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Palynostratigraphy and Palaeogeography of the Upper Ordovician Gorgan Schists (Southeastern Caspian Sea), Eastern Alborz Mountain Ranges, Northern Iran

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Keywords: Acritarchs; Chitinozoans; Upper Ordovician; Biostratigraphy; Palaeogeography; Gondwana; Palaeo-Tethys rifting; Eastern Alborz Range; Gorgan Schists.

Abstract: Determination of the exact age and palaeogeographic position of the low grade metamorphic rocks of the so-called "Gorgan Schists" exposed in the northern Alborz Mountains of northern Iran has been long debated. Therefore, 163 samples were collected for palynological analysis throughout the entire thickness of the metasedimentary succession. In addition, three samples from the overlying non-metamorphic limestones were also analyzed micropalaeontologically. Most of the Gorgan Schists samples yielded abundant and well-preserved acritarchs (29 species belonging to 17 genera), chitinozoans (35 species belonging to 16 genera), scolecodonts (counted, but not identified to species), and some graptolite remains. Of the 35 species of chitinozoans present, two new species, *Belonechitina kordkuyensis* and *Spinachitina aidaiae,* are erected.

Based on the presence of well-known chitinozoan and acritarch species, a Late Ordovician (Katian-Hirnantian) age has been assigned to the Gorgan Schists for the first time. The characteristics of the palynological assemblages also suggest a shallow marine depositional environment for these metasediments before metamorphism. Therefore, the Gorgan Schists are time-equivalent to sediments of the non-metamorphic Ghelli Formation, and are clearly older than the Soltan Maidan Basalts. Based on the presence of foraminifers in three samples, a Late Cretaceous age is suggested for the overlying non-metamorphic, fossiliferous limestones of the Gorgan Schists. The encountered chitinozoan assemblages in the Gorgan Schists permit the recognition of the *Belonechitina robusta, Armoricochitina nigerica, Ancyrochitina merga, Tanuchitina elongata and Spinachitina oulebsiri* chitinozoan Biozones, which have been previously established in the northern Gondwanan Domain.

The palynological results thus indicate that the northeastern Alborz Mountain Range was part of Gondwanan Domain during the Late Ordovician. The shallow marine volcano-sediments coupled with flood basalts of the Gorgan Schists are indicative of the Late Ordovician rift-related volcanic events affecting the northern margin of Gondwana during the opening process of the Palaeo-Tethys. This marginal rift assemblage was metamorphosed during the closure of the Palaeo-Tethys and its collision with the Laurasia during the Early Triassic (Rhaetian).

Palavras-chave: Acritarcas, Quitinozoários, Ordovícico Superior, Biostratigrafia, Paleoecologia, Paleogeografia, Gondwana, *Rifting to* Paleo-Tétis, Montanhas de Alborz, Xisto Gorgan.

Resumo: A determinação da idade e posição paleogeográfica das rochas de baixo grau metamórfico pertencentes ao Xisto Gorgan, aflorantes na parte norte das montanhas de Alborz, no norte do Irão, têm sido o centro de inúmeras controvérsias. Cento e sessenta e três amostras representando toda a distribuição estratigráfica do Xisto de Gorgan, em conjunto com três amostras de calcários não metamorfizados localizados a topo, foram processadas por técnicas palinológicas e o seu conteúdo orgânico estudado. A maioria dos amostras do Xisto de Gorgan contêm abundantes acritarcas, quitinozoários, escolecodontes e restos de quitinosos de graptólitos. Nas amostras estudadas foram identificadas 29 espécies de acritarcas, correspondentes a 17 géneros, 35 espécies (incluindo duas novas espécies, *Belonechitina kordkuyensi*s e *Spinachitina aidaensis*) de quitinozoários pertencentes a 16 géneros e, ainda, númerosos restos não identificados de escolecodontes e graptólitos.

Com base nos acritarcas e quitinozoários foi atribuída, pela primeira vez, uma idade de Ordovícico Superior (Katiano - Hirnantiano) ao Xisto de Gorgan. As três amostras de calcários fossilíferos a topo do Xisto Gorgan, indicam uma idade de Cretácico Superior. As espécies de quitinozoários do Xisto Gorgan pertencem às biozonas *Belonechitina robusta*, *Armoricochitina nigerica, Ancyrochitina merga, Tanuchitina elongata,* e *Spinachitina oulebsiri,* definidas para o Domínio Norte Gondwana. As biozonas de quitinozoários sugerem que a parte nordeste das montanhas de Alborz pertenceram ao Supercontinente Gondwana durante o Ordovícico Superior. As rochas vulcano-sedimentares de baixa profundidade pertencentes ao Xisto Gorgan, são contemporâneas da Formação Ghelli, e mais antigas do que os basaltos Soltan Maidan do Landoveriano. As rochas sedimentares depositadas em ambientes pouco profundas em conjunto com as escoadas basálticas encontradas no Xisto Gorgan, são indicativas de processos vulcânicos associados a fenómenos de *rifting* localizados na margem norte do Gondwana durante a abertura do Paleo-Tétis. Esta associação de depósitos relacionados com processos de *rifting,* foi posteriormente metamorfizada durante o fecho do Paleo-Tétis devido à sua colisão com a margem sul da Laurasia durante o Triásico.

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1. INTRODUCTION AND GEOLOGICAL SETTING

The low-grade metamorphic rocks of the Gorgan Schists form high mountains in an area about 110-125 km long and 2-10 km wide southeast of the Caspian Sea, extending from the Gorgan to Behshahr and Aliabad (Radkan area: Fig. 1). This conspicuous metasedimentary complex has best exposure in the southern flank of the mountains of the Caspian Sea with a thickness in excess of 2000m. It was first investigated by Tietze (1877) and Stahl (1911) who described a sequence of alternating phyllites, sericite-chlorite-schists, and quartzites, with questionable ophiolitic rock interbeds in its lower part. Successively, Gansser (1951) named this metasedimentary complex the "Gorgan Schists" with reference to an outcrop exposed at southern Gorgan city, northern Iran (Fig. 1). The exact nature, protolith and metamorphic age, and geological significance of the Gorgan Schists have remained a puzzle since their initial discovery and description. Jenny (1977) was the first to suggest the green schist facies (prehnite-pumpellyite with temperatures 250°C) for the metamorphic rocks of the Gorgan Schists. The age of the protoliths as well as the metamorphism of the Gorgan Schists have been considered as Precambrian by several authors (Gansser, 1951; Hubber, 1957; Jenny, 1977; Stöcklin, 1971; Salehi-Rad, 1979; Afshar-Harb, 1979; 1994). Delaloye *et al.* (1981) obtained an isochron age of 211 Ma for the metamorphism. Berberian *et al.* (1973) showed that the Permian fusulinid limestone formations adjacent to the Gorgan Schists complex were characterized by the development of pressure solution structures around the fusulinid fossils, indicating regional post-Permian (Middle-Late Triassic) orogenic movement. Moreover, they noted that the Gorgan Schists are unconformably covered by non-metamorphic sediments (the Upper Triassic-Jurassic Shemshak Formation) which include a basal conglomerate, containing metamorphic pebbles coming from the Gorgan Schists.

Concerning the protolith age, Hubber (1957) reported questionable Silurian-Devonian tentaculites and Hamdi (1995) reported two Palaeozoic conodonts (without specifying Lower or Upper Palaeozoic) from the Gorgan Schists. A few, isolated samples from the Gorgan Schists were palynologically investigated by Ghavidel-syooki (1992); results from this study were ambiguous, but were interpreted by Shahpesandzadeh (1992) as evidencing a Devonian-Carboniferous age. More recently, Velayati (2004) even suggested a Miocene age for the protoliths of the metamorphic complex of the Gorgan Schists.

The author herein presents a detailed, high-resolution palynological analysis of the Gorgan Schists succession, with the aim of verifying its exact age and palaeogeographic position (e.g., Gondwanan *vs.* Laurentia palaeo-provinces of the protoliths).

2. THE RADKAN TRANSECT

The Radkan study area is located approximately 25 km to the south of Kordkuy city (Fig. 1). The author measured and sampled a transect (the total measured thickness of the sampled section is 2379m) in this area starting from the Neka River (base of the section: 36˚ 37' 49"N, 54˚ 8' 13" E) and ending near the Deraznau village (top of the section: 36˚ 39' 44" N, 54˚ 8' 42 "E; Fig.1). In this area, the base of the Gorgan Schists succession is cut by a fault (Radkan fault), and its top is unconformably covered by non-metamorphic fossiliferous limestones.

Based on the petrographic study of the collected samples, the metamorphic rock sequence of the study area can be divided into two units (Fig. 2): (i) the 'Lower Schists' unit, consisting of a succession of unfoliated to weakly foliated very fine-grained sandy to silty metasediments of originally mixed siliciclastic and carbonate components, interrupted by two igneous horizons (trachyandesites), and (ii) the 'Upper metavolcanics and metasediments' unit, consisting of a stratal sequence of mainly unfoliated metamorphic volcanics (meta-tuff-like sediments, trachytes and trachyandesites). The metamorphic grade of the Gorgan Schists has been evaluated to correspond to the green schist's facies, with maximum temperatures of less than 250°C.

3. MATERIALS AND METHODS

Palynological study was carried out on 163 surface samples (MG-8295D to MG-8295A, MG-8296 -MG-8366, and MG-8366A to MG-8366T, MG-8367 to MG-8430) from the entire thickness of the Gorgan Schists. In addition, three samples (MG-8431 to MG-8433) from the overlying non-metamorphic limestones were also analyzed micropalaeontologically. The field and laboratory descriptions of samples have been plotted on the stratigraphic column (Fig. 2). Each sample is designated with the National Iranian Oil Company Code number with the prefix MG- 8295D to MG -8433.

Palynomorphs were extracted from the metasedimentary samples by using the standard palynological techni-

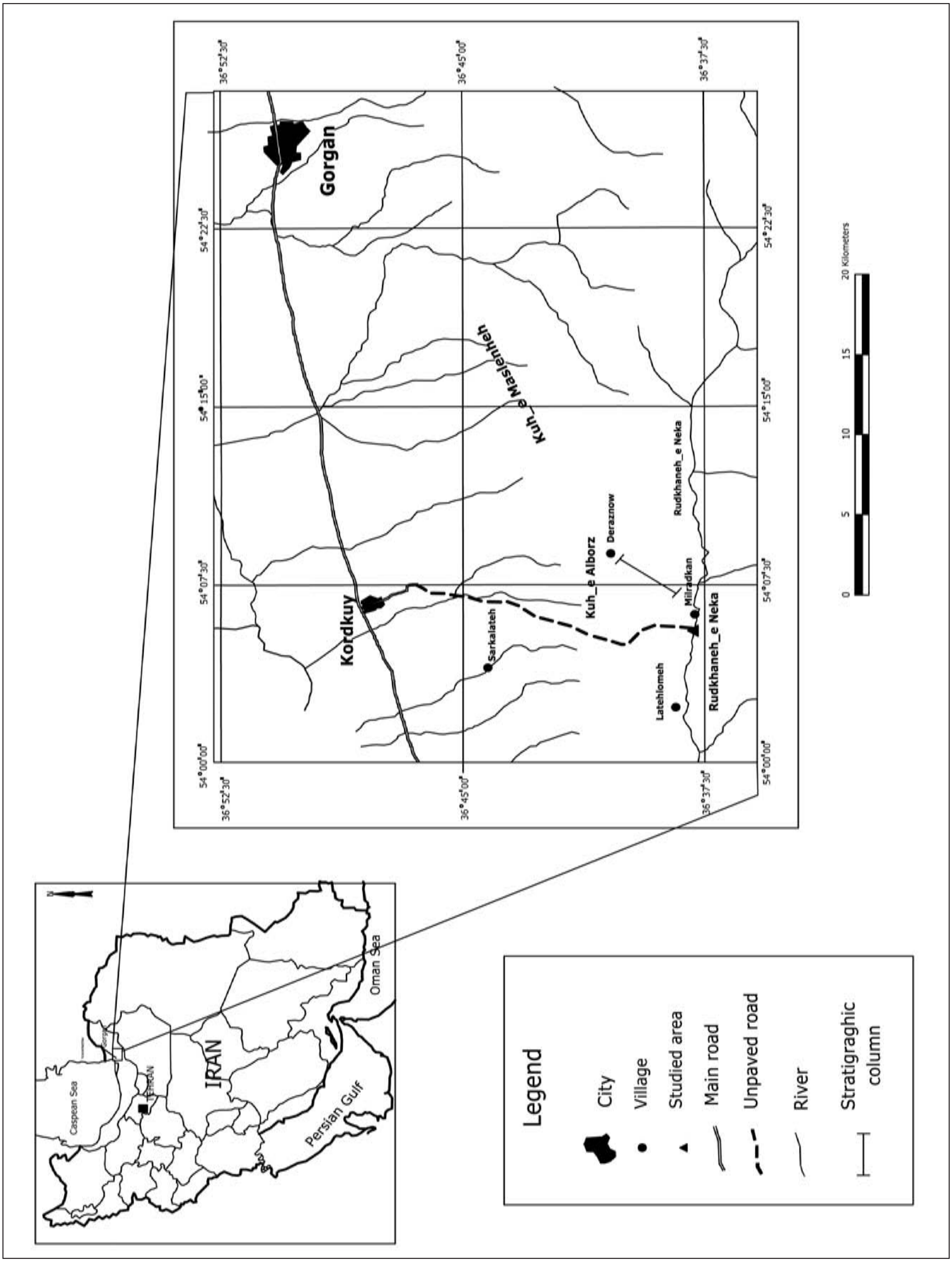

Fig. 1 – Location map of studied area and conection to adjacent areas.

que of treatment in HCl and HF to remove carbonates and silicates respectively, and neutralizing the residues in distilled water after each acid treatment. Samples were not oxidized, and the resultant residues of each sample were treated with 30 ml of saturated zinc bromide with a specific gravity of 1.95. The remaining organic residue was then sieved through a 15 µm nylon mesh sieve to separate the organic residues from the inorganic materials. Extensive scanning electron and transmitted light microscopic examinations were applied on selected specimens during the study. Most samples contain well-preserved and abundant palynomorphs (acritarchs, chitinozoans, scolecodonts and graptolite remains), ranging in colour from grey to dark brown, which indicates a high thermal maturity for the organic materials of the Gorgan Schists (TAI=4; overmature organic matter) in this part of the Alborz Mountains. All slides used in this study are housed in the Palaeontological Collections of the Exploration Directorate of the National Iranian Oil Company under the sample numbers MG-8295D to MG-8433, and MG-8366A to MG-8366T. Three petrological thin sections (MG-8431 - MG-8433) were prepared from the non-metamorphic limestones overlying the Gorgan Schists; these contained well-preserved and abundant foraminifers and oligostiginids. Abundance values are expressed semi-quantitatively, as follows: rare = 2-3 identified specimens; uncommon = 4-8 identified specimens; common = 9-20 identified specimens; abundant > 20 identified specimens.

Systematic Palaeontology: Incetae sedis group *Chitinozoa* Eisenack, 1931

Subfamily *Belonechitininae* Paris, 1981

Genus *Belonechitina* Jansonius, 1964

Type species: *Conochitina micracantha* subsp. *robusta* Eisenack, 1959.

Belonechitina kordkuyensis n.sp.

Plate X, Fig.2; Plate XVI, Fig. 1

Holotype: PlateVIII, Fig. I

Type Stratum: Sample number MG-8366Q of Gorgan Schist, in the Radkan area, 25km south of Kordkuy city.

Derivation of name: From Kordkuy city which is a major city nearby the Radkan area (study area).

Description: This species has a relatively long vesicle and varies from cylindrical to claviform. The flanks taper towards the fringed aperture and show gentle flexure. The basal edges are broadly rounded and the base ranges from flat to concave. The surface is covered by simple spines. Most specimens of the Gorgan Schist of the Radkan area have broken spines and show strong definite spine bases. Where spines have survived, they are short and simple.

Comparison: *Belonechitina kordkuyensis is* similar in some extent to *Belonechitina wesenbergensis* (Eisenack, 1959) and *Belonechitina robusta* (Eisenack, 1959). However, this species differs in shape, size and ornamentation from *Belonechitina wesenbergensis* (Eisenack, 1959) as well as *Belonechitina robusta* (Eisenack, 1959). On the other hand, this species is associated with characteristic chitinozoan species of Ashgillian strata (Paris *et al.,* 2007; Ghavidel-syooki and Winchester-Seeto, 2002). Belonechitina kordkuyensis is present in the Gorgan schists of Radkan area with rare to abundant frequencies in samples MG-8400 to MG-8430.

Measurements: Total length =L=111(150.5)290µm; Maximum diameter of chamber=D=55 (74.5)94 µm; lc-71; ln=229; L /D=1.5-3;lc/L= 0.24; ln/L= 0.8; lc/ln=0.3. Twenty-five specimens measured.

Order Prosomatifera Eisenack, 1972

Subfamily *Spinachitininae* Paris, 1981

Genus *Spinachitina* Schallreuter, 1963. emend. Paris, Grahn, Nestor and Lakova, 1999

Type species: *Conochitina cervicornis* Eisenack, 1931.

Spinachitina aidaiae n.sp.

Plate IX, Fig.5

Holotype: Plate IX, Fig.5

Type stratum: Sample number MG-8366Q from the Gorgan schists in the Radkan area, 25km southern Kordkuy city.

Derivation name: From *Aida* a little daughter of my colleague (Behroz, Ariafar) who helped me on the field for preparing samples.

Description: This species has a subconical chamber and cylindrical neck. It has distinctive shoulders with discerned flexure. The neck flares towards the oral pole and the collar has serrate edge. The basal edge is well-rounded and the base is flat. Maximum diameter of chamber occurs in the lower third of chamber. The vesicle is covered by simple short spines. The basal margin has several short, robust, broad –based spines. This species is present in the samples of Gorgan Schists, in the Radkan area with rare frequency in samples MG-8400 to MG-8430.

Comparison: *Spinachitina aidaiae* differs from other species of this genus in having dense spinose ornamentation over the whole surface of specimens as well as definite shoulder, gentle flexture and size. *Spinachitina aidaiae* is present in the Gorgan Schists of Radkan area with rare to abundant frequencies in samples MG-8400 to MG-8430.

Measurement: Total length of Vesicle =L=172(220)268µm; Maximum diameter of chamber=D=70 (84)98 µm;

length of neck=ln= 100(105)110μm; Length of chamber=lc= 102 (130)158μm; width of aperture= 52(56) 60μm Total length of vesicle/ Maximum diameter of chamber=L/D= 2.5-2.7. Fifteen specimens measured.

4. RESULTS: BIOSTRATIGRAPHY

Thirty-five species of chitinozoans, two of which are new, belonging to 16 genera and 29 species of acritarchs assigned to 17 genera were identified. Based on the analysis of several thousands of specimens and their distributions plotted on figure 2, five chitinozoan biozones in the Gorgan Schists and one foraminiferal biozone in the overlying non--metamorphic fossiliferous limestone were established. The chitinozoans biozones of Radkan area are quite similar to those of North Gondwana Domain (Paris, 1990; Oulebsir and Paris, 1995; Paris *et al.,* 2000b; Paris *et al.,* 2007) and discussed below in ascending stratigraphic order. The acritarch assemblages associated with the recognized chitinozoan formal biozones are also discussed below. The scanning electron microscopic or transmitted light microscopic photographs were prepared for all the selected acritarch and chitinozoan taxa and illustrated on Plates I-VIII.

4.1. *Belonechitina robusta* Biozone

This chitinozoan biozone has been recognized in the lower part of the Gorgan Schists, ranging through a thickness of 361m (Fig. 2); it corresponds to the partial range of the eponymous species, from its first appearance up to first occurrence of *Armoricochitina nigerica,* the index species of the succeeding biozone. In the present material, *Belonechitina robusta* occurs in samples MG-8295D through MG-8327 (Fig. 2); it is well recognizable for its characteristic multi-rooted spines on the surface of vesicle.

B. robusta has previously been reported from numerous localities, but because of the poor preservation or insufficient illustrations, some of these previous records are not longer considered herein. In Central Portugal, this index species is well-represented in the upper part of the Louredo Formation (Paris, 1979; 1981). In the Toledo Province, Central Spain, *Belonechitina robusta* occurs in the upper part of the Pizzaras intermedias of the Herrera del Duque Syncline (Robardet, 1980; Paris, 1981). In the Armorican Massif, this species has been recorded as an important component of the chitinozoan assemblages of the Pont-de-Caen Formation, in the Sées syncline (Robardet *et al.,* 1972). In Great Britain, this species has also been recorded from the Balclatchie Group (lower Caradoc) of Scotland (Jansonius, 1964) and the Marshbrookian of Shropshire (Paris, 1979). Grahn (1981; 1982) has noted that *Belonechitina robusta* is abundant in the Late Ordovician of Baltoscandia. The known range of this index species in Baltoscandia and Shropshire begins at least in the Marshbrookian. Likewise, the restricted range of *B. robusta* in the lower part of the Viola Springs Formation (Jenkins, 1969), in Oklahoma, would support the late Sandbian to early Katian age (*C. wilsoni-D. clingani* graptolite biozones; see Ross, 1982). This species has recently reported from the lower Katian sediments of Ceylandinar#1 of Turkey (Paris *et al.,* 2007).

The associated chitinozoan species of this biozone are: *Angochitina communis, Belonechitina micracantha, B. wesenbergensis, Belonechitina* sp. A., *Conochitina chydea, Cyathochitina campanulaeformis, Desmochitina piriformis, Euconochitina communis, Pistillachitina pistillifrons and Rhabdochitina usitata.*

Belonechitina wesenbergensis is present in the Gorgan Schists, in the Radkan area, with rare to uncommon frequencies in the samples MG-8298 to MG-8425. This species has been recorded from Darriwilian to Upper Ordovician strata in Sweden, Finland and Estonia (Grahn, 1981; 1982; 1984; Nolvak *et al.,* 1995), from the U.S.A. (Jenkins, 1969; Grahn and Bergstrom, 1984) and Iran (Ghavidel-syooki and Winchester-Seeto, 2002). This species has also been recorded from the upper Katian (Ashgill) sediments in southwest of France (Paris, 1981); the Louredo Formation, the Upper Ordovician of Portugal (Paris, 1979); the Darriwilian of Algerian Sahara (Oulebsir and Paris, 1995); the Middle to Upper Ordovician of Saudi Arabia (Al-Hajri, 1995); the Middle Ordovician of Morocco (Elaouad-Debbaj, 1984); the Vitrival–Bruyére Formation (upper Sandbian to lower Katian) of Belgium (Vammeirhaeghe, 2006); the Upper Ordovician (Katian) of Greenscoe section in southern Lake District of the United Kingdom (Van Nieuwenhove *et al.,* 2006); the Darwillian of Turkey (Paris *et al.,* 2007).

Conochitina chydea is present in the Gorgan Schists of the Radkan area, with rare to common frequencies in samples MG-8295D to MG-8336. This species has been recorded from the Darriwilian to Sandbian of the Shelve and Caradocian districts of Shropshire; the upper Darriwilian to Sandbian of southwest of Europe (Paris, 1981); the Louredo Formation (Upper Ordovician) of Portugal (Paris, 1979); the upper Darriwilian to Sandbian

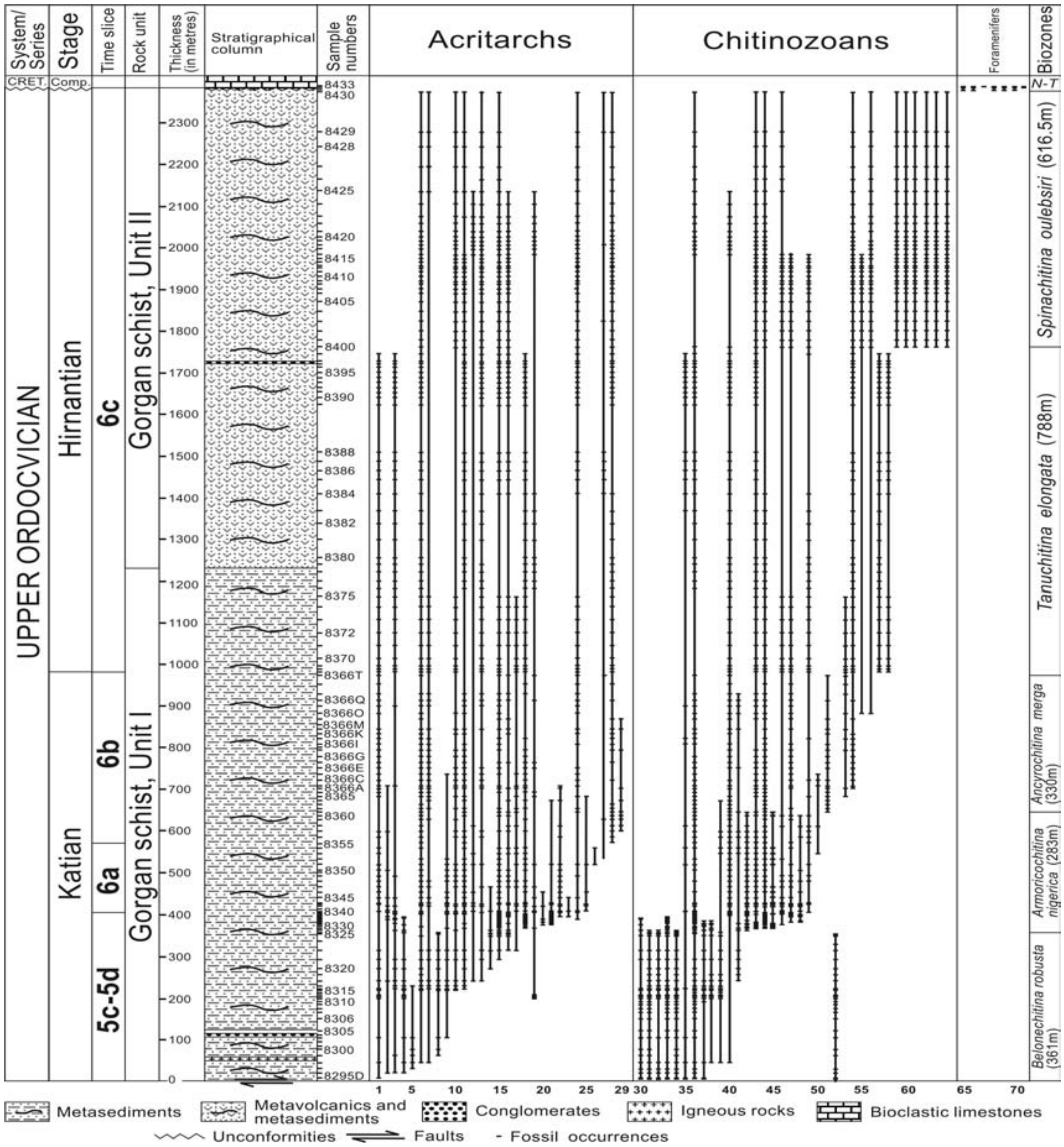

Fig. 2 – Stratigraphic distributions of selected palynomorph taxa in the Gorgan Schists of Radkan area, southern Kordkuy city, southeastern Caspian Sea, northern Iran (numbers refer to the corresponding columns in the figure). 1 = Evittia remota; 2 = Navifusa ancepsipuncta; 3 = Baltisphaeridium oligopsakium; 4 = Dactylofusa platynetrella; 5 = Gorgonisphaeridium antiquum; 6 = Veryhachium trispinosum; 7 = Multiplicisphaeridium bifurcatum; 8 = Baltisphaeridium longispinosum subsp. delicatum; 9 = Actinotodissus crassus; 10 = Veryhachium lairdii; 11 = Polygonium gracile; 12 = Veryhachium europaeum; 13 = Multiplicisphaeridium irregulare; 14 = Pirea ornata; 15 = Baltisphaeridium perclarum; 16 = Villosacapsula setosapellicula; 17 = Veryhachium reductum; 18 = Ordovicidium elegantulum; 19 = Orthosphaeridium rectangulare; 20 = Dactylofusa cabottii; 21 = Tunisphaeridium eisenackii; 22 = Dactylofusa striata; 23 = Disparifusa psakadoria; 24 = Orthosphaeridium insculptum; 25 = Veryhachium triangulatum; 26 = Neoveryhachium carminae; 27 = Villosacapsula irrorata; 28 = Veryhachium subglobosum; 29 = Sylvanidium paucibrachium; 30 = Desmochitina piriformis; 31 =Belonechitina robusta; 32 =-Belonechitina sp.A; 33 = Conochitina chydea 34 = Belonechitina wesenbergensis; 35 = Cyathochitina sp. A; 36 = Cyathochitina campanulaeformis; 37 = Euconochitina communis; 38 = Rhabdochitina usitata; 39 = Conochitina sp. A.; 40 = Belonechitina micracantha; 41 = Pistillachitina pistilliformis; 42 = Armoricochitina nigerica; 43 = Lagenochitina baltica; 44 = Desmochitina minor; 45 = Lagenochitina prussica; 46 = Calpichitina lenticularis; 47 = Desmochitina nodosa; 48 = Desmochitina cocca; 49 = Rhabdochitina gracilis; 50 = Spinachitina bulmani; 51 = Ancyrochitina merga; 52 = Angochitina comuunis; 53 = Plectochitina sylvanica; 54 = Euconochitina lepta; 55 = Hercochitina sp.; 56 = Hercochitina crickmayi; 57 = Tanuchitina elongata; 58 = Tanuchitina ontatiensis; 59 = Euconochitina moussegoudaensis; 60 = Spinachitina aff. oulebsiri; 61 = Belonechitina kordkuyensis; 62 = Spinachitina aidaensis; 63 = Spinachitina oulensiri; 64 = Tanuchitina aff. Elongata; 65 = Nezzazata sp.; 66 = Marsonella trochus; 67 = Ticinella sp.; 68 = Hedbergella planispira; 69 = Globotruncana pseudolinneiana; 70 = Calcisphaerula innominata; 71= Pithonella ovalis.

of Poland (Wrona *et al.,* 2001). *Desmochitina piriformis* is present in the Gorgan Schists of Radkan area with rare to abundant frequencies within the samples of MG-8295D to MG-8335. This species has previously been recorded from the Upper Ordovician of Portugal (Paris, 1979) and the Dalby to Skagen formations (Sandbian) of Sweden (Laufeld, 1967). *Rhabdochitina usitata* occurs in the Gorgan Schists of Radkan area with rare to uncommon frequencies in samples MG-8298 to MG-8333. This species has so far been recorded from the Middle to Upper Ordovician (Llanvirn-Caradoc) of Shropshire, England (Jenkins, 1967); the Middle Ordovician of Anticosti Island (Achab, 1984) and western Newfoundland (Albani *et al.,* 2001) in Canada; and the Seyahou Formation (Upper Ordovician) of the Zagros Basin in southern Iran (Ghavidel-syooki, 2000).

Angochitina communis is present in the Gorgan Schists of Radkan area with rare to common frequencies in samples MG-8295D to MG-8327. This species has so far been reported from the Upper Ordovician (upper Caradoc) of Shropshire, England (Jenkins, 1967).

Pistillachitina pistillifrons occurs in the Gorgan Schists of the Radkan area with rare to uncommon frequencies in samples MG-8318 to MG-8366R. This species has recorded from the Upper Ordovician of Potugal (Paris, 1979). Paris (1990) has stated that *Pistillachitina pistillifrons* ranges from the *Lagenochitina deunffi* to *Lagenochitina dalbyensis* chitinozoan biozones (Sandbian).

Likewise, this chitinozoan biozone is characterized by co-occurrence of the acritarch taxa, including *Actinotodissus crassus, Baltisphaeridium oligopsakium,B. perclarum, B. longispinosum delicatum, Dactylofusa platynetrella, Evittia remota, Gorgonisphaeridium antiquum, Multiplicisphaeridium bifurcatum, M. irregulare, Navifusa ancepsipuncta , Polygonium gracile, Pirea ornata, Veryhachium europaeum, V. lairdii, V. trispinosum and Villosacapsula setosapellicula.*

Amongst the above-mentioned characteristic acritarch species of this zone. *Villosacapsula setosapellicula* has been recorded from the Richmondian (Katian) of Oklahoma (Loeblich, 1970; Playford and Wicander, 2006), Missouri (Wicander *et al.,* 1999), from the Katian of Algerian Sahara (Jardiné *et al.,* 1974) and Libya (Paris and Molyneux, 1985; Hill and Molyneux, 1988), the upper Katian of Canada (Jacobson and Achab, 1985), the Upper Ordovician of Morocco (Elaouad-Debbaj, 1988) and Jordan (Keegan *et al.,* 1990). Furthermore, *Baltisphaeridium perclarum* has been recorded from the Richmondian (Katian) of Oklahoma (Loeblich and Tappan, 1978; Playford and Wicander, 2006), Missouri (Robertson, 1997; Wicander et al., 1999), Michigan (Wicander and Playford, 2008), and the Katian of Canada (Jacobson and Achab, 1985).

Moreover, such acritarch species as *Actinotodissus crassus, Baltisphaeridium oligopsakium, Multiplicisphaeridium bifurcatum, M. irregulare, and Navifusa ancepsipuncta* are typical for the Upper Ordovician sediments in North America (Miller, 1991; Wicander *et al.,* 1999; Jacobson and Achab, 1985), Portugal (Elaouad-Debbaj, 1981; Playford and Wicander, 2006), and Morocco (Elaouad-Debbaj, 1988). However, it should be mentioned that some of the acritarch species from this zone such as *Veryhachium trispinosum, V. europaeum, Polygonium gracile, and Evittia remota* have been recorded elsewhere from the whole Palaeozoic strata, in particular, in Sweden (Kjellstrom, 1971; Górka, 1987), Britain (Turner, 1985), the United States (Colbath, 1979; Loeblich and Tappan, 1978), the Czech Republic (Vavrdová, 1988), Saudi Arabia (Jachowicz, 1995), and Iran (Ghavidel-syooki, 2000; 2001; 2003). Therefore, based on acritarch and chitinozoan taxa, this part of the Gorgan Schists is assigned to the upper Sandbian - lower Katian (time slices of 5b-5c after Webby *et al.,* 2004) of the North Gondwanan Domain.

4.2. *Armoricochitina nigerica* Biozone

This chitinozoan biozone also occurs in the metasediments of lower part of the Gorgann Schists, in the Radkan area and includes a thickness of 283.5 m (Fig. 2). *Armoricochitina nigerica* is present in the Gorgan Schists of the studied area, with rare to common frequencies within the samples of MG-8327 to MG-8361.This biozone corresponds to the partial-range biozone of *Armoricochitina nigerica* (Bouché, 1965) from its first appearance up to first occurrence of *Ancyrochitina merga* (Bouché, 1965), the index species of succeeding biozone. Based on standard chitinozoan biozonation, the *Armoricochitina nigerica* Biozone in the Gorgan Schists of the Radkan area represents the time slice of 6a from the Upper Katian Stage in the North Gondwana Domain (Webby *et al.,* 2004). The associated chitinozoan taxa in this biozone include *Calpichitina lenticularis, Desmochitina minor, D. nodosa, D. cocca, Lagenochitina baltica, L. prussica, Rhabdochitina gracilis and Spinachitina bulmani.*

Calpichitina lenticularis occurs in the Gorgan Schists of the Radkan area with rare to common frequencies within the samples of MG-8330 to MG-8430. This species has previously been recorded from the Upper Ordovician (Seyahou Formation) of the Iran (Ghavidel-syooki, 2000; Ghavidel-syooki and Winchester-seeto, 2002), North Gondwana Domain (Paris, 1979; 1981; Elaouad-Debbaj, 1984; Paris and Molyneux, 1985; Oulebsir and Paris, 1995) and of the Quwarah Member of the Qasim Formation and the Sarah Formation in northern and central Saudi Arabia (Al-Hajri, 1995; Paris and Verniers, 2000a).

Spinachitina bulmani is present in the Gorgan Schists of the Radkan area with rare to uncommon frequencies within the samples of MG-8357 to MG-8366D. This species has been known from the Sandbian of Scotland and Shropshire (Jansonius, 1964; Jenkins, 1970); from the Upper Ordovician of Morocco (Elaouad-Debbaj, 1986); from the Katian of Anticosti (Achab, 1978), Norway (Grahn *et al.,* 1994), Libya (Paris and Molyneux, 1985). Paris (1990) has stated that *Spinachitina bulmani* is a common species in the *Armoricochitina nigerica* Biozone in the North Gondwana Domain.

Desmochitina minor appears in the Gorgan Schists of the Radkan area, with rare to abundant frequencies in the samples MG-8328 to MG-8430. This species is apparently very long-ranging and cosmopolitan species. This species is claimed to be found elsewhere in strata which range from the Floian to Katian elsewhere (Grahn, 1984). *Desmochitina nodosa* is present in the Gorgan Schists of the Radkan area, with rare to uncommon frequencies within the samples of MG-8332 to MG-8416. This species has been previously recorded from the Sandbian of Estonia and Sweden (Laufeld, 1967; Bergström *et al.,* 1967; Grahn and Nõlvak, 2007)); the Sandbian erratic boulders (Schallreuter, 1963; Grahn, 1981); the Vitrival-Bruyére and Fosses formations (Sandbian to Katian) of Belgium (Vammeirhaeghe, 2006). The Iranian specimens are quite similar to those from Belgium (Vammeirhaeghe, 2006). *Desmochitina cocca* occurs in the Gorgan Schists of the Radkan area with rare to common frequencies in the samples MG-8332 to MG-8360. This species has previously been recorded from the upper Darriwilian to Sandbian of Estonia (Eisenack, 1962); the Middle to Upper Ordovician of Russia (Umnova, 1969); the Upper Ordovician of France (Rauscher, 1973); the Sandbian of Portugal (Paris, 1979); and the Vitrival-Bruyére and Fosses formations (Upper Ordovician) of Belgium (Vammeirhaeghe, 2006).

Lagenochitina baltica is present in the Gorgan Schists of Radkan area with rare to common frequencies within the samples of MG-8328 to MG-8430. This species is well- known in the Upper Ordovician (Katian) both in the Gondwana and Baltica. So far, this species has been reported in the Katian of Baltic (Laufeld, 1967; Grahn, 1982; Grahn *et al.,* 1994); the Middle Ordovician sediments from southern Appalachians, the United States (Grahn and Bergström, 1984); the Upper Ordovician (Caradoc) of Shropshire, Britain (Jenkins, 1967); the Upper Ordovician of Portugal (Paris, 1979) and Libya (Paris and Molyneux, 1995); the Formation de Hassi et Hadjar of Algerian Sahara (Oulebsir, 1995; Paris *et al.,* 2000b); the Upper Ordovician of the Iran (Ghavidel-syooki, 2000; Ghavidel-syooki and Winchester-seeto, 2002); the Upper Ordovician (Katian) of Greenscoe section, of the southern Lake district in Britain (Van Nieuwenhove *et al.,* 2006); the Upper Ordovician (Katian) Vitrival-Bruyére and Fosses formations of Belgium (Vanmeirhaeghe, 2006); the Katian of southeastern Turkey (Paris *et al.,* 2007).

Likewise, *Lagenochitina prussica* is present in the Gorgan Schists of Radkan area with rare to uncommon frequencies within the samples of MG-8328 to MG-8361. This species has been reported from the Molodova Formation (Katian) of Podolia, Ukraine (Laufeld, 1971); the Fjäcka Shale (lower Katian) of Dalarna, Sweden (Laufeld, 1967), the Vormsi Regional Stage (lower Katian) of Estonia (Nolvak, 1980; Grhan, 1980); the uppermost part of the Bios de Presles Member and the lower part of the Faulx les Tomber Member of the Fosses Formation (Upper Ordovician) of Belgium (Vanmeirhaeghe, 2006). *Rhabdochitina gracilis* is present in the Gorgan Schists of the Radkan area with rare to uncommon frequencies within the samples of MG-8339 to MG-8416. This species is recorded from Iran for the first time. Rhabdochitina gracilis has been recorded from the uppermost Darriwilian to lowermost Sandbian (Uhaku to Kukruse regional stages) of North Estonia (Eisenack, 1962, Grahn, 1984); the Seby to the Lower Dalby limestones (Darriwilian to Sandbian) of Öland (Grahn, 1980; 1981) and the Darriwilian of Dalarna, Sweden (Eisenack, 1962).

This chitinozoan biozone is also characterized by co--occurrence of the Late Ordovician acritarch taxa, including *Dactylofusa striata, D. cabottii, , Disparifusa psakadoria, Neoveryhachium carminae, Ordovicidium elegantulum, Orthosphaeridium insculptum, O. rectangulare, Sylvanidium paucibrachium, Tunisphaeridium eisenackii, Veryhachium triangulatum, V. subglobosum and Villosacapsula irrorata.* Amongst the above-mentioned characteristic acritarch species of this chitinozoan biozone, *Villosacapsula irrorata* has previously been recorded from the Sylvan Shale (Katian) of southern Oklahoma, U.S.A. (Loeblich, 1970; Playford and

Wicander, 2006); Maquoketa Shale (Katian) north-eastern Missouri, U.S.A. (Wicander *et al.,* 1999); the Upper Ordovician of Kansas, U.S.A. (Wright and Meyers, 1981); the lower Katian of Indiana, U.S.A. (Colbath, 1979); the Caradoc Series of Shropshire, England (Turner, 1984); the Upper Ordovician of the Czech Republic (Vavrdová, 1988) and Morocco (Elaouad-Debbaj, 1988); the Katian of north-eastern Libya (Paris and Molyneux, 1985; Hill and Molyneux, 1988); the Upper Ordovician of Jordan (Keegan *et al.,* 1990) and Iran (Ghavidel-syooki, 1997; 2000; 2001; 2003; 2006).

Orthosphaeridium insculptum has been recorded from the Upper Ordovician Sylvan Shale (Katian) of Oklahoma, U.S.A. (Loeblich, 1970; Playford and Wicander, 2006); the Upper Ordovician Maquoketa Shale (Katian) of north-eastern Missouri, U.S.A. (Wicander *et al.,* 1999); the Vauréal Formation (Katian) of Anticosti Island, Québec, Canada (Jacobson and Achab, 1985); the Upper Ordovician of the Czech Republic (Vavrdovà, 1988); the Katian of Portugal (Elaouad-Debbaj, 1981); the Katian of Morocco (Elaouad-Debbaj, 1988); the uppermost Ordovician Seyahou Formation (Katian) of the Zagros Basin, southern Iran (Ghavidel-syooki, 1997)' and the Upper Ordovician (Katian) Ghelli Formation of the Kopeh-Dagh Region in north-eastern Iran (Ghavidel-syooki, 2000; 2001).

Orthosphaeridium rectangulare has previously been recorded from the Sylvan Shale (Katian) of southern Oklahoma, U.S.A. (Playford and Wicander, 2006; as Orthosphaeridium inflatum Loeblich, 1970); The Maquoketa Shale (Katian) of northeastern Missouri, U.S.A. (Wicander *et al.,* 1999); the Richmondian-Gamachian of Anticosti Island, Québec, Canada (Jacobson and Achab, 1985); the Katian of Estonia (Uutela and Tynni, 1991) and Morocco (Elaouad-Debbaj, 1988); the Katian of Jordan (Keegan *et al.,* 1990; as *Orthosphaeridium* cf. *O. inflatum*) and the Upper Ordovician of Iran (Ghavidel--syooki, 2000; 2001; 2003; 2006; as *Orthosphaeridium inflatum*).

Sylvanidium paucibrachium has been recorded from the Upper Ordovician Sylvan Shale of Oklahoma, U.S.A (Loeblich, 1970). *Ordovicidium elegantulum* has previously been recorded from the upper Ordovician deposits of Saudi Arabia (Jachowicz, 1995); the Caradoc Series of Shropshire, England (Turner, 1984); the Katian of Algerian Sahara (Vecoli, 1999) and the Prague Basin, the Czech Republic (Vavrdová, 1988); the Upper Ordovician of Ohio, U.S.A. (Colbath, 1979) and China (Li and Wang, 1997; Li *et al.,* 2006); the Upper Ordovician of Rapla borehole in Estonia (Uutela and Tynni, 1991); the Öjlemyrflint erratic boulders of Gotland, Sweden (Eiserhardt, 1992); and the Upper Ordovician of Iran (Ghavidel-syooki, 2000; 2001; 2006).

Tunisphaeridium eisenackii has previously been recorded from the Sylvan Shale (Katian) of southern Oklahoma, U.S.A. (Loeblich and Tappan, 1978; Playford and Wicander, 2006); the Maquoketa Shale (Katian) of Missouri, U.S.A. (Miller, 1991); the Vauréal Formation (upper Katian) of Anticosti Island, Québec, Canada (Jacobson and Achab, 1985); and the Upper Ordovician deposits of Iran (Ghavidel-syooki, 2000).

Veryhacium subglobosum has previously recorded from the Upper Ordovician of Algeria (Jardiné *et al.,* 1974; Vecoli, 1999); Libya (Hill and Molyneux, 1988); Iran (Ghavidel-syooki, 1996; 2006); Jordan (Keegan *et al.,* 1990) and Saudi Arabia (Jachowics, 1995). *Dactylofusa striata* has been recorded from the Upper Ordovician deposits of Libya (Paris and Molyneux, 1985); the upper Katian sediments of North Africa (Vecoli, 1999); the upper Katian strata of Anticosti Island, Canada (Staplin *et al.,* 1965; Jacobson and Achab, 1985); the Upper Ordovician of the Kopeh-Dagh region, Iran (Ghavidel-syooki, 2000); and the Upper Ordovician of Anticosti Island, Québec Province, Canada (Loeblich and Tappan, 1978). *Dactylofusa cabottii* has been recorded from the Llandovery sediments of New York State, U.S.A. (Cramer, 1971); the Katian to Llandovery of Belgium (Martin, 1974); the Caradoc Series of Shropshire, England (Turner, 1984); the Upper Ordovician Seyahou Formation of the Zagros Basin, southern Iran (Ghavidel-syooki, 1990); and the Upper Ordovician of northwestern China (Li *et al.,* 2006).

So far, *Disparifusa psakadoria* has been recorded from the Upper Ordovician Sylvan Shale of Oklahoma, U.S.A (Loeblich and Tappan, 1987). However, based upon acritarch biostratigraphy of the *Dicellogratus complanatus* graptolite zone from the Vauréal Formation (upper Katian) of the Anticosti Island, Quebec, Canada (Jacobson and Achab, 1985) and the Maquoketa shale (Katian) of north-eastern Missouri (Wicander *et al.,* 1999), all acritarch species of this assemblage zone of the Gorgan Schists have been assigned to the upper Katian Stage. Therefore, both acritarch and chitinozoan taxa, suggest the time slice 6a of the upper Katian Stage in the North Gondwana Domain (Webby *et al.,* 2004) for this part of the Gorgan Schists.

4.3. *Ancyrochitina merga* Biozone

This chitinozoan biozone occurs in the upper part of metasediments of the Gorgan Schists of the Radkan area and includes a thickness of 330m. It extends from the sample of MG-8361 to 8366T (Fig. 2). This biozone corresponds to the total-range of biozone *Ancyrochitina merga* (JENKINS, 1970) from its first appearance up to the first occurrence of *Tanuchitina elongata,* the index species of succeeding biozone. *Ancyrochitina merga* is present in the Gorgan Schists of Radkan area with common frequency within the samples of MG-8361 to MG-8366T. This species is a well-known Upper Ordovician (Hirnantian) species, which has previously been recorded from the Sylvan Shale of Oklahoma (JENKINS, 1970), Libya (PARIS and MOLYNEUX, 1985; PARIS, 1988), Morocco (ELAOUAD--DEBBAJ, 1984), Saudi Arabia (AL-HAJRI, 1995; PARIS, *et al.,* 2000a), and Iran (GHAVIDEL-SYOOKI, 2000; GHAVIDEL-SYOOKI and WINCHESTER-SEETO, 2002). The total range of this species was used by Paris (1990) to define the *Ancyrochitina merga* Biozone in the North Gondwana Domain. The associated chitinozoan species of this biozone are, *Euconochitina lepta, E. communis* and *Plectochitina sylvanica.*

Plectochitina sylvanica is present in the Gorgan Schists of the Radkan area, with rare to uncommon frequencies in the samples of MG-8365 to MG-8375.This species has also been known from the Upper Ordovician (Katian) of Oklahoma (JENKINS, 1970), Libya (PARIS and MOLYNEUX, 1985), Morocco (ELAOUAD-DEBBAJ, 1984; 1986), Saudi Arabia (AL-HAJRI, 1995) and Iran (GHAVIDEL-SYOOKI, 2000; GHAVIDEL-SYOOKI and WINCHESTER-SEETO, 2002). Paris (1990) has stated that *Plectochitina sylvanica* occurs in the *Ancyrochitina merga* biozone.

Euconochitina lepta is present in the Gorgan Schists of the Radkan area with rare to common frequencies within the samples of MG-8366A to MG-8430. This species is well-known in the Upper Ordovician of Oklahoma (JENKINS, 1970), Morocco (ELAOUAD-DEBBAJ, 1984), Algeria (OULEBSIR and PARIS, 1995; PARIS *et al.,* 2000b), Saudi Arabia (AL--HAJRI, 1995; PARIS *et al.,* 2000a), Iran (GHAVIDEL-SYOOKI, 2000) and Turkey (PARIS *et al.,* 2007).

Euconochitina communis is also present in the Gorgan Schists of the Radkan area with rare to common frequencies within the samples of MG-8295D to MG-8333. This species has been recorded from the Late Ordovician Sarah Formation of Saudi Arabia (PARIS *et al.,* 2000a); the Upper Ordovician sediments of Saudi Arabia (AL-HAJRI, 1995) and south-eastern Turkey (PARIS *et al.,* 2007). In addition, most of acritarch taxa of preceding biozones without major change enter in this chitinozoan biozone. This chitinozoan biozone of the North Gondwanan Domain is used to define the time slice of 6b (the uppermost Katian) for this biozone of the Gorgan Schists in the Radkan area.

4.4. *Tanuchitina elongata* Biozone

This biozone occurs in the upper part of the Gorgan Schists in the Radkan area and includes a thickness of 788 m and extends from the sample of MG-8366T to MG-8400 (Fig. 2). This biozone corresponds to the partial-range biozone of *Tanuchitina elongata* (BOUCHÉ, 1965) from its first occurrence up to the first appearance of *Spinachitina oulebsiri* (WEBBY *et al.,* 2004), the index species of succeeding biozone. *Tanuchitina elongata* is present in the Gorgan Schists of the Radkan area with rare to uncommon frequencies in the samples of MG-8367 to MG-8399. It is worthy to note that the *Tanuchitina elongata* biozone was previously used to be the highest chitinozoan biozone in the North Gondwana Domain (PARIS, 1990). Later on, PARIS *et al.* (2000b) carried out a research work on the Late Ordovician marine glacial sediments in well NI-2 (NE-Algerian Sahara) that was resulted in a new chitinozoan species of *Spinachitina oulebsiri* from the M' Kratta Formation, suggesting the Latest Hirnantian age.

The Tanuchitina elongata herein regarded as senior synonym of Tanuchitina bergstroemi (LAUFELD, 1967). This biozone is well-documented in North Africa (Morocco, Tunisia, Libya, Algeria, Nigeria; see BOUCHÉ, 1965; ELAOUAD-DEBBAJ, 1988; PARIS, 1990; OULEBSIR and PARIS, 1995), and the Ra'an Shale of the Tabuk Formation in Saudi Arabia (MCCLURE, 1988). PARIS (1990) has stated that at least the upper part of Ra'an Shale in Saudi Arabia is referred to Tanuchitina elongata Biozone, which is associated with *Glyptograptus persculptus* graptolite zone, suggesting the Hirnantian. The associated chitinozoan taxa of this biozone are *Tanuchitina ontariensis and Tanuchitina aff elongata, Hercochitina crickmayi* and *Hercochitin*a sp.

Tanuchitina ontariensis also occurs in the Gorgan Schists of the Radkan area with rare to uncommon frequencies within the samples of MG-8367 to MG-8399. This species is characteristic species of the Late Ordovician, and so far, it has reported from the Late Ordovician Zagros Basin, southern Iran (GHAVIDEL-SYOOKI, 2000), and the Kopeh-Dagh region of Iran (GHAVIDEL-SYOOKI and WINCHESTER-SEETO, 2002), the Sylvan Shale of Oklahoma

(Jenkins, 1970), Ontario (Jansonius, 1964), Saudi Arabia (Al-Hajri, 1995), and Turkey (Paris *et al.,* 2007). Most acritarch and chitinozoan taxa of preceding biozones enter in this chitinozoan biozone.

Therefore, the well-known chitinozoan taxa suggest that this part of the Gorgan Schists is assigned to the lower Hirnantian (Webby *et al.,* 2004).

Hercochitina crickmayi is present in the Gorgan Schists of Radkan area with rare frequency from the sample of MG-8366O to MG-8430. This species is another associated species in this chitinozoan biozone and it has previously been recorded from the Upper Ordovician Simcoe Group in southern Ontario (Melchin and Legault, 1985) and the Upper Thumb Mountain Formation of Little Cornwallis Island in Canada (Achab and Asselin, 1995).

4.5. *Spinachitina oulebsiri* Biozone V

This chitinozoan biozone occurs in the uppermost part of the Gorgan Schists in the Radkan area and includes a thickness of 616.5m and extends from sample of MG-8400 to MG-8430 (Fig. 2). This biozone is marked by first appearance of *Spinachitina oulebsiri* in the sample MG-8400. *Spinachitina oulebsiri* is present in the Gorgan Schists of Radkan area with common to abundant frequencies within the samples of MG-8400 to MG-8430. This species has been previously recorded from the Upper Member of the M' Kratta Formation, north-east Algerian Sahara, Bordj Nili area (Paris *et al.,* 2000b). This species was used by Paris *et al.* (2000b) to define the *Spinachitina oulebsiri* biozone in the uppermost Hirnantian sediments in the Algerian Sahara and later on, Webby *et al.* (2004) used this species as *Spinachitina oulebsiri* Biozone for the uppermost of Hirnantian strata in the North Gondwana Domain. The associated chitinozoan species of this biozone are *Euconochitina moussegoudaensis (=Euconochitina sp.) and Spinachitina 'aidaiae* n. sp. and *Belonechitina kordkuyensis* n. sp.

Euconochitina moussegoudaensis (*Euconochitina* sp.) is present in the Gorgan Schists of Radkan area with uncommon to common frequencies in the samples of MG-8400 to MG-8430. This species is recoded for the first time from the upper part of the Gorgan Schists of Radkan area. In 2006, the author requested from Professor Florentine Paris to check my identified chitinozoan taxa and he assigned one of the chitinozoans of Gorgan Schists to *Euconochitina moussegoudaensis* (herein, it has used as *"Euconochitina sp".*) reffering to his paper that he has not published it yet. He also mentioned that this species belongs to the Uppermost Ordovician (Hirnantian) where he has studied. In the Radkan area, Euconochitina sp. is present, associating with both *Tanuchitina elongata* and *Spinachitina oulebsiri* chitinozoan biozones.

Moreover, many acritarch and few chitinozoan taxa of preceding biozones continue into this chitinozoan biozone. The two new chitinozoan species of *Spinachitina aidaiae* n. sp., and *Belonechitina kordkuyensis* n. sp., are also present in this biozone.

Therefore, both acritarch and chitinozoan taxa suggest the uppermost part of time slice 6c (the upper Hirnantian) for this part of the Gorgan Schists (Webby *et al.,* 2004).

4.6. *Nezzazata-Globutruncana* foraminiferal biozone

This foraminiferal biozone is present in the non-metamorphic fossiliferous limestone which unconformably rests on the Gorgan Schists (Fig.2). The studied samples of the limestone unit contain abundant foraminifers and bloom of oligostiginids, which are associated with recycled fragments of the Gorgan Schists (the size of the Gorgan Schists fragments gradually decreases upward). This biozone is marked by diagnostic foraminiferal and oligostiginid species, including *Nezzazata* sp., *Ticinella* sp., *Marsonella trochus, Hedbergella planispira, Marginotrunca (Globutruncana) pseudolinneiana* and *Calcisphaerula lenticularis, Calcisphaerula innominata, and Pithonella ovalis,* and they extend through a thickness 10m(MG-8430 to MG-8433). The above-mentioned microfossils have so far been recorded from the Late Cretaceous sediments elsewhere (e.g. the Sarvak Formation in the Zagros Basin (Jams and Whynd, 1965). Thus, the overlying, non-metamorphic, fossiliferous limestone, which unconformably rests on the Gorgan Schists, belongs to the Upper Cretaceous. Therefore, the assignment of the overlying non-metamorphic fossiliferous limestone to the Lar Formation (Upper Jurassic-Lower Cretaceous) is not warranted anymore (Berra *et al.,* 2007).

5. INTERPRETATION AND CONCLUSIONS

The Gorgan Schists of the Radkan area contains well--preserved and abundant microfossils, including acritarchs, chitinozoans, scolecodonts and graptolite remains (Fig.2). Five chitinozoan biozones in the Gorgan Schists and one Foraminiferal biozone in the overlying non-metamorphic Fossiliferous limestone were established and they are discussed in ascending stratigraphic order.

The chitinozoan *Belonechitina robusta* Biozone appears in the basal part of the Gorgan Schists and extends through a thickness of 361m. Based on the chitinozoan and acritarch taxa, a Late Ordovician (late Sandbian to early Katian) age, or part of time slices of 5b -5c (after WEBBY *et al.* 2004) is suggested for this thickness of the Gorgan Schists in the Radkan area. The chitinozoan *Armoricochitina nigerica* Biozone, succeeds the *Belonechitina robusta* Biozone, and extends throughout a thickness 283.5m of the Gorgan Schists, indicating the Katian (time slice 6a after WEBBY *et al.,* 2004). The chitinozoan *Ancyrochitina merga* Biozone is present in the middle part of the Gorgan Schists and includes a thickness of 330m, representing the uppermost Katian (time slice 6b after WEBBY *et al.,* 2004). The chitinozoan *Tanuchitina elongata* Biozone is present in associated metavolcanics and metasediments of the Gorgan Schists, and extends through a thickness 788m, indicating the lower Hirnantian (time slice 6c after WEBBY *et al.,* 2004). Finally, the chitinozoan *Spinachitina oulebsiri* Biozone occurs in the uppermost part of the Gorgan Schists, and extends through a thickness of 616.5m, suggesting uppermost Hirnantian (time slice 6c after WEBBY *et al.* 2004).

Comparison of the acritarch taxa of the Radkan area with those elsewhere indicates broad similarity with taxa from Libya, Morocco, Algeria, Saudi Arabia, Portugal, England, the United States, and Canada, suggesting a cosmopolitan nature for acritarch taxa during the Late Ordovician (Sandbian to Late Hirnantian), whereas the encountered chitinozoan taxa of the Gorgan Schists show distinct Gondwanan affinity. The chitinozoan biozones, especially the *Belonechitina robusta, Armoricochitina nigerica, Ancyrochitina merga, Tanuchitina elongata* and *Spinachitina oulebsiri,* have been well- established only in the North Gondwana Domain (PARIS, 1990; OULEBSIR and PARIS, 1995; PARIS *et al.,* 2000b; PARIS *et al.,* 2007).

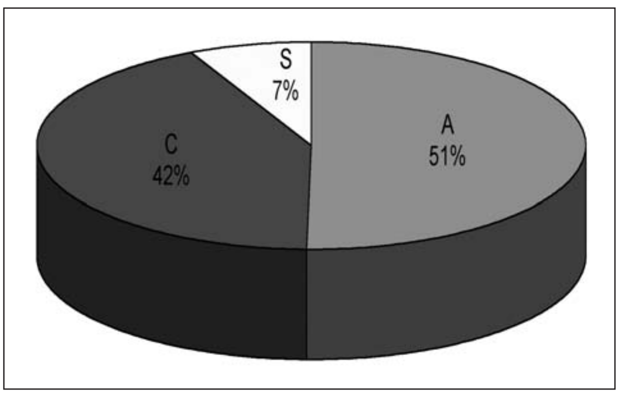

Fig. 3 – Illustration of relative percentage of acritarch(A), chitinozoan (C) and Scolecodont (S) in the Gorgan Schists.

The presence of the Gondwanan chitinozoan biozones in the Upper Ordovician Gorgan Schists suggests that the study area has been part of the Gondwanan supercontinent during the time interval represented by the Gorgan Schists. Moreover, the presence of abundant diverse chitinozoan, acritarch and scolecodont taxa (Fig.3) in the Gorgan Schists suggest a shallow marine environment for the Gorgan Schists with cold climatic condition in the high latitude for this part of the Alborz Mountains. Finally, based on the encountered foraminifers and oligostiginids in the non-metamorphic fossiliferous limestone, which unconformably overlies the Gorgan Schists, a Late Cretaceous age is assigned to the limestone. The volcano-sediments of the Upper Ordovician Gorgan Schists seem to be equivalent to the Ghelli Formation, and are older than the Soltan Maidan basalts (STAMPFLI, 1978; 2000). The shallow marine sediments coupled with flood basalts of the Gorgan Schists are indicative of the rift-related volcanic events affecting the northern margin of the Gondwana during the Late Ordovician, and opening process of the Palaeo-Tethys. Apparently, this marginal rift assemblage was metamorphosed during the closure of the Palaeo-Tethys and collision with the southern Laurentia during the Early Triassic (Rhaetian).

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PLATES

PLATE I

Fig. 1 – *Orthosphaeridium rectangulare* (EISENACK, 1963) EISENACK, 1968.

Fig. 2 – *Dactylofusa striata* (STAPLIN, *et al.* 1965) FENSOME, *et al.* 1990.

Fig. 3 – *Veryhachium triangulatum* Konzalova-Mazancova, 1969.

Fig. 4 – *Dactylofusa cabottii* (Cramer, 1971) FENSOME, WILLIAMS, BRASS, FREEMAN, and HILL, 1990.

Fig. 5 – *Pirea ornata* (Burmann) EISENACK, CRAMER, and DÍEZ, 1976.

Fig. 6 – *Neovryhachium carminae* (Cramer) CRAMER, 1971.

Fig. 7 – *Tunisphaeridium eisenackii* LOEBLICH and TAPPAN, 1978.

Fig. 8 – *Veryhachiun europaeum* STOCKMANS and WILLIERI, 1960.

Fig. 9 – *Navifusa ancepsipuncta* Loeblich, 1970 *ex* EISENACK, CRAMER and DÍEZ, 1979.

Fig. 10 – *Disparifusa psakadoria* LOEBLICH and TAPPAN, 1978.

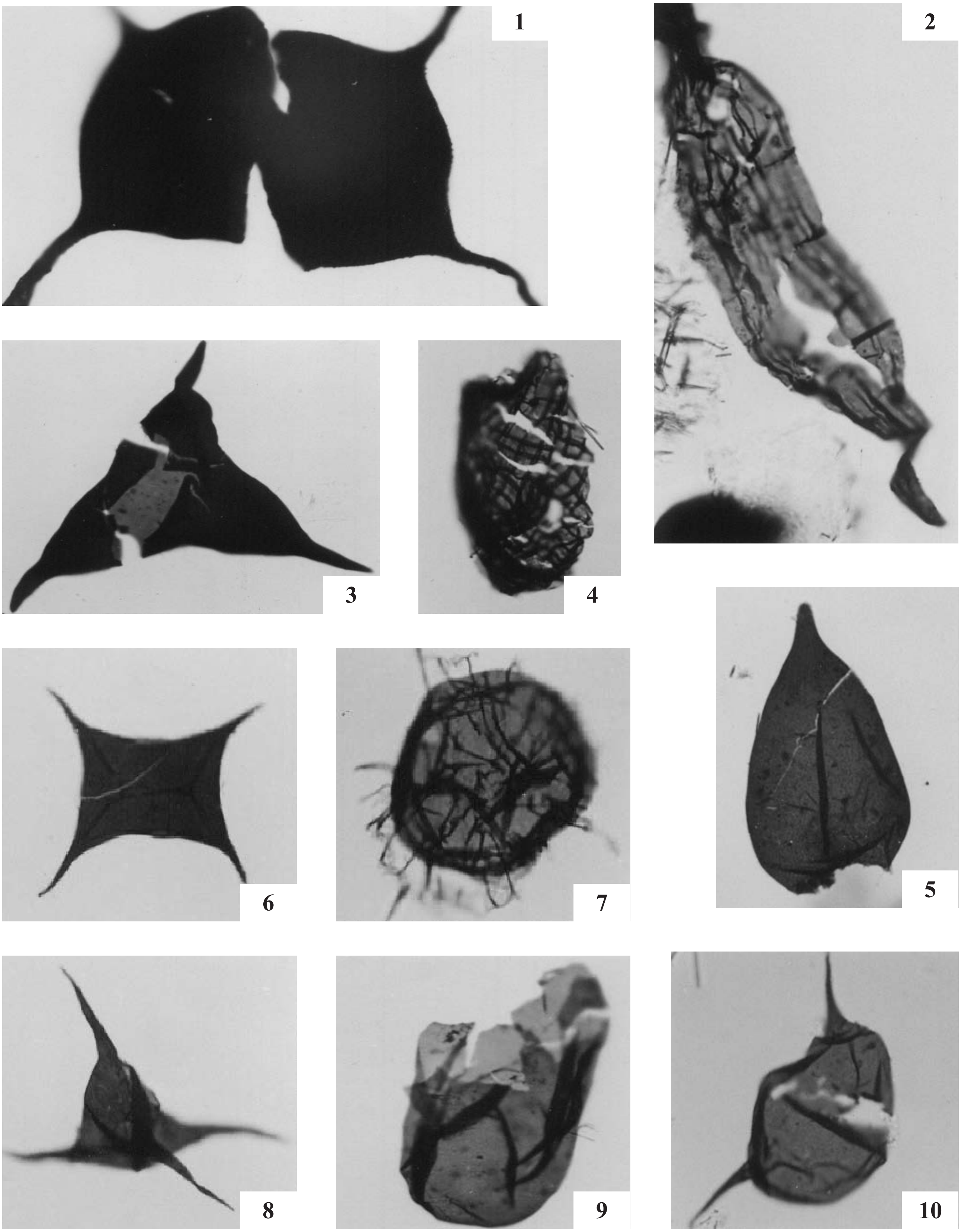
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PLATE II

Fig. 1 – *Baltisphaeridium perclarum* LOEBLICH and TAPPAN, 1978.

Fig. 2 – *Orthosphaeridium insculptum* LOEBLICH, 1970.

Fig. 3 – *Veryhachium subglobosum* JARDINE *et al.,* 1974.

Fig. 4 – *Villosacapsula setosapellicula* (LOEBLICH,1970) LOEBLICH and TAPPAN, 1976.

Fig. 5 – *Baltisphaeridium oligopsakium* LOEBLICH and TAPPAN, 1978.

Fig. 6 – *Veryhachium lairdii* (Deflandre) DEUNFF, 1959 ex DOWNIE, 1959.

Fig. 7 – *Dactylofusa platynetrella* LOEBLICH and TAPPAN, 1978.

Fig. 8 – *Evittia remota* (Deunff) LISTER, 1970.

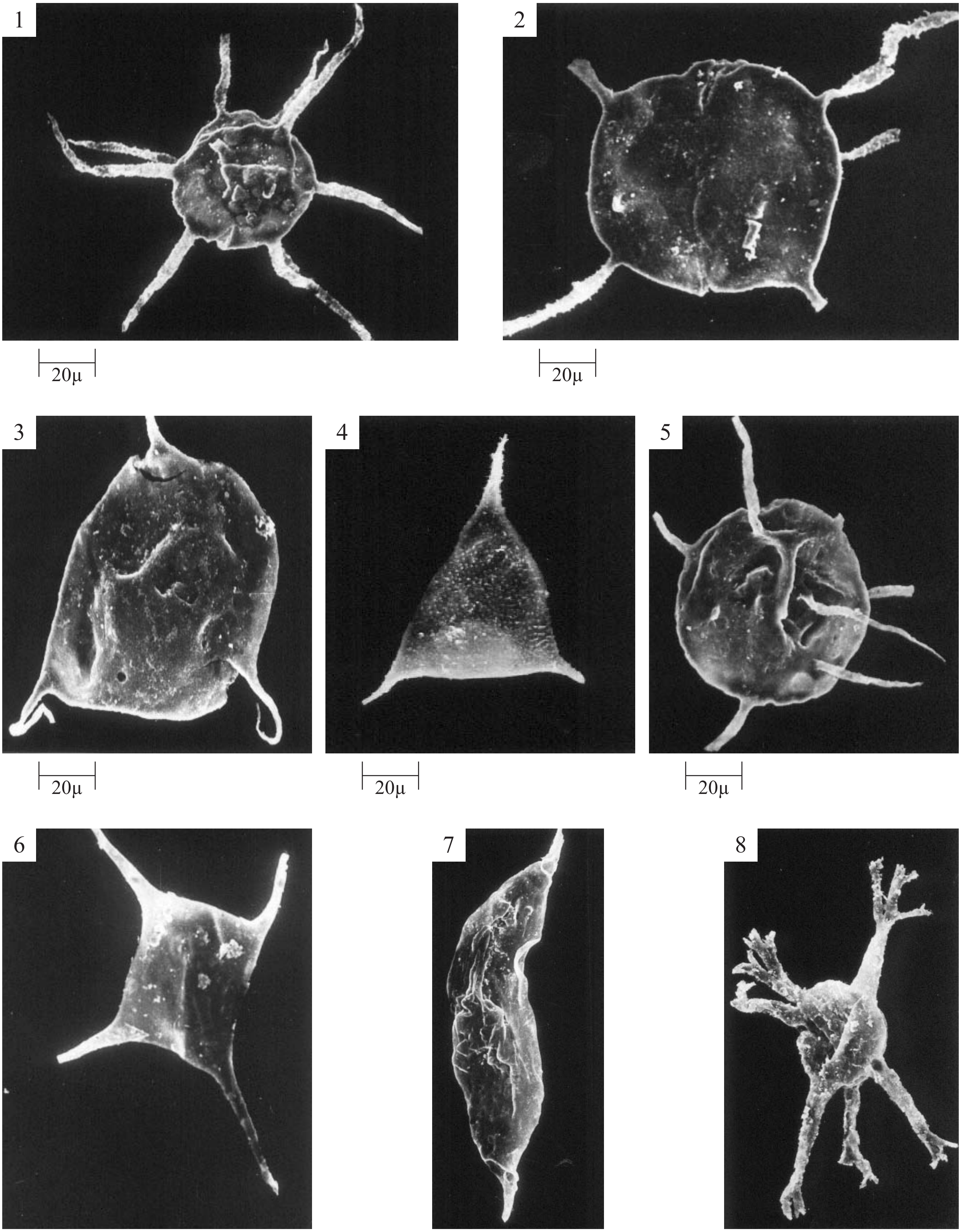
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PLATE III

Fig. 1 – *Gorgonisphaeridium antiquum* LOEBLICH and TAPPAN, 1978.

Fig. 2 – *Baltisphaeridium longispinosum delicatum* TURNER, 1984.

Fig. 3 – *Ordovicidium elegantulum* TAPPAN and LOEBLICH, 1971

Fig. 4 – *Multiplicisphaeridium bifurcatum* Staplin, JANSONIUS and POCOCK, 1965.

Fig. 5 – *Villosacapsula irrorata* (LOEBLICH and TAPPAN, 1978) FENSOME, WILLIAMS, BARSS, FREEMAN and HILL, 1990.

Fig. 6 – *Multiplicisphaeridium irregulare* Staplin, JANSONIUS and POCOCK, 1965.

Fig. 7 – *Polygonium gracile* VAVRDOVÁ, 1966 emend. SARJEANT and STANCLIFFE, 1994.

Fig. 8 – *Actinotodissus crassus* LOEBLICH and TAPPAN, 1978.

Fig. 9 – *Sylvanidium paucibrachium* Loeblich, 1970.

Pl. III

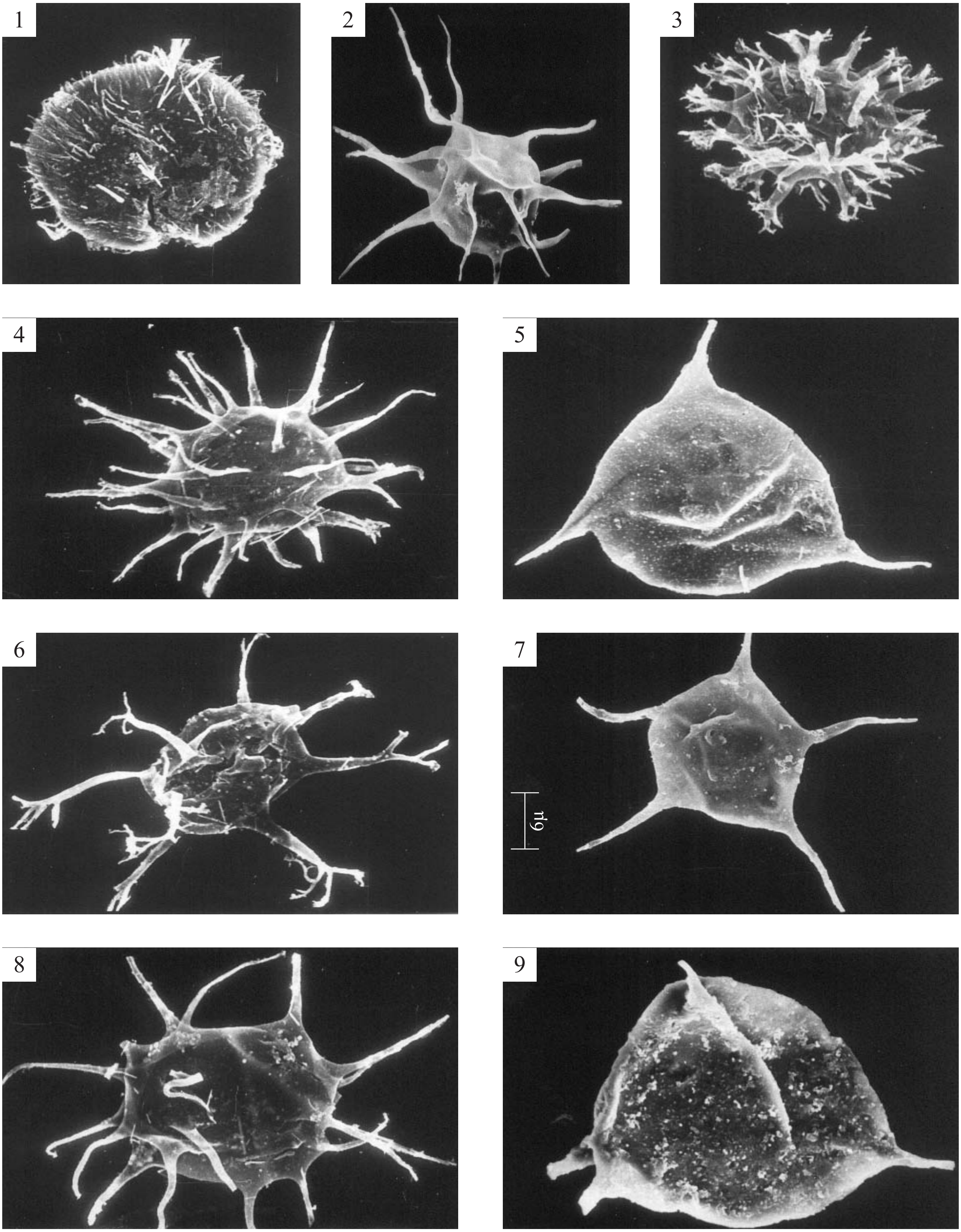

PLATE IV

Fig. 1 – *Desmochitina piriformis* LAUFELD, 1967.

Fig. 2 – *Desmochitina cocca* EISENACK, 1931.

Fig. 3 – *Plectochitina sylvanica* JENKINS, 1970.

Fig. 4 – *Cyathochitina campanulaeformis* (EISENACK, 1931) EISENACK, 1955b.

Fig. 5 – *Euconochitina lepta* (JENKINS, 1970) emend. PARIS, GRAHN, NESTOR and LAKOVA, 1999.

Fig. 6 – *Pistillachitina pistilliformis* EISENACK, 1939.

Fig. 7 – *Spinachitina bulmani* JANSONIUS, 1964.

Fig. 8 – *Euconochitina moussegoudaensis* nomen nudum *(Euconochitina sp.).*

Fig. 9 – *Ancyrochitina merga* JENKINS, 1970.

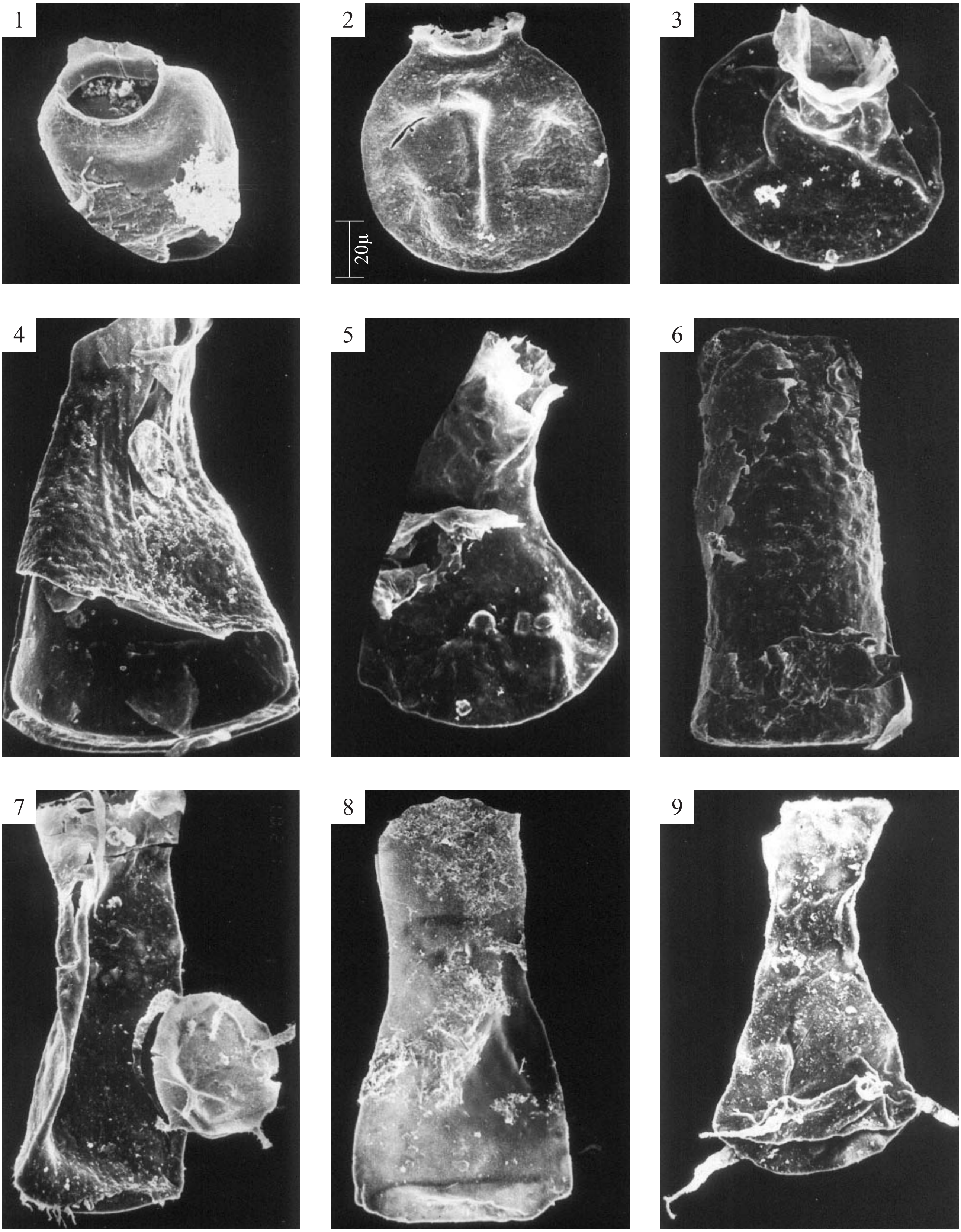
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PLATE V

Fig. 1 – *Angochitina communis* JENKINS, 1967.

Fig. 2 – *Hercochitina* sp.

Fig.3 – *Lagenochitina prussica* EISENACK, 1931

Fig. 4 – Enlargement of basal part of chamber of Fig. 1

Fig. 5 – Enlargement of basal part of chamber of Fig.3.

Fig. 6 – *Hercochitina crickmayi* JANSONIUS, 1964.

Fig.7 – *Belenochitina wesenbergensis* EISENACK, 1959.

Fig. 8 – *Spinachitina aidaiae* n. sp.

Fig. 9 – *Rhabdochitina usitata* JENKINS, 1967.

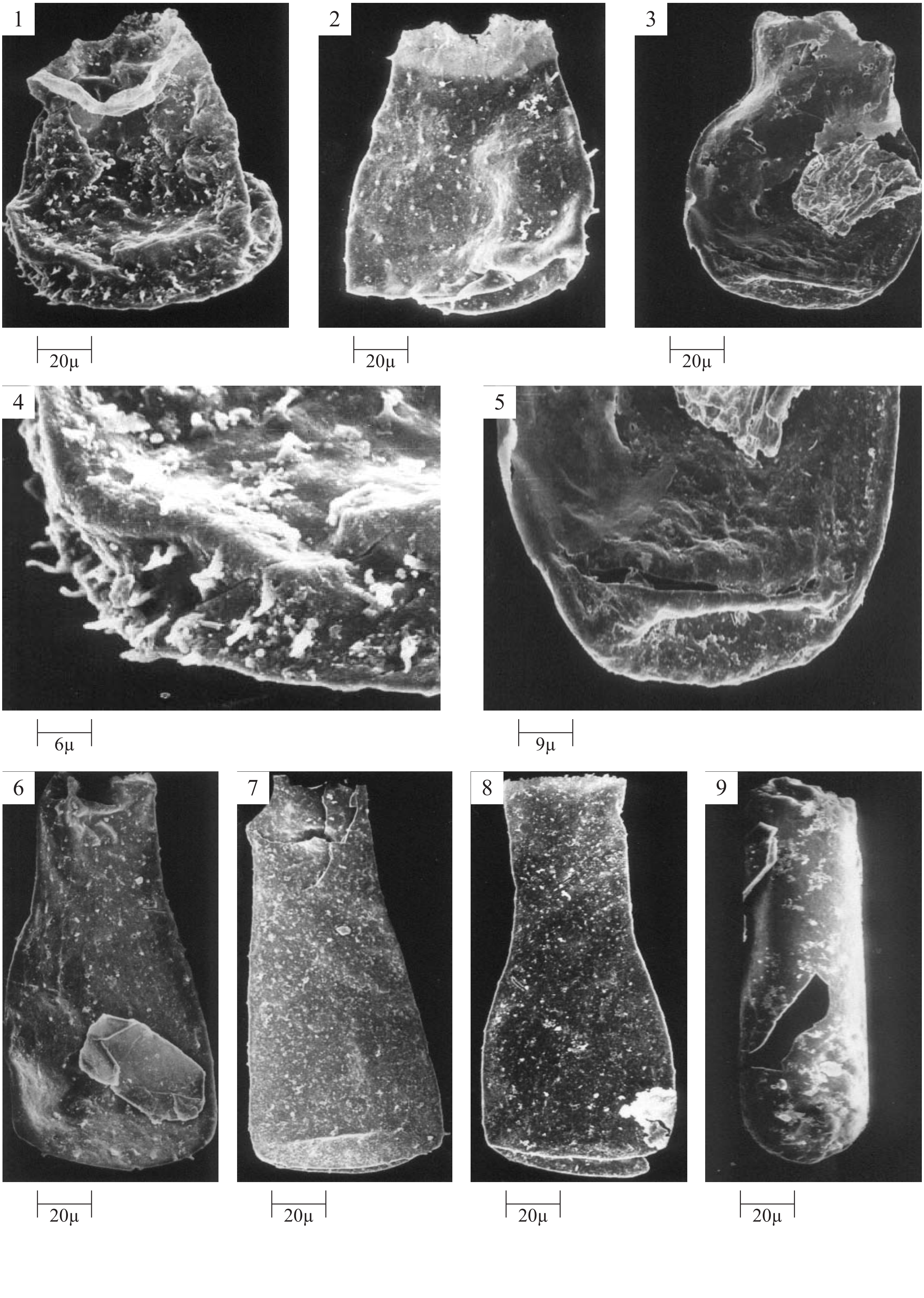
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PLATE VI

Fig. 1 – Conochitina sp. A

Fig. 2 – *Conochitina chydaea* JENKINS, 1967.

Fig. 3 – *Belonechitina* sp. A

Fig. 4 – *Desmochitina minor* EISENACK, 1931.

Fig. 5 – Enlargement of basal part of chamber of fig.2.

Fig. 6 – Enlargement of basal part of chamber of Fig.3.

Fig. 7 – *Tanuchitina elongata* (BOUCHÉ, 1965).

Fig. 8 – *Spinachitina oulebsiri* PARIS, *et al.* 2000b.

Fig. 9 – *Belonechitina micracantha* EISENACK, 1931.

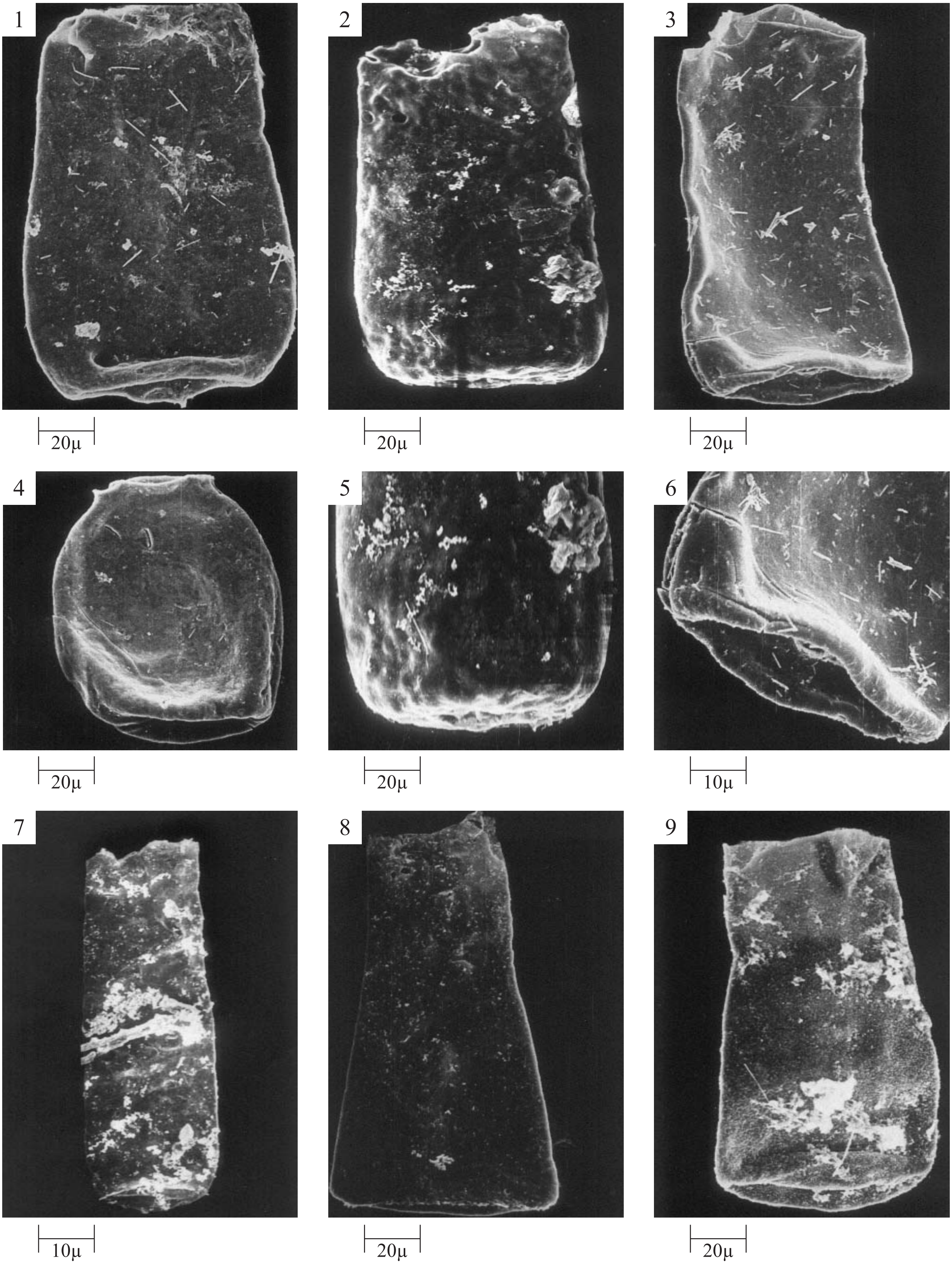
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PLATE VII

Fig. 1 – *Tanuchitina elongata* (BOUCHÉ, 1965).

Fig. 2 – *Spinachitina oulebsiri* PARIS *et al.,* 2000b.

Fig. 3 – *Rhabdochitina gracilis* EISENACK, 1931.

Fig. 4 – Enlargement of basal part of chamber of fig.1, showing, attached carina.

Fig. 5 – Enlargement of basal part of chamber of fig.2, showing arrangement of spines.

Fig. 6 – Enlargement of basal part of chamber of fig.3, showing lack of ornamentation.

Fig. 7 – *Euconochitina communis* TAUGOURDEAU, 1961.

Fig. 8 – *Lagenochitina baltica* EISENACK, 1931.

Fig. 9 – *Armoricochitina nigerica* (BOUCHÉ, 1965)

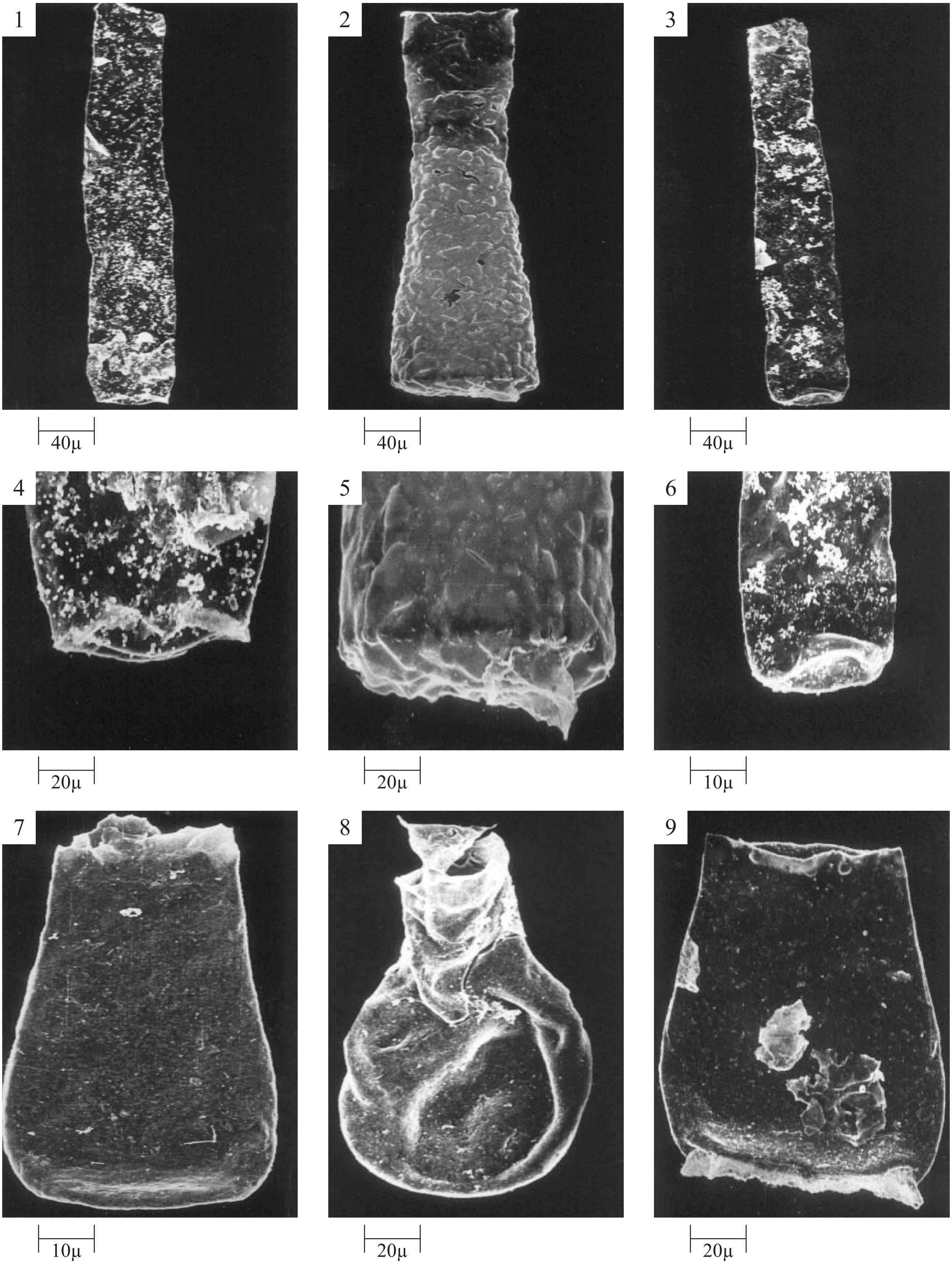
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PLATE VIII

Fig. 1 – *Belonechitina kordkuyensis* n. sp.

Fig. 2 – *Tanuchitina ontariensis* JANSONIUS, 1964.

Fig. 3 – *Belonechitina robusta* EISENACK, 1959.

Fig. 4 – Enlargement of basal part of chamber of Fig. 1, showing brocken stout spines.

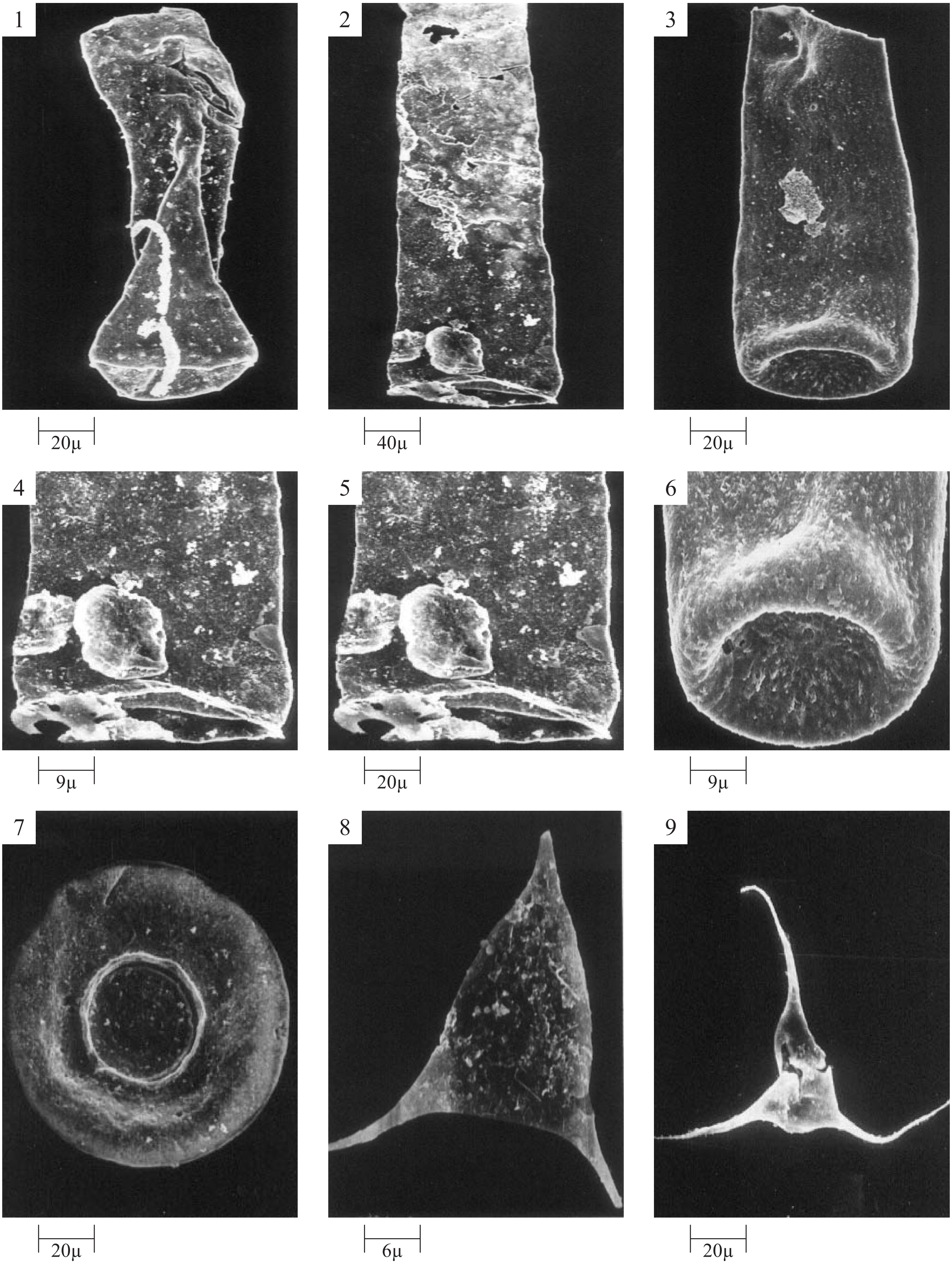
Fig. 5 – Enlargement of basal part of chamber of fig. 2, showing attached carina.

Fig. 6 – Enlargement of basal part of chamber of fig. 3, showing multirood spines.

Fig. 7 – *Calpichitina lenticularis* (BOUCHÉ, 1965).

Fig. 8 – *Veryhachium reductum* (DEUNFF, 1958) de JEKHOWSKY, 1961.

Fig. 9 – *Veryhachium trispinosum* (EISENACK) DEUNFF, 1954 ex DOWNIE, 1954.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