# Chitinozoans from the Middle Ordovician (Darriwilian) Goldwyer and Nita formations, Canning Basin (Western Australia)

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Chitinozoans from seven cores in the Middle Ordovician upper Goldwyer and Nita formations are documented, and three assemblages are delineated. Six out of twelve species found in the Canning Basin, in eastern Gondwana, are also found in Laurentia, confirming the close relationship between chitinozoans in the two palaeocontinents. The assemblages correlate with Zone 05 of Combaz & Peniguel, and the undefined zone immediately overlying the *Cyathochitina jenkinsi* Zone in the biozonation designed for Laurentia. The relationship between contemporaneous assemblages in Baltica, Avalonia and the northern Gondwana Domain is discussed with a small number of species in common with Baltica and Avalonia, and no definite links with northern Gondwana. Two new species *Calpichitina windjana,* and *Belonechitina vibrissa* are described.

Key words: Middle Ordovician, Darriwilian, Chitinozoans, Canning Basin, biozonation, Australia,

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## Introduction

The Canning Basin, situated in the northwest of Australia (Fig. 1) has been the focus of extensive research, largely accelerated by petroleum exploration in the 1980's. The sedimentary succession ranges in age from Early Ordovician to Holocene, but most of the Ordovician strata are subsurface, represented by the Nambeet, Willara, Goldwyer,

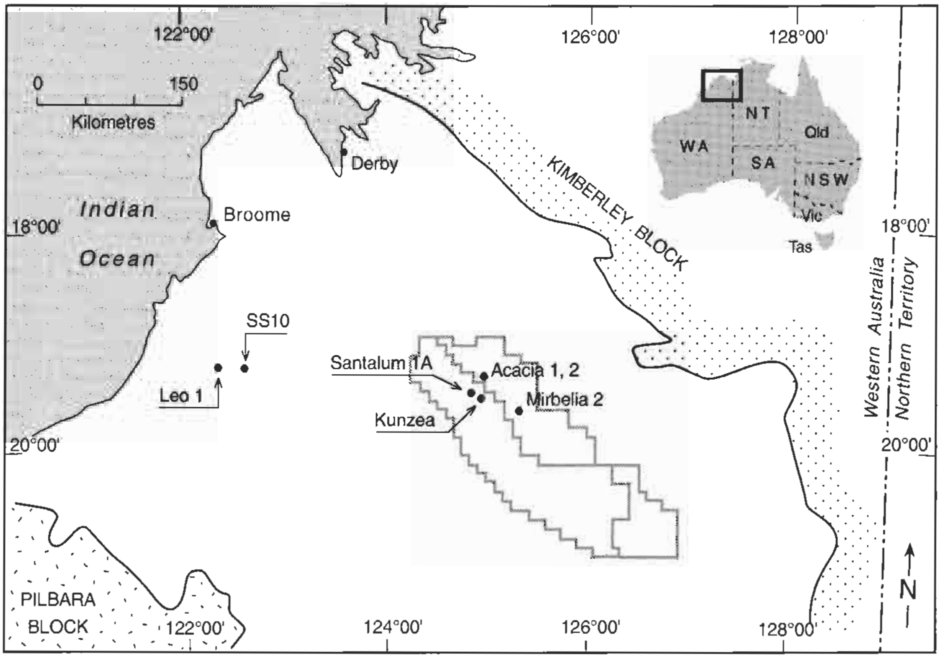

Fig. 1. Map of Canning Basin showing location of the wells used in this study, with outline of Exploration Permits EP 143 and EP 225. Stippled areas show the surrounding structural blocks.

Nita formations and Caribuddy Group. The Goldwyer Formation consists of a 500 m thick succession of siltstones, sandstones, shales, limestones and dolostones, and can be subdivided into 4 units based on lithology and E-log characteristics (Foster *et al.* 1986); it is conformably overlain by the Nita Formation. The upper part of the Goldwyer Formation (units 3 and 4) and the lower part of the Nita Formation are the focus of this study.

Macrofossils from the Goldwyer Formation include trilobites, nautiloids, brachiopods and molluscs, and the microflora and fauna consist of chitinozoans, acritarchs, scolecodonts, hydrozoans and cyanobacteria (Combaz & Peniguel 1972; Playford & Martin 1984; Foster *et al.* 1986; Foster *et al.* 1999; Winchester-Seeto *et al.* 2000), and conodonts (Nicoll 1984; Watson 1988; Nicoll *et al.* 1993). The fossils confirm the depositional environment as a warm, shallow epeiric sea, the western arm of the Larapintine seaway that extended across northern Australia throughout most of the Ordovician (e.g., Webby 1978; Nicoll *et al.* 1989, 1993). Palaeogeographic reconstructions of the time interval (Scotese & McKerrow 1990) show the Canning Basin a few degrees north of the equator.

Middle Ordovician sediments of the Goldwyer Formation, Nita Formation and Carribuddy Group were deposited in a progressively shallowing environment, from subtidal basinal lithologies to supratidal evaporitic redbeds of the Carribuddy (Romine *et al.* 1994). Detailed sedimentological studies of the Nita Formation, cored in five wells on the Barbwire Terrace of the Canning Basin, were completed by Hillock (1988) and the Western Mining Corporation (WMC) Canning Basin Group (1989).

Winchester-Seeto *et al.* (2000) conducted an environmental analysis of the changes of faunal assemblages from 31 samples in three WMC wells (Santalum 1A, Acacia 2, Kunzea 1), which showed that changes in abundance of chitinozoans were correlated to trangressive/regressive cycles.

The age of the Goldwyer Formation has previously been determined as Late Arenig to Darrwilian based on acritarchs (Playford & Martin 1984). The conodonts from the upper Goldwyer and Nita formations indicate a general age of Darriwilian, Da3 (mid-Llanvirn) (Watson 1988); Nicoll *et al.* (1993) show the lower Goldwyer Formation as *Histiodella holodentata* Conodont Zone and the upper Goldwyer and Nita Formation as *Phragmodus plectodina* Conodont Zone.

The present study examines chitinozoans from the upper Goldwyer and Nita formations in 33 samples from 7 cores (Santalum 1A, Acacia 1, Acacia 2, Kunzea 1, SS10, Leo 1 and Mirbelia 2; Fig. 1). The aims of this research are to document the chitinozoan taxa, and to show how the present investigation relates to the work of Combaz & Peniguel (1972). This study will also compare the fauna from the upper Goldwyer and Nita formations to contemporaneous assemblages globally, particularly to the regional biozonations for Laurentia, northern Gondwana and Baltica.

## Middle Ordovician chitinozoans

Studies of Ordovician chitinozoans in Australia are scarce and encompass only the Canning and Georgina basins. In the Canning Basin, Evans (1961) identified five genera, and Combaz & Peniguel (1972) conducted an extensive study of four cores, drilled through the Early and Middle Ordovician Nambeet, Willara and Goldwyer formations. Achab & Millepied (1980) identified *Conochitina symmetrica* Taugourdeau & de Jekhowsky from Arenig strata, and Foster *et al.* (1999) and Winchester-Seeto *et al.* (in press) investigated transgression/regression cycles and their effect on chitinozoan abundance. The Georgina Basin boasts two chitinozoan studies, Combaz (1965) identified one species from Bedourie SH 1, from the Mithaka Formation, and Playford & Miller (1988) conducted a brief study of nine samples from Kelly Creek, Coolibah and Nora formations, in the Toko Syncline.

Globally this time interval has been quite extensively studied in some regions, but others have received scant attention. Achab (1989) erected a biozonation based on Ordovician chitinozoans for Quebec and western Newfoundland. The Middle Ordovician interval is based primarily on studies by Neville (1974) and Achab (1982, 1983, 1984, 1986a, b). Other papers concerning Middle Ordovician chitinozoans from Canada include Martin (1983) and Achab & Asselin (1995). Studies from elsewhere in Laurentia include Taugourdeau (1965), Jenkins (1969) and Grahn & Bergström (1984).

Similarly the Baltic region has received a great deal of attention, and a regional biozonation was constructed by Nõlvak & Grahn (1993) and Nõlvak (1999). Middle Ordovician chitinozoans from the Baltic region have been described from Sweden and Estonia (Eisenack 1937, 1955, 1962, 1968, 1976; Grahn 1980, 1981a, b, 1984; Grahn *et al.* 1996; Nõlvak *et al.* 1999) and Finland (Nõlvak *et al.* 1995).

Middle Ordovician chitinozoans from Avalonia have been described from Shropshire, UK (Jenkins 1967), and from Belgium (Samuelsson & Verniers in press; Verniers *et al.* 1999).

Paris (1990) proposed a chitinozoan biozonation of the Ordovician from the northern Gondwana Domain, which includes what is presently western Europe, e.g., France (Rauscher 1970, 1973; Rauscher & Doubinger 1967, 1970; Paris 1981), Portugal (Paris 1979); and North Africa, e.g., western Sahara (Benoît & Taugourdeau 1961), Algeria (Combaz & Poumot 1962), Morocco (Elaouard-Debbaj 1984a, b). Other studies from northern Gondwana include Algeria (Oulebsir & Paris 1993, 1995), and Saudi Arabia (McClure 1988; Al-Hajri 1995).

Isolated studies have also been conducted in China, where a preliminary zonation has been erected (Wang & Chen 1994; Chen & Wang 1996), and in Spitsbergen (Bockelie 1980).

## Methods and general results

Samples were collected in 1986 from WMC core in seven wells, and organic-walled microfossils were extracted using standard palynological techniques. Sampling targeted units 3 and 4 of the Goldwyer Formation, and the overlying Nita Formation. The relative positions of samples from three cores (Kunzea 1, Santalum 1A and Acacia 2) could be determined from the gamma logs (Fig. 2); these logs show basin-wide changes related to transgression/regression patterns which can be correlated from well to well (Winchester-Seeto *et al.* 2000).

The organic walled microfauna, i.e., larger than 40 μm, consists of scolecodonts, hydrozoans, linings of agglutinated foraminifers and chitinozoans. The cynanobacterium *Gloeocapsomorpha prisca* Zalessky, 1917, occurs in large concentrations in the upper Goldwyer, and has been used as a marker for correlating cores (Combaz & Peniguel 1972; Foster *et al.* 1986).

The chitinozoans varied in abundance, from approximately 5 per gram of rock to 75 per gram of rock, with an average of 31 specimens per gram of rock for yielding samples. This average yield, which refers only to the samples from Santalum 1A, is high compared to other low and middle latitude sites (Foster *et al.* 1999). Preservation of chitinozoans is relatively good, but many specimens were completely flattened. Thermal maturity is quite low, and even some thick walled specimens have a dark brown colour. Well preserved specimens were selected for examination and photography with a Scanning Electron Microscope.

## Stratigraphic distribution in Australia

Chitinozoan species present in the six cores studied include:

*Calpichitina windjana* sp. n.
*Desmochitina* spp. aff. *minor* Eisenack, 1931
*Conochitina kryos* Bockelie, 1980
*Conochitina poumoti* Combaz & Peniguel, 1972

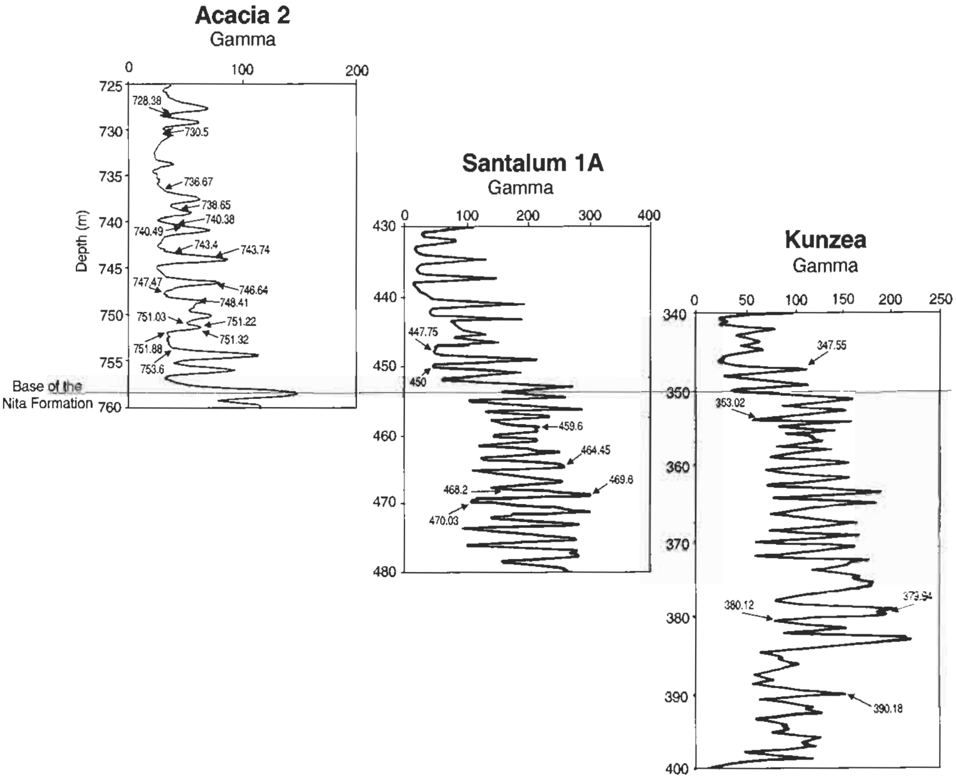

Fig. 2. Chart showing correlation of three of the cores from this study, based on gamma logs (after Winchester-Seeto *et al.* in press).

*Conochitina subcylindrica* Combaz & Peniguel, 1972
*Belonechitina* cf. *cactacea* (Eisenack, 1937)
*Belonechitina chydaea* (Jenkins, 1967)
*Belonechitina micracantha* (Eisenack, 1931)
*Belonechitina vibrissa* sp. n.
*Belonechitina* sp. A
*Belonechitina* sp. B
*Cyathochitina hunderumensis* Grahn, Nõlvak, & Paris, 1996

The alignment of gamma logs from Kunzea 1, Santalum 1A, and Acacia 2 is shown on Fig. 2, giving the stratigraphic order of the samples. A composite range chart for these three wells, showing the ranges for those cores where relative position is definite is given in Figs. 3 and 4 shows the distribution of all chitinozoans used in the study.

There are three discernible chitinozoan assemblages revealed on the range chart. The first includes the three lowest samples from Kunzea 1, all from Goldwyer unit 3, and is characterised by the occurrence of *Belonechitina* sp. A, *B. chydaea*, *B.* cf. *cactacea*, *C. kryos*, and the two new species *C. windjana* and *B. vibrissa*. One ques-

| Core | Acacia 1 | | | | | Kunzea 1 | | | | | Leo 1 | | SS10 | | | | Mirbelia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Formation | | | | | | Goldwyer | Goldwyer | Goldwyer | Goldwyer | Nita | | | | | | | |
| Depth (m) | 874.30 | 830.80 | 798.21 | 792.90 | 782.70 | 390.18 | 380.12 | 379.94 | 353.02 | 347.55 | 1587.80 | 1587.61 | 1645.00 | 1622.00 | 1595.00 | 1591.00 | SWC 10 |
| *Conochitina poumoti* | | | 5 | 1 | 15 | | | | | | | | | | | | |
| *Desmochitina* spp aff. *minor.* | | | | | | | | | | | | 1 | | | | | |
| *Cyathochitina hunderumensis* | | | | | | | 1? | | 5 | 78 | | | | | 1 | | |
| *Belonechitina micracantha* | | | | | | | | | | | | | | | | | |
| *Belonechitina* sp. B | | | 1 | 6 | | | | | | | | | | 8 | | | |
| *Conochitina subcylindrica* | | | | | | | | | | | | | 1 | 3 | 1 | | |
| *Belonechitina* cf. *cactacea* | 5 | 1 | 11 | 27 | 5 | | 1 | | | | 3? | | | | | | |
| *Belonechitina vibrissa* | 1? | | 133 | 110 | 11 | | 10 | 44 | | | 12 | 11 | | | | | |
| *Calpichitina windjana* | | | 650 | 6 | 23 | | 6 | | 12 | 2 | | | | | 2 | 2 | |
| *Belonechitina chydaea* | 6 | | 89 | 123 | 22 | 251 | 16 | | 17 | | 4 | 2 | | 4 | 2 | 3 | 1 |
| *Conochitina kryos* | 2 | | | | | | 17 | 29 | | 13 | | | | | | | |
| *Belonechitina sp. A* | 14 | | 171 | 175 | 23 | 183 | 30 | 18 | 15 | 16 | | 1 | 2 | 2 | 2 | 2 | |
| spp. indet | 3 | | 20 | 29 | 1 | 52 | 10 | 3 | 3 | 3 | | | | | | | |

| Core | Santalum 1A | | | | | | | Acacia 2 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Formation | Goldwyer | Goldwyer | Goldwyer | Goldwyer | Goldwyer | Nita | Nita | Nita | Nita | Nita | Nita | Nita | Nita | Nita | Nita |
| Depth (m) | 470.00 | 469.55 | 468.20 | 464.75 | 459.60 | 450.00 | 447.75 | 753.62 | 751.88 | 751.32 | 751.22 | 751.03 | 748.41 | 747.47 | 746.64 |
| *Conochitina poumoti* | | | 13 | 6 | 54 | 13 | 9 | | 1 | | | | | 32 | |
| *Desmochitina* sp. | | | 3 | 2 | 4 | | | | | | | | | | |
| *Cyathochitina hunderumensis* | | 422 | 215 | 627 | | 3 | 8 | 12 | 1 | 65 | 40 | 1 | 2 | 13 | 1 |
| *Belonechitina micracantha* | 8 | 25 | 90 | 28 | 130 | 12 | 5 | | | | | | | | |
| *Belonechitina* sp. B | | 2 | 9 | | 18 | | | | | | | | | | |
| *Conochitina subcylindrica* | | 5 | 7 | 5 | 28 | | 1 | | | | | | | | |
| *Belonechitina* cf. *cactacea* | | | | | | 54 | | | | | | | | | |
| *Belonechitina vibrissa* | | 133 | 588 | 126 | 472 | | 34 | | 1 | | | 1 | 8 | | |
| *Calpichitina windjana* | | 6 | 3 | 4 | 60 | | 5 | | | | | | | | |
| *Belonechitina chydaea* | | | | | | | | | | | | | | | |
| *Conochitina kryos* | | | | | | | | | | | | | | | |
| *Belonechitina* sp. A | 1 | 50 | 78 | 40 | 152 | 7 | 1 | | | | | | | | |
| spp. indet | | | | | | | | | | | | | | | 4 |

Fig. 3. Distribution chart for chitinozoan species in studied samples.

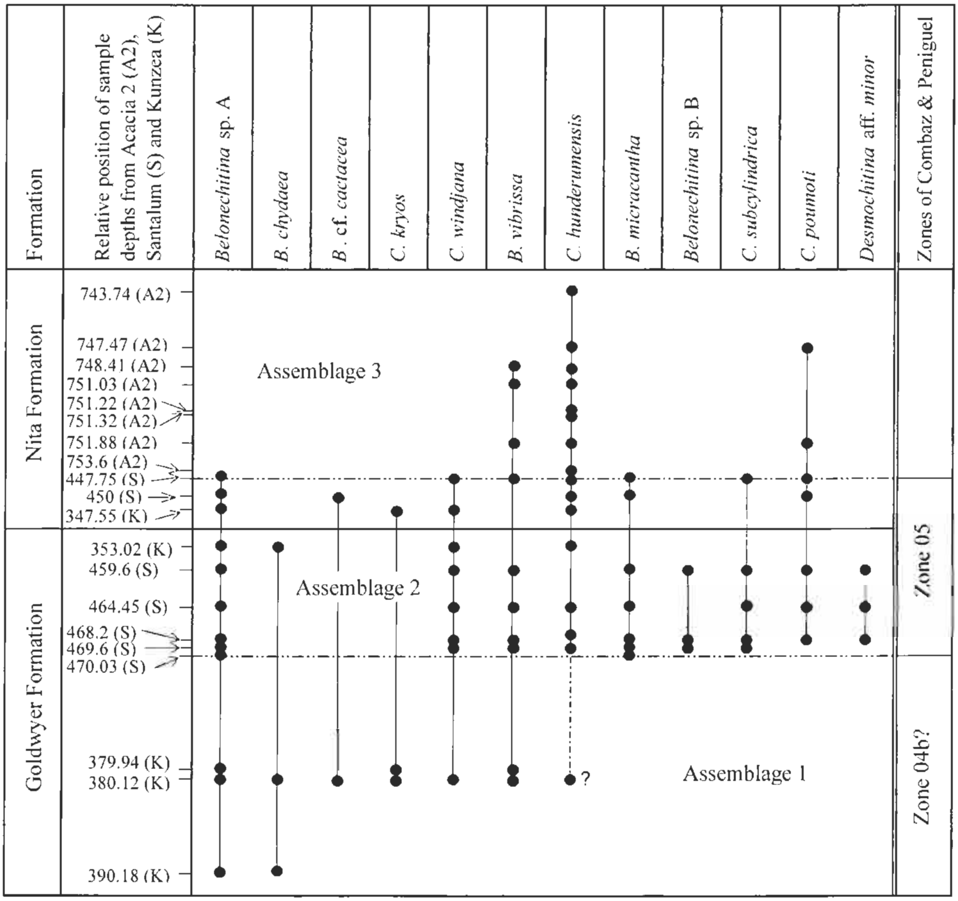

Fig. 4. Range chart of chitinozoans showing relative position of samples from Kunzea 1 (K), Santalum 1A (S) and Acacia 2 (A2), based on the correlation of gamma logs; distance between samples is approximate only.

tionable specimen of *C. hunderumensis* was found in Kunzea 1, depth 380.12 m. There is a small gap, followed by the second assemblage, which starts with the oldest sample from Goldwyer unit 4 (Santalum 1A, depth 470.03 m) and finishes in the lower part of the Nita Formation (Santalum 1A, depth 447.75 m). All of the species from Assemblage 1 continue into Assemblage 2; but several species also make their first appearance, i.e. *B. micracantha, Belonechitina* sp. B, *C. subcylindrica*, *C. poumoti*, and the *Desmochitina* spp. The highest assemblage is typified by the disappearance of most species and the continuation of only *B. vibrissa*, *C. hunderumensis*, and *C. poumoti.* The Nita Formation is a period of rapid shallowing and it is unclear whether the upper assemblage is a result of successive loss of species or of changing environmental conditions, or both. *Belonechitina micracantha* in this study is restricted to Santalum 1A, but the reasons are unknown.

Assuming that the composite range chart gives a reasonably accurate picture of the ranges of the species, it is possible to correlate the other samples in this study. The presence of *C. poumoti* in Acacia 1 depths 798.21 m, 792.9 m, and 782.7 m suggests that this part of the core belongs to the second assemblage; *B. chydaea* occurs throughout the Acacia 1 samples, but is restricted to the Goldwyer Formation, implying that the three uppermost samples of Acacia 1 lie within Goldwyer Unit 4. The two lower samples of Acacia 1 (depths 874.3 m and 830.8 m) containing *B.* cf. *cactacea, B. vibrissa, B. chydaea, C. kryos*, and *Belonechitina* sp. A suggest that these belong to Goldwyer Unit 3, or are possibly even lower. The presence of *Belonechitina* sp. A and of a species of *Desmochitina* in the uppermost of the two samples from Leo 1, suggests that these samples belong to Assemblage 2. The four samples from SS10 probably belong to Assemblage 2, based on the presence of *C. subcylindrica* and *Belonechitina* sp. A. Sample SWC 10 from Mirbelia contains only *B. chydaea* and may fit into Assemblage 1 or 2.

Combaz and Peniguel's work (1972) in the Canning Basin established a zonation based on chitinozoans and microflora. The presence of the cyanobacterium *G. prisca* is restricted in their scheme to zones 04b, 05a and 05b, however the greatest concentrations occur in Zone 05b. Whole core fluorescence indicates the presence of *G. prisca* throughout the interval yielding chitinozoans in Santalum 1A i.e., from 470 m to 447.75 m; this coincides with Assemblage 2. There may be some environmental conditions that favour certain species of chitinozoans and *G. prisca*, but in this instance, a stratigraphic interpretation is also feasible. The correlation of Assemblage 2 with Zone 05 of Combaz & Peniguel (1972) is confirmed by the range of *B. micracantha,* which is confined to Zone 05.

Thus if Assemblage 2 is equivalent to Zone 05, then the ranges of *C. subcylindrica, C. hunderumensis* (= *C. campanulaeformis*), *C. windjana* (= *Hoegichitina complanata*) and *C. poumoti* extend further back in time in the Canning Basin than found in the present small study. *Conochitina poumoti* also ranges stratigraphically much higher than found by Combaz & Peniguel (1972).

Chitinozoans from the Georgina Basin (Playford & Miller 1988) share only one species with the present study; their *Conochitina* sp. A from the Coolibah and Nora formations is possibly *B. chydaea.* The Coolibah and Nora formations are somewhat older than the Canning Basin material, dated as Arenig by Playford & Miller.

## Comparison with contemporaneous assemblages

Chitinozoan assemblages from the Darriwilian (Llanvirn) of Canada have the greatest similarity with those found in this study of the Canning Basin. A number of studies of the Table Head Group in western Newfoundland, have found species in common with the Goldwyer and Nita formations; Neville (1974) found two species, *B. chydaea* and *Desmochitina* cf. *D. lata* (= *C. windjana* in the present study), that are also in the Canning Basin. Achab (1983) documented *Desmochitina* cf. *D lata* (= *C. windjana*), *C. poumoti* and *C. subcylindrica*, and Albani *et al.* (1998) list a species that is the same as *Belonechitina* sp. A as part of the fauna. Similarly, the Lévis Formation in Quebec yields *C. kryos* and *C poumoti* in common with the Canning Basin (Achab 1982; 1986b). Interestingly, Spitsbergen also has *C. kryos* and *C. poumoti* (Bockelie 1980). Achab & Asselin (1995) document *C. subcylindrica* from the Arctic Platform.

Achab (1989) erected a biozonation for Canada, based on chitinozoans. This zonation shows *C. subcylindrica* and *D. lata* (= *C. windjana*) occurring together in the *C. subcylindrica/C. turgida* Zone and in the *C. jenkinsi* Zone. However, work by Albani *et al.* (1998) shows the presence of a species that is the same as that identified as *Belonechitina* sp. A in this study (R. Albani personal communication 1999), in a section of the Table Head Group, which corresponds to a stratigraphic interval not studied by Achab (1989). *Belonechitina* sp. A has been recovered from samples from the Goldwyer and Nita formations that also contain *C. subcylindrica* and *C. windjana*, thus it appears that the range of these latter two species extends stratigraphically higher in the Canning Basin than has been found in Canada. *Conochitina poumoti* is also found to co-occur with *Belonechitina* sp. A, and its range might similarly be extended. Conversely, it is also possible that *Belonechitina* sp. A may make its first appearance in the Canning Basin before its appearance in the Cape Cormorant Formation. The absence of *C. subcylindrica* and *C. windjana* from Achab's undefined interval may be an artifact due to lack of suitable section, rather than true last appearance. Work in progress on older material from the Canning Basin may shed light on this point.

Middle Ordovician chitinozoans from the Baltic and Avalonia show some similarities to those from the Canning Basin. *Cyathochitina hunderumensis* has been recovered in Sweden (Eisenack 1976; Grahn 1980; Grahn *et al.* 1996) and possibly in the Hope Shales from Britain (Jenkins 1967). Grahn (1981a, 1984) documents two occurrences of *Desmochitina complanata* Eisenack which may in fact be *C. windjana.* The Hope Shales from Shropshire also yield *B. chydaea* (Jenkins, 1967).

Studies of Middle Ordovician chitinozoans from the upper Yangtze Region of China display one chitinozoan species in common with the Canning Basin (Wang & Chen 1994). *Conochitina kryosa* (= *C. kryos*) ranges from the Arenig (their *E. baculata* chitinozoan biozone) to Darriwilian (their *B. connulus* (sic) biozone). It is also possible that *Cyathochitina campanulaeformis* cited in this study may be *C. hunderumensis.*

There are few species definitely in common between the Canning Basin and the north Gondwanan Domain, as described by Paris (1990), except for *B. micracantha* which is a cosmopolitan species, seemingly found in almost all faunas of this age. Paris (1990: pp. 195–196) lists *C. chydaea* as a component of the *Armoricochitina armoricana* and *Laufeldochitina clavata* chitinozoan biozones; however, it is unclear how *C. chydaea* as identified by Paris relates to *B. chydaea* found in Australia, Canada, and Shropshire, as they appear to be quite different.

At present there are regional biozonations pertaining to Laurentia (Achab 1989), Baltica (Nõlvak & Grahn 1993; Nõlvak 1999 ), north Gondwana (Paris 1990), and more recently to Avalonia (Samuelsson & Verniers in press). Palaeogeographic reconstructions for the Darriwilian show Laurentia and Australia in the low latitudes, Baltica and Avalonia in the middle latitudes, and north Gondwana surrounding the south pole. The results of this study are in line with palaeobiogeographic studies by Achab *et al.* (1992), with Middle Ordovician chitinozoans from Australia being closest to those from Laurentia, corroborating the hypothesis that chitinozoan distribution is controlled in part by latitude. The chitinozoans in the present study show that the upper Goldwyer and Nita formations correlate with the undefined zone lying immediately stratigraphically above the *C. jenkinsi* Zone of Achab (1989); it is also possible that these formations range down into the *C. jenkinsi* Zone.

Paris *et al.* (1999b) reviewed the regional biozonations and tried to find species that could act as links between the schemes. In this evaluation, the *C. jenkinsi* Zone from Laurentia is directly aligned with the *C. jenkinsi* Zone from north Gondwana. Thus the material in the present study would correlate with the zones immediately overlying the *C. jenkinsi* Zone in north Gondwana, i.e. the *Laufeldochitina clavata* or the *Linochitina pissotensis* zones.

## Conclusions

(1) Chitinozoans are useful for intra-basin correlation of Darriwilian strata from the Canning Basin.

(2) Six of the 12 species recovered from the upper Goldwyer and Nita formations in this study, have also been found in Laurentia/Spitsbergen (excluding the cosmopolitan species *B. micracantha*). This confirms the links between Laurentia and Australia and suggests that the regional biozonation for Laurentia may be able to be used for the Middle Ordovician of Australia.

(3) Two of the 12 species (and possibly a third one) from this study are found in contemporaneous strata in Baltica or Avalonia. One species possibly also occurs in China.

(4) There are no definite links to contemporaneous faunas from North Gondwana.

(5) The chitinozoan assemblage from the upper Goldwyer and Nita formations can be correlated with the presently 'undefined zone' immediately above the *Cyathochitina jenkinsi* Zone in the Laurentian biozonation.

## Systematic Palaeontology

Suprageneric and generic classification follows Paris *et al.* (1999a). All measurements are taken in microns (µm). Abbreviations used in the text are: L = total length of vesicle; Ln = length of neck; Dmax = maximum diameter of chamber; Dn = minimum diameter of neck; Da = diameter of aperture; H = height of chamber; Lsp = length of spine.

A correction factor of 0.7 has been used on all individuals where the diameter has been distorted by complete flattening; this follows, in part, the precedent set by Jaglin (1986).

Type and figured specimens are housed in the collections of the Australian Museum, Sydney, Australia, and the numbers are prefixed by AMF.

### Order Operculatifera Eisenack, 1931

### Family Desmochitinidae Eisenack, 1931 emend. Paris, 1981

### Subfamily Desmochitininae Paris, 1981

### Genus *Calpichitina* Wilson & Hedlund, 1964

Type species: *Calpichitina scabiosa* Wilson & Hedlund, 1964.

### *Calpichitina windjana* sp. n.

Fig. 5C–G.

*Hoegichitina complanata* (Eisenack); Combaz & Peniguel 1972: p. 144–145, pl. 4: 17, 18.

*Desmochitina* cf. *D. lata* Schallreuter; Neville 1974: p. 198–199, pl. IV: 1–21.

*Desmochitina* cf. *D. lata* Schallreuter; Achab 1983: p. 924, pl. 2: 1–4.

?*Desmochitina complanata* Eisenack; Grahn 1981a: p. 38–39, pl. 14: A–D.

?*Desmochitina complanata* Eisenack; Grahn 1984: p. 19–20. pl. III: C, D.

Holotype: AM F113080 (Fig. 5C).

Type horizon and locality: Acacia 1, depth 798.21 m, Goldwyer Formation, Canning Basin, Western Australia.

Derivation of name: Named for a famous Aboriginal sacred site in the Canning Basin, Windjana Gorge.

**Material**. — 780 specimens from Acacia 1 (depths 798.21 m, 792.9 m, 782.7 m); Santalum 1A (depths 469.6 m, 468.2 m, 464.45 m, 459.6 m, 447.75 m); SS10 (depths 1595 m, 1591 m); Kunzea 1 (depths 380.12 m, 353.02 m, 347.55 m).

**Diagnosis**. — A relatively small species of *Calpichitina*, with a smooth, finely granular, or slightly roughened (scabrate) ornament. A thin, moderately wide collar surrounds the aperture, and the diameter of the aperture is 30–50% of the maximum diameter.

**Description**. — The chamber shape is significantly affected by the degree of flattening and ranges from sub-spherical in uncompressed specimens to lenticular and even 'button-shaped' where the specimens have been flattened. The chamber wall is usually ornamented, with a finely granular appearance, resembling sand-blasting, or a slightly roughened appearance, which may represent organic, oily residue adhering to the chamber surface; smooth specimens also occur, but this may be due to surface erosion. The collar is quite thin and unornamented. It is relatively wide, and is suberect, when viewed in cross-section. The diameter of the aperture ranges from 29–53% of the maximum diameter. When in place, the operculum is flat and sometimes exhibits concentric rings near the periphery.

**Remarks**. — This species is somewhat problematic because there are a number of poorly defined species of *Calpichitina* from the Middle and Late Ordovician. Neville (1974) and Achab (1983) refer specimens from the Table Head Group in Newfoundland to *Desmochitina* cf. *D lata* Schallreuter, whose general dimensions, shape and ornament closely resemble the material from the Canning Basin. Achab (1989) subsequently referred to this species as *D. lata.* Reexamination of the material from the Table Head Group by E. Asselin and A. Achab (personal communication 1999) confirm the close relationship between the two groups; silhouette photographs of specimens from the Table Head Group show concentric rings on the operculum, a similar range of chamber shapes, a maximum diameter of 95–147 μm (av. 96 μm), and an apertural diameter between 31–55% of the chamber diameter. However, a small number of the Table Head specimens display small spines that are not found on the Canning Basin specimens; the implications for generic placement are somewhat unclear.

Grahn (1984) figures two specimens from the Llanvirn of Estonia, assigned to *Desmochitina complanata* (Eisenack) (Pl. III: C, D), whose chamber surface appears to be granular, and whose apertural diameter is approximately 0.45 of the maximum diameter; these may also belong to *C. windjana.*

Neville (1974) suggests that specimens from Newfoundland may belong to a number of taxa. However, *C. windjana* appears to be a distinct Darriwilian species, with a characteristic ornament and a moderately wide aperture, now found in Canada and Australia.

*Calpichitina windjana* can be distinguished from *C. lata* by the relatively smaller apertural diameter (Da/Dmax = 0.6–0.81 for *C. lata* vs. 0.29–0.5 for *C. windjana*), and by the much shorter, thinner suberect collar on *C. windjana* in contrast to the divergent collar on *C. lata. Calpichitina windjana* can be differentiated from *C. complanata* by the ornament on the vesicle of *C. windjana*, compared with the smooth wall of *C. complanata*; *C. windjana* can also be separated from *C. lenticularis* by the

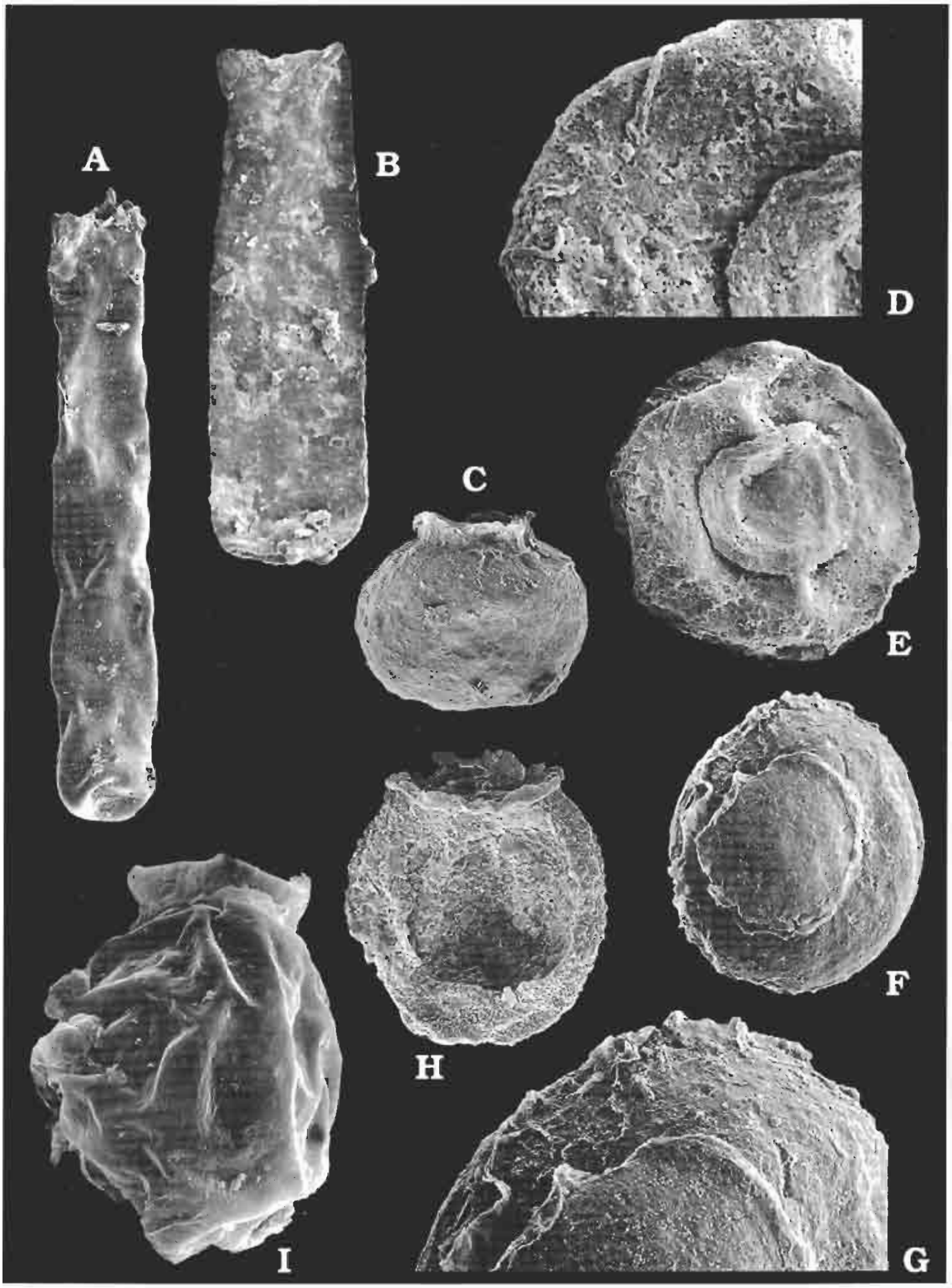

Fig. 5. **A**. *Conochitina kryos*. Specimen AMF 113119 from Kunzea 347.55; × 100. **B**. *Conochitina subcylindrica*. Specimen AMF 113112 from Santalum 1A, 464.45; × 250. **C–G**. *Calpichitina windjana* sp. n. **C**. Holotype AMF 113080 from Acacia 1, 798.21; × 400. **D**, **E**. Specimen AMF 113081 from Santalum 1A, 459.6; × 400 (**E**) and enlargement of upper chamber wall and collar (**D**) × 1100. **F**, **G**. Specimen AMF 113082 from Acacia 1, 798.21; × 300 (**F**) and enlargement of upper chamber wall and collar (**G**) × 700. **H**, **I**. *Desmochitina* sp. aff. *D. minor.* H. Specimen AMF 113083 from Santalum 1A, 459.6; × 400. **I**. Specimen AMF 113084 from Leo 1, 1587.61; × 400.

aperture of *C. windjana* which ranges to a wider diameter (Da/Dmax = approx. 0.3–0.4 for *C. lenticularis* e.g. Jenkins 1967; Paris 1981; note: Elaouad-Debbaj 1984b: p. 55, synonomised Jenkins' *H. complanata* with *C. lenticularis*).

**Dimensions**. — Taken from 19 specimens from Acacia 1 (depth 798.21 m), Santalum 1A (depths 459.6 m, 468.2 m, and 469.6 m), and from SS10 (depths 1591 m and 1595 m). L = 65–116 (av. 90.5); Dmax = 68–130 (av. 102 ); Dn = 25–67 (av. 44 ); Da/Dmax = 0.29–0.5.

**Stratigraphic occurrence**. — Darriwilian, (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia; Darriwilian, Table Head Group, Newfoundland (= Da2–Da3, according to Achab 1983); and Darriwilian (upper Kunda – Uhaku stages), northern Estonia.

## Genus *Desmochitina* Eisenack, 1931

Type species: *Desmochitina nodosa* Eisenack, 1931.

### *Desmochitina* spp. aff. *minor* Eisenack, 1931

Fig. 5H, I.

**Material**.— 10 specimens from Santalum 1A (depths 468.2 m, 464.45 m, 459.6 m); Leo 1 (depth 1587.61 m).

**Remarks**.— There are at least two subspecies of *D. minor* represented in the Goldwyer and Nita formations (Fig. 5H, I). Both species are larger than the holotype material, and, although they have the general shape of *D. minor*, they do not have the spines that Eisenack (1931) mentions in his original description. However, the size and surface ornament, or lack thereof, do fit some of the wide range of groups that are now united under this name in the literature. The apparent long range of this 'group' i.e. Arenig to Ashgill seems to confirm the comments of Grahn *et al.* (1994) that *D. minor* has become a waste basket taxon.

The collection of specimens in the present study are too few and too poorly preserved to sort out the true taxonomic assignment.

**Dimensions**. — Taken from 1 specimen from Santalum 1A (depth 459 m). L = 82.5; Dmax = 57.8; Da = 29.8; L/Dmax = 1.4; Da/Dmax = 0.5.

Taken from 1 specimen from Leo 1, depth 1587.61m. L = 120; Dmax = 86.7; Da= 40; L/Dmax = 1.4; Da/Dmax = 0.46

**Stratigraphic occurrence**. — Darriwilian, (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia.

## Order Prosomatifera Eisenack, 1972

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

## Subfamily Conochitininae Paris, 1981

## Genus *Conochitina Eisenack*, 1931 emend. Paris, Grahn, Nestor & Lakova, 1999a

Type species: *Conochitina claviformis* Eisenack, 1931.

### *Conochitina kryos* Bockelie, 1980

Fig. 5A.

*Conochitina kryos* sp. n. Bockelie, 1980: p. 10, pl. 1: 1, 9, 10, 12, 14, 15, 20.
*Conochitina kryos* Bockelie; Achab, 1986: p. 689, pl. 1: 4, 5, pl. 3: 5–8.
*Conochitina* cf. *C. kryos* Bockelie; Achab 1982: p. 1302, pl. 2: 4–7.
*Conochitina kryosa* (sic) Wang & Chen 1994: p. 728, pl. 1: 9, 10.

**Material**. — 61 specimens from Kunzea (depths 380.12 m, 379 m, 347.55 m); Acacia 1 (depth 874.3 m).

**Remarks**. — This species is very similar in shape and general appearance to *C. kryos* from Spitsbergen, except for the unusual 'reticulate' surface described by Bockelie (1980: p. 11); this type of surface, however, is most probably an artifact or diagenetic feature. The specimens from the Canning Basin are generally compressed, resulting in a concave or flat base, which contrasts with the convex base on the specimens from Spitsbergen.

The length of the individuals from the Canning Basin is equal to or greater than those from Spitsbergen and China (Wang & Chen 1994) but fits the full size range from Lévis Formation Québec (Achab 1982, 1986b). Similarly the proportion of length divided by maximum diameter (L/Dmax) of the Canning Basin collection is generally less than that for Spitsbergen and China.

There are also some similarities to *Conochitina changyangensis* Wang & Chen (1994) (= *Conochitina* sp. aff. *elegans* (Grahn 1980, 1981a, b) but this species has a more pronounced neck than *C. kryos*.

Achab (1986) first mentioned the presence of *C. kryos* in Canning Basin, and this is the first full documentation and illustration of this species in Australia.

**Dimensions**. — Taken from 7 specimens from Kunzea (depths 347.55 m and 379 m) and Acacia 1 (depth 874.3 m). L = 492–786 (av. 616.7); Dmax = 70–105 (av. 89.1); Dn = 54–80 (av. 68.1); L/Dmax = 6–8.3.

**Stratigraphic occurrence**. — Darriwilian, (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia; middle Arenig–late Llanvirn, Upper Yangtze Region, China; middle Arenig, Lévis Formation, Québec; late Arenig, Shumardia limestones, Lévis Formation, Québec; late Arenig, Valhallfona Formation, Spitsbergen.

## *Conochitina poumoti* Combaz & Peniguel, 1972

Fig. 11A, B.

*Conochitina poumoti* sp. n.; Combaz & Peniguel 1972: p. 140, pl. 4: 3–5.
*Conochitina poumoti* Combaz & Peniguel; Bockelie 1980: p. 11, pl. 1: 3, 4, 16, 23.
*Conochitina poumoti* Combaz & Peniguel; Achab 1982: p. 1302, pl. 1: 6–11.
*Conochitina poumoti* Combaz & Peniguel; Achab 1983: p. 930, pl. 4: 5–13.
*Conochitina poumoti* Combaz & Peniguel; Achab 1986b: p. 689, pl. 1: 1–3.

**Material**. — 149 specimens from Acacia 1 (depths 798.21 m, 792.9 m, 782.7 m); Acacia 2 (depths 751.88 m, 747.47 m); Santalum 1 (depths 468.2 m, 464.45 m, 459.6 m, 450 m, 447.75 m).

**Remarks**. — The shape and general appearance of specimens from this study resembles that illustrated previously from the Canning Basin (Combaz & Peniguel 1972), and from Spitsbergen (Bockelie 1980) and Canada (Achab 1982, 1983, 1986b). However, the length of the individuals is much shorter than that found in any previous studies (L = 511–900 µm, compiled from all previous studies). The size is much closer to that cited for *Conochitina langei* Combaz and Peniguel for the Canning Basin; the latter can be easily distinguished by its more convex flanks.

The range chart presented by Combaz & Peniguel (1972) is somewhat misleading. They show *C. poumoti* as being restricted to their zones 03, 04a and 04b; however, their correlation chart (1972: p. 154) clearly shows the samples that are listed as containing *C. poumoti* also include Zone 05.

**Dimensions**. — Taken from 14 specimens from Acacia 2 (depths 748.41 m, 751.88 m), and from Santalum 1 (depths 450 m, 459.6 m). L = 373–589 (av. 480.5); Dmax = 56–148 (av. 105); Dn = 28–110 (av. 73.9) L/Dmax = 2–5.9.

**Stratigraphic occurrence**. — Arenig–Darriwilian, (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia; middle Arenig, Valhallfona Formation, Spitsbergen; middle – late Arenig, Lévis Formation, Québec, Canada; Llanvirn, Table Head Group, Newfoundland, Canada.

## *Conochitina subcylindrica* Combaz & Peniguel, 1972

Fig 5B.

*Conochitina subcylindrica* sp. n.; Combaz & Peniguel 1972: p. 143, pl. 3: 8, 9.

*Conochitina subcylindrica* Combaz & Peniguel; Achab 1983: p. 924, pl. 1: 6, 6a.
*Conochitina subcylindrica* Combaz & Peniguel; Achab & Asselin 1995: pl. 1: 6.

**Material**. — 51 specimens from Santalum 1A (depths 469.6 m, 468.2 m, 464.5 m, 459.6 m, 447.75 m); SS10 (depths 1645 m, 1622 m, 1595 m).

**Dimensions**. — Taken from 6 specimens from Santalum 1A, (depth 464.5 m) and from SS10 (depths 1595 m, 1622 m, 1645 m). L = 171–268 (av.198.9); Ln = 36–75 (av. 56.6); Dmax = 40–70 (av. 58.9 ); Dn = 30–52 (av. 42.7 ) L/Dmax = 2.4–4.5.

**Stratigraphic occurrence**. — Darriwilian (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia; Llanvirn, Table Head Group, western Newfoundland, Canada; Llanvirn, Ship Point Formation, Rowley Island, Arctic Platform, northern Canada; Llanvirn, Bay Fiord Formation, Little Cornwallis Island, northern Canada.

## Subfamily Belonechitininae Paris, 1981

## Genus *Belonechitina* Jansonius, 1964

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

**Remarks**. — Simple forms of chitinozoans can cause enormous difficulties in separating individuals into species and in correct, consistent identification. There are three options for a taxonomist faced with this group. Firstly you can lump together all specimens that look even slightly similar. While this procedure has the advantage of being a tidy way of dealing with the problem, it may also disguise stratigraphically significant variants and/or species. The second alternative is to separate the variations, but leave the groups in open nomenclature. There is some advantage with this approach, but it does nothing to assist in solving the larger problem. The third tactic is to erect new species where there are large numbers of specimens that consistently show a combination of features that are unique, albeit subtle. This last approach has been adopted by this author.

### *Belonechitina* cf. *cactacea* (Eisenack 1937)

Fig. 6E–H.

**Material**. — 107 specimens from Acacia 1 (depths 874.3 m, 830.8 m, 798.21 m, 792.9 m, 782.7 m); Kunzea 1 (depth 380.12 m); ?Leo 1 (depth 1587.8 m); Santalum 1A (depth 450 m).

**Description**. — A species of *Belonechitina* with a subconical chamber and a short cylindrical neck; the flanks are straight or weakly convex, with a poorly defined flexure and no shoulders. The neck is relatively short, less than one third of the total length, is thin and slightly flaring. The base is flat or weakly convex and the basal edge is rounded to well rounded. The ornamentation consists of short (< 3 µm), densely spaced spines that are most developed at the basal edge and become sparser towards the neck, where they are very rare. The spines are dominantly simple, but lambda forms also occur, and some are connected at their distal end, forming short ridges, some spines are branching. In some specimens the spines are somewhat aligned, but in many specimens the spines are eroded to small cones.

**Remarks**. — *Belonechitina* cf. *cactacea* closely matches the type specimen in size, shape and general dimensions, but the length of the ornamentation on the type material is much longer than for the specimens from the Canning Basin. (Note: Eisenack (1937: p. 223) mentions that the proportion of total length versus maximum diameter ranges from 1.8–2.2; the specimens from the Goldwyer and Nita formations match these dimensions if their uncorrected width measurements are used.) The neotype selected by Eisenack (1959) exhibits the same shape and spine form, but again the length of the spines is much shorter on the Canning collection.

Laufeld (1967) describes *Conochitina cactacea* from the Late Llanvirn and Caradoc of Sweden, which is almost identical, except that the spines on *C. cactacea* range from 3–12 µm. Jenkins (1970) mentions that specimens of *C. cactacea* from the Sylvan Shale in Oklahoma show spines that align themselves in longitudinal rows, and that the ends coalesce to form ridges; this feature is also seen on some specimens from the Goldwyer and Nita formations (which may suggest the genus *Hercochitina*

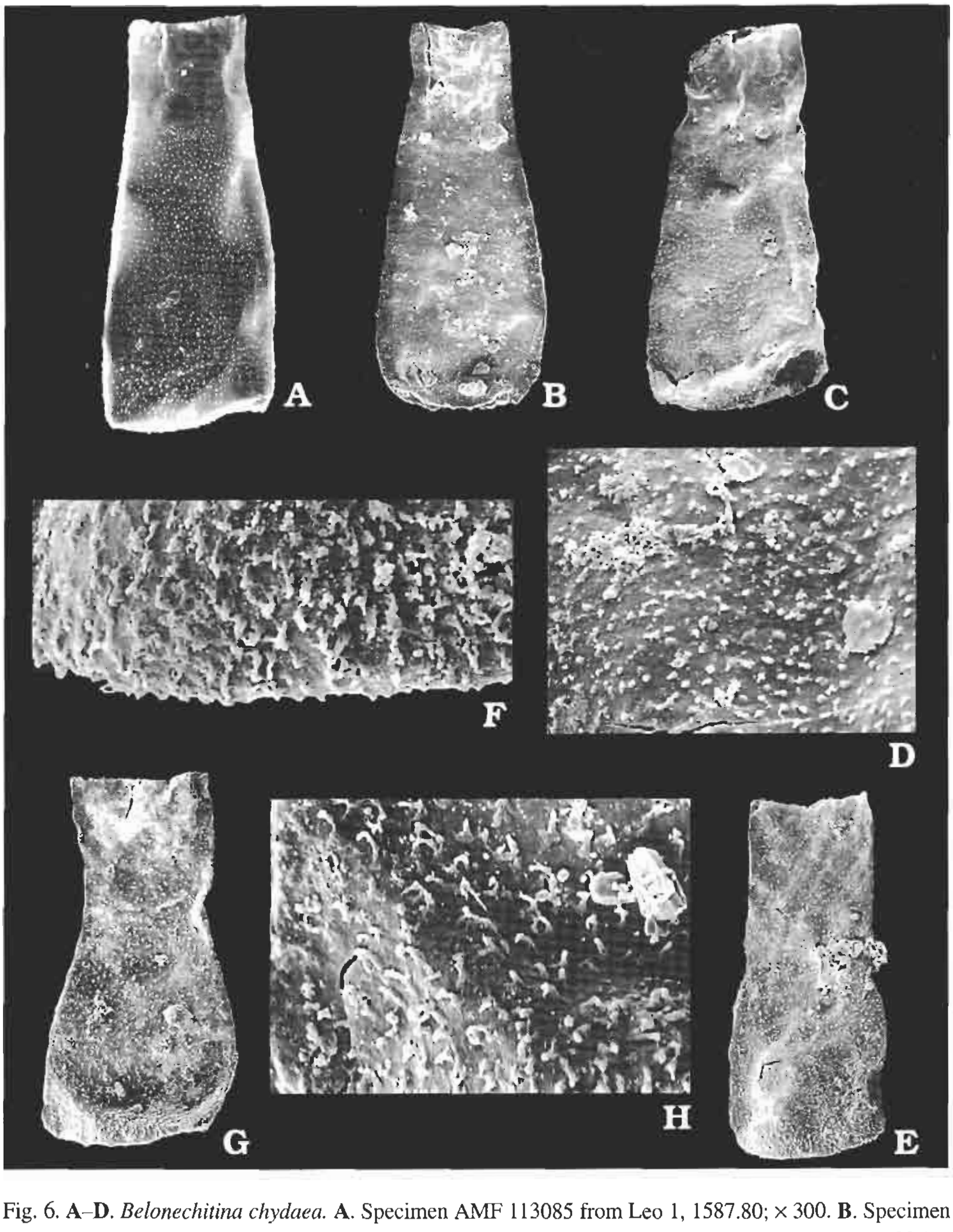

Fig. 6. **A–D**. *Belonechitina chydaea*. **A**. Specimen AMF 113085 from Leo 1, 1587.80; × 300. **B**. Specimen AMF 113086 from Acacia 1, 798.21; × 300. **C, D**. Specimen AMF 113087 from Acacia 1, 798.21; × 300 (**C**) and enlargement of chamber wall (**D**) × 1800. **E–H**. *Belonechitina* sp. cf. *B. cactacea*. **E, F**. Specimen AMF 113088 from Acacia 1, 792.9; × 300 (**E**) and enlargement of lower chamber wall near base (**F**) × 1700. **G, H**. Specimen AMF 113089 from Acacia 1, 792.9; x 300 (**G**) and enlargement of lower chamber wall (**H**) × 1550.

Jansonius, but the relationship is uncertain at this point). Grahn (1981a, 1982) illustrates specimens of *B. cactacea* from the Caradoc of Gotland and Öland, which differ markedly from the present specimens in having longer and much sparser ornamentation. The species figured in silhouette by Achab & Asselin (1995: pl. III: 2) also fits the general shape of the Canning Basin material, but the spines

| | L | Ln | Dmax | Dn | L/Dmax | Ln/L |
|---|---|---|---|---|---|---|
| *B. vibrissa* | 152–240 (187.2) | 24–43 (32.6) | 53–100 (69) | 28–74 (47) | 2.3–3.3 | 0.15–0.23 |
| *B. micracantha* | 212–311.8 (265.4) | | 68–94 (78.8) | 41–65 (49) | 2.9–3.9 | |
| *B. chydaea* | 130–194 (163.9) | 30–55 (41.5) | 44–100 (59.6) | 27–53 (35.6) | 2.0–3.8 | 0.17–0.36 |
| *B.* cf. *B. cactacea* | 128–176 (146.8) | 28–60 (37) | 47–70 (55.7) | 27–50 (35) | 2.0–3.1 | 0.2–0.4 |
| *Belonechitina* sp. A | 148–282 (198) | 30–76 (52) | 39–73 (57.8) | 27–52 (37) | 2.4–4.7 | 0.2–0.4 |
| *Belonechitina* sp. B | 117–192 (146) | 23–68 (38.4) | 48–78 (58.8) | 23–35 (27.8) | 2.0–3.4 | 0.19–0.35 |

Fig. 7. Table showing the dimensions of species of *Belonechitina* from this study.

are much sparser. Thus the specimens from the Canning Basin have been kept in open nomenclature, pending the discovery of specimens with better preserved ornamentation, that may show the relationship to *B. cactacea.*

*Belonechitina* cf. *cactacea* differs from *Conochitina hirsuta* Laufeld in having shorter spines and a more conical shape, from *Conochitina tribulosa* Jenkins and *Conochitina conulus* Eisenack in having more complex spines, from *Conochitina robusta* Eisenack in being much smaller and from *Angochitina communis* Jenkins in having a flatter base.

*Belonechitina* sp. A can be differentiated by being generally larger (figs. 7, 8) having a more cylindrical chamber, with straight flanks versus the more pronounced flexure than *B.* cf. *cactacea.*

**Dimensions.** — Taken from 15 specimens from Acacia 1 (depths 792.9 m, 798.21 m). L = 128–176 (av. 146.8); Ln = 28–60 (av. 37.1); Dmax = 47–70 (av. 55.7 ); Dn = 27–50 (av. 35.1 ); Lsp = 0.5–2.5; L/Dmax = 2–3.1; Ln/L = 0.2–0.33; Dn/Dmax = 0.47–0.74.

**Stratigraphic occurrence.** — Darriwilian (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia.

## *Belonechitina chydaea* (Jenkins, 1967)

Fig. 6A–D.
*Conochitina chydaea* sp. n.; Jenkins 1967: pp. 453–454 , pl. 70: 4–8.
?*Eucochitina micracantha tenera* n. subsp.; Combaz & Peniguel 1972: pp. 143–144, pl. 3: 3, 4.
*Conochitina chydaea* Jenkins; Neville 1974: p. 194–195, pl. 1: 2–27.
?*Conochitina chydaea* Jenkins; Paris 1981: pp. 178–179, pl. 12: 10, 14, pl. 13: 18, pl. 17: 3.
*Conochitina* cf. *C. bulmani* Jansonius, 1964; Achab 1983: p. 922, pl. 1: 1–5.
?*Conochitina* sp. A; Playford & Miller 1988: pp. 23–24, pl. 1: 8–11, pl. 4: 6–8.

**Material.** — 539 specimens from Acacia 1 (depths 874.3 m, 798.21 m, 792.9 m, 782.7 m); Kunzea 1 (depth 390.18 m, 353.02 m); Leo 1 (depths, 1587.8 m, 1587.61 m); SS10 (depths 1622 m, 1595 m, 1591 m); Mirbelia 2 (depth SWC 10).

**Remarks.** — Individuals of *B. chydaea* from Australia are similar in shape to those described from Shropshire (Jenkins, 1967), but tend to be rather more 'squat' in appearance. The Australian material is slightly smaller (average length of specimens from Shropshire is 199 µm, versus 166.6 µm from the Canning Basin), but other proportions fit within the same range (e.g., length of neck/total length ranges from 0.16 to 0.4 for the Shropshire species, and total length/maximum diameter ranges from 2.6 to 3.5; measurements were taken from Jenkins 1967: pl. 70: 4–8). The Australian material also fits within the range of variation in shape and the general size range described by Neville (1974) for *C. chydaea*, and by Achab (1983) for *C.* cf. *bulmani* (note that Achab (1986b) suggested that *C.* cf. *bulmani* was possibly equivalent *C. chydaea,* but later retained *S. bulmani* for this species). Paris (1981) suggests that some of material depicted by Neville (1974) should not be included because it has a more 'squat' shape; however, the present study shows that there is a great variation in shape which includes these shorter, stouter individuals.

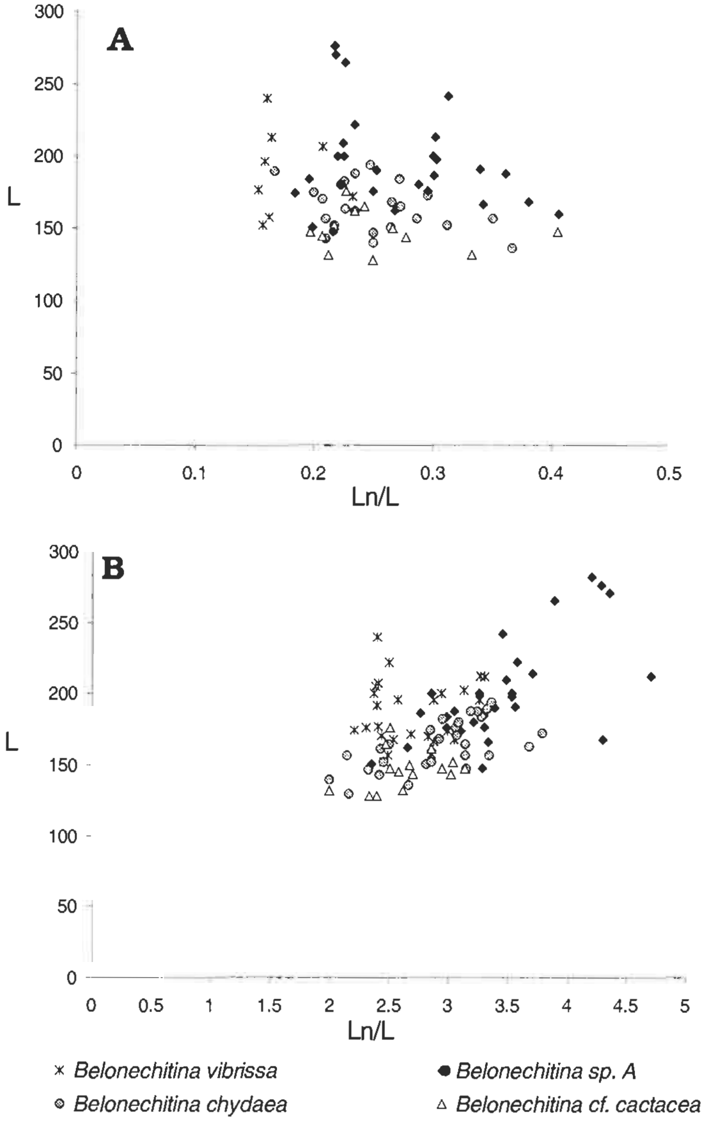

Fig. 8. **A**. Biometric plot of total length (L) versus length of neck/total length (Ln/L) for *Belonechitina vibrissa* sp. n., *Belonechitina chydaea, Belonechitina* sp. A and *Belonechitina* cf. *cactacea*. **B**. Biometric plot of total length (L) versus length of neck/maximum diameter (L/Dmax) for *Belonechitina vibrissa* sp. n., *Belonechitina chydaea, Belonechitina* sp. A and *Belonechitina* cf. *cactacea*.

Jenkins (1967) and Neville (1974) refer to ornamentation in the form of small cones on some, but not all of the populations they describe; these cones also feature on about half the individuals from the Canning Basin. Achab (1983) makes no mention of such cones and Paris (1981) disputes the inclusion of individuals with such ornament in this species. Observation of the whole population from the Canning Basin shows few differences between individuals with ornament and those without, there is no real difference in size, shape or general proportions. Some of the individuals depicted by Paris

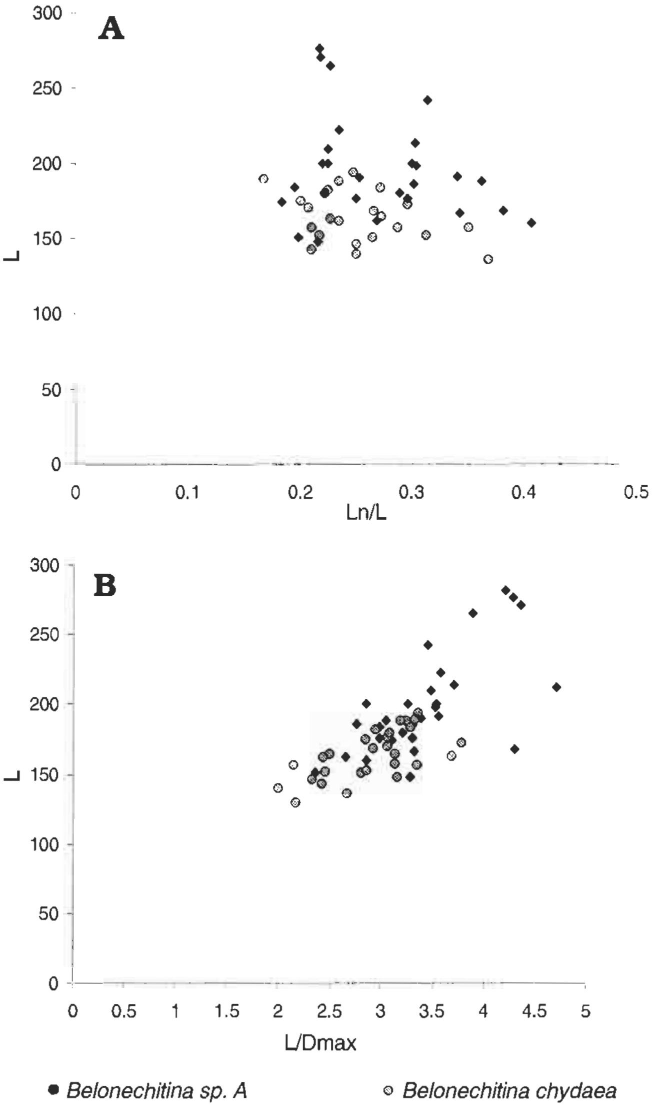

Fig. 9. **A**. Biometric plot of total length (L) versus length of neck/total length (Ln/L) for *Belonechitina* sp. A and *Belonechitina chydaea*. **B**. Biometric plot of total length (L) versus length of neck/maximum diameter (L/Dmax) for *Belonechitina* sp. A and *Belonechitina chydaea*.

(1981: pl. 12: 10, 14; pl. 13: 18) have a more angular basal edge than that observed in the Canning Basin, and it is possible that the material from Portugal and from the Canning Basin do not belong to the same species.

Playford & Miller (1988) describe *Conochitina* sp. A from the Georgina Basin, whose general shape, proportions and dimensions are very similar to *B. chydaea* from the Canning Basin. *Conochitina* sp. A, however, differs in having no surface ornament. This species may be conspecific with *B. chydaea*, especially as many specimens of *B. chydaea* have no spines or cones on the vesicle surface.

There is some overlap in the dimensions and proportions of *B. chydaea* and of *Belonechitina* sp. A (Figs. 7, 9), but *Belonechitina* sp. A is slightly longer and the proportion of L/Dmax is generally higher, viz. L/Dmax for *B. chydaea* is 2–3.8, whilst this value for *Belonechitina* sp. A is 2.4–4.7. The two groups may be further distinguished by the presence of spines on *Belonechitina* sp. A and the presence of cones on some individuals of *B. chydaea.*

**Dimensions.** — Taken from 34 specimens from Acacia 1 (depths 792.9, 798.21 m), Kunzea 1 (depth 347.55 m), Leo 1 (depths 1587.61 m, 1587.8 m), SS10 (depths 1591 m, 1595 m, 1622 m), and from Mirbelia 2 (depth SWC 10). L = 130–212.5 (av. 166.6); Ln = 30–55 (av. 41.2); Dmax = 44–100 (av. 59.6); Dn = 26.7–53 (av. 35.6); Ln/L = 0.17– 0.37; L/Dmax = 2.2–3.8; Dn/Dmax = 0.4–0.9.

**Stratigraphic occurrence.** — ?middle–late Arenig, Coolibah and Nora formations, Queensland, Australia; Darriwilian (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia; Llanvirn, Hope Shales to Glenburrell beds, Shropshire, UK; Llanvirn, Table Head Group, western Newfoundland, Canada.

## *Belonechitina micracantha* (Eisenack, 1931)

Fig. 10E–H.

**Material.** — 298 specimens from Santalum 1A (depths 470.03 m, 469.6 m, 468.2 m, 464.45 m, 459.6 m, 450 m, 447.75 m).

**Remarks.** — This is a distinctive species that is long ranging and with a wide geographic distribution. The limited number of specimens precludes a detailed analysis on the complex taxonomic history of this species.

The specimens from the Canning Basin all have the characteristic constriction of the vesicle near the basal margin, although the amount of constriction varies with the degree of flattening. These specimens have an ornament of simple spines or cones that are distributed over the vesicle, though more concentrated on the basal portion of the vesicle. There are no coalescent spines as found on *B. robusta* (Eisenack).

**Dimensions.** — Taken from 7 specimens from Santalum 1A, depths 469.6 m and 470.03 m. L = 212–312 (av. 265.4); Dmax = 68–94 (av. 79); Dn = 41–65 (av. 49 ); L/Dmax = 2.9–3.9; Dmax/Dn = 1.2–2.3.

**Stratigraphic occurrence.** — See Grahn & Bergström (1984) for a review of the stratigraphic occurrence; additional occurrences are: Darriwilian (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia; Ashgill, Ktaoua Formation, Anti-Atlas, Morocco (Elaouad-Debbaj 1984)

## *Belonechitina vibrissa* sp. n.

Fig. 10C, G–H.

Holotype: AM F113095 (Fig. 8G, H).

Type horizon and locality: Santalum 1A core, depth 468.2 m, Goldwyer Formation, Canning Basin, Western Australia.

Derivation of name: From the Latin word '*vibrissa*' meaning whisker, referring to the short spines on the vesicle surface.

**Material.** — 1695 specimens from Acacia 1 (depths ?874.3 m, 798.21 m, 792.9 m, 782.7 m); Leo 1 (depths 1587.8 m, 1587.61 m); Santalum 1A (depths 469.6 m, 468.2 m, 464.45 m, 459.6 m, 447.75 m); Acacia 2 (depths 753.6 m, 751.22 m, 751.03, 748.41 m).

**Diagnosis.** — A species of *Belonechitina* with a slim cylindro-conical or subcylindrical vesicle, that is covered with densely spaced cones or short, simple spines.

**Description.** — This species has a relatively slim vesicle that ranges in shape from cylindro-conical to subcylindrical, has straight flanks and the maximum diameter occurs near the basal edge. The neck is short, less than one quarter of the total length of the vesicle, and is generally poorly differentiated from the chamber, with a short, thin, slightly flared collar. The basal edge is broadly rounded; the

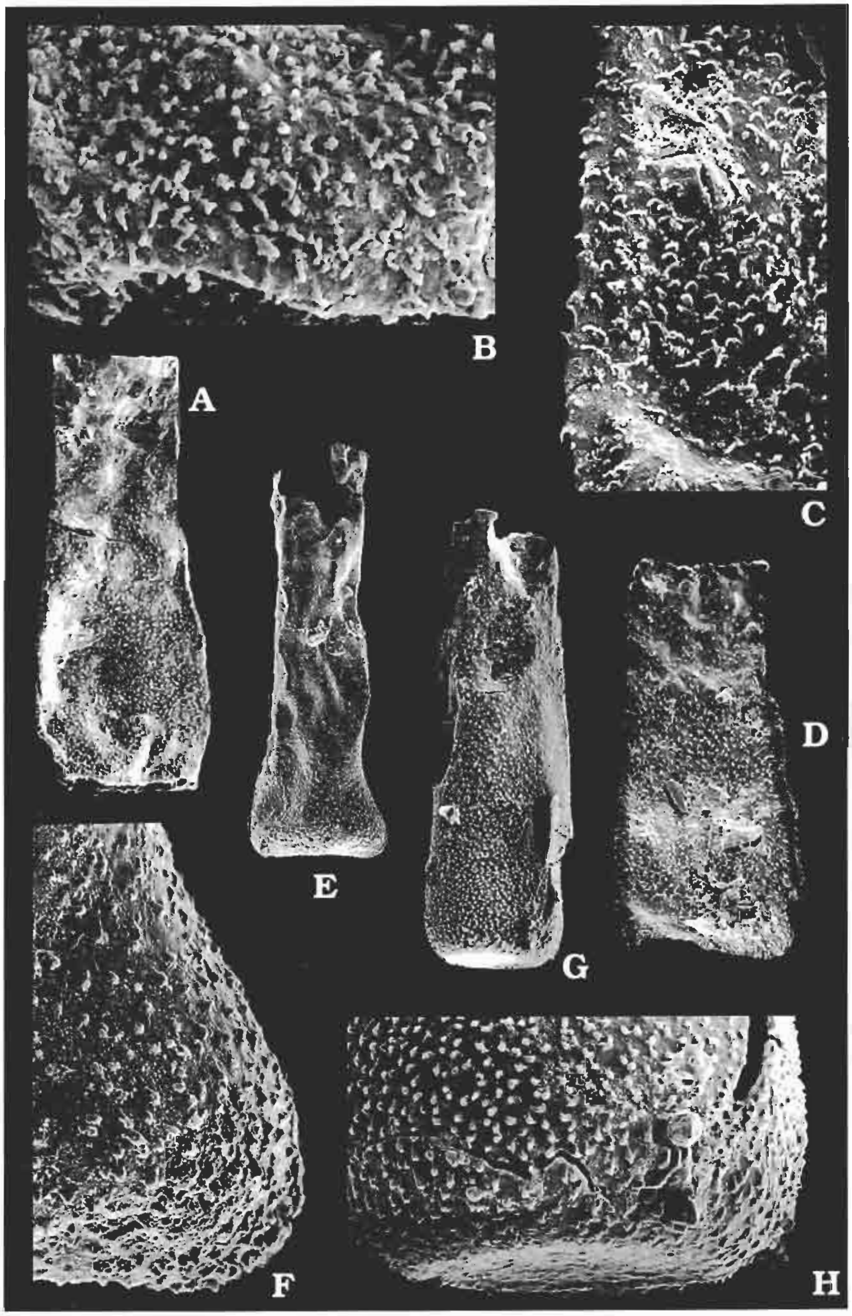

Fig. 10. **A–D**. *Belonechitina* sp. A. **A**, **B**. Specimen AMF 113090 from Acacia 1, 792.9; × 300 (**A**) and enlargement of lower chamber wall near base (**B**) × 1800. **C**, **D**. Specimen AMF 113091 from Acacia 1, 792.9; × 300 (**D**) and enlargement of lower chamber wall (**C**) × 1250. **E–H**. *Belonechitina micracantha*. **E**, **F**. Specimen AMF 113116 from Santalum 1A, 470.03; × 250 (**E**) and enlargement of lower chamber wall (**F**) × 1400. **G**, **H**. Specimen AMF 113092 from Acacia 1, 792.9; × 300 (**G**) and enlargement of lower chamber wall (**H**) × 1100.

base is flat or weakly concave, with a wide basal callus. Ornamentation consists of very short (< 2μm) simple, thornlike spines or cones or verrucae that cover the vesicle and neck (but not the base). The spines are fairly densely spaced (9–26 spines per 100 μm$^2$; av. 15).

**Remarks.** — *Belonechitina vibrissa* is superficially similar to some specimens of a number of Middle and Upper Ordovician species; however, in each case the holotype and specimens from the type locality, and original diagnoses and descriptions are clearly different to this new species. *Belonechitina vibrissa* differs from *Belonechitina conulus* (Eisenack), in having a less conical vesicle, no fringe at the aperture and in a flat to slightly concave base; it differs from *Belonechitina tribulosa* (Jenkins) on having a more robust vesicle with a thicker wall, especially near the base, and in having a less well differentiated neck; it differs from *Belonechitina wesenbergensis* (Eisenack) in having a less pronounced neck and shorter spines; and it differs from *Belonechitina micracantha* (Eisenack) in having no constriction of the vesicle just above the basal edge.

Specimens of *B. micracantha* (Eisenack) from the Canning Basin can be distinguished from *Belonechitina vibrissa* by being much longer (fig. 7). *Belonechitina* sp. A from the Canning Basin has narrower vesicle and a relatively longer neck (Ln/L = 0.2–0.4 for *Belonechitina* sp. A compared with 0.15–0.23 for *B. vibrissa*; Fig. 8) and the spines on *Belonechitina* sp. A are generally more complex e.g. bifurcated or lambda shaped. *Belonechitina vibrissa* also differs from *Belonechitina* sp. A. in having a more pronounced flexure and well differentiated neck, in having only cones and no spines, and in having the maximum diameter about 2/3 of the way down the chamber, thus giving a more convex flanks.

Grahn & Bergström (1984: pl. 2: D, E) figure specimens assigned to *Conochitina wesenbergensis* Eisenack from the late Llanvirn and early Caradoc of the southern Appalachians, which are very similar to *B. vibrissa*, and may be conspecific. Similarly specimens designated *C. wesenbergensis* from late Llanvirn and early Caradoc strata of the Arbuckle Mountains (Grahn & Miller 1986) may also belong to this new species.

**Dimensions.** — Taken from 21 specimens from Santalum 1A (depths 459.6 m, 468.2m and 469.6 m), Acacia 1 (depths 792.9 m, 798.21 m), Acacia 2 (depths 751.22 m, 753.6 m), and Leo 1 (depth 1587.1). L = 139–240 (av. 183.3); Ln = 20–42.9 (av. 31.4); Dmax = 52–100 (av. 69.2 ); Dn = 28–74 (av. 47.2 ) L/Dmax = 1.9–3.3; Dn/Dmax = 0.32–0.83; Ln/L = 0.15–0.23.

**Stratigraphic occurrence.** — Darriwilian (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia.

## *Belonechitina* sp. A

Fig. 10A–D.

**Material.** — 982 specimens from Acacia 1 (depths 874.3 m, 798.21 m, 792.9 m, 782.7 m); Kunzea 1 (depths 390.18 m, 380.12 m, 379.94 m, 353.02 m, 347.55 m); Santalum 1A (depths 470 m, 469.6 m, 464.45 m, 459.6 m, 450 m, 447.75 m); SS10 (depths 1645 m, 1622 m, 1595 m, 1591 m); Leo 1 (depth 1587.61 m).

**Description.** — This is a species of *Belonechitina* with a subcylindrical vesicle, with straight to slightly convex flanks. The base is straight to weakly convex, with a rounded basal edge. Flexure is poorly defined, leading to a short neck, topped with a short, thin collar. The vesicle is covered with short, fairly densely spaced spines. The spines vary from simple to lambda shaped, and the tips may be curved to give the impression of bent thorns. The density and length of the spines may decrease on the neck.

**Remarks.** — Specimens of *Belonechitina* sp. A from the Canning Basin resemble a new species of *Belonechitina* reported from Newfoundland in shape and ornamentation (Albani *et al.* 1998; R. Albani personal communication 1999). The collection from the Canning Basin are slightly smaller (average length of specimens from Newfoundland is 223.5 μm), but the proportions of neck length v. total length and total length v. maximum diameter are similar. The Australian material has a more subconical chamber, and consequently more concave flanks, than that on individuals from New-

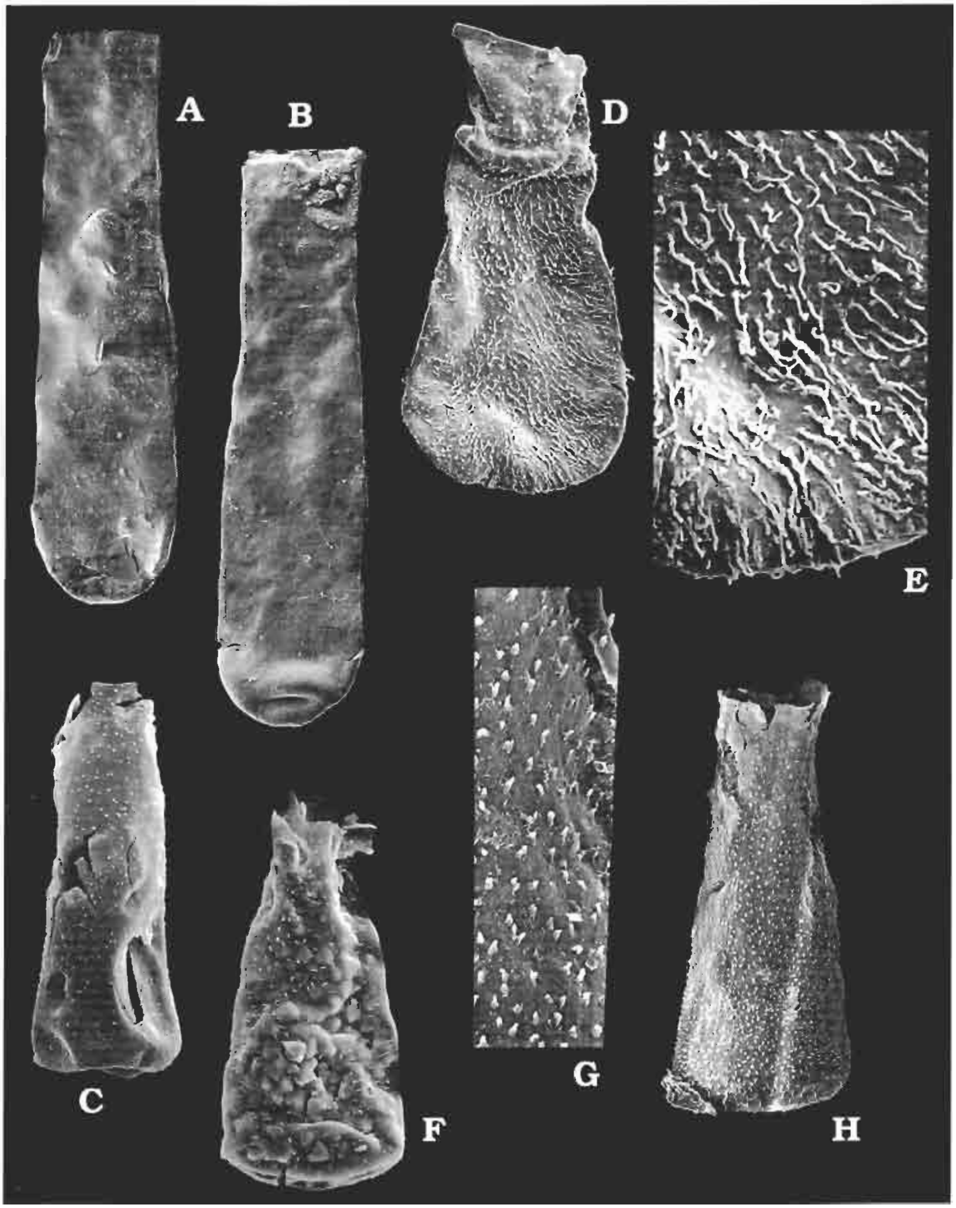

Fig. 11. **A**, **B**. *Conochitina poumoti*. **A**. Specimen AMF 113093 from Santalum 1A, 459.6; × 150. **B**. Specimen AMF 113109 from Santalum 1A, 450; × 150. **C**, **G**, **H**. *Belonechitina vibrissa* sp. n. **C**. Specimen AMF 113111 from Acacia 2, 751.22; × 300. **G**, **H**. Holotype AMF 113095 from Santalum 1A, 468.2; × 300 (**H**) and enlargement of chamber wall (**G**) × 1100. **D**–**F**. *Belonechitina* sp. B. **D**, **E**. Specimen AMF 113117 from Santalum 1A, 469.6; × 300 (**D**) and enlargement of lower chamber wall (**E**) x 1600. **F**. Specimen AMF 113094 from SS10 1622; × 400.

foundland (R. Albani personal communicaton 1999); the more convex bases from Australian specimens may reflect the high degree of flattening.

Specimens of *Belonechitina* sp. A from Santalum 1A are larger than those from Acacia 1, Kunzea, SS10 and Leo1, but lie within the range of those from Newfoundland (see Fig. 9).

**Dimensions.** — Taken from 27 specimens from Acacia 1 (depths 792.9 m, 798.21 m, 874.3 m), Kunzea 1 (depth 379 m), SS10 (depths 1591 m, 1595 m, 1622 m, 1645 m), and Leo 1 (depth 1587.61 m). L = 148–222 (av. 182.2); Ln = 30–68 (av. 49.3); Dmax = 39–73 (av. 57.8); Dn = 27–52 (av. 37 ); L/Dmax = 2.4–4.7; Ln/L = 0.2–0.34; Dmax/Dn = 1.2–1.9.

Taken from 6 specimens from Santalum 1A from 459.6 m and 469.6 m. L = 198–286.7 (av. 259.2); Dmax = 56–70 (av. 64.9); Dn = 36.4–44.5 (av. 40.2 ); L/Dmax = 3.5–4.4; Dmax/Dn = 1.2–1.8

**Stratigraphic occurrence.** — Darriwilian (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia; Llanvirn, Cape Cormorant Formation, Table Head Group, western Newfoundland, Canada.

## *Belonechitina* sp. B

Fig. 11D–F.

**Material.** — 44 specimens from Acacia 1 (depths 798.21 m, 792.9 m); SS10 (depth 1622 m); Santalum 1A (depths 469.6 m, 468.2 m, 459.6 m).

**Description.** — *Belonechitina* sp. B is relatively small species, with a conical chamber, surmounted by a short neck (i.e. less than one third of the vesicle length). The chamber flanks are straight to weakly convex, and flexure is poorly defined; the basal edge is well rounded and the base ranges from weak to strongly convex; the shape of the base is strongly affected by compression of the vesicle, with some specimens showing invagination of the base. The collar is thin and flares slightly. Ornamentation consists of short, simple and lambda spines, with occasional bifurcating and T-shaped tips. The spines are randomly and fairly sparsely placed. Fig. 11D–F show the range of intraspecific variation in the shape of the base and density of the spines.

**Remarks.** — *Belonechitina* sp. B can be differentiated from *Belonechitina hirsuta* (Laufeld) by the lack of long, complex multiramose ornament found on *B. hirsuta*, and from *Belonechitina cactacea* (Eisenack) by the straighter flanks, lack of well defined flexure and more convex base on *Belonechitina* sp. B.

Within the material from the Canning Basin, *B.* cf. *cactacea* is similar in dimensions and general shape, but can be distinguished by the less definite flexure, more convex base.

Grahn & Miller (1986: fig. 7.2) describe and figure a specimen designated *Conochitina* sp. from the Early Caradoc Bromide Formation in Oklahoma, which is similar to *Belonechitina* sp. B in vesicle shape, spine density, and length of neck. However, Grahn and Miller refer only to simple and coalescent spines, and not the lambda shaped spines found on *Belonechitina* sp.(Fig. 11D–F).

**Dimensions.** — Taken from 9 specimens from Santalum 1A (depths 459.6m and 469.6 m), and from SS10 (depth 1622 m). L = 117–192 (av.146); Ln = 23–68 (av. 38.4); Dmax = 48–78 (av. 58.8); Dn = 22.8–35 (av. 27.8); Lsp = 2–7; L/Dmax = 2–3.4; Ln/L = 0.19–0.35.

**Stratigraphic occurrence.** — Darriwilian (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia.

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

## Subfamily Cyathochitininae Paris, 1981

## Genus *Cyathochitina* Eisenack, 1955 emend. Paris, Grahn, Nestor & Lakova, 1999

Type species: *Cyathochitina campanulaeformis* Eisenack, 1931.

## *Cyathochitina hunderumensis* Grahn, Nõlvak, & Paris, 1996

Fig. 12A, B.

?*Cyathochitina campanulaeformis* Eisenack; Jenkins 1967: pp. 456–458, pl. 71: 8–11.

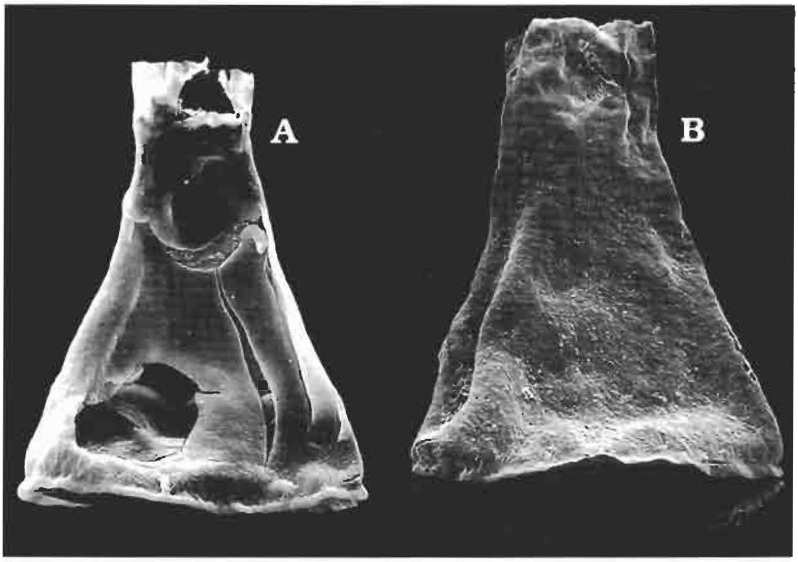

Fig. 12. *Cyathochitina hunderumensis*. **A**. Specimen AMF 113096 from Acacia 2, 751.32; × 300. **B**. Specimen AMF 113110 from Santalum 1A, 468.2, × 300.

*Cyathochitina campanulaeformis* Eisenack; Eisenack 1976: p. 187, pl. 2: 4.
*Cyathochitina campanulaeformis* Eisenack; Combaz & Peniguel 1972: p. 141, pl. 4: 13, 15.
*Cyathochitina* cf. *C. campanulaeformis* Eisenack; Grahn 1980: pp. 25–27, pl. 15: A–D.
*Cyathochitina hunderumensis* sp. n.; Grahn, Nõlvak & Paris 1996: pp. 28–29, pl. 1: 1, 10, 11.

**Material**. — 1495 specimens from Kunzea 1 (depths ?380.12 m, 353.02 m, 347.55 m); SS10 (depth 1595 m); Santalum 1 (depths 469.6 m, 468.2 m, 464.45 m, 450 m, 447.75 m); Acacia 2 (depths 753.62 m, 751.88 m, 747.47 m, 751.32 m, 751.22 m, 751.03 m, 748.41 m, 747.47 m, 746.64 m).

**Remarks**. — The specimens from the Goldwyer and Nita formations closely resemble those from the Baltic (Grahn 1980; Grahn *et al.* 1996) in size, shape and the presence of a thickened carina, but are smaller than the microfossils from Shropshire (Jenkins 1967).

The neck comprises between one third and one half of the total length of the test (Ln/L = 0.31–0.47, except one specimen which is 0.55). Grahn (1980) reports that 82% of the population from Öland has a length to maximum diameter ratio of 1.25–2.1:1, and Jenkins (1967) reports a ratio of 1.18–1.82:1 (average 1.58:1); 85% of the Canning Basin specimens fall into the range of 1.25–2.1, but have a slightly higher average than that of Shropshire (average 1.84:1).

None of the specimens has the longitudinal thickenings that characterise other species, but the presence of folds or creases on the carina and lower part of the base can be observed on many specimens.

**Dimensions**. — Taken from 38 specimens from Santalum 1 (depths 464.45 m, 468.2 m, 469.6 m) and from Acacia 2 (depths 747.47 m, 751.03 m, 751.22 m, 751.32 m, 751.88 m, 753.62 m). L = 121–235 (av. 186.8); Ln = 33–107 (av. 74.6); Dmax = 61–142 (av. 101.7 ); Dn = 29–60 (av. 40); Lcarina = 4–14 (av. 7.5); L/Dmax = 1.28–2.4; Dmax/Dn = 1.96–3.3; Ln/L = 0.31–0.55.

**Stratigraphic occurrence**. — Darriwilian (Llanvirn), Goldwyer and Nita formations, Canning Basin, Western Australia; late Arenig – early Llanvirn, Öland and from the Granby crater, Sweden; early Llanvirn, Hope Shales, Shropshire, Britain.

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# Chitinozoa ze środkowoordowickich formacji Golwyer i Nita w basenie Canning (Australia Zachodnia)

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## Streszczenie

Omówiono Chitinozoa ze środkowoordowickich odcinków siedmiu rdzeni wiertniczych obejmujących strop formacji Goldwyer i formacji Nita z basenu Canning w Australii Zachodniej i zaliczono je do trzech zespołów. Stwierdzono ich użyteczność do wewnątrzbasenowej

korealcji warstw darriwilianu (lanwirn). Sześć z dwunastu gatunków basenu Canning należącego do wschodniej Gondwany znanych jest także z Laurencji/Spitsbergenu (z wyłączeniem kosmopolitycznego gatunku *B. micracantha*), co potwierdza bliskie pokrewieństwa fauny chitinozoowej obu prakontynentów i wskazuje na możliwość zastosowania regionalnego podziału na biopoziomy z Laurencji również w odniesieniu do środkowego ordowiku Australii. Badania Chitinozoa z ordowiku Australii są wciąż nieliczne i ograniczone do basenów Canning i Georgina. Obok przedstawienia dokumentacji taksonomicznej odniesiono również obecne badania i nowoopisane zespoly do najobszerniejszego opracowania ordowickich Chitinozoa z basenu Canning z czterech wierceń obejmujących formacje Nambeet, Willara i Goldwyer (Combaz & Peniguel 1972). Opisane w niniejszej pracy zespoły można skorelować z tymi z poziomu 05 w basenie Canning (Combaz & Peninguel 1972). Najwieksze podobieństwo wykazują opisane zespoły z górnej części formacji Goldwyer i formacji Nita do zespołów Chitinozoa z darriwilianu Kanady i mogą być korelowane z poziomem „niezdefiniowanym" bezpośrednio nadległym nad poziomem *Cyathochitina jenkinsi* w podziale stosowanym dla Laurencji, zaś w podziale przyjętym dla Gondwany, można je korelować z poziomem *Laufeldochitina clavata* lub *Linochitina pissotensis*. Spośród dwunastu gatunków opisanych z basenu Canning, dwa (*Calpichitina windjana* sp. n. =?*Desmochitina complanata* i *Cyathochitina hunderumensis*), a być może i trzeci (*Belonechitina chydaea*) znane są także z równowiekowych skał Baltiki i Avalonii, zaś jeden gatunek (*Conochitina kryos*) prawdopodobnie występuje również w Chinach. Nie stwierdzono wyraźnych powiązań z równowiekowymi zespołami północnej Gondwany. Wyniki paleobiogeograficznych badań autorów są zgodne z wynikami badań Achab *et al.* (1992) i wskazując, że zespoły środkowo-ordowickich Chitinozoa z Australii są najbliższe laurentyjskim, dobrze potwierdzają zależność rozmieszczenia gatunków Chitinozoa od szerokości geograficznej. Również związki pomiędzy równowiekowymi zespołami Baltiki, Avalonii i północnej Gondwany są zgodne z paleogeograficznymi rekonstrukcjami rozmieszczenia kontynentów w środkowym ordowiku (darriwilian), które umiejscawiają Laurencję i Australię w niskich szerokościach, Baltikę i Avalonię w średnich, a północną Gondwanę w pobliżu bieguna południowego. Opisano dwa nowe gatunki *Calpichitina windjana* i *Belonechitina vibrissa*.