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Biostratigraphy and palaeogeography of Late Ordovician chitinozoans from the northeastern Alborz Range, Iran

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Abstract

Chitinozoans were extracted from Upper Ordovician strata in the northeastern Alborz Range (Kopet Dagh Region); 31 chitinozoan species are recorded. Four successive biozones are recognised within the Ghelli Formation, viz. *Tanuchitina fistulosa*, *Acanthochitina barbata*, *Armoricochitina* cf. *nigerica* and *Ancyrochitina merga* biozones. Correlation of these biozones with those of the North Gondwana Domain suggests that the middle and upper parts of the Ghelli Formation range from Late Caradoc to mid Ashgill. The number of species in common with the North Gondwana Domain suggests a close relationship between Iran and North Gondwana. However, there are a number of cosmopolitan species occurring in the Ashgill. Three new species are described: *Armoricochitina alborzensis*, *Armoricochitina iranica* and *Ancyrochitina persica*.

Keywords: Chitinozoa; Late Ordovician; North Gondwana; biostratigraphy; palaeobiogeography

1. Introduction

Chitinozoans from Palaeozoic strata of the Iranian platform have received minimal attention since the discovery of the group by Eisenack (1931). This paper aims to demonstrate the utility of chitinozoan taxa in providing a powerful tool not only for chronostratigraphy but also for palaeobiogeography in Upper Ordovician sediments of northeastern Alborz Range, along the southern shores of Caspian Sea.

The only previous study of Late Ordovician chitinozoans from Iran concerned the Seyahou Formation in southern Iran (Ghavidel-syooki, 2000), where three chitinozoan assemblage zones were defined. Recent work from Saudi Arabia by Al-Hajri (1995) and Paris et al. (2000) provides a basis for comparison and potential for accurate regional correlation.

The Ordovician has proven to be difficult for cross-continental correlation, due to the peculiar configuration of palaeoplates resulting in pronounced provincialism (Paris et al., 1999a,b). Thus several regional biozonations have been constructed, one for the high latitude North Gondwana Domain (Paris, 1990), one for Baltica (Nõlvak and Grahn, 1993; Nõlvak, 1999), another for

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the Brabant Massif in Avalonia (Samuelsson and Verniers, 2000), and one for Laurentia (Achab, 1989) which can also be applied to other low latitude faunas such as Australia (Winchester-Seeto et al., 2000).

One of the main aims of this study is to determine the extent to which the biozones constructed for the North Gondwana Domain could be applied to northeastern Iran.

2. Stratigraphy

The area is located near Ghelli village, in the western part of Kuh-e-Saluk (Kuh means mountain), approximately 55 km southwest of Bojnourd city (Fig. 1). The road from Garmeh to Bojnourd city is the principle link to the study area. A thick Lower Palaeozoic sequence is well-developed in Kuh-e-Saluk, consisting of, in ascending stratigraphic order, the Mila, Lashkarak, Ghelli and Niur formations (Fig. 2).

The study area is part of the northeastern

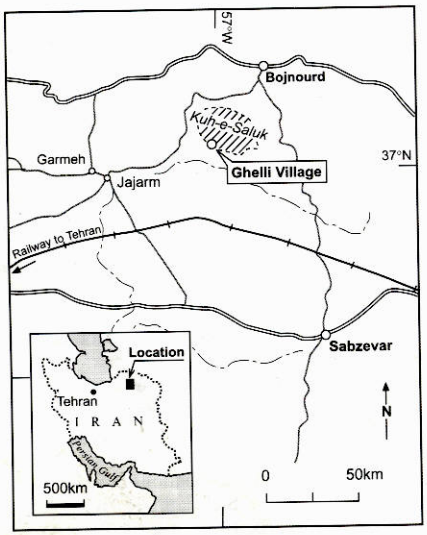


Fig. 1. Locality map of studied area.

Alborz Range (Kopet Dagh Region), where the rock units extend towards the southern and eastern parts of the Caspian Sea. The Mila Formation consists mainly of limestone, with poorly preserved brachiopods and trilobite remains. Based on stratigraphic position (Afshar-Harb, 1979) and acritarch taxa (Ghavidel-syooki, 1998) it has been assigned to the Middle and Upper Cambrian. The lower contact of the Mila Formation is not clear due to the presence of a fault, but its upper contact is conformable with the Lashkarak Formation. The Lashkarak Formation is 250 m thick and it consists of olive-grey shales with stringers of rubbly limestones. Both lower and upper contacts of this formation are conformable with underlying and overlying formations. Based on acritarch assemblage zones, this rock unit has been assigned to the Lower Ordovician (Ghavidel-syooki, 1998).

The Ghelli Formation is 1000 m thick in the study area (type locality), and consists mainly of dark to olive-grey shales with subordinate siltstones and fine-grained sandstones. This formation has been intruded in the basal and upper parts by igneous sills and dykes. The lower and upper contacts of Ghelli Formation are apparently conformable with underlying Lashkarak Formation, and the overlying Niur Formation. The Ghelli Formation contains straight nautiloids, a brachiopod fauna and trace fossils (trails, tracks and burrows) in some intervals (Fig. 2), but no attempt has yet been made to identify these faunas. Based on palynological data, the Ghelli Formation has been assigned to the Middle and Upper Ordovician (Ghavidel-syooki, 1998). The Niur Formation is the youngest Lower Palaeozoic rock unit in the study area and consists of fossiliferous limestone and black shale. Based on palaeontological data, it has been assigned to the Silurian (Afshar-Harb, 1979; Ghavidel-syooki, 1998).

3. Materials and methods

Surface samples (199) were treated and investigated for chitinozoan taxa (sample numbers of MG 2680–MG 2878); 183 were from the Ghelli

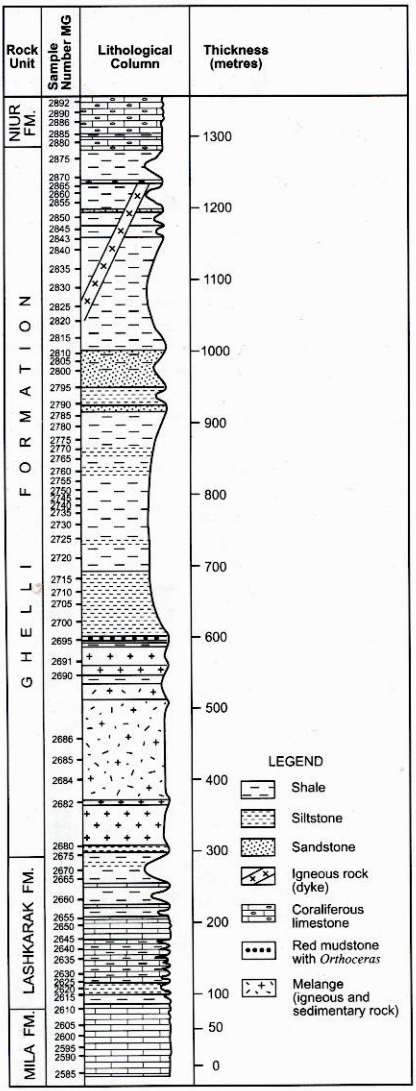


Fig. 2. Stratigraphic column of the lower Palaeozoic rock units in this study area, showing relative position of samples; not all samples are marked, the position of unmarked samples may be inferred from those above and below.

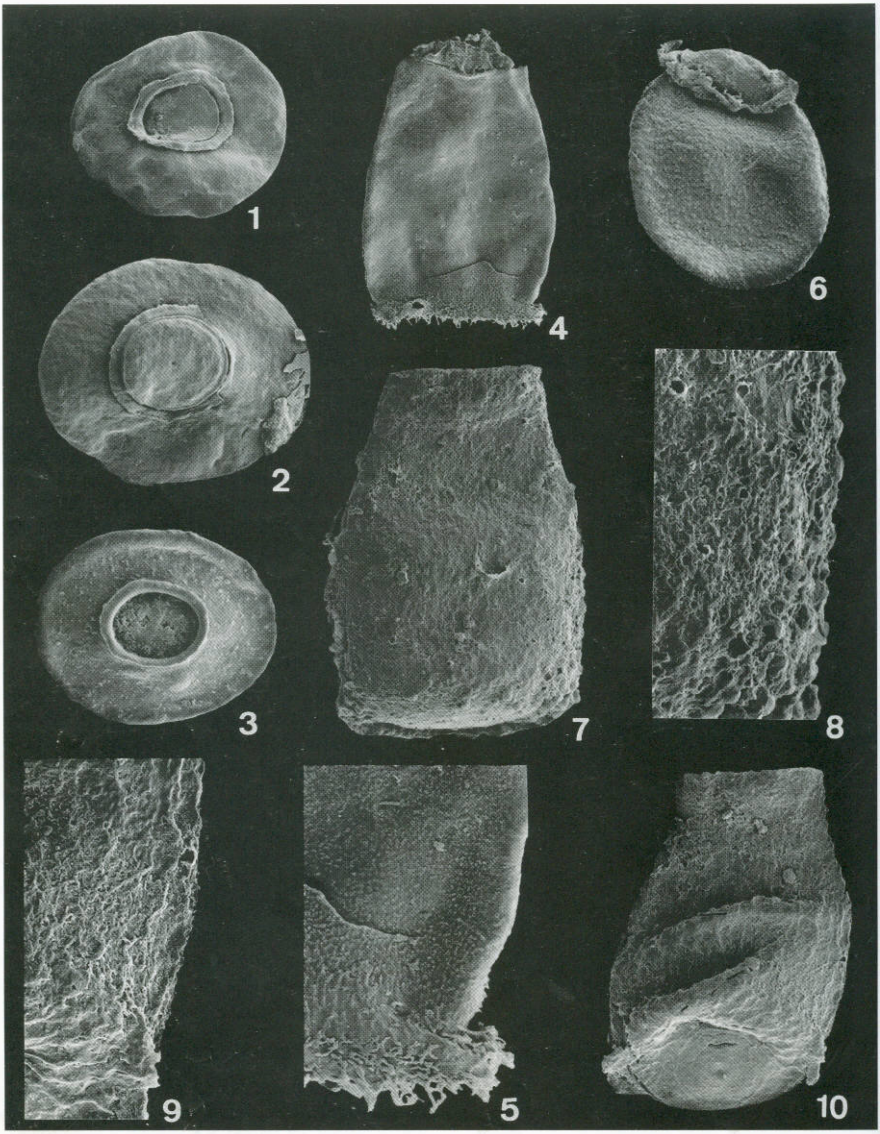
Formation, and 94 of these yielded chitinozoans. The palynomorphs were extracted from shale, siltstone and fine-grained sandstone by standard palynological procedures, including treatment of the residues of each sample with 30 ml of saturated zinc bromide in order to separate the organic residues from the inorganic materials, and screening of the organic residues through 20 micron nylon mesh sieves. Extensive scanning electron and transmitted light microscopic examination was carried out on selected specimens throughout the study.

Most samples contained well-preserved and abundant palynomorphs (chitinozoans, acritarchs, small trilete spores and scolecodonts), except for the lower part of the formation (sample numbers MG 2680–MG 2687). In general the chitinozoans are very abundant and moderately well-preserved. The thermal maturity is quite low (colours range from dark brown to almost black), but many specimens are flattened. Diversity is relatively high, ranging from 5 to 25 species per sample.

4. Systematic palaeontology

The classification system used in this study follows Paris et al. (1999a), except for *Jenkinochitina* (see discussion). Many of the species have been well-described elsewhere and therefore only relevant remarks are made herein. Brief descriptions of species in open nomenclature have been provided and new species have been fully described. All measurements are given in microns (μm). Most of the measurements were on three-dimensional specimens, however, where necessary a correction factor of 0.7 was used on individual flattened specimens.

Type and figured specimens with the prefix AM F are lodged in the collections of the Australian Museum, Sydney, Australia. The other samples,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designated NIDC, are part of the collection housed in the Museum of the Geological Research Laboratories of the Exploration Division of the National Iranian Oil Company.

Order Operculatifera Eisenack, 1931
Family Desmochitinidae Eisenack, 1931 emend. Paris, 1981
Subfamily Desmochitininae Paris, 1981
Genus ***Calpichitina*** Wilson and Hedlund, 1964

Type species: *Calpichitina scabiosa* Wilson and Hedlund, 1964

Calpichitina lenticularis (Bouché, 1965) (Plate I, figs. 1–3)
Remarks: For description see Bouché (1965) and Elaouad-Debbaj (1984). This species is distinguished by the smooth vesicle surface and the relatively small aperture, i.e. approximately one third to one half of the maximum diameter. Following the synonymy of Elaouad-Debbaj (1984), *Calpichitina lenticularis* is commonly found in Caradoc and Ashgill strata in southern Iran (Ghavidel-syooki, 2000), North Gondwana (Paris, 1979, 1981; Elaouad-Debbaj, 1984; Oulebsir and Paris, 1995), Avalonia (Jenkins, 1967), Laurentia (Achab, 1978; Martin, 1980) and Baltica (Grahn, 1982).

Dimensions: Based on eight specimens. Max. diameter = 79–119 (Av. 91.7); diameter of aperture = 30–53.2 (Av. 38.9); diameter of aperture/max. diameter = 0.35–0.48

Genus ***Desmochitina*** Eisenack, 1931
Type species: *Desmochitina nodosa* Eisenack, 1931

Desmochitina minor spp. Eisenack, 1931 (Plate I, fig. 6)
Remarks: For descriptions see Eisenack (1931), Laufeld (1967) and Paris (1981). There may be more than one species represented here.
Desmochitina minor is an apparently very long-ranging, cosmopolitan species, and is claimed to be found in strata that range from Arenig to Ashgill. Grahn (1984) maintains that this species may have become a 'waste basket taxon', however, the material from the Alborz Range is inadequate for undertaking taxonomic revision.

Subfamily Pterochitininae Paris, 1981
Genus ***Armoricochitina*** Paris, 1981

Type species: *Linochitina? ceneratiensis* Paris, 1976

Armoricochitina alborzensis n. sp. (Plate I, figs. 4 and 5)

Plate I. Specimens housed with the Australian Museum are prefixed by the number AM F; other specimens, designated NIDC, are housed in the collections of the museum of the Geological Research Laboratories of the Exploration Division of the National Iranian Oil Company, in Iran. Sample numbers have the prefix MG; for their relative position see the stratigraphic column (Fig. 2) and the range chart (Fig. 3)

1–3 *Calpichitina lenticularis* (Bouché)
1 AM F117693, ×300, MG 2834
2 AM F117694, ×300, MG 2834
3 AM F117695, ×300, MG 2811
4, 5 *Amoricochitina alborzensis* n. sp.
4 Holotype, AM F117696, ×300, MG 2834
5 enlargement of 4, ×1100
6 *Desmochitina minor* Eisenack, AM F117697, ×300, MG 2834
7–10 *Amoricochitina iranica* n. sp.
7 Holotype, AM F117698, ×300, MG 2811
8 enlargement of 7, ×600
9 enlargement of 10, ×550
10 AM F117699, ×250, MG 2811

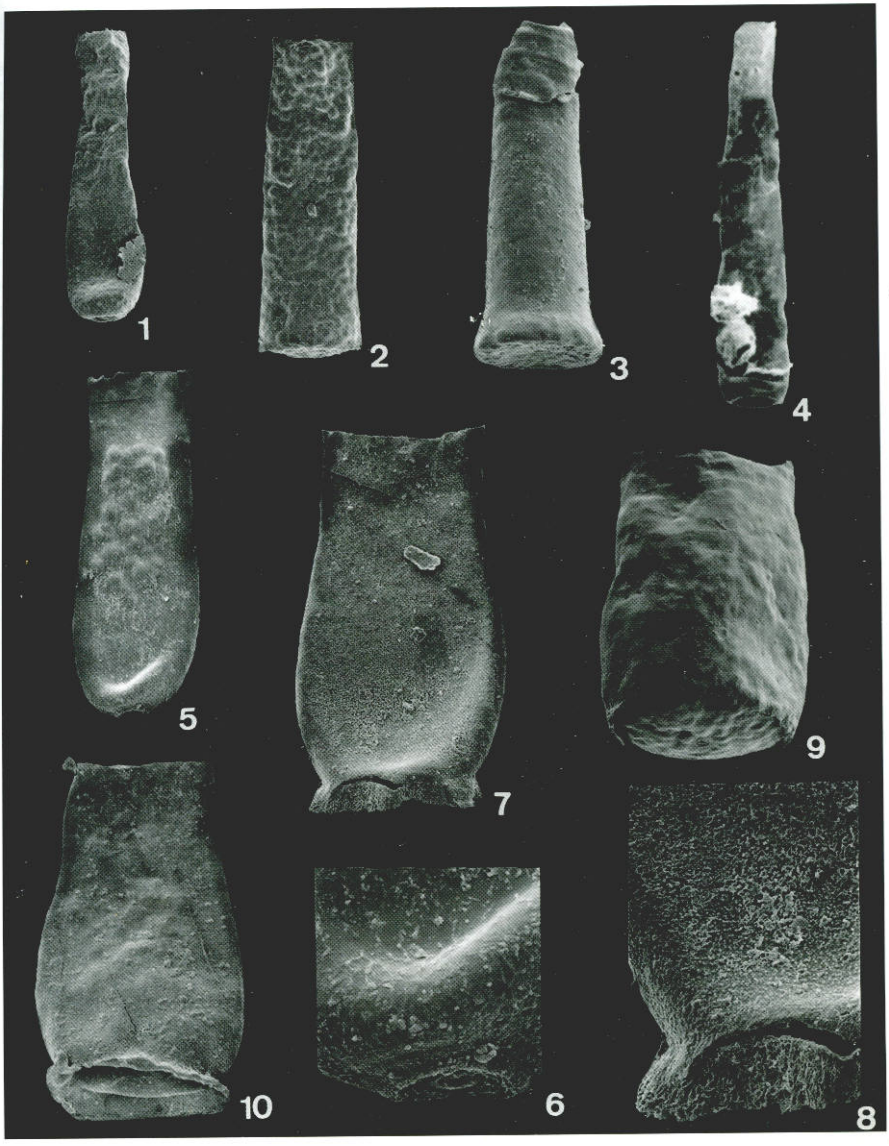
Holotype: Plate I, figs. 4 and 5; AM F117696
Type stratum: Ghelli Formation, sample number MG 2834, 55 km southwest of Bojnourd city, northeastern Alborz Mountain Range, northeastern Iran.
Derivation name: Referring to the Alborz Mountain Range, northern Iran.
Material: Several hundred specimens.
Diagnosis: A species of *Armoricochitina* with a ragged, fringed carina.
Description: This species has a cylindro-ovoid vesicle, with a short neck. Maximum diameter found in the middle part of chamber. The vesicle surface may be smooth or granular; on some specimens the ornament increases in size and density towards the base of the chamber, and resembles small spines. The carina varies in width, and is fringed. The operculum may be flat or slightly domed.
Remarks: *Armoricochitina alborzensis* can be differentiated from other species of *Armoricochitina* by the ornamented carina.
Dimensions: Based on 49 specimens. Length = 150–250 (holotype = 250; Av. 200); max. diameter = 113–141 (holotype = 141; Av. 127); length of carina = 22–45 (holotype = 45; Av. 33.5)

Armoricochitina iranica n. sp. (Plate I, figs. 7–10)
Holotype: Plate I, figs. 7 and 8; AM F117698
Type stratum: Ghelli Formation, sample number MG 2811, 55 km southwest of the town of Bojnourd, northeastern Alborz Mountain Range, northeastern Iran.
Derivation of name: Refers to Iran, the country in which the species was first discovered.
Material: A few hundred specimens.
Diagnosis: This is a species of *Armoricochitina* with a spongy ornament on the chamber surface.
Description: *Armoricochitina iranica* has an ovoid to cylindro-conical test. Maximum diameter may be in the middle of the chamber, or the chamber flanks may be sub-parallel, depending on the degree of compression and distortion of the test. The chamber narrows to a short neck, which occupies approximately one quarter to one third of the total length. The base is flat, with a distinct basal scar, and the carina is relatively short. The chamber is covered with a dense, spongy ornament, which increases in density towards the base.
Remarks: This species differs from other species of *Armoricochitina* in having a spongy ornament on the chamber.
Dimensions: Based on 21 specimens. Length = 200–214 (holotype 214); length of chamber = 136–148 (holotype 148); length of neck = 53–68 (holotype 66); max. diameter = 150–163 (holotype 152); min. diameter = 95–108 (holotype 95); length/max. diameter = 1.41–1.45 (holotype 1.41); max. diameter/min. diameter = 1.6–1.65 (holotype 1.6)

Armoricochitina cf. *nigerica* (Bouché, 1965) (Plate II, figs. 7, 8, 10)
Description: *Armoricochitina* cf. *nigerica* has an elongate, moderately sized vesicle, with an ovoid chamber topped with a short, cylindrical neck.

Plate II.

1 *Conochitina* cf. *dolosa* Laufeld, AM F117700, ×150, MG 2834
2 *Hyalochitina* sp., AM F117701, ×250, MG 2811
3 *Pistillachitina* cf. *pistillifrons* Eisenack, AM F117702, ×250, MG 2811
4 *Conochitina* sp. 2, NIDC, ×250
5, 6 *Conochitina* sp. 1
5 AM F117703, ×250, MG 2811
6 enlargement of the base of 5, ×1300
7, 8, 10 *Armoricochitina* cf. *nigerica* (Bouché)
7 AM F117704, ×300, MG 2811
8 enlargement of 7, showing the carina, ×900
10 AM F117705, ×300, MG 2811
9 *Armoricochitina* sp., AM F117706, ×300, MG 2834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The aperture is surrounded by a fine fringe. The basal edge is well-rounded, with a conspicuous carina directly below. The vesicle surface is covered with fine granules.

Remarks: This species resembles some examples of *Armoricochitina nigerica* (Bouché), but differs from the holotype in having a more elongate vesicle, with a more distinct neck.

Armoricochitina cf. *nigerica* is very similar to *A. armoricana*; however, the species from Iran is much smaller and more elongate than that illustrated by Paris (1981), pl. 12, figs. 1–8. In contrast to the specimens found by Rauscher and Doubinger (1967) and Paris (1981), the vesicle surface on specimens from the Alborz Range exhibits some ornament.

Dimensions: Based on 12 specimens. Length = 170–238 (Av. 208); max. diameter = 70–97 (Av. 88); min. diameter = 39–73 (Av. 57); length of carina = 12–19; length/max. diameter = 2.1–2.6; min. diameter/max. diameter = 0.4–0.8

Armoricochitina sp. (Plate II, fig. 9)

Remarks: This species of *Armoricochitina* has a smooth to granular, subcylindrical chamber. The carina is represented only by broken remnants, and most of the individuals are broken, with varying degrees of compression of the vesicle; thus the species has been left in open nomenclature. *Armoricochitina* sp. is similar to *Armoricochitina* sp. aff. *armoricana* (Elaouad-Debbaj, 1984) from the upper Ashgill of Morocco, but is less conical in shape.

Dimensions: Based on seven specimens. Length = 131–220 (Av. 176); max. diameter = 98–152 (Av. 121.9); min. diameter = 73–125 (Av. 92); length/max. diameter = 1.4–1.7; min. diameter/max. diameter = 0.7–0.9

Order Prosomatifera Eisenack, 1972
Family Conochitinidae Eisenack, 1931 emend. Paris, 1981
Subfamily Conochitininae Paris, 1981
Genus ***Conochitina*** Eisenack, 1931 emend. Paris, Grahn, Nestor and Lakova, 1999

Type species: *Conochitina claviformis* Eisenack, 1931

Conochitina cf. *dolosa* Laufeld, 1967 (Plate II, fig. 1)

Description: *Conochitina* cf. *dolosa* is a subcylindrical to claviform species, with a flat to convex base. The maximum diameter lies just above the basal edge and then the vesicle tapers towards the aperture. The flanks may be straight, or have a slight flexure. The base has a wide, fairly prominent mucron and the vesicle wall is smooth.

Remarks: This species fits the range of shapes for *Conochitina dolosa* depicted by Laufeld (1967), fig. 11 and general description. However, *Conochitina* cf. *dolosa* is about half to one third of the length of *C. dolosa*. There is also some similarity to *Conochitina* sp. 1 from Assemblage 3 of the Qasim Formation in Saudi Arabia (Paris et al., 2000).

Dimensions: Based on two specimens. Length = 323–331; max. diameter = 85–88; min. diameter = 53–62; length/max. diameter = 3.8; min. diameter/max. diameter = 0.6–0.7

Conochitina sp. 1 (Plate II, figs. 5 and 6)

Description: *Conochitina* sp. 1 has a short, subcylindrical to claviform vesicle, with the maximum diameter occurring approximately one third of the length of the vesicle from the aboral pole. The base is hemispherical, but appears flattened in compressed specimens. The basal edge is well-rounded and a prominent basal scar and/or pit occurs at the centre of the base. The vesicle widens towards the aperture, and the surface is smooth.

Remarks: This somewhat squat species superficially resembles several taxa, but the closest is *Conochitina* sp. 2 from Assemblage 3, in the Ra'an Member of the Qasim Formation (Paris et al., 2000). Paris et al. (2000) correlate Assemblage 3 to the *Tanuchitina fistulosa* chitinozoan biozone, from the upper Caradoc.

Dimensions: Based on eight specimens. Length = 178–264 (Av. 218.6); max. diameter = 76–94 (Av. 82.3); min. diameter = 52–80 (Av. 62.6); length/max. diameter = 2–2.7; min. diameter/max. diameter = 0.7–0.9

Conochitina sp. 2 (Plate II, fig. 4)

Description: This is a short, slender species of *Conochitina*. The maximum diameter is located

near the basal margin, and the vesicle tapers towards the aperture. The base ranges from flat to invaginated, and the basal edge is well-rounded. The vesicle surface is smooth to finely granular in appearance.
Dimensions: Based on one specimen. Length = 275; max. diameter = 52

Genus ***Pistillachitina*** Taugourdeau, 1966

Type species: *Rhabdochitina pistillifrons* Eisenack, 1939

Pistillachitina cf. *pistillifrons* (Eisenack, 1939) (Plate II, fig. 3)
Remarks: This species is very similar in size and shape to *Pistillachitina* cf. *pistillifrons* from Portugal, illustrated by Paris (1981), pl. 15, fig. 9. The main differences between the species from the Alborz Range and Portugal and the material originally described by Eisenack from Germany is the relatively smaller size and proportionally shorter neck. Paris (1990) shows *Pistillachitina pistillifrons* ranging from the *L. deunffi* to *L. dalbyensis* chitinozoan biozones, i.e. in the lower and middle Caradoc.
Dimensions: Based on one specimen. Length = 236; max. diameter = 92; length/max. diameter = 2.6

Genus ***Jenkinochitina*** Paris, 1981

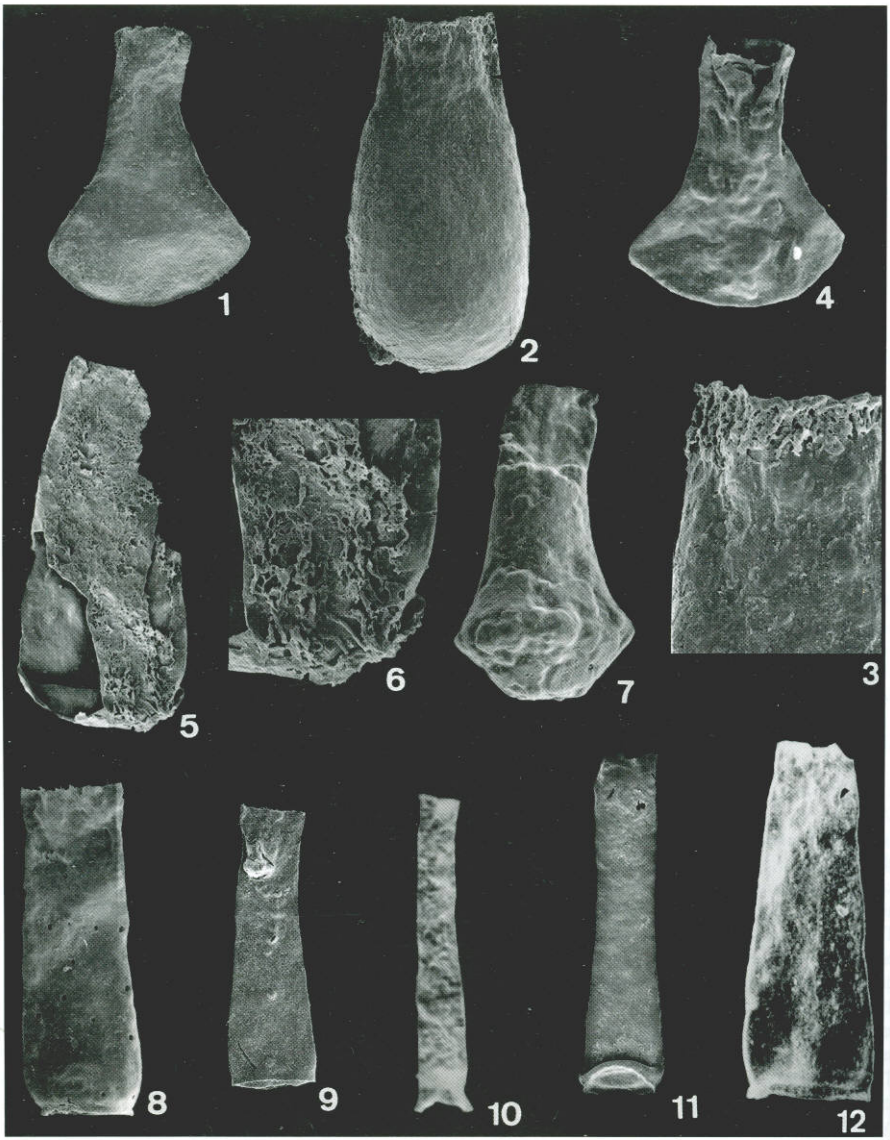
Type species: *Conochitina oelandica* Eisenack, 1955
In the recent reorganisation of the systematics of chitinozoans (Paris et al., 1999a), the genus *Jenkinochitina* was presented as a junior synonym of an amended form of *Euconochitina* Taugourdeau. The emendation of *Euconochitina* precluded species with ornamentation. According to the original description of *Jenkinochitina lepta* (Jenkins, 1970), this species can either be smooth or have small, simple spines distributed across the vesicle surface (see for example Plate II, figs. 1 and 4). Thus the genus *Jenkinochitina* has been retained in this study.

Jenkinochitina lepta (Jenkins) (Plate III, figs. 1 and 4)
Remarks: For description see Jenkins (1970) and Elaouad-Debbaj (1984). *Jenkinochitina lepta* is well known from the Ashgill of Oklahoma (Jenkins, 1970), Morocco (Elaouad-Debbaj, 1984), Algeria (Oulebsir and Paris, 1995), Saudi Arabia (Al-Hajri, 1995) and Turkey (Steemans et al., 1996) and southern Iran (Ghavidel-syooki, 2000). Al-Hajri (1995) and Paris (1990) cite *J. lepta* as part of the *Armoricochitina nigerica* and *Ancyrochitina merga* chitinozoan biozones from the North Gondwana Domain.
Dimensions: Based on two specimens. Length = 111–140; length of neck = 43–49; max. diameter = 62–70; min. diameter = 24–26; length/max. diameter = 1.8–2; min. diameter/max. diameter = 0.37–0.39

Subfamily Tanuchitininae Paris, 1981
Genus ***Hyalochitina*** Paris and Grahn 1999

Type species: *Cyathochitina hyalophrys* Eisenack, 1959

Hyalochitina sp. (Plate II, fig. 2)
Description: This is a relatively small species of *Hyalochitina*, with a subcylindrical vesicle that gently tapers towards the aperture. The base is flat to weakly convex, with a small, faint basal scar at the centre. A short carina is found on the sharp basal edge; the carina is broken in all specimens seen so far from the Alborz Range. The aperture has a straight edge and the surface of the vesicle is smooth.
Remarks: *Hyalochitina* sp. differs from *Tanuchitina ontariensis* (Jansonius) in lacking evidence of a neck and in having the carina on the basal edge, rather than below the basal edge. *Tanuchitina bergstroemi* Laufeld differs in being proportionally more elongate, and much longer.
Dimensions: Based on five specimens. Length = 219–279 (Av. 254); max. diameter = 67–100 (Av. 85); min. diameter = 48–70 (Av. 56); length/max. diameter = 2.3–3.3; min. diameter/max. diameter = 0.5–0.85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Genus ***Tanuchitina*** Jansonius, 1964 emend. Paris, Grahn, Nestor and Lakova, 1999

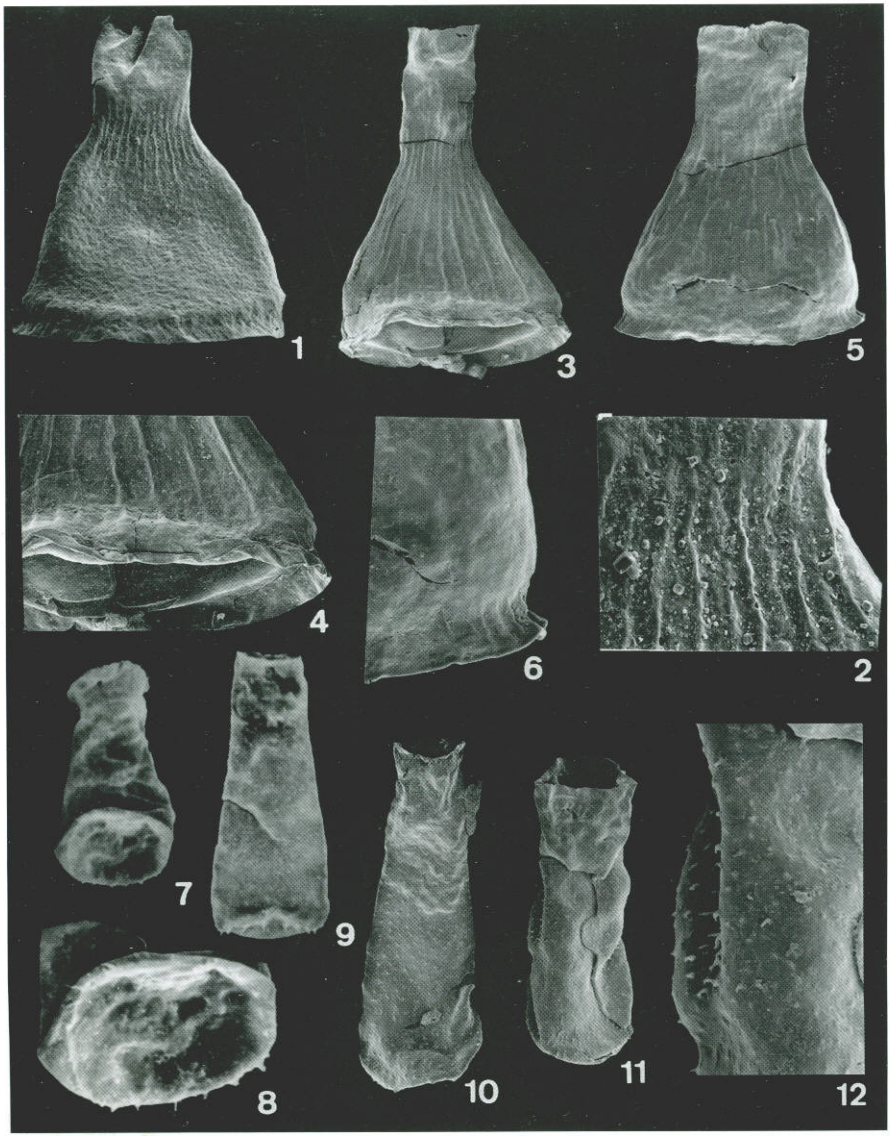
Type species: *Tanuchitina ontariensis* Jansonius, 1964

Tanuchitina fistulosa (Taugourdeau and de Jekhowsky, 1960) (Plate III, fig. 10)
Remarks: For description see Taugourdeau and de Jekhowsky (1960). Although more slender than those figured by Taugourdeau and de Jekhowsky (1960), the specimens from the Alborz Range fit into the range of variation accepted for this species (e.g. Paris et al., 2000, pl. 2, figs. 1 and 2). Similar species, with a shorter and more squat vesicle have been tentatively assigned to *Tanuchitina* sp. aff. *fistulosa*.
Tanuchitina fistulosa is known from the Late Caradoc of the Sahara (Taugourdeau and de Jekhowsky, 1960), possibly from Morocco (Elaouad-Debbaj, 1986; Paris et al., 2000 claim that the species identified as *Tanuchitina ontariensis* by Elaouad-Debbaj probably belongs to *Tanuchitina fistulosa*) and Saudi Arabia (Paris et al., 2000). This species has been selected as the index species of a new zone within the previously undefined interval between the *robusta* and *nigerica* biozones in the northern Gondwana biozonation of Paris (1990).
Dimensions: Based on one specimen. Length = 432; max. diameter = 68; min. diameter = 47; length of carina = 32; length/max. diameter = 6.33

Tanuchitina sp. aff. *fistulosa* (Taugourdeau and de Jekhowsky, 1960) (Plate III, fig. 12)
Description: This is a relatively short species of *Tanuchitina* with a subcylindrical vesicle. The flanks of the chamber are weakly convex, with maximum diameter occurring approximately one third of the length of vesicle from the base; the vesicle then narrows slightly. The top of the 'neck' has a short, flared collar, with a serrate edge. The basal edge is broadly rounded, followed by a short carina. The surface of the vesicle is smooth.
Remarks: The species from the Alborz Range closely resembles that designated *Tanuchitina* n. sp. aff. *fistulosa* by Al-Hajri (1995), pl. IV, figs. 1 and 2, although the material from Saudi Arabia is slightly larger. This species differs from *Tanuchitina fistulosa* in having a shorter, less elongate vesicle, and in having a shorter carina. However, since the two species have very similar ranges, it is possible that they are conspecific.
Tanuchitina n. sp. aff. *fistulosa* from Saudi Arabia is used to define the *Tanuchitina* n. sp. aff. *fistulosa* zone, from the Late Caradoc (Al-Hajri, 1995).
Dimensions: Based on six specimens. Length = 197–218 (Av. 207); max. diameter = 64–65; length/max. diameter = 3.1–3.3

Plate III.

1, 4 *Jenkinochitina lepta* (Jenkins)
1 AM F117707, ×350, MG 2834
4 AM F117708, ×350, MG 2834
2, 3 *Acanthochitina* sp. aff. *rashidi* Jenkins
2 AM F117709, ×250, MG 2811
3 enlargement of 2, showing remnants of ornament on the neck, ×800
5, 6 *Acanthochitina barbata* Eisenack
5 AM F117710, ×250, MG 2834
6 enlargement of the lower chamber on 5, showing ornament, ×600
7 *Sphaerochitina*? sp., AM F117711, ×350, MG 2834
8 *Tanuchitina* sp., AM F117712, ×300, MG 2834
9, 11 *Tanuchitina ontariensis* Jansonius
9 AM F117713, ×200, MG 2811
11 AM F117714, ×150, MG 2811
10 *Tanuchitina fistulosa* Taugourdeau and Jekhowsky, NIDC, ×250
12 *Tanuchitina* sp. aff. *fistulosa* Taugourdeau and Jekhowsky, NIDC, ×280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Tanuchitina ontariensis Jansonius, 1964 (Plate III, figs. 9 and 11)
Remarks: For descriptions see Jansonius (1964) and Jenkins (1970). This distinctive species is characteristic of Late Ordovician assemblages from southern Iran (Ghavidel-syooki, 2000), Saudi Arabia (Al-Hajri, 1995), the Sylvan Shale, Oklahoma (Jenkins, 1970) and Ontario (Jansonius, 1964). Paris (1990) places the Sylvan Shale in the *Ancyrochitina merga* biozone, i.e. representing middle Ashgill, and in Saudi Arabia, Al-Hajri (1995) shows *Tanuchitina ontariensis* as ranging from the *Calpichitina lenticularis* biozone to mid *Armoricochitina nigerica* biozone (mid Caradoc to mid Ashgill).
Dimensions: Length = 210–364 (Av. 270); max. diameter = 67–100 (Av. 85); min. diameter = 48–85 (Av. 61); length/max. diameter = 2.3–3.8; min. diameter/max. diameter = 0.6–0.9

Tanuchitina sp. (Plate III, fig. 8)
Description: The vesicle ranges from cylindrical to subcylindrical, with no evidence of a neck. The maximum diameter, occurring just above the basal edge, is broadly rounded. The top of the vesicle has a small, slightly flared collar, with a serrate edge. A short carina is found just below the basal edge, and the vesicle is smooth.
Dimensions: Based on one specimen. Length = 172; max. diameter = 72; min. diameter = 60; length/max. diameter = 2.4; min. diameter/max. diameter = 0.8

Subfamily Belonechitininae Paris, 1981
Genus ***Acanthochitina*** Eisenack, 1931

Type species: *Acanthochitina barbata* Eisenack, 1931

Acanthochitina barbata Eisenack, 1931 (Plate III, figs. 5 and 6)
Remarks: For description see Eisenack (1931), Jenkins (1967) and Laufeld (1967). All specimens from the Alborz Range show some degree of degradation of their ornament, but clearly show the classic surface of *Acanthochitina barbata*. The specimens from Iran are generally smaller than those described previously.
Acanthochitina barbata has previously been reported from Germany (Eisenack, 1931), Great Britain (Jenkins, 1967), Sweden and Gotland (Laufeld, 1967; Grahn, 1982), Canada (Achab, 1977), Libya (Molyneux and Paris, 1985), Saudi Arabia (Al-Hajri, 1995, and southern Iran (Ghavidel-syooki, 2000). Paris (1992) shows *A. barbata* as ranging from Late Caradoc to middle Ashgill, and Nõlvak (1999) lists the *barbata* chitinozoan subzone within the *bergstroemi* zone, at the base of the Ashgill.
Dimensions: Based on two specimens. Length =

Plate IV.

1, 2, 5, 6	*Cyathochitina* cf. *campanulaeformis* Eisenack
1	AM F117715, ×250, MG 2811
2	enlargement of the neck are of 2, ×900
5	AM F117716, ×250, MG 2834
6	enlargement of 5, showing the lower chamber and carina, ×550
3, 4	*Cyathochitina* cf. *costata* Grahn
3	AM F117717, ×200, MG 2834
4	enlargement of 4, showing the vertical thickenings on the lower chamber and carina, ×350
7, 8	*Spinachitina bulmani* Jansonius
7	NIDC, ×350
8	enlargement of 7, showing the spines on the basal edge
9	*Spinachitina* sp., NIDC, ×350
10–12	*Belonechitina* cf. *wesenbergensis* Eisenack
10	AM F117718, ×250, MG 2834
11	AM F117719, ×300, MG 2834
12	enlargement of 11, showing the spinose ornamentation, ×1200

228–265; max. diameter = 120–175; min. diameter = 125; length/max. diameter = 2.2–2.6; min. diameter/max. diameter = 0.45–0.7

Acanthochitina sp. aff. *rashidi* Jenkins 1970 (Plate III, figs. 2 and 3)
Remarks: Although larger than *Acanthochitina rashidi* described by Jenkins (1970) from the Ashgill of Oklahoma, this species fits the range of shapes. The surface ornament is very eroded, but the little left intact resembles that of *A. rashidi*, thus this species has been left in open nomenclature.
Dimensions: Based on one specimen. Length = 242; max. diameter = 120; min. diameter = 78; length/max. diameter = 2; min. diameter/max. diameter = 0.66

Genus ***Belonechitina*** Jansonius, 1964

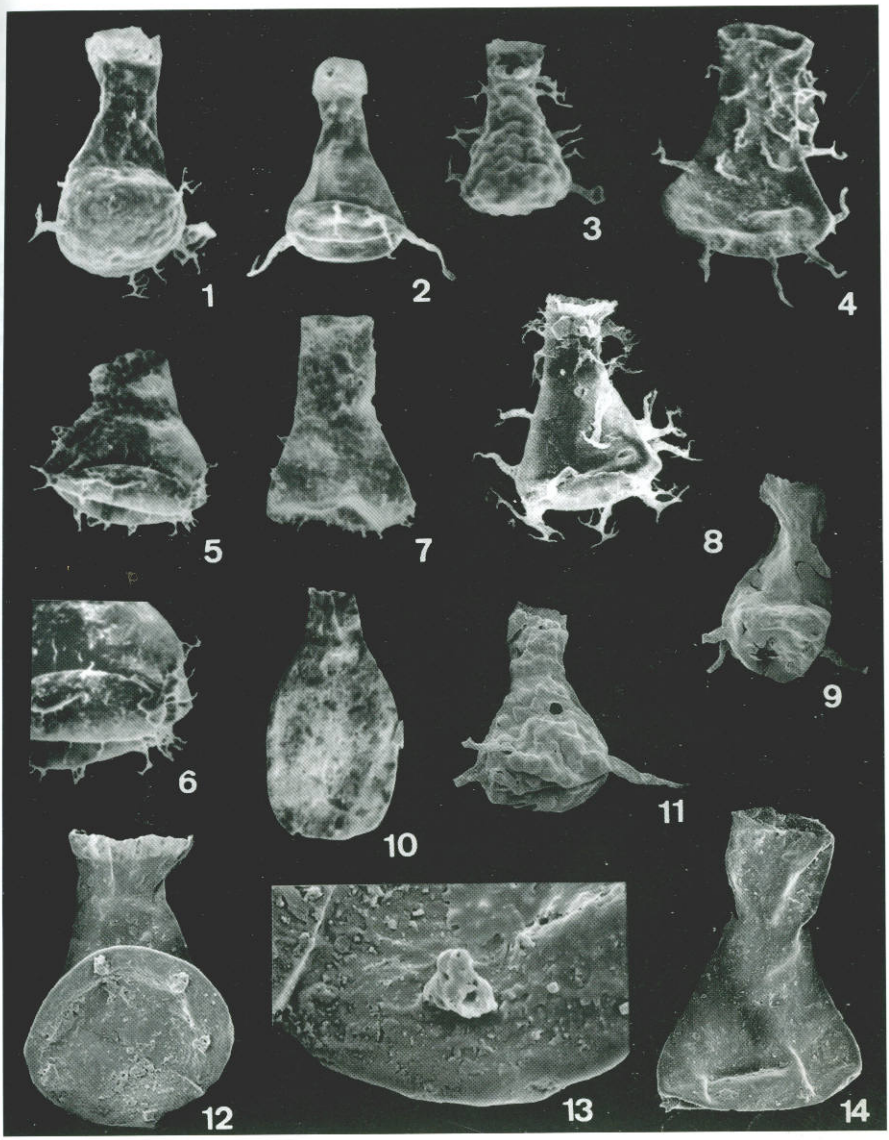
Type species: *Conochitina micracantha* subsp. *robusta* Eisenack, 1959

Belonechitina cf. *wesenbergensis* Eisenack, 1959 (Plate IV, figs. 10–12)
Description: The relatively short vesicle varies from subcylindrical to slightly claviform. The flanks taper towards the fringed aperture, and may show gentle to marked flexure. The basal edge is broadly rounded and the base ranges from flat to weakly convex; in compressed specimens, the base may be invaginated. The surface is covered in spines; on most specimens from the Alborz Range, the spines have broken off, leaving only strong, definite spine bases. Where spines have survived, they are short and most are simple, but a few are coalesced, creating a lambda spine.
Remarks: This species fits the range of variation of size and shape of *Belonechitina wesenbergensis* described by many authors; however, the lack of intact spines precludes more definite species assignment.
Belonechitina wesenbergensis is known from Llanvirn to Ashgill strata in Sweden, Finland and Estonia (Grahn, 1981, 1982, 1984; Nõlvak et al., 1995) and from the USA (Jenkins, 1969; Grahn and Bergström, 1984).
Dimensions: Based on six specimens. Length = 160–255 (Av. 215); max. diameter = 53–93 (Av. 60); min. diameter = 48–70 (Av. 62); length/max. diameter = 2.2–3.8; min. diameter/max. diameter = 0.6–0.9

Subfamily Spinachitininae Paris, 1981
Genus ***Spinachitina*** Schallreuter, 1963 emend.

Plate V.

1, 2	*Ancyrochitina merga* Jenkins
1	NIDC, ×350
2	NIDC, ×350
3, 4, 8	*Ancyrochitina persica* n. sp.
3	Holotype, NIDC, ×350
4	NIDC, ×350
8	NIDC, ×350
5–7	*Ancyrochitina* cf. *merga* Jenkins
5	NIDC, ×350
6	enlargement of the lower chamber, showing spines, ×600
7	NIDC, ×350
9, 11	*Plectochitina sylvanica* Jenkins
9	AM F117720, ×300, MG 2834
11	AM F117721, ×300, MG 2834
10	*Lagenochitina baltica* Eisenack, ×350, NIDC
12, 13	*Plectochitina* sp.
12	AM F117722, ×300, MG 2834
13	enlargement of 12, showing the process attachment, ×2000
14	*Ancyrochitina* sp., AM F117723, ×400, MG 2834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Paris, Grahn, Nestor and Lakova, 1999

Type species: *Conochitina cervicornis* Eisenack, 1931

Spinachitina bulmani (Jansonius, 1964) (Plate IV, figs. 7 and 8)
Remarks: For description see Jansonius (1964) and Jenkins (1967). Specimens of this species from the Alborz Range range in shape from sub-conical to those with a slight flexure; the spines from the basal edge are simple or anastomosed, but most are poorly preserved.
Spinachitina bulmani is known from the Early Caradoc of Scotland and Shropshire (Jansonius, 1964; Jenkins, 1967), from the Late Caradoc–Early Ashgill of Morocco (Elaouad-Debbaj, 1986), and from the Ashgill of Anticosti (Achab, 1978), Norway (Grahn et al., 1994), and Libya (Molyneux and Paris, 1985). Paris (1990) lists *S. bulmani* as a common species in the *Armoricochitina nigerica* biozone in the North Gondwana Domain.
Dimensions: Based on seven specimens. Length = 145–223 (Av. 180); max. diameter = 52–83 (Av. 63.4); min. diameter = 29–43 (Av. 38); length/max. diameter = 2.6–3.4; min. diameter/max. diameter = 0.5–0.7

Spinachitina sp. (Plate IV, fig. 9)
Description: This relatively small species of *Spinachitina* has a short, subcylindrical neck and a subconical chamber. The neck is surmounted with a slightly flared collar. Maximum diameter occurs in the lower third of the chamber; the basal edge is well-rounded. Several short, robust, simple, broad-based spines are found on the basal edge.
Remarks: *Spinachitina* sp. differs from *Spinachitina bulmani* in being slightly shorter, and in having thicker spines.
Dimensions: Based on two specimens. Length = 140–168; max. diameter = 68–69; min. diameter = 39–43; length/max. diameter = 2–2.5; min. diameter/max. diameter = 0.6

Family Lagenochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Lagenochitininae Eisenack, 1931 emend. Paris, Grahn, Nestor and Lakova, 1999
Genus ***Lagenochitina*** Eisenack, 1931 emend. Paris, Grahn, Nestor and Lakova, 1999

Type species: *Lagenochitina baltica* Eisenack, 1931

Lagenochitina baltica Eisenack, 1931 (Plate V, fig. 10)
Remarks: For description see Eisenack (1931) and Laufeld (1967). This well known species has been reported in the Late Caradoc to Early Ashgill of the Baltic (Laufeld, 1967; Grahn, 1982; Grahn et al., 1994), Shropshire (Jenkins, 1967), Portugal (Paris, 1979), Libya (Molyneux and Paris, 1985), Algeria (Oulebsir and Paris, 1995), and southern Iran (Ghavidel-syooki, 2000). Paris et al. (1999a,b) use *Lagenochitina baltica* as a species linking the chitinozoan biozonations of Laurentia and North Gondwana; in North Gondwana, *L. baltica* ranges from the base of the *Acanthochitina barbata* biozone to the top of the *Ancyrochitina merga* biozone.
Specimens of *Lagenochitina baltica* found in this study appear to have a thick, felt-like ornament. This is most probably due to accumulation of a secondary organic residue on the test surface.
Dimensions: Based on one specimen. Length = 250; length of neck = 58; max. diameter = 131; min. diameter = 50; length/max. diameter = 1.9

Genus ***Sphaerochitina*** Eisenack, 1955 emend. Paris, Grahn, Nestor and Lakova, 1999

Type species: *Lagenochitina sphaerocephala* (Eisenack, 1932)

Sphaerochitina? sp. (Plate III, fig. 7)
Description: This is a relatively small species, with a long neck and a subspherical chamber. Flexure is gentle, but distinct. The maximum diameter occurs near the middle of the chamber, the lower part of the chamber is conical to ogival in shape. The base may be flattened or pointed.
Remarks: Al-Hajri (1995), pl. V, figs. 3 and 4, illustrates a very similar species that he refers to as *Haplochitina* sp. P, which is found in the

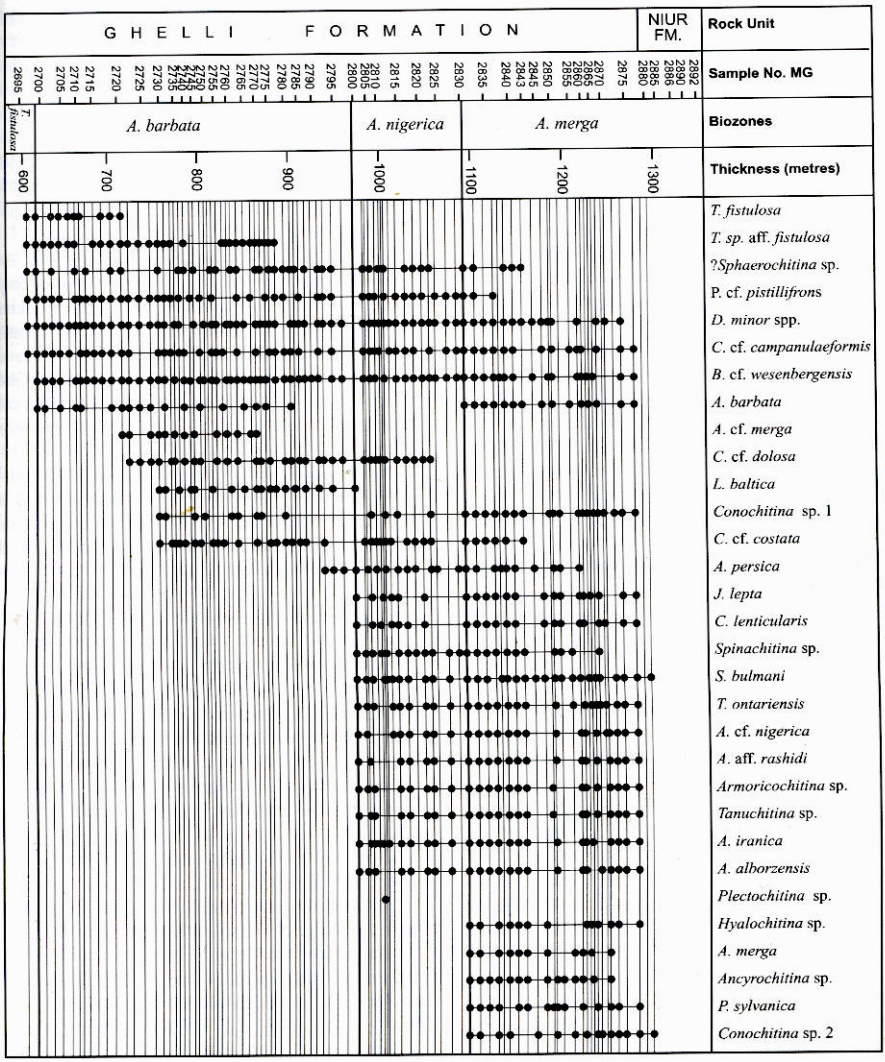

Fig. 3. Chart showing the stratigraphic range of the Upper Ordovician species in the Ghelli Formation; the position of every fifth sample is shown, and the position of the others may be inferred.

Ashgill of Saudi Arabia, ranging from his *A.* n. sp. aff. *fistulosa* into the *Ancyrochitina merga* zone.

Dimensions: Based on two specimens. Length = 118–133; length of neck = 44–63; max. diameter = 59–78; min. diameter = 25; length/max. diameter = 1.7–2

Subfamily Cyathochitininae Paris, 1981
Genus ***Cyathochitina*** Eisenack, 1955 emend. Paris, Grahn, Nestor and Lakova, 1999

Type species: *Conochitina campanulaeformis* (Eisenack, 1931)

Cyathochitina cf. *C. campanulaeformis* (Eisenack, 1931) (Plate IV, figs. 1, 2, 5 and 6)

Remarks: *Cyathochitina campanulaeformis* is a very wide-spread, long-ranging species (see for example Paris, 1990). The species encountered in the present study fits the range of size, shape and ornament found in many other places, but has a consistently shorter neck than most. The age range does not fit with known examples of the species. This species differs from *Cyathochitina kuckersiana* (Eisenack, 1934) in having concave flanks and a narrower carina.

Dimensions: Based on 10 specimens. Length = 194–247 (Av. 223); length of neck = 64–88 (Av. 72.3); max. diameter = 122–182 (Av. 144); min. diameter = 45–82 (Av. 58.7); length/max. diameter = 1.35–1.86; length of neck/length = 0.28–0.36

Cyathochitina cf. *C. costata* (Grahn, 1982) (Plate IV, figs. 3 and 4)

Remarks: For description of *Cyathochitina costata* see Grahn (1982). In contrast to the species from the Alborz Range, *C. costata* has a subcylindrical body; however, the presence of longitudinal thickenings from the base to the aperture suggests a close relationship.

Nõlvak and Grahn (1993) show *Cyathochitina costata* to occur in the *A. recticulifera* subzone of the *Tanuchitina bergstroemi* chitinozoan biozone, in the Late Caradoc of Baltica.

Dimensions: Based on one specimen. Length = 309; length of neck = 109; max. diameter = 200; min. diameter = 64; length/max. diameter = 1.55; length of neck/length = 0.35

Subfamily Ancyrochitininae Paris, 1981
Genus ***Ancyrochitina*** Eisenack, 1955

Type species: *Conochitina ancyrea* Eisenack, 1931

Ancyrochitina merga Jenkins, 1970 (Plate V, figs. 1 and 2)

Remarks: For description see Jenkins (1970). *Ancyrochitina merga* is a well known Ashgill species, observed in the Sylvan Shale, Oklahoma (Jenkins, 1970), Libya (Molyneux and Paris, 1985; Paris, 1988), Morocco (Elaouad-Debbaj, 1984), Saudi Arabia (Al-Hajri, 1995) and southern Iran (Ghavidel-syooki, 2000). The total range of this species was used by Paris (1990) to define the *A. merga* biozone.

Dimensions: Based on eight specimens. Length = 109–124 (Av. 112.5); length of neck = 27–34 (Av. 24.2); max. diameter = 63–73 (Av. 69); min. diameter = 23–34 (Av. 30); length/max. diameter = 1.5–2; length of neck/length = 0.25–0.3

Ancyrochitina cf. *merga* Jenkins, 1970 (Plate V, figs. 5–7)

Description: The vesicle is small and fungiform. The sub-conical chamber is relatively long, approximately half the total length. Flexure is gentle, with no development of shoulders. Maximum diameter occurs near the basal edge, which is rounded. The base ranges from flat to weakly convex. The neck is cylindrical and the oral edge has small spines. Spines cover most of the vesicle, but are longest and densest at the basal edge. The spines on the chamber and lower neck vary from simple, to lambda-shaped, or may join to form arches. The spine tips may be T- or Y-shaped.

Remarks: This species closely resembles some of the specimens designated as *Ancyrochitina merga* by Jenkins (1970), pl. 47, figs. 14–17, from the basal part of the Sylvan Shale. These specimens were found by Jenkins in only one sample near the base of the section; specimens of *A. merga* from higher in the Sylvan Shale were either smooth, or had very short, simple spines. It is

possible that *A.* cf. *merga* is a separate species or subspecies of *A. merga*, which occurs stratigraphically lower than *A. merga* itself.

Ancyrochitina cf. *merga* also superficially resembles *Belonechitina hirsuta* (Laufeld, 1967), but differs in having a more conical chamber, with a flatter base, and in having a shorter, less complex ornament on the chamber and lower neck.

Dimensions: Based on one specimen. Length = 115; length of neck = 52; max. diameter = 78; min. diameter = 41; length/max. diameter = 1.5; length of neck/length = 0.45

Ancyrochitina persica n. sp. (Plate V, figs. 3, 4 and 8)

Holotype: Plate V, fig. 3

Type stratum: Sample number MG 2790 from Ghelli Formation, 55 km southwestern Bojnourd city, northeastern Alborz Mountain Range

Derivation name: From the Latin *Persia*, referring to the ancient name of Iran.

Diagnosis: *Ancyrochitina persica* is a small species with a cylindro-conical vesicle, bearing several long, complex branching spines at the basal edge and over the chamber and neck.

Description: This species has a small, cylindro-conical vesicle, which flares toward the aperture. The neck is surmounted by a short, fringed collar. Flexure is distinct, but gentle, and the maximum diameter occurs at the bluntly rounded basal edge. The base ranges from flat to weakly convex. Numerous spines are found on the basal edge and over the chamber and neck. The spines range from simple to complex, with most showing 2–3 orders of branching. Many spines have quite broad bases, and are quite thick for much of their length.

Remarks: This species bears some resemblance to *Ancyrochitina merga* Jenkins (1970), but the new species differs in having fewer appendices and dimensions of test. There is also a similarity to *Ancyrochitina onniensis* Jenkins (1967), but *Ancyrochitina persica* can be distinguished by the presence of large, complex spines all over the vesicle, not just on the basal edge.

Dimensions: Based on 58 specimens. Length = 91–133 (holotype = 91; Av. 109); length of neck = 26–43 (holotype = 33; Av. 35.5); max. diameter = 59–87 (holotype = 59; Av. 72); min. diameter = 23–42 (holotype = 24; Av. = 30); length of spines = 24–34 (holotype = 24); length/max. diameter = 1.4–1.8; length of neck/length = 0.28–0.4

Ancyrochitina sp. (Plate V, fig. 14)

Description: *Ancyrochitina* sp. is a relatively small species, with a conical chamber, and a sub-conical neck. Flexure is distinct, but gentle, with no shoulders. The neck, comprising approximately one third of the length of the vesicle, widens considerably, and is surmounted by a conspicuous, flaring collar with a straight edge. The basal edge is well-rounded, but may appear sharp in compressed specimens. The only ornament is a set of up to eight appendices attached to the basal edge; however, most of the specimens show only broken spines or spine bases. Where intact, the appendices show one or two orders of branching.

Remarks: *Ancyrochitina* sp. differs from *Ancyrochitina merga* in having a sub-conical neck, fewer appendages and a flatter base. This species is similar to *Ancyrochitina ancyrea* Eisenack, but differs in having a much shorter neck, which is sub-conical in shape.

Dimensions: Based on four specimens. Length = 100–160 (Av. 124); length of neck = 36–65 (Av. 47.3); max. diameter = 53–68 (Av. 61.3); min. diameter = 17–28 (Av. 22.6); length/max. diameter = 1.9–2.4; length of neck/length = 0.36–0.4

Genus ***Plectochitina*** Cramer, 1964

Type species: *Plectochitina carminae* Cramer, 1964

Plectochitina sylvanica (Jenkins, 1970) (Plate V, figs. 9–11)

Remarks: For descriptions see Jenkins (1970) and Elaouad-Debbaj (1984, 1986). Many specimens are distorted by the growth of pyrite in the vesicle, and most have broken appendages, however, they all show the shape and features typical of *Plectochitina sylvanica*.

Plectochitina sylvanica is known from the Ashgill in Oklahoma (Jenkins, 1970), Libya (Molyneux and Paris, 1985), Morocco (Elaouad-Debbaj, 1984, 1986), neighbouring Saudi Arabia (Al-Hajri, 1995) and southern Iran (Ghavidel-syooki,

2000). Paris (1990) shows *P. sylvanica* occurring in the *Ancyrochitina merga* biozone.
Dimensions: Based on 10 specimens. Length = 86–145 (Av. 123); length of neck = 26–57 (Av. 37.3); max. diameter = 50–80 (Av. 60.6); min. diameter = 20–57 (Av. 24.7); length/max. diameter = 1.5–2; length of neck/length = 0.28–0.4

Plectochitina sp. (Plate V, figs. 12 and 13)
Description: All specimens are compressed and their shapes and dimensions are distorted. This is a small species, with a conical chamber and a short, subcylindrical neck, surmounted by a flared collar. The flexure is gentle, but distinct. The basal edge is sharp, though this may be exaggerated by the compression of the vesicle. On, or just below the basal margin, there is evidence of the prior attachment of about eight thick spines.
Remarks: This species has been left in open nomenclature due to poor preservation.
Dimensions: Based on two specimens.
Length = 115–130; length of neck = 50–57; max. diameter = 49–56; min. diameter = 22–33; length/max. diameter = 2–2.3; length of neck/length = 0.4–0.43

5. Biostratigraphy

Thirty one species of chitinozoan were identified, and their stratigraphic distribution is plotted on Fig. 3. Chitinozoans were only extracted from the middle and upper parts of the Ghelli Formation. The lowermost 305 m of the Ghelli Formation consist of a melange of igneous and sedimentary rocks. Nonetheless, some samples from the intercalated shales yielded the acritarch species *Veryhachium reductum*. Based on stratigraphic position, this part of Ghelli Formation has been assigned to the Middle Ordovician (Ghavidel-syooki, 1998).

In the middle and upper parts of the Ghelli Formation, four chitinozoan biozones are recognised, namely: *Tanuchitina fistulosa*, *Acanthochitina barbata*, *Armoricochitina* cf. *nigerica* and *Ancyrochitina merga*. These biozones are very similar to the chitinozoan biozones erected for the North Gondwana Domain (Paris, 1990; Paris et al., 2000), ranging from upper Caradoc to middle Ashgill.

5.1. *Tanuchitina fistulosa biozone*

This assemblage appears just above a barren interval and is only present in the lowermost yielding sample of the section (MG 2697). The assemblage consists of *Tanuchitina fistulosa* (Taugourdeau and Jekhowsky), *Tanuchitina* sp. aff. *fistulosa*, ?*Sphaerochitina* sp., *Pistillachitina* cf. *pistillifrons* (Eisenack), and specimens of *Desmochitina*, probably related to *Desmochitina minor* Eisenack.

Tanuchitina fistulosa was recently selected as the index species of a chitinozoan biozone in the upper Caradoc for Saudi Arabia (Paris et al., 2000). This biozone was erected for the upper Caradoc of the North Gondwana Domain, immediately overlying the *B. robusta* biozone. The presence of *T. fistulosa* suggests that the first yielding sample of the Ghelli Formation is Late Caradoc in age.

Al-Hajri (1995) shows *A.* n. sp. aff. *fistulosa* as the index species of a biozone in the upper Caradoc of Saudi Arabia; this species is the equivalent of *Tanuchitina* sp. aff. *fistulosa* in the present study. The species designated *Sphaerochitina*? sp. from the Ghelli Formation is referred to as *Haplochitina* sp. P by Al-Hajri (1995), and ranges down into only the uppermost Caradoc, thus confirming the position of this sample as being very close to the Caradoc–Ashgill boundary.

5.2. *Acanthochitina barbata biozone*

This biozone starts with the first occurrence of *Acanthochitina barbata* (Eisenack), and ranges to sample MG 2800. The assemblage consists of all the species from the preceding biozone, as well as *A. barbata*, *Cyathochitina* cf. *campanulaeformis* (Eisenack), *Belonechitina* cf. *wesenbergensis* (Eisenack), *Ancyrochitina* cf. *merga* Jenkins, *Conochitina* cf. *dolosa* (Laufeld), *Lagenochitina baltica* Eisenack, *Conochitina* sp. 1, *Cyathochitina* cf. *costata* (Grahn), and the new species *Ancyrochitina persica* in the upper part of the biozone.

Paris et al. (2000) selected *Acanthochitina bar-*

bata as the index species of a biozone that immediately succeeds the *Tanuchitina fistulosa* biozone in the North Gondwana Domain. This zone spans the Caradoc–Ashgill boundary. Similarly Nõlvak and Grahn (1993) and Nõlvak (1999) place the *A. barbata* subzone of the *bergstroemi* zone at the base of the Ashgill in their biozonation of Baltica. *A. barbata* also occurs in association with *Calpichitina lenticularis*, *Lagenochitina baltica* and *T.* aff. *fistulosa* in the Assemblage Zone 2 of the Zagros Basin, southern Iran (Ghavidel-syooki, 2000).

Conochitina sp. 1 and *Conochitina* cf. *dolosa* are both similar to species depicted by Paris et al. (2000) from Assemblage 3 within the Ra'an Member of the Qasim Formation, from the upper Caradoc of Saudi Arabia. *Lagenochitina baltica* is known in Gondwana from the upper Caradoc to the upper Ashgill (Paris, 1990; Nõlvak and Grahn, 1993).

5.3. *Armoricochitina cf. nigerica biozone*

Starting with the first occurrence of *Armoricochitina* cf. *nigerica* (Bouché), this biozone extends to sample MG 2830. Characteristic species of this assemblage zone are: *Tanuchitina* sp. aff. *fistulosa*, *Sphaerochitina*? sp., *Pistillachitina* cf. *pistillifrons*, *Desmochitina minor*, *C.* cf. *campanulaeformis* (Eisenack), *Belonechitina* cf. *wesenbergensis* (Eisenack), *Conochitina* cf. *dolosa* (Laufeld), *Conochitina* sp. 1, *Cyathochitina* cf. *costata* (Grahn) and *Ancyrochitina persica*, all of which continue from the previous zones. Other species starting in this biozone include *Jenkinochitina lepta* Jenkins, *Calpichitina lenticularis* (Bouché), *Spinachitina* sp., *Spinachitina bulmani* (Jansonius), *Tanuchitina ontariensis* Jansonius, *Acanthochitina* aff. *rashidi* Jenkins, *Armoricochitina* sp., *Tanuchitina* sp., two new species *Armoricochitina iranica* and *Armoricochitina alborzensis*, as well as *A.* cf. *nigerica*.

Armoricochitina nigerica is the index species of the *A. nigerica* biozone for the North Gondwana Domain (Paris, 1990; Paris et al., 2000). Although not typical of the shape of *A. nigerica*, specimens of *A.* cf. *nigerica* from the Ghelli Formation may be conspecific. Paris (1990) states that *Spinachitina bulmani* is a common species in the *A. nigerica* biozone, and the range of *A.* cf. *nigerica* and *S. bulmani* in the present study is very similar. The presence of these two species suggests that this zone is the same as the *A. nigerica* zone defined by Paris (1990).

In southern Iran, *Armoricochitina nigerica* co-occurs with *Tanuchitina ontariensis* and *T.* cf. *anticostiensis* in Assemblage Zone 3 from the Zagros Basin (Ghavidel-syooki, 2000).

5.4. *Ancyrochitina merga biozone*

The uppermost biozone encountered in the Ghelli Formation is the *Ancyrochitina merga* biozone, defined by the first appearance of *A. merga* Jenkins in sample MG 2830, and extending to near the end of the section. Species that first appear in this biozone include: *Hyalochitina* sp., *A. merga*, *Ancyrochitina* sp., *Plectochitina sylvanica* Jenkins and *Conochitina* sp. 2. Species continuing into this biozone from preceding biozones are: *Sphaerochitina*? sp., *Pistillachitina* cf. *pistillifrons*, *Desmochitina minor*, *C.* cf. *campanulaeformis* (Eisenack), *Belonechitina* cf. *wesenbergensis* (Eisenack), *Acanthochitina barbata*, *Conochitina* sp. 1, *Cyathochitina* cf. *costata* (Grahn), *Ancyrochitina persica*, *Jenkinochitina lepta* Jenkins, *Calpichitina lenticularis* (Bouché), *Spinachitina* sp., *Spinachitina bulmani* (Jansonius), *Tanuchitina ontariensis* Jansonius, *Acanthochitina* aff. *rashidi* Jenkins, *Armoricochitina* sp., *Tanuchitina* sp., *Armoricochitina iranica* and *Armoricochitina alborzensis*, and *Armoricochitina* cf. nigerica.

Paris (1990) and Paris et al. (2000) show the *Ancyrochitina merga* biozone from the North Gondwana Domain occurring in the middle Ashgill. This biozone is defined by the total range of *A. merga* and has *Plectochitina sylvanica*, *Armoricochitina nigerica*, *Calpichitina lenticularis* and *Jenkinochitina lepta*, amongst others, as associated species.

As found in the present study, *Ancyrochitina merga*, *Plectochitina sylvanica* and *Jenkinochitina lepta* were found to occur together in Assemblage Zone 4 of the Zagros Basin, southern Iran (Ghavidel-syooki, 2000).

6. Palaeobiogeography

Discounting the three new species, and long-ranging species such as *Desmochitina minor*, *Belonechitina* cf. *wesenbergensis* and *C.* cf. *campanulaeformis*, there are 25 other species found in the Ghelli Formation. Of these, 48% are in common with Saudi Arabia, 64% are in common with areas of North Gondwana, 20% with Avalonia, 16% with Baltica and 32% with Laurentia. This gives a clear indication of a close affinity with Late Ordovician North Gondwanan chitinozoan faunas.

Nearly one third of the species are in common with Laurentia, with a significant number co-occurring in Avalonia and Baltica. This confirms the fairly cosmopolitan nature of Ashgill chitinozoans touted by Al-Hajri (1995).

7. Conclusions

(a) Thirty one chitinozoan species are recognised and arranged in four biozones: *Tanuchitina fistulosa*, *Acanthochitina barbata*, *Armoricochitina* cf. *nigerica*, and *Ancyrochitina merga*. Assemblage zones similar to the upper three biozones were previously found in the Seyahou Formation from the Zagros Basin in southern Iran.

(b) The three new species described, *Armoricochitina alborzensis*, *Armoricochitina iranica* and *Ancyrochitina persica*, have restricted ranges in northern Iran. *A. alborzensis* ranges from the top of the *Acanthochitina barbata* biozone, while *A. alborzensis* and *A. persica* are present throughout the *Armoricochitina nigerica* and *Ancyrochitina merga* biozones.

(c) The middle and upper parts of the Ghelli Formation are shown to be Late Caradoc–middle Ashgill in age. Chitinozoans have demonstrated their utility in giving accurate age determinations in the Late Ordovician of Iran.

(d) Four successive biozones from the North Gondwana Domain can be recognised in strata from the Alborz Range in northern Iran. Three of these are also found in southern Iran, giving the potential for more accurate interregional correlation based on chitinozoan data.

(e) Chitinozoan assemblages of Ghelli Formation are quite similar to those of the Upper Ordovician strata in southern Iran, Saudi Arabia, Libya, Morocco, Algeria, Nigeria, and SW Europe, suggesting close relationship between the northeastern Alborz Range and Northern Gondwana Domain during the Late Ordovician.

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References

Achab, A., 1977. Les chitinozoaires de la zone á *Dicellograptus complanatus* Formation de Vauréal, Ordovicien supérieur, Ile d'Anticosti, Québec. Can. J. Earth Sci. 14, 413–425.

Achab, A., 1978. Sur quelques Chitinozoaires de la Formation de Vauréal et la Formation Macasty (Ordovicien supérieur); Ile d'Anticosti, Québec, Canada. Rev. Palaeobot. Palynol. 25, 295–314.

Achab, A., 1989. Ordovician chitinozoan zonation of Quebec and western Newfoundland. J. Paleontol. 63, 14–24.

Afshar-Harb, A., 1979. The stratigraphy, tectonics and petroleum geology of the Kopet Dagh region, northern Iran. Ph.D. thesis, Petroleum Geology section, Royal School of Mines, Imperial College, London, 316 pp.

Al-Hajri, S., 1995. Biostratigraphy of the Ordovician Chitinozoa of northwestern Saudi Arabia. Rev. Palaeobot. Palynol. 89, 27–48.

Bouché, P.M., 1965. Chitinozoaires du Silurien s.l. du Djado (sahara nigérien). Rev. Micropaléontol. 8, 151–164.

Eisenack, A., 1931. Neue mikrofossilien des baltischen Silurs I. Paläontol. Z. 13, 74–118.

Eisenack, A., 1939. Chitinozoen und Hystrichosphaerideen im Ordovizium des Rheinischen Schiefergebirges. Senckenbergiana 21, 135–152.

Eisenack, A., 1959. Neotypen baltischer Silur-Chitinozoen und neue Arten. Neues Jahrb. Geol. Paläontol. Abh. 108, 1–20.
Elaouad-Debbaj, Z., 1984. Chitinozoaires Ashgilliens de l'Anti-Atlas (Maroc). Geobios 17, 45–68.
Elaouad-Debbaj, Z., 1986. Chitinozoaires de la Formation du Ktaoua Inférieur Ordovicien Supérieur de l'Anti-Atlas (Maroc). Hercynica II, 35–55.
Ghavidel-syooki, M., 1998. Chitinozoan biostratigraphy and Palaeogeography of the Late Ordovician and Early Silurian strata at southwestern Bojnurd city in northeastern Alborz mountain Range (Kopet Dagh region), southern Caspian Sea. Abstracts of the CIMP Symposium, Pisa, p. 14.
Ghavidel-syooki, M., 2000. Biostratigraphy and Palaeobiogeography of Late Ordovician and Early Silurian chitinozoans from the Zagros Basin, southern Iran. Hist. Biol. 15, 29–39.
Grahn, Y., 1981. Middle Ordovician Chitinozoa from Öland. Sver. Geol. Unders. Ser. C 784, 1–51.
Grahn, Y., 1982. Caradocian and Ashgillian Chitinozoa from the subsurface of Gotland. Sver. Geol. Unders. Ser. C 788, 1–66.
Grahn, Y., 1984. Ordovician Chitinozoa from Tallinn, northern Estonia. Rev. Palaeobot. Palynol. 43, 5–31.
Grahn, Y., Bergström, S.M., 1984. Lower Middle Ordovician Chitinozoa from the southern Appalachians, United States. Rev. Palaeobot. Palynol. 43, 89–122.
Grahn, Y., Idil, S., Ostvedt, A.M., 1994. Caradocian and Ashgillian chitinozoan biostratigraphy of the Oslo-Asker and Ringerike districts, Oslo Region, Norway. Geol. Fören. Förh. 116, 147–160.
Jansonius, J., 1964. Morphology and classification of some Chitinozoa. Bull. Can. Petrol. Geol. 12, 901–918.
Jenkins, W.A.M., 1967. Ordovician Chitinozoa from Shropshire. Palaeontology 10, 436–488.
Jenkins, W.A.M., 1969. Chitinozoa from the Ordovician Viola and Fernvale Limestones of the Arbuckle Mountains, Oklahoma. Spec. Pap. Palaeontol. 5, 1–44.
Jenkins, W.A.M., 1970. Chitinozoa from the Ordovician Sylvan shale of the Arbuckle Mountains, Oklahoma. Palaeontology 13, 261–288.
Laufeld, S., 1967. Caradocian Chitinozoa from Dalarna, Sweden. Geol. Fören. Stockholm Förh. 89, 275–349.
Martin, F., 1980. Quelques Chitinozoaires et Acritarches ordoviciens supérieurs de la Formation de White Head en Gaspésie, Québec. Can. J. Earth Sci. 17, 106–119.
Molyneux, S.G., Paris, F., 1985. Late Ordovician Palynomorphs. J. Micropalaentol. 4, 11–26.
Nõlvak, J., 1999. Ordovician chitinozoan biozonation of Baltoscandia. Acta Univ. Carol. Geol. 43, 287–290.
Nõlvak, J., Grahn, Y., 1993. Ordovician chitinozoan zones from Baltoscandia. Rev. Palaeobot. Palynol. 79, 245–269.
Nõlvak, J., Meidla, T., Uutela, A., 1995. Microfossils in the Ordovician erratic boulders from southwestern Finland. Bull. Geol. Soc. Finl. 67, 3–26.
Oulebsir, L., Paris, F., 1995. Chitinozoaires ordoviciens du Sahara algérien: biostratigraphie et affinités paléogéographiques. Rev. Palaeobot. Palynol. 86, 49–68.
Paris, F., 1979. Les Chitinozoaires de la Formation de Louredo, Ordovicien Supérieur du Synclinal de Buçaco (Portugal). Palaeontogr. Abt. A 164, 24–51.
Paris, F., 1981. Les chitinozoaires dans le Paléozoïque du sud-ouest de l'Europe. Mém. Soc. Géol. Minéral. Bretagne 26, 1–412.
Paris, F., 1988. Late Ordovician and Early Silurian chitinozoans from Central and southern Cyrenaica. In: El-Arnauti, A., Owens, B., Thusu, B. (Eds.), Subsurface Palynostratigraphy of Northeast Libya. Garyounis University Publications, Benghazi, pp. 61–71.
Paris, F., 1990. The Ordovician biozones of the Northern Gondwana Domain. Rev. Palaeobot. Palynol. 66, 181–209.
Paris, F., 1992. Application of chitinozoans in long-distance Ordovician correlations. In: Webby, B.D., Laurie, J.R. (Eds.), Global Perspectives on Ordovician Geology. Balkema, Rotterdam, pp. 23–33.
Paris, F., Grahn, Y., Nestor, V., Lakova, I., 1999a. A revised chitinozoan classification. J. Paleontol. 73, 549–570.
Paris, F., Verniers, J., Achab, A., Albani, R., Ancilletta, A., Asselin, E., Brocke, R., Chen, X., Fatka, O., Grahn, Y., Molyneux, S., Nolvak, J., Samuelsson, J., Sennikov, N., Soufiane, A., Wang, X., Winchester-Seeto, T., 1999b. Correlation of Ordovician regional chitinozoan biozonations. Acta Univ. Carol. Geol. 43, 291–294.
Paris, F., Verniers, J., Al-Hajri, S., 2000. Ordovician Chitinozoans from Central Saudi Arabia. In: Al-Hajri, S., Owens, B. (Eds.), Stratigraphic Palynology of the Palaeozoic of Saudi Arabia. Special GeoArabia Publication. Gulf PetroLink, Bahrain, pp. 42–56.
Rauscher, R., Doubinger, J., 1967. Associations de chitinozoaires de Normandie et comparisons avec les faunes déjà décrites. Bull. Serv. Carte Géol. Alsace Lorraine 20, 307–328.
Samuelsson, J., Verniers, J., 2000. Ordovician Chitinozoa Biozonation of the Brabant Massif, Belgium. Rev. Palaeobot. Palynol. 113, 105–123.
Steemans, P., Le Hérisse, A., Bozdogan, N., 1996. Ordovician and Silurian cryptospores and miospores from southeastern Turkey. Rev. Palaeobot. Palynol. 93, 35–76.
Taugourdeau, P., de Jekhowsky, P., 1960. Répartition et description de chitinozoaires Siluro-Dévoniens de quelques sondages de la CREPS, de la CFPA, et de la SN REPAL au Sahara. Rev. Inst. Fr. Pét. 15, 1199–1260.
Wilson, L.R., Hedlund, R.W., 1964. Calpichitina scabiosa, a new chitinozoan from the Sylvan Shale (Ordovician) of Oklahoma. Oklahoma Geological Notes 24, 161–164.
Winchester-Seeto, T., Foster, C.B., O'Leary, T., 2000. Chitinozoans from the Middle Ordovician (Darriwilian) Goldwyer and Nita formations, Canning Basin (Western Australia). Acta Palaeontol. Pol. 45, 271–300.