoketa Shale of Northeastern Missouri [47], all acritarch species of this assemblage zone are present in the Lower Palaeozoic succession of Kuh-e- Kurkhud in the north of the Robat-e-Gharabil village, indicating a Late Ordovician (Katian) age. The presence of Lower Ordovician acritarch taxa such as *Ampullula suetica*, *Vulcanisphaera africana*, *Lua erdaopuziana*, *Caldariola glabra* and *Ninadiacrodium caudatum* in this assemblage zone suggests the onset of erosive processes probably related to local tectonic readjustment, or alternatively the marine transgressive events from the late Cambrian (Furongian) , Tremadocian, Floian, Darriwilian and Sandbian). This reworked acritarch event has also been reported in Saudi Arabia, Libya, Morocco, Algeria, Turkey [40] and Zagros Basin of Iran [19].

2. 2. 2. Acritarch assemblage II

This acritarch assemblage is marked by the first appearance datum (FAD) of several acritarch taxa in the sample MG-SB-28 and extends within the succeeding biozones (Fig. 2). This assemblage is well defined by appearance of the Upper Ordovician acritarch taxa, consisting of the *Inflatarium trilobatum* [28] *Baiomeniscus camurus* [32], *Orthosphaeridium insculptum* [31] and *Tunisphaeridium eisenackii* [32]. Likewise, the majority acritarch taxa from preceding acritarch assemblage zone continue to this assemblage. These taxa are also associated with the reworked Lower Ordovician (Tremadocian - Floian) acritarch taxa (e. g. *Ampullula suetica*, *Vulcanisphaera africana*, *Lua erdaopuziana*, *Caldariola glabra* and *Ninadiacrodium caudatum*), which probably originated from neighboring areas with short transport distance since they have good preservation. Amongst the aforementioned taxa, the Upper Ordovician acritarch taxa of this zone, *Orthosphaeridium insculptum* has been recorded from the Sylvan Shale (Katian) of Oklahoma, U. S. A. [31]; the Maquoketa Shale (Katian), Northeastern Missouri [47]; the Vaureal Formation (Katian) of the Anticosti Island, Québec, Canada [24]; the Upper Ordovician of Czech Republic [51]; the Ashgill deposits of Portugal [8] and Morocco [8]; the Katian, Seyahou Formation of the Zagros Mountains, southern Iran [19], and the Ghelli Formation (Katian), Kopeh-Dagh Region, NE Alborz Mountain [16]. *Inflatarium trilobatum* has been recorded from uppermost Ordovician (Hirnantian), the Quwarah and Sarah Members of the Qasim Fromation in the Saudi Arabia [28]. *Tunisphaeridium eisenackii* has previously been recorded from the Sylvan Shale (Katian) of southern Oklahoma, U.S.A. [32] ; the Maquoketa Shale (Katian) of Missouri, U.S.A. [34]; the Vaureal Formation (upper Katian) of Anticosti Island, Quebec, Canada [24]; and the Upper Ordovician deposits of Iran [15, 17].Amongst the acritarch species of this assemblage zone, *Baiomeniscus camurus* has previously been recored from the Maplewood Shale, Silurian in USA [31], then this species was recorded from Upper Ordovician strata, Ghelli Formation in Khoshyeilagh area, NE Iran [17 and this paper]. In brief, based on the stratigraphic potential of the aforementioned acritarch taxa, latest Katian-earliest Hirnantian is suggested for this assemblage zone.

2. 2. 3. Acritarch assemblage III

This acritarch assemblage is marked by the first appearance datum (FAD) of several acritarch taxa in the sample MG-SB-50 and extends within the rest of Lower Palaeozoic succession (Fig. 2). This assemblage is well defined by appearance of new acritarch taxa, consisting of the *Goniosphaeridium iranense* n. sp., *Goniosphaeridium persianense* n. sp, *Neoveryhachium carminae* [7] and *Baltisphaeridium hirsutoides* [9] associating with taxa from the preceding assemblage zones such as the *Inflatarium trilobatum* [30]. The *Neoveryhachium carminae* Silurian, Belgium [35] Late Ordovician-Silurian, France (Rauscher, 1974); late Caradocian-Silurian, northern Gondwana [52]; Hirnantian, southeastern Turkey [40]; Hirnantian, southern Tunisia [1], Late Ordovician (Hirnantian)-Early Silurian (Rhuddanian), northern Chad and southeastern Libya [29], Hirnantian, the Zagros Mountains, southern Iran [19]. It should be mentioned that the encountered reworked acritarch taxa are still present in this assemblage zone.

2. 3. Chitinozoans

In this study 24 chitinozoan species (15 genera) were identified as the followings (Plates IV-VI)

Order Operculatifera [9]

Family Desmochitinidae [9, emend. 37]

Subfamily Desmochitininae [37]

Genus *Desmochitina* [9]

Desmochitina typica [9] [PlateVI, 9]

Genus *Calpichitina* [47]

Calpichitina lenticularis [5] [Plate VI, 10]

Subfamily Pterochitininae [37]

Genus *Armoricochitina* [37]

Armoricochitina alborzensis [17] [Plate VI, 2, 6]

Armoricochitina nigerica [37] [Plate VI, 1, 5]

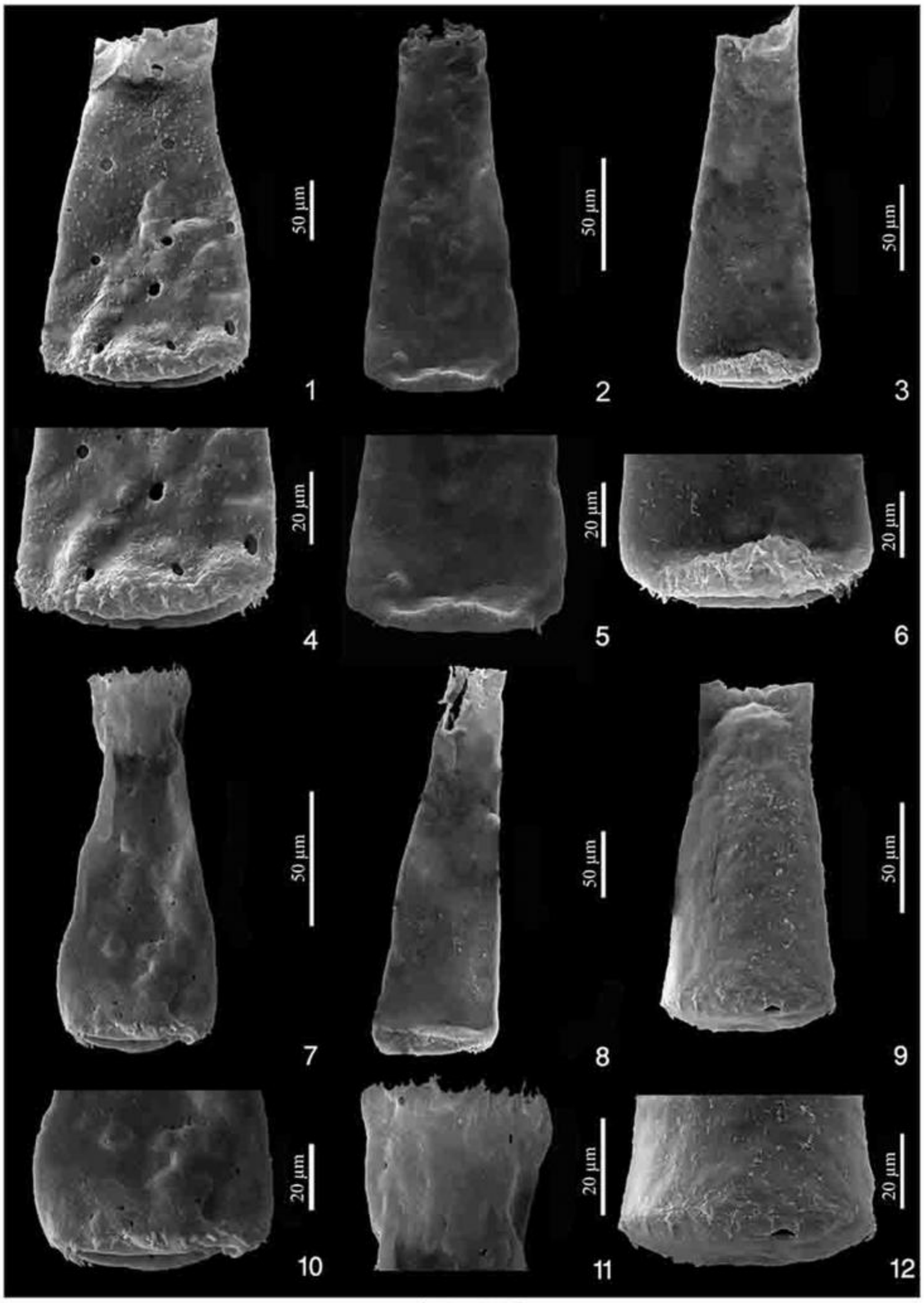

plate IV

Plate IV (Scale bars represent with um on each photos)
Figs.1-12. *Spinachitina oulebsiri* [38].

Subfamily Ancyrochitininae [37]
Genus *Ancyrochitina* [10]
Ancyrochitina merga [26] [Plate V, 20]
Ancyrochitina ellisbayensis [44] [PlateVI, 15, 19]
Genus Fungochitina [48]
Fungochitina spinifera [9] [Plate V, 17]
Genus *Plectochitina* [36]
Plectochitina sylvanica [26] [Plate V, 19]
Subfamily Belonechitininae [37]
Genus *Belonechitina* [25]
Belonechitina wesenbergensis [11] [Plate VI, 13, 17]
Belonechitina micracantha [9] [PlateVI, 14, 18]
Belonechitina tenuicomata [41] [Plate V, 11, 12, 15, 16]

Order Prosomatifera [37]
Subfamily Conochitininae [37]
Conochitina rotundata [41] [Plate V, 10, 14]
Genus *Euconochitina* [29]

Euconochitina moussegoudaensis [29] [Plate VI, 16, 20]
Euconochitina lepta [26] [PlateV, 18]
Genus *Pistillachitina* [48]

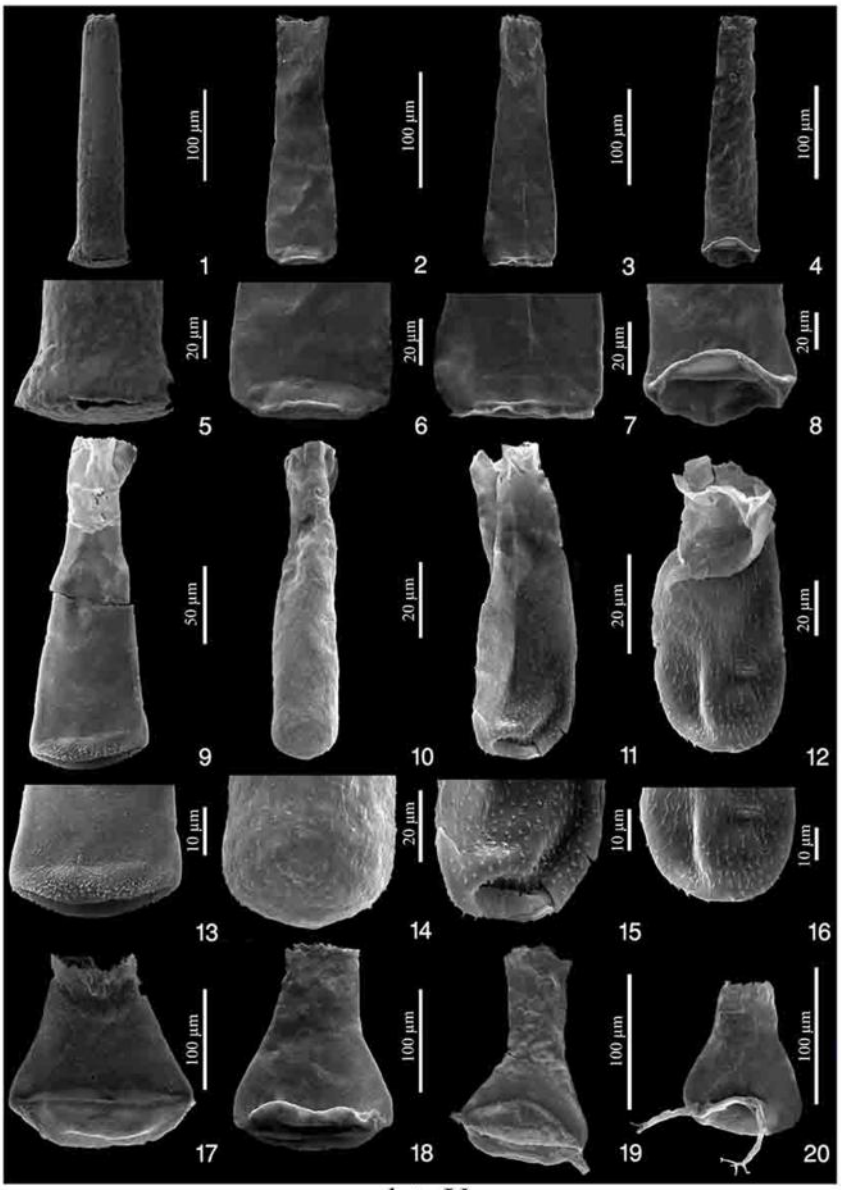

plate V

Plate V (Scale bars represent with um on each photos)
Figs.1, 5. *Pistillachitina pistillifrons* [10].
Figs. 2, 6. *Pistillachitina comma* [11].
Figs.3, 7. *Tanuchitina anticostiensis* [2].
Figs. 4, 8. *Tanuchitina ontariensis* [26].
Figs.9, 13. *Spinachitina bulmani* [26].
Figs.10, 14. *Conochitina rotundata* [41].
Figs.11, 12, 15, 16. *Belonechitina tenuicomata* [41].
Fig.17. *Fungochitina spinifera* [9].
Fig.18. *Euconochitina lepta* [27].
Fig.19. *Plectochitina sylvanica* [27].
Fig.20. *Ancyrochitina merga* [27].

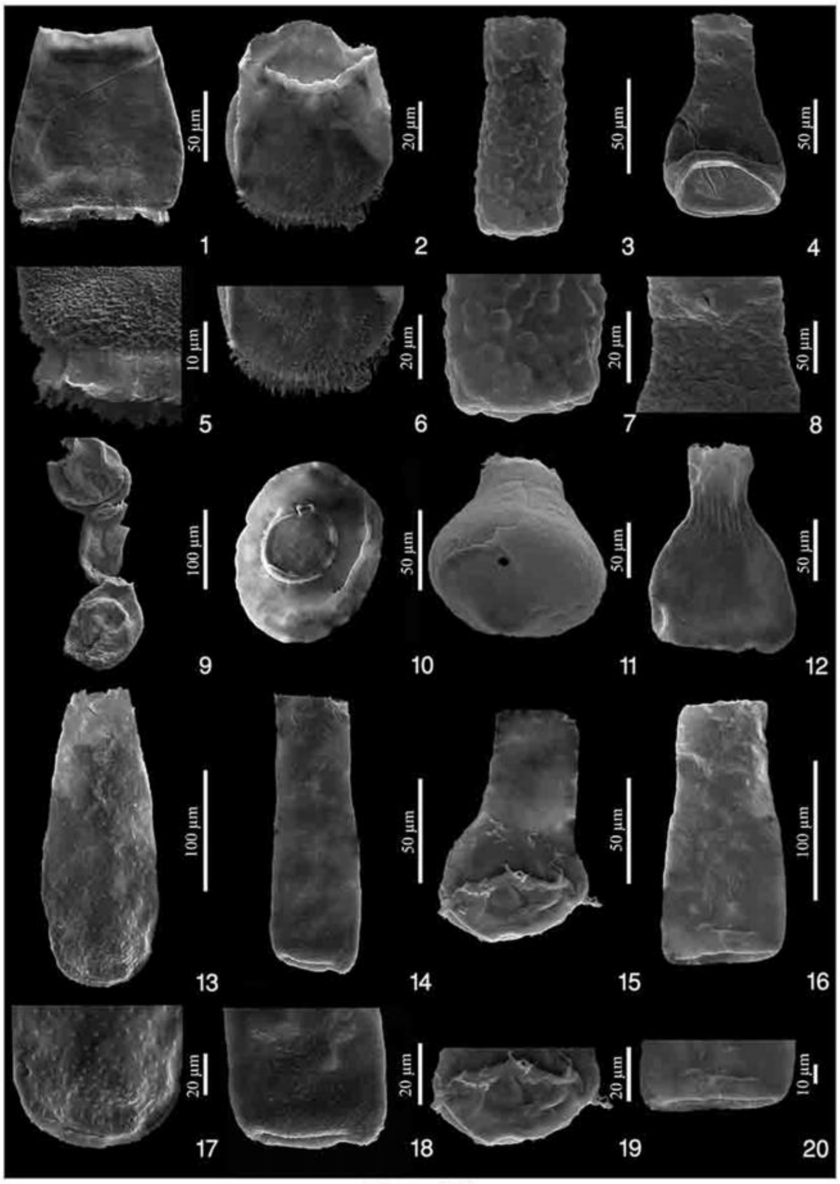

Plate VI

Plate VI

Figs. 1, 5. *Armoricochitina nigerica* [37].
Figs.2, 6. *Armoricochitina alborzensis* [17].
Figs.3, 7. *Hyalochitina hyalophrys* [41].
Figs.4, 8. *Cyathochitina campanulaeformis* [10].
Fig.9. *Desmochitina typica* [9].
Fig.10. *Calpichitina lenticularis* [5].
Fig.11. *Lagenochitina baltica* [9].
Fig.12. *Cyathochitina caputoi* [41].
Figs.13, 17. *Belonechitina wesenbergensis* [11].
Figs.14, 18. *Belonechitina micracantha* [9].
Figs.15, 19. *Ancyrochitina ellisbayensis* [44].
Figs. 16, 20. *Euconochitina moussegoudaensis* [30].

Pistillachitina pistillifrons [10] [Plate V, 1, 5]
Pistillachitina comma [11] [Plate V, 2, 6]
Subfamily Cyathochitininae [37]
Genus *Cyathochitina* [10. emend. 38]
Cyathochitina campanulaeformis [10] [Plate VI, 12]
Cyathochitina caputoi [41] [Plate VI, 4, 8]

Family Lagenochitinidae [37].
Subfamily Lagenochitinidae [9. emend. 38].
Genus *Lagenochitina* [9]
Lagenochitina baltica [9] [Plate VI, 11]
Subfamily Tanuchitininae [37]
Genus *Tanuchitina* [25. emend. 38]
Tanuchitina ontariensis [25] [Plate V, 4, 8]
Tanuchitina anticostiensis [2] [Plate V, 3, 7]
Genus *Hyalochitina* [38]
Hyalochitina hyalophrys [41] [Plate VI, 3, 7]
Order Prosomatifera [41]
Subfamily Spinachitininae [37]
Genus *Spinachitina* [38]
Spinachitina oulebsiri [38] [Plate IV, 1-12]
Spinachitina bulmani [25] [Plate V, 9, 13]

The distribution of the aforementioned chitinozoan taxa in the study section of Kuh-e-Kurkhud in the Robat-e-Gharabil village (Fig. 2) allows recognition of the two biozones which are discussed in ascending stratigraphical order as follows:

2. 3. 1. Ancyrochitina merga Biozone I

This biozone is marked by the first appearance datum (FAD) of *Ancyrochitina merga* in sample MG-SB-02 and extends through a thickness of 63m to sample MG-SB-57 (Fig. 2). According to Paris [36] and subsequent studies Bourahrouh et al. [5], the *Ancyrochitina merga* Biozone is an interval-range zone between the FAD of *Ancyrochitina merga* and the FAD of *Tanuchitina elongata*, the index species of the succeeding biozone. Arguments concerning the biostratigraphic age of this biozone have been presented in Paris [36], Bourahrouh et al. [5] and Ghavidel-Syooki [16] supporting a Late Katian age. Co-occurring species are *Armoricochitina* nigerica, *Calpichitina lenticularis, Desmochitina typica, Cyathochitina campanulaeformis, Spinachitina bulmani, Euconochitina lepta, Conochitina rotundata, Tanuchitina ontariensis, Euconochitina moussegoudaensis, Pistillachitina comma, Pistillachitina pistillifrons, Fungochitina spinifera, Hyalochitina hyalophrys,* and *Belonechitina micracantha* which range through the present biozone from the underlying *Armoricochitina nigerica* Biozone (see Fig. 2). The aforementioned of taxa make their first inception at the base of the present biozone, in sample MG-SB-2. So far, *Plectochitina sylvanica* has been recorded from Katian of Oklahoma, USA [26]; Libya [1]; Morocco [8]; Saudi Arabia [41] and Iran [15, 16, and 17]. *Plectochitina sylvanica* is a commonly co-occurring species of the *Ancyrochitina merga* Biozone in the Northern Gondwana Domain [5, 8, 16]. *Euconochitina lepta* is also a well-known species from the Katian of Oklahoma [26], Morocco [1], Algeria [35], Saudi Arabia [39], Iran [16] and Turkey [40]. *Cyathochitina campanulaeformis* Eisenack [9] is a very wide-spread and long-ranging species throughout the Late Ordovician and Early Silurian [6, 36]. The *Fungochitina spinifera* is also present in this interval zone. This species has so far recorded from late Sandbian, Gotland [9]; Ashgillian (Pushgilian-Cautleyan), UK [49]; late Hirnantian, Bir Tlacsin Formation, Libya [1] *Spinachitina bulmani* is well present in this assemblage zone. This species has recorded from early Sandbian, Scotland and Shropshire, UK [25]; Ashgillian, Morocco [8], Anticosti Islands of Canada [1, 2], UK [48]; Late Ordovician (Sandbian - Ashgillian, Iran [16, 17, 18] and Late Ordovician (Sandbian-Katian), Belgium [50].

2. 3. 2. Spinachitina oulebsiri Biozone II

This chitinozoan biozone coincides with the first appearance datum (FAD) of *Spinachitina oulebsiri* in sample MG-SB-57 and extends to MG-SB-112 in a thickness of 120m (Fig. 2). This species has been originally established in the Upper Member of the M' Kratta Formation, northeast Algerian Sahara, Bordj Nil area [39], and was indirectly correlated with the *persculptus* graptolite zone, of latest Hirnantian age [46]. Likewise, *Spinachitina oulebsiri* has recorded from Hirnantian, Morocco [30], Iran [15, 16, 18]; Late Ordovician (latest Hirnantian)-Early Silurian (Rhuddanian), northern Chad and Libya [23]. Accordingly, the *Spinachitina oulebsiri* chitinozoan biozone is particular interest for the correlation of latest Ordovician strata and for the recognition of the Ordovician-Silurian boundary. Therefore, this chitinozoan biozone of the North Gondwana Domain is used to define the uppermost Ordovician (Hirnantian) for this biozone in the Lower Palaeozoic succession of Kuh-e- Kurkhud in the north of Robat-e-Gharabil village. Co-occurring species are *Tanuchitina anticostiensis, Ancyrochitina ellisbayensis Armoricochitina alborzensis, Lagenochitina baltica, Cyathochitina caputoi, Belonechitina wesenbergensis* and *Belonechitina tenuicomata*. The co- occurring taxa with *Spinachitina oulebsiri* are *Belonechitina tenuicomata*, *Tanuchitina anticostiensis*, and *Cyathochitina caputoi*, which extend within this assemblage zone. The *Tanuchitina anticostiensis* and *Ancyrochitina ellisbayensis* are diagnostic taxa in the Upper Ordovician (Katian-Hirnantian) and they have recorded from the Vaureal Formation, Upper Ordovician (Katian) [2] and the Ellisbay Formation, Ordovician-Silurian boundary (Hirnantian-Rhuddanian) island of Anticosti Quebec Canada [44]. The *Belonechitina tenuicomata* has so far recorded from the

Sarah Sandstone Member of the Sarah Formation, latest Ordovician (Hirnantian) the Arabian Penensula [41]. *Tanuchitina alborzensis* makes its first inception at the base of the present biozone, in the sample MG-SB-57 of the Lower Palaeozoic succession in Kuh-e-Kurkhud in the north of Robat-e-Gharabil village. The *Lagenochitina baltica* is present in this assemblage zone (Fig.2). This species is well-known in the Upper Ordovician (Katian) both in the Gondwana and Baltica. So far, these species have been recorded in the Katian of Baltic [35]; the Upper Ordovician (Sandbian) of Shropshire, Britain [26]; the Upper Ordovician of Portugal [36], Libya [1]; the Formation de Hassi et Hadjar of Algerian Sahara [35, 39]; the Upper Ordovician of the Iran [15, 16, 18]; the Upper Ordovician (Katian) of southeastern Turkey [40]. Paris, et al. [38] used *Lagenochitina baltica* as a species linking the chitinozoan biozonations of Laurentia and North Gondwana. The *Cyathochitina caputoi* has so far recorded from the late Katian-Hirnantian of England [48], lower Llandovery (Rhuddanian) of Saudi Arabia [35] and Latest Ordovician (Hirnantian), Dargaz Formation in the Zagros Basin, Southern Iran [19].

Integrated acritarch and chitinozoan biostratigraphy

Despite the fact that recent studies have demonstrated the potential for a refined biozonation that would allow the recognition of several acritarch biozones at least for the Katian–Hirnantian interval [17, 18, 52], no formal acritarch zonation exists to subdivide the Upper Ordovician. It is only by means of further detailed studies of the Upper Ordovician sedimentary successions worldwide in which independent age evidence is present that progress towards a stable acritarch biozonation can be achieved [52].These results should be considered as a contribution towards such a goal, and the distribution of the acritarchs are mainly discussed in the context of a chronostratigraphic framework suggested by chitinozoans, where they are present. The vertical distribution of acritarch species highlights three major changes of the acritarch taxa throughout the study sequence. The very diagnostic acritarch taxa consist of *Inflatarium trilobatum*, *Villosacapsula setosapellicula*, *Multiplicisphaeridium irregulare*, *Orthosphaeridium insculptum*, *Orthosphaeridium rectangulare*, *Acanthodiacrodium crassus*, *Ordovicidium elegantulum*, *Baltisphaeridium perclarum*, *Veryhachium lairdii* group, *Navifusa ancepsipuncta*, *Veryhachium trispinosum* group, *Tylotopalla* sp., and *Neoveryhachium carminae* at stratigraphic levels MG-SB-02 to MG-SB-38, MG-SB-50, corresponding to the base of the Ghelli Formation up to the base of the Padeha Formation. On other hand, according to the standard Ordovician chitinozoan biozonations [36], there is a hiatus between the Ghelli and Barut formations corresponding to *Lagenochitina destombesi* to *Belonechitina robusta* chitinozoan Biozones (Floian-middle Katian). The absence of these chitinozoan biozones affirms that a tectonic activity (faulting) happened between the chitinozoan *Ancyrochitina merga* and Barut formation, possibly coinciding with the Caledonian Orogeny. In North Africa, the aforementioned acritarch species become extinct at the base of the *oulebsiri* chitinozoan Biozone which is associated with glacial-related sedimentary setting [5]. In the study area, the effects of the well-known Hirnantian glaciation on acritarch Assemblages I- III of the lower Palaeozoic succession of Kuh-e kurkhud in the north of Robat-e-Gharabil village is difficult to evaluate due to the presence of fault at base of the Lower Palaeozoic succession and hiatus at the top. All of the chitinozoan species found in the Upper Ordovician of the Ghelli Formation in Kuh-e-kurkhud of north of the Robat-e-Gharabil village have been recorded from the North Gondwana Domain (including Morocco, Algeria, Tunisia, Libya, and Nigeria; the Middle East: Saudi Arabia, Syria, Jordan, Iran; southwestern Europe: Italy, France, Spain, and Portugal; Czech Republic). In particular, *Armoricochitina nigerica*, *Ancyrochitina merga, Tanuchina elongata*, and *Spinachitina oulebsiri* have never been recorded outside the North Gondwana Domain [36, 46]. In conclusion, evidence from acritarch and chitinozoan biogeographic affinities indicates that the study area belongs to a peri-Gondwanan palaeogeographical domain; this is clearly consistent with recent palaeogeographic reconstructions which place northern Iran at the periphery of the Gondwana supercontinent.

Results and Discussion

The Lower Palaeozoic succession of north of the Robat-e-Gharabil village contains well-preserved and abundant palynomorph entities, consisting of acritarch, chitinozoan, scolecodont and graptolite remains. The encountered acritarch taxa in the Ghelli Formation consist of 42 acritarch species (23 genera), arranging in three local assemblage zones. The acritarch assemblages I-III have broad similarities with Libya, Morocco, Algeria, Saudi Arabia, Portugal, England, the United States and Canada, indicating a cosmopolitan nature for acritarch taxa during the Late Ordovician. The encountered chitinozoan fauna are 24 chitinozoan species (15 genera) and represent two well-known chitinozoan biozones such as *Ancyrochitina merga*, and *Spinachitina oulebsiri*, indicating affiliation to the North

Gondwanan Domain. Based on palynological data, one major hiatus are present throughout the Lower Palaeozoic succession of study area, encompassing the Silurian period.

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