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Integrated correlation of Late Silurian (Přídolí *s.l.*) – Devonian chitinozoans and miospores in the Solimões Basin, northern Brazil

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ABSTRACT:

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Chitinozoans from the Late Silurian (Přídolí *s.l.*) and Devonian, and miospores from the Middle and Late Devonian, have been investigated from the Solimões Basin in northern Brazil. Of the 37 chitinozoan species encountered, 16 are retained in open nomenclature, because of an insufficient number of well-preserved specimens, and *Ramochitina jutaiense* is newly described. Three or four miospore zones have been recognized: the LE - LN and VH zones of late to latest Famennian age, and a poorly characterized interval not older than the AP zone of latest Emsian – early Eifelian age. A regional chitinozoan biozonation, consisting of six zones, is proposed for the investigated interval. These zones are, from the oldest to the youngest: concurrent range zone of *Ancyrochitina ancyrea* and *Ancyrochitina* aff. *A. libyensis* (Přídolí *s.l.*); interval range zone of *Angochitina filosa* (early Lochkovian); concurrent range zone of *Urochitina loboi* and *Ramochitina jutaiense* sp. nov. (late Lochkovian); concurrent range zone of *Ancyrochitina arirambaense* and *Alpenachitina eisenacki* (Eifelian *s.l.* – early Givetian); interval range zone of *Angochitina mourai* (Frasnian – middle Famennian); and total range zone of *Fungochitina ultima* (late Famennian).

Key words: Late Silurian, Devonian, Solimões Basin, Chitinozoa, Miospores, Brazil.

INTRODUCTION

A thick Mesozoic and Cenozoic cover and the absence of outcrops made it impossible for many years to observe Paleozoic strata in the Solimões Basin. MORALES (1959) considered the Solimões Basin to be a part of the Amazonas Basin. DAEMON & CONTREIRAS (1971) made the first attempts at a biozonation of the Solimões Basin sedimentary rocks and correlated them with those in the Amazonas Basin. Through the work of CAPUTO (1984) and SILVA (1987), it became clear that the geology of the Solimões Basin is partly different from that of the adjacent Amazonas Basin. The classic pre-Carboniferous lithostratigraphic units of the Amazonas Basin cannot be easily correlated with coeval rocks in the Solimões Basin, and the two basins seem to have evolved independently of each other (MELO 1988). CAPUTO (1984) defined the Jutaí Formation, on the Carauari High, for a supposed equivalent of the Silurian Pitinga Formation in the Amazonas Basin. SILVA (1987, 1988) and QUADROS (1988) abandoned the previous lithostratigraphic framework and terminology of the Solimões Basin. They lumped the Silurian rocks (first recognized by DAEMON & CONTREIRAS 1971) into the Devonian by considering them to be no older than Emsian. This was also the opinion of GRAHN (1988b). Later, GRAHN (1989, 1990a, b, 1992a) found palynological evidence of Lochkovian rocks above the Silurian, but not of Pragian or Emsian strata. A regional biozonation of pre-Carboniferous strata in the Solimões Basin, based on acritarchs and some chitinozoans, was drawn up by QUADROS (1988). GRAHN (1992a) found the chitinozoan biostratigraphy inconsistent with the current formations, and subdivided the Silurian and Devonian of the Solimões Basin into six unconformity-bounded sequences or depositional cycles above the early Ordovician Benjamin Constant Formation. This approach was adopted by EIRAS & *al.* (1994), who redefined CAPUTO's (1984) Jutaí Formation, as well as the formations introduced by SILVA (1987, 1988). The miospore investigations of LOBOZIAK & *al.* (1994a, b) are in permissive agreement with these conclusions.

GEOLOGIC SETTING AND BIOSTRATIGRAPHY

The intracratonic Solimões Basin covers an area of approximately 600,000 km^2 in northern Brazil (Text-fig. 1). It is delimited by the Iquitos Arch in the west and the Purus Arch in the east. The Carauari High subdivides the main basin into two depositional centres, the older and deeper Jandiatuba Sub-basin to the west, and the younger and shallower Juruá Sub-basin to the east (SILVA 1987, MELO 1988). In the Jandiatuba Sub-basin, the early Ordovican Benjamin Constant Formation (SILVA 1987, QUADROS 1988, GRAHN 1988a, 1992b) is unconformably overlain by the Jutaí Formation and the Marimari Group *sensu* EIRAS & *al.* (1994). The latter is divided into the Jandiatuba and Uerê formations. In the Juruá Sub-basin, the Benjamin Constant and Jutaí formations are missing, and the Uerê Formation laps directly onto the Precambrian basement in this region.

Jutaí Formation

The Jutaí Formation was originally proposed by CAPUTO (1984) for a supposed Silurian sequence on the Carauari High. Depth interval 1483-1573 m in well 2-JT-1-AM (Rio Jutaí) was choosen as a type section. RODRIGUES & *al.* (1971) considered this interval to be equivalent to the upper part of the Trombetas Group in the Amazonas Basin. The formation was redefined by EIRAS & *al.* (1994) to include Silurian – Lochkovian strata formerly attributed to the Jandiatuba and Biá formations *sensu* SILVA (1987). The latter is now considered as a member of the Jutaí Formation, and is of Lochkovian

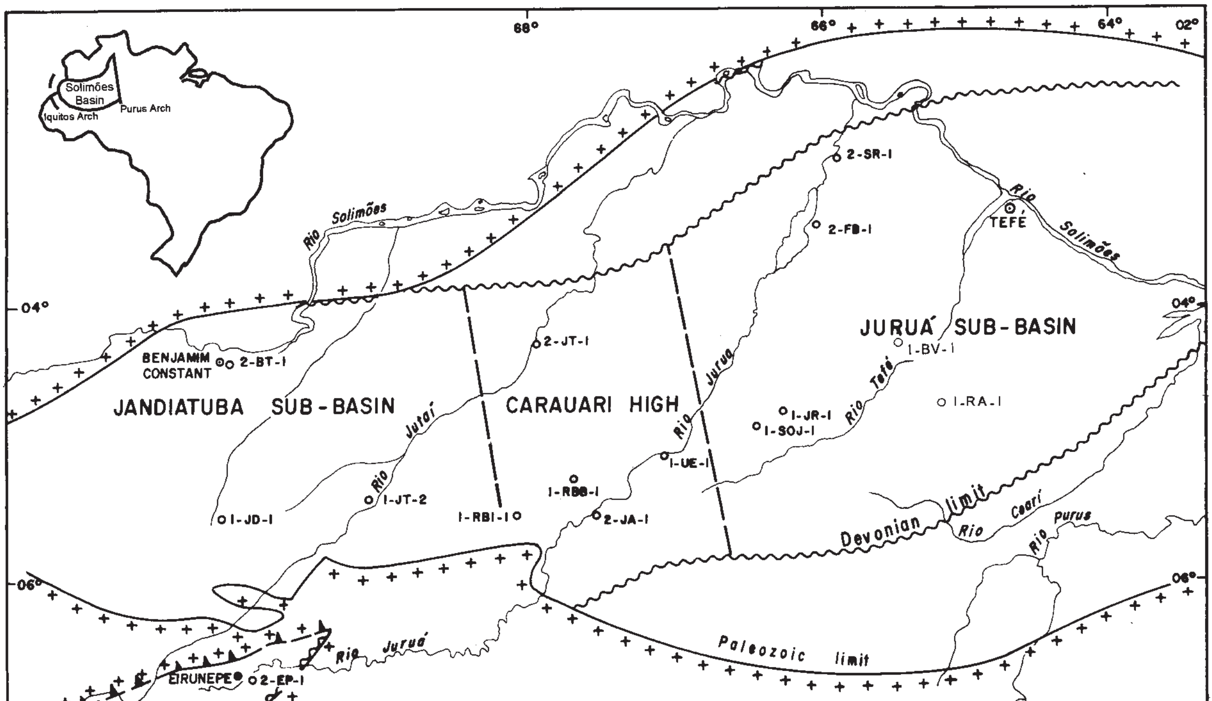

Fig. 1. Location map of the Solimões Basin wells discussed in this study

age. The type section of the redefined Jutaí Formation is depth interval 2415-2497 m in well 1-JT-2-AM (Rio Jutaí; Eiras & *al*. 1994, fig. 3.5), and that of the Biá Member is depth interval 1805-1870 in well 1-RBI-1-AM (Rio Biá; Eiras & *al*. 1994, fig. 3.6). The Jutaí Formation corresponds to cycles 1-3 of Grahn (1992a). Grahn (1992a) included middle Silurian strata in the Jutaí Formation (his cycle 1), but this has not been confirmed by the present study. The formation is known from the Jandiatuba Sub-basin and the Carauari High, although the oldest (Late Silurian) part of the formation is only present in the central part of the sub-basin. The lithologies consist of dark shales with interstratified siltstones and fine-grained sandstones, which eastwards laterally grade into the coarse sandstones with micaceous siltstones, black shales and intercalated dolomites of the Biá Member. The maximum thickness is estimated as ca. 150 m (Eiras & *al*. 1994). Janvier & Melo (1987) mentioned minute pyritized tentaculitids from the top of Jutaí Formation (late Lochkovian) in well 1-JD-1-AM (Jandiatuba). Rubinstein & *al*. (2000) reported acritarchs (*Schizocystia pilosa*, *Riculasphaera fissa*, *Winwaloeusia distracta*, and *Thysanoprobolus polykion*) and miospores (*Dictyotriletes granulatus*, *Iberoespora glabella*, *Chelinospora favosa*, *Chelinospora baculoreticulata* and *Dibolisporites eifeliensis*) from 18 levels within the top of the Jutaí Formation in well 1-JD-1-AM, suggesting a Lochkovian age.

Jandiatuba Formation

The Jandiatuba Formation is widely distributed over much of the Jandiatuba and Juruá sub-basins. The formation was originally proposed by Silva (1987, 1988) for a Silurian to Early Carboniferous sequence typified by the interval between 2186-2541 m of well 1-JD-1-AM. It was redefined by Eiras & *al*. (1994) to include only Middle Devonian to Early Carboniferous strata. The interval between 2103-2406 m in well 1-JT-2-AM was choosen as a type section (Eiras & *al*. 1994, fig. 3.10), and the interval 2186-2414 m in well 1-JD-1-AM as a reference section (Eiras & *al*. 1994, fig. 3.11). The main lithologies consist of organic-rich dark shales, siltstones and sandstones with spiculites. The sandstone content increases towards the top. The Jandiatuba Formation laps onto, and in part grades laterally into the Uerê Formation. The glaciogenic beds of the Jaraqui Formation *sensu* Caputo (1984) and Silva (1987, 1988) are now considered as a member of the Jandiatuba Formation (Eiras & *al*. 1994). They are of latest Famennian to Early Carboniferous age, whereas the Jandiatuba Formation as a whole ranges from Eifelian *s.l.* to Early Carboniferous. The type section for the Jaraqui Member is within the depth interval 2103-2406 m in well 1-JT-2-AM (Eiras & *al*. 1994, fig. 3.12), and the reference section is between 3130-3195 m in well 1-BV-1-AM (Eiras & *al*. 1994, fig. 3.13). The glaciogenic beds extend from the Jandiatuba Sub-basin into the Juruá Sub-basin where they are best developed. Cycles 4 - 6 of Grahn (1992a) are represented partly within the Jandiatuba Formation. The maximum thickness is estimated as ca. 310 m (Eiras & *al*. 1994). Janvier & Melo (1987) reported Late Devonian actinopterygian fish scales, and Hünicken & *al*. (1988) documented contemporaneous conodonts from the formation's radioactive black shales in well 1-JD-1-AM (core 3).

Uerê Formation

The Uerê Formation was proposed by Silva (1987, 1988) for a sequence of chert, spiculite and siliceous shale. Its original definition was slightly modified by Eiras & *al*. (1994), who restricted its fine-grained, kaolinitic sandstones to the Arauá Member of the Uerê Formation. The type section of the redefined Uerê Formation is at a depth of 2030-2100 m in well 1-UE-1-AM (Uerê; Eiras & *al*. 1994, fig. 3.7), and the reference section is between 2788-2900 m in well 1-JR-1-AM (Juruá; Eiras & *al*. 1994, fig. 3.8). The type section of the Arauá Member, of which the former Urucu Formation (Silva 1987, 1988) is a part, occurs between 2865-2975 m and 3015-3060 m in well 1-RA-1-AM (Eiras & *al*. 1994, fig. 3.9). Cycles 4-6 of Grahn (1992a) are represented partly within the Uerê Formation. The maximum thickness of the formation is estimated as ca. 160 m (Eiras & *al*. 1994), and it comprises Eifelian *s.l.* to Famennian strata.

MATERIAL AND METHODS

During 1988-1990 a total of 138 Silurian and Devonian samples from 15 PETROBRAS deep-drillings in the Solimões Basin were examined for chitinozoans, and in addition 367 palynological slides from the Solimões Basin were studied in 2001. Most of the earlier studied samples were cuttings, which frequently are contaminated with microfossils from younger beds. In general the preservation is poor as most palynomorphs are badly corroded and carbonized. In this study 11 representative wells are discussed (Text-fig. 1). Well 1-JD-1-AM has been chosen as a reference section for the chitinozoan biostratigraphy in the Solimões Basin (Text-fig. 2). Results from other wells investigated are shown in the Appendix. The miospores were inves-

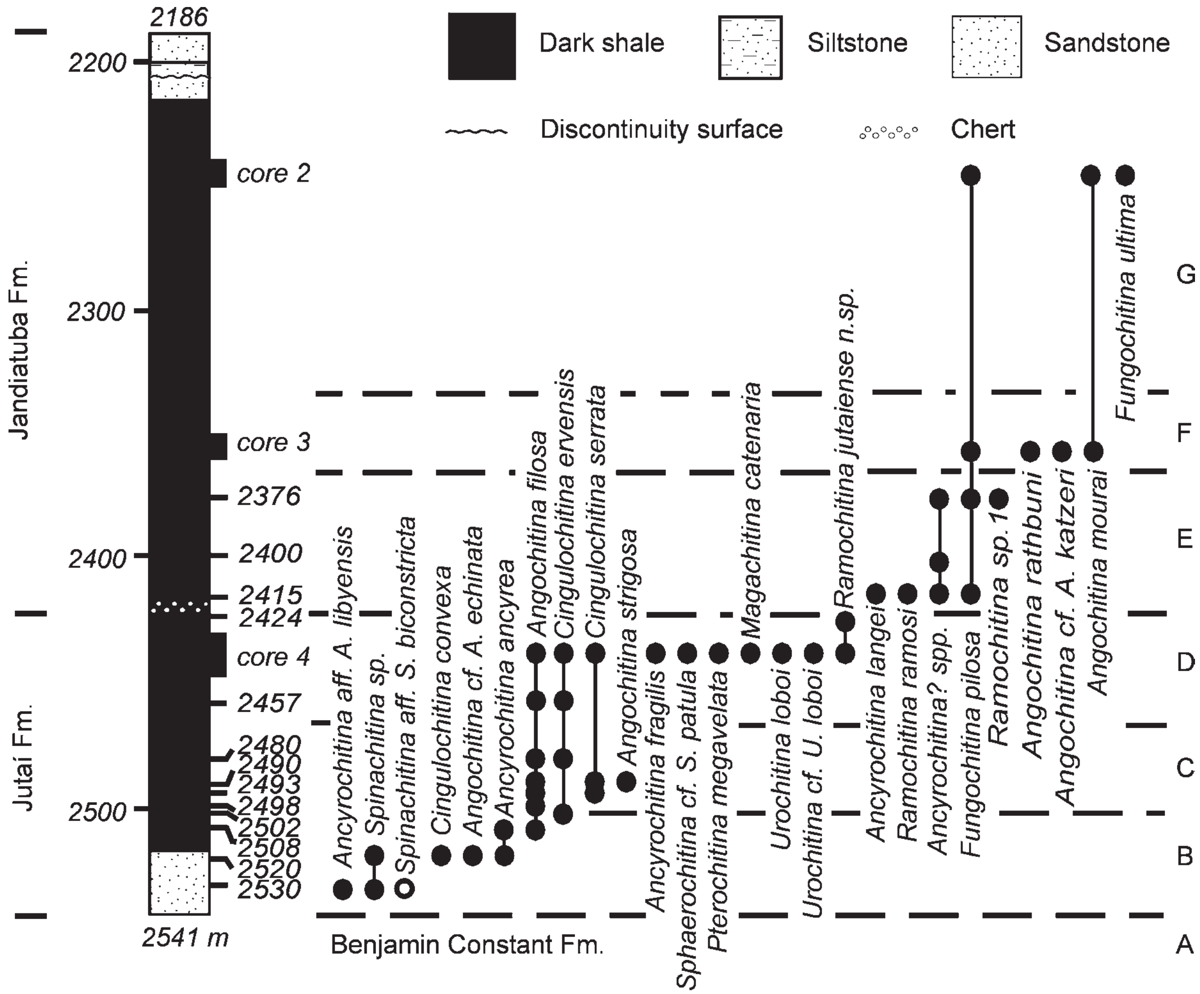

Fig. 2. Lithologic column and chitinozoan range chart for the reference well 1-JD-1-AM (5° 35' 55" S, 70° 1' 20" W). Open circle indicates the displaced occurrence of *Spinachitina* aff. *S. biconstricta* in contaminated cuttings within the Jutaí Formation derived from Middle Devonian source strata in the overlying Jandiatuba Formation. A = Late Arenig – early Llanvirn. B = Přídolí *s.l.* C = Early Lochkovian. D = Late Lochkovian. E = Eifelian *s.l.* – early Givetian. F = Frasnian – middle Famennian. G = Late Famennian

tigated from 1094 palynological slides representing 23 PETROBRAS wells during years 1993-1994. Five of these wells yielded diagnostic results from the Devonian sections (see below), including well 1-JD-1-AM, which was also discussed by RUBINSTEIN & *al.* (2000). The residues were studied for chitinozoans under a binocular microscope, and representative chitinozoan specimens were picked for analysis with a Scanning Electron Microscope performed in co-operation with Gerência de Bioestratigrafia e Paleoecologia Aplicada (BPA) at Centro de Pesquisas e Desenvolvimento LEOPOLDO A. MIQUEZ DE MELLO (CENPES), PETROBRAS, in Rio de Janeiro. Sample processing and SEM-preparations were carried out at BPA and the Geological Laboratory (LGPA) of the Geological Faculty at Universidade do Estado do Rio de Janeiro according to the techniques described by LAUFELD (1974). Photographed chitinozoans are stored at the Department of Stratigraphy and Paleontology at Universidade do Estado do Rio de Janeiro, and the miospores at BPA (CENPES), PETROBRAS, in Rio de Janeiro.

SYSTEMATIC PALEONTOLOGY

Thirty-seven chitinozoan species were identified in the present study. Their stratigraphic ranges are given in Text-fig. 3. Those left in open nomenclature and the new species will be commented upon below. Most of the specimens recovered are compressed, and a correction factor of 0.8 (PARIS 1981b, JAGLIN 1986) was used to calculate the uncompressed dimensions (values given within brackets) of the specimens. The taxonomy follows that proposed by PARIS & *al.* (1999).

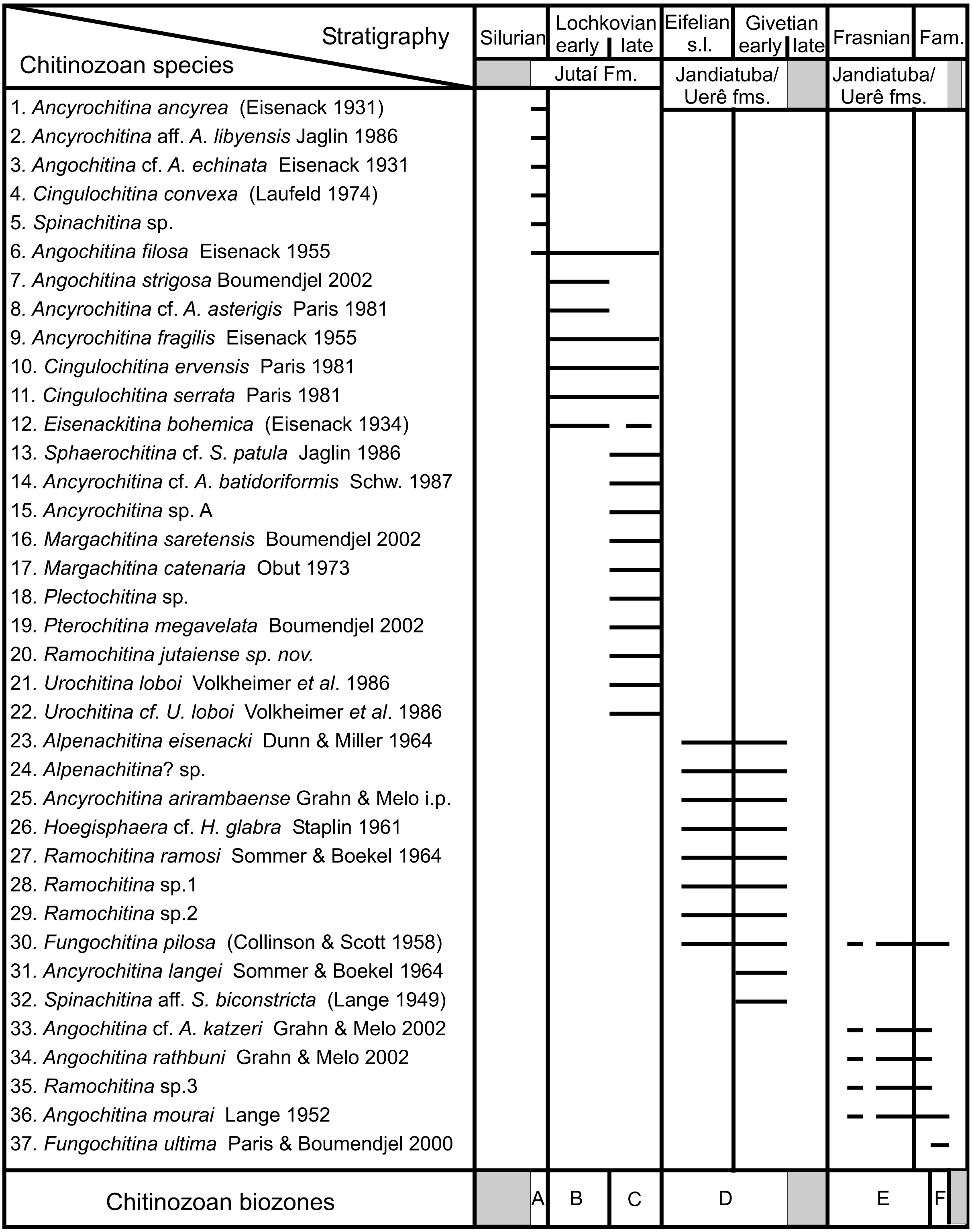

Fig. 3. Chitinozoan ranges and biozones in the Silurian and Devonian of the Solimões Basin. A = Concurrent range zone of *Ancyrochitina ancyrea* and *Ancyrochitina* aff. *A. libyensis*. B = Interval range zone of *Angochitina filosa*. C = Concurrent range zone of *Urochitina loboi* and *Ramochitina jutaiense*. D = Concurrent range zone of *Ancyrochitina arirambaense* and *Alpenachitina eisenacki*. E = Interval range zone of *Angochitina mourai*. F = Total range zone of *Fungochitina ultima*

Group Chitinozoa EISENACK 1931
Order Operculatifera EISENACK 1931
Family Desmochitinidae EISENACK 1931 emend. PARIS 1981b
Subfamily Desmochitininae PARIS 1981b

Genus *Hoegisphaera* STAPLIN 1961 emend. PARIS, GRAHN, NESTOR & LAKOVA 1999

Hoegisphaera cf. *glabra* STAPLIN 1961
(Pl. 1, Fig. 1)

1972. *Hoegisphaera glabra* STAPLIN; URBAN, p. 23-24, pl. 4, figs. 4-12.
1976. *Hoegisphaera* sp. aff. *glabra* STAPLIN; PARIS, p. 105, pl. 22, figs. 7, 10-13.
1980. *Hoegisphaera* cf. *glabra* STAPLIN; WRONA, p. 143-144, pl. 32, figs. 2-11.
1981a. *Hoegisphaera* sp. aff. *glabra* STAPLIN; PARIS, p. 68, pl. 3, fig. 15.
1985. *Hoegisphaera glabra* STAPLIN; PARIS & *al*., pl. 28, fig. 11.
1987. *Hoegisphaera* sp. aff. *glabra* STAPLIN; BOUMENDJEL, p. 67-68, pl. 18, figs. 8, 11.
2002. Hoegisphaera sp.; GRAHN, pl. 4, fig. A.

DESCRIPTION: *Hoegisphaera* cf. *glabra* is characterized by a smooth vesicle wall, the absence of a well-defined collar, and in having a wide aperture. *Hoegisphaera glabra s.s*. has a distinct collar and a smaller aperture.

DIMENSION (1 specimen measured): Total width 80 μm; width of aperture 20 μm.

OCCURRENCE IN BRAZIL: Solimões Basin; lower Uerê Fm. (Eifelian *s.l.* – early Givetian), well 2-JT-1-AM. Parnaíba Basin (GRAHN & MELO in press), Itaim – lower Pimenteira fms. (Eifelian *s.l.* – early Givetian). Paraná Basin (GRAHN in GRAHN & *al*. 2002), lower São Domingos Fm. (early Givetian).

OCCURRENCE OUTSIDE BRAZIL: Bolivia (GRAHN 2002), upper Tarabuco Fm. (late Lochkovian). United States, Iowa (URBAN 1972), Cedar Valley Fm. (Givetian). France (PARIS 1976, 1981a), Lochkovian to Pragian strata of the Saint-Cénére Formation at Mayenne, and from the late Emsian Foulerie and Marettes fms. at Lézais, Massif Armoricain. Poland (WRONA 1980), Early Devonian beds in the Radom – Lublin area. Libya (PARIS & *al*. 1985), late Eifelian strata. Algeria (BOUMENDJEL 1987), Emsian – Eifelian strata in the Alrar and Teferguenit formationss of the Illizi Basin.

Order Prosomatifera EISENACK 1972
Family Conochitinidae EISENACK 1931 emend. PARIS 1981b
Subfamily Spinachitininae PARIS 1981b

Genus *Spinachitina* SCHALLREUTER 1963

Spinachitina aff. *biconstricta* (LANGE 1949)
(Pl. 1, Fig. 7)

non 1949. *Conochitina biconstricta*; LANGE, p. 289, pl. 6-8.
non 1967. *Cladochitina biconstricta* (LANGE); LANGE, p. 77-78, pl. 2, figs 21-23.
1982. *Cladochitina biconstricta* (LANGE); QUADROS, p. 42, pl. 2, fig. 8.
2002. *Spinachitina biconstricta* (LANGE); GRAHN, fig. 7F.
2002. *Spinachitina biconstricta* (LANGE); GRAHN *in* GRAHN & *al*., pl. 7, figs B-C.

DESCRIPTION: Specimens attributed to *Spinachitina* aff. *S. biconstricta* have no ornamentation on neck and body, and it is only in this aspect do they differ from the typical specimens of *Cladochitina* (*Conochitina*) *biconstricta* described by LANGE (1949, 1967).

DIMENSION (1 specimen measured): Total length 313 μm, maximum width 65 (52) μm, width of aperture 44 (35) μm, length of appendices $\leq$ 33 μm.

OCCURRENCE IN BRAZIL: Solimões Basin, Jandiatuba Fm. (early Givetian), well 1-JD-1-AM (cavings in cuttings at 2530 m). Parnaíba Basin (QUADROS 1982, GRAHN & MELO in press), lower Pimenteira Fm. (late Eifelian – middle Givetian). Paraná Basin (GRAHN in GRAHN & *al*. 2002), lower São Domingos Fm. (early Givetian).

OCCURRENCE OUTSIDE BRAZIL: Bolivia (GRAHN 2002), upper Los Monos Formation (early - middle Givetian).

Spinachitina sp.
(Pl. 2, Fig. 7)

DESCRIPTION: A *Spinachitina* species with an elongate conical body that slightly widens near the aperture. Flexure inconspicuous. Vesicle smooth except for the basal margin, which is provided with small simple appendices, and the aperture which bears small simple spines.

DIMENSIONS (2 specimens measured): Total length

308-353 μm, maximum width 67 (54)-74 (59) μm, width of aperture 37 (30)-59 (47) μm.

OCCURRENCE IN BRAZIL: Solimões Basin, lower Jutaí Fm. (Přídolí *s.l.*), well 1-JD-1-AM (cuttings 2520 and 2530 m).

Family Lagenochitinidae EISENACK 1931 emend. PARIS 1981b
Subfamily Lagenochitininae PARIS 1981b

Genus *Sphaerochitina* EISENACK 1955

Sphaerochitina cf. *patula* JAGLIN 1986
(Pl. 3, Fig. 1)

DESCRIPTION: This *Sphaerochitina* species has an ovoid body, distinct flexure, and a neck that slightly widens aperturewards. The vesicle is perfectly smooth.

DIMENSIONS: (2 specimens measured): Total length 212-218 μm, maximum width 97 (78)-119 (95) μm, width of aperture 71 (57)-86 (69) μm.

OCCURRENCE IN BRAZIL: Solimões Basin, upper Jutaí Fm. (late Lochkovian), well 1-JD-1-AM (core 4) and well 2-EP-1-AM (cuttings 1113 m and core 11 between 1112.8-1115.8 m).

Subfamily Urochitininae PARIS 1981b

Genus *Urochitina* TAUGOURDEAU & JEKHOWSKY 1960

Urochitina cf. *loboi* VOLKHEIMER & *al*. 1986
(Pl. 2, Fig. 10, Pl. 3, Fig. 3)

DESCRIPTION: *Urochitina loboi* has a comparatively short peduncle with a distinct constriction in its middle part. *Urochitina* cf. *U. loboi* differs from *U. loboi* in having a long slender peduncle.

DIMENSIONS (3 specimens measured): Total length excluding peduncle 183-238 μm, maximum width 54 (43)-68 (54) μm, width of aperture 23 (18)-31 (25) μm, length of peduncle 32-54 μm.

OCCURRENCE IN BRAZIL: Solimões Basin, upper Jutaí Fm. (late Lochkovian), well 1-JD-1-AM (core 4 between 2428 and 2446 m) and well 2-BT-1-AM (cuttings 1017 m).

Subfamily Angochitininae PARIS 1981b

Angochitina cf. *echinata* EISENACK 1931
(Pl. 3, Fig. 8)

1987. *Angochitina* cf. *echinata* EISENACK 1931; BOUMENDJEL, p. 103-104, pl. 2, fig. 6, pl. 3, figs 4, 6, 8.

DESCRIPTION: See BOUMENDJEL (1987). An important feature of this species is a less dense ornamentation, and a smaller size than *A. echinata* EISENACK, 1931.

DIMENSION (1 specimen measured): Total length 195 μm, maximum width 86 (69) μm, width of aperture 39 (31) μm, length of neck 1/2 of the total length.

OCCURRENCE IN BRAZIL: Solimões Basin, lower Jutaí Fm. (Přídolí *s.l.*), well 1-JD-1-AM (cuttings 2520 m).

OCCURRENCE OUTSIDE BRAZIL: Algeria (BOUMENDJEL 1987), lower Mehaiguène Formation (Ludlow – Přídolí).

Angochitina cf. *katzeri* GRAHN & MELO 2002
(Pl. 1, Figs 8-9)

DESCRIPTION: For a description of *A. katzeri* see GRAHN & MELO (2002). *A.* cf. *katzeri* differs from *A. katzeri* in being much larger.

DIMENSIONS (3 specimens measured): Total length 210-235 μm, maximum width 88 (70)-91 (73) μm, width of aperture 40 (32)-57 (46) μm, length of spines 5 μm, length of neck 33-40% of the total length.

OCCURRENCE IN BRAZIL: Solimões Basin, lower Jandiatuba and Uerê formations (Frasnian – early Famennian), well 1-JD-1-AM (core 3 between 2353.0 and 2355.5 m) and well 2-JA-1-AM (core 22 between 1725 and 1727 m).

Genus *Ramochitina* SOMMER & VAN BOEKEL 1964 emend. PARIS & *al*. 1999

Ramochitina jutaiense sp. nov.
(Pl. 1, Fig. 11; Pl. 3, Fig. 9; Pl. 5, Fig. 9)

1996. *Ramochitina* aff. *ramosi* SOMMER & VAN BOEKEL 1964; LE HÉRRISÉ & *al*., pl. 3, fig. 8.

DERIVATION OF NAME. Latin, *jutaiense*, referring to the Jutaí Formation, from where the species is described.

DIAGNOSIS. A *Ramochitina* species with an elongate, ovoid body and a short cylindrical neck. The vesicle is provided with 12 crests of multirooted and simple spines.

HOLOTYPE: Plate 3, Fig. 9. CENPES stub collection G3/11821

TYPE LOCALITY: Well 1-UE-1-AM, Jutaí Fm. (Biá Mbr.), cuttings 2112 m.

DESCRIPTION: This *Ramochitina* species is characterized by its elongated and ovoid vesicle, short cylindrical neck, and 12 crests of multirooted, occasionally simple spines.

DIMENSIONS (7 specimens measured): Total length 150-277 μm. Holotype 230 μm, maximum width 65 (52)-107 (86) μm. Holotype 65 (52) μm, width of aperture 28 (22)-69 (55) μm. Holotype 28 (22) μm, length of spines $\leq$ 32 μm. Holotype 12 μm, length of neck 1/5-1/3 of the total length. Holotype 1/5 of the total length.

OCCURRENCE IN BRAZIL: Solimões Basin, upper Jutaí Fm. and Biá Mbr. (late Lochkovian), well 1-JD-1-AM (cuttings 2424 m, core 4 between 2428 and 2446 m), well 2-JA-1-AM (cuttings 1745 and 1751 m), well 1-JT-2-AM (cuttings 2445 m), well 2-JT-1-AM (reworked in core 14 between 1549 and 1551 m), 1-RBI-1-AM (cuttings 1824 m), and well 1-UE-1-AM (cuttings 2112 m).

OCCURRENCE OUTSIDE BRAZIL: Argentina (Le Hérrisé & *al.*, 1996), lower Talacasto Formation (Lochkovian).

Ramochitina sp. 1
(Pl. 3, Fig. 7)

DESCRIPTION: This small *Ramochitina* species which has a conical body and a short cylindrical neck. The vesicle is provided with 12 crests of simple spines. These have broad bases which gives them a triangular profile. The flexure is inconspicuous.

DIMENSION (1 specimen measured): Total length 150 μm, maximum width 90 (72) μm, width of aperture 45 (36) μm, length of spines 9 μm, length of neck 1/5 of the total length.

OCCURRENCE IN BRAZIL: Solimões Basin, lower Jandiatuba Fm. (Eifelian *s.l.* – early Givetian), well 1-JD-1-AM (cuttings 2376 m).

Ramochitina sp. 2
(Pl. 3, Fig. 10)

DESCRIPTION: *Ramochitina* sp. 2 has a slender appearance with a conical body and a long cylindrical neck. The vesicle has 16 crests of densely distributed simple spines. The flexure is distinct.

DIMENSION (1 specimen measured): Total length 200 μm, maximum width 60 (48) μm, width of aperture 40 (32), length of spines 4 μm, length of neck 2/5 of the total length.

OCCURRENCE IN BRAZIL: Solimões Basin, lower Uerê Fm. (Eifelian *s.l.* – early Givetian), well 2-FB-1-AM (core 41 between 2206 and 2207 m).

Ramochitina sp. 3
(Pl. 4, Fig. 2)

DESCRIPTION: A *Ramochitina* species with a conical body and a cylindrical neck widening at the aperture. The vesicle wall is covered by thick simple spines. The amount of crests cannot be determined in the present material.

DIMENSION (1 specimen measured): Total length 170 μm, maximum width 101 μm, width of aperture 42 μm, length of spines 13 μm, length of neck 1/2 of the total length.

OCCURRENCE IN BRAZIL: Solimões Basin, Uerê Fm. (Frasnian – early Famennian), well 2-JA-1-AM (core 22 between 1725 and 1727 m).

Subfamily Ancyrochitininae Paris 1981b

Genus *Ancyrochitina* Eisenack 1955

Ancyrochitina cf. *asterigis* Paris 1981b
(Pl. 4, Fig. 4)

DESCRIPTION: For a description of *A. asterigis* see Paris (1981b). *Ancyrochitina* cf. *asterigis* differs in having less numerous and thicker spines on the neck.

DIMENSION (1 specimen measured): Total length 134 μm, maximum width 67 μm, width of aperture 32 μm, length of appendices $\leq$ 23 μm, length of spines $\leq$ 12 μm, length of neck 2/5 of the total length.

OCCURRENCE IN BRAZIL: Solimões Basin, Jutaí Fm. (early Lochkovian), well 1-JT-2-AM (cuttings 2496 m).

Ancyrochitina cf. *batidoriformis* SCHWEINEBERG 1987
(Pl. 5, Fig. 2)

DESCRIPTION: *A*. cf. *batidoriformis* differs from *A*. *batidoriformis* SCHWEINEBERG 1987 in having much smaller appendices and spines on the neck.

DIMENSION (1 specimen measured): Total length 192 μm, maximum width 112 (90) μm, width of aperture 48 (38) μm, length of appendices and spines 32 μm, length of neck 45% of the total length.

OCCURRENCE IN BRAZIL: Solimões Basin, Jutaí Fm., Biá Mbr. (late Lochkovian), well 1-UE-1-AM (cuttings 2112 m).

Ancyrochitina aff. *libyensis* JAGLIN 1986
(Pl. 4, Fig. 6)

2002. *Ancyrochitina* aff. *A. libyensis* JAGLIN; GRAHN, p. 318, fig. 4 F.

DESCRIPTION: For a description of *A*. *libyensis* see JAGLIN (1986). *A*. aff. *libyensis* differs from typical *A*. *libyensis* in having less complex appendices and no spines on the neck.

DIMENSION (1 specimen measured): Total length 159 μm, maximum width 121 (97) μm, width of aperture 64 (51) μm, length of spines $\leq$ 12 μm, length of neck 1/3 of total length.

OCCURRENCE IN BRAZIL: Solimões Basin, lower Jutaí Formation (Přídolí *s.l.*), well 1-JD-1-AM (cuttings 2530 m).

OCCURRENCE OUTSIDE BRAZIL: Bolivia (GRAHN 2002), lower Tarabuco Formation (Přídolí).

Ancyrochitina sp. A
(Pl. 4, Fig. 7)

DESCRIPTION: This *Ancyrochitina* species has a conical body, a distinct flexure and a short cylindrical neck, which is provided with short simple spines. The aperture is straight. The basal margin has short and simple appendices.

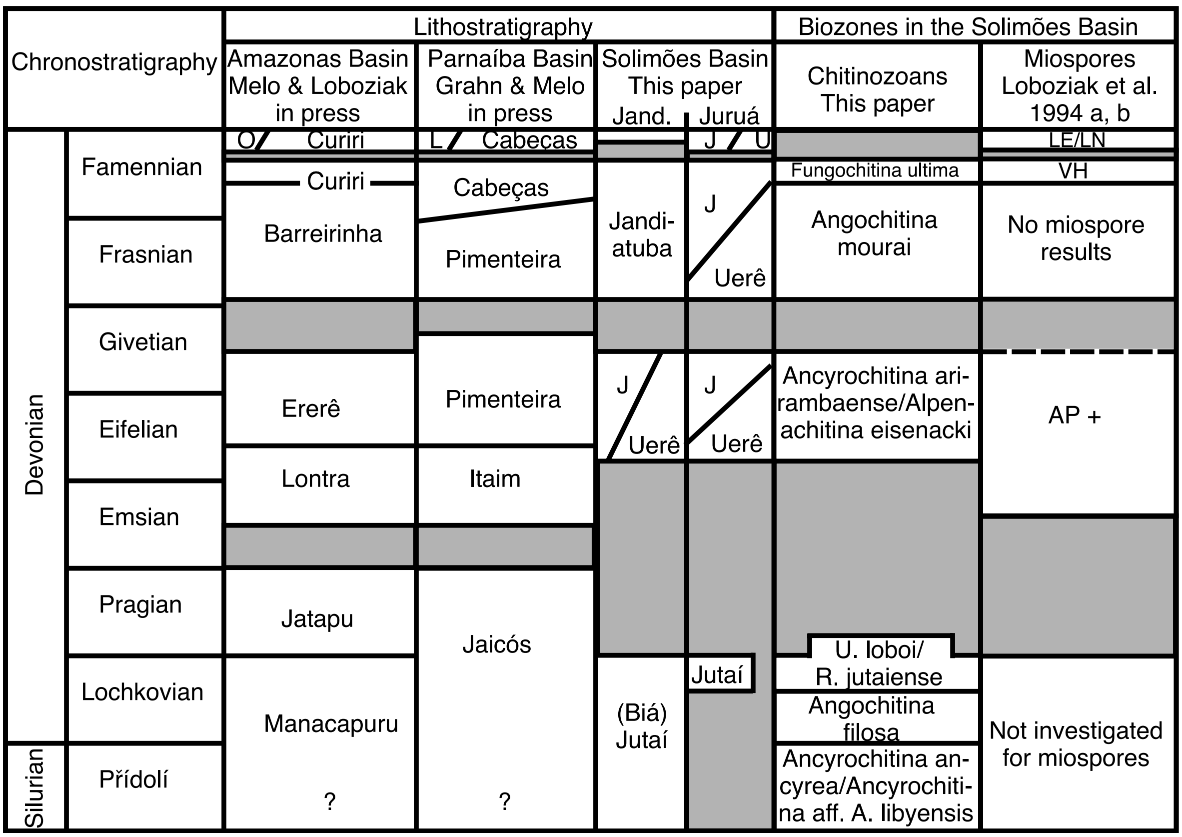

Fig. 4. Silurian and Devonian correlation chart of the Solimões, Amazonas and Parnaíba basins. O = Oriximiná Fm. L = Longá Fm. Jand. = Jandiatuba Sub-basin. J = Jandiatuba Fm. Juruá = Juruá Sub-basin and Carauari High. U = Uerê Fm. The symbol "+ " following "AP " means "or younger biozone"

DIMENSION (2 specimens measured): Total length 110-130 μm, maximum width 80 (64)-89 (71) μm, width of aperture 30 (24)-32 (26) μm, length of appendices 6-10 μm, length of spines 4-5 μm, length of neck 2/5-1/2 the total length.

OCCURRENCE IN BRAZIL: Solimões Basin, Jutaí Formation (late Lochkovian), well 2-JA-1-AM (cuttings 1735 and 1745 m).

Genus *Plectochitina* CRAMER 1964

Plectochitina sp.
(Pl. 5, Figs 5-6)

DESCRIPTION: *Plectochitina* sp. has a subconical, almost ovoid body, a distinct flexure and a cylindrical neck. The body is covered with small simple spines and the basal margin displays six, thick, complex appendices, consisting of two broad-based spines united in a single simple spine at their tips.

DIMENSIONS (3 measured specimens): Total length 155-185 μm, maximum width 85-104 μm, width of aperture 35-49 μm, length of appendices 20-37 μm, length of neck 2/5-1/2 of the total length.

OCCURRENCE IN BRAZIL: Solimões Basin, upper Jutaí Formation (late Lochkovian), well 2-BT-1-AM (cuttings 1023 m), well 2-JA-1-AM (cuttings 1735 m), and well 1-UE-1-AM (cuttings 2112 m).

Genus *Alpenachitina* DUNN & MILLER 1964

Alpenachitina? sp.
(Pl. 4, Fig. 10)

DESCRIPTION: A species with an elongated, ovoid body and a cylindrical neck. Spines occur in a crown on the shoulder. This is a feature of *Alpenachitina*, but the lack of further ornamentation, and the bad preservation of the vesicle prevents a more distinct designation.

DIMENSION (1 specimen measured): Total length 260 μm, maximum width 109 μm, width of aperture 50 μm, length of spines 10 μm, length of neck 1/3 of the total length.

OCCURRENCE IN BRAZIL: Solimões Basin, lower Jandiatuba Formation (Eifelian s.l. – early Givetian), well 2-EP-1-AM (cuttings 1104 m).

CHITINOZOAN BIOSTRATIGRAPHY

The Silurian and Devonian chitinozoans from the Solimões Basin can be used to recognize six biozones (Text-fig. 4). The chitinozoan biozones are described below.

Ancyrochitina ancyrea and *Ancyrochitina* aff. *libyensis* Concurrent range Zone

DEFINITION: This biozone is defined by the co-occurrence of the two index species. It extends vertically from the first occurrence of *A*. aff. *libyensis* in the lower part of the Jutaí Formation to the first occurrence of *Cingulochitina ervensis*. *A*. *ancyrea* is common in the upper part of the biozone.

TYPE INTERVAL AND LOCALITY: The type interval for the zone is defined in the lower Jutaí Formation (Přídolí *s.l*). The type locality is in well 1-JD-1-AM between 2502 and 2541 m (Text-fig. 2).

CHARACTERISTIC CHITINOZOANS: The appearance of *Ancyrochitina* aff. *libyensis* JAGLIN 1986 (Pl. 4, Fig. 6) at the base of the zone indicates the Přídolí Series. This dating is further strengthened by the presence of *Angochitina* cf. *echinata* EISENACK 1931 (Pl. 3, Fig. 8), and the first occurrence of *Angochitina filosa* EISENACK 1955 at the top of this interval, together with *Ancyrochitina ancyrea* (EISENACK 1931; Pl. 5, Fig. 1), which is a latest Ordovician - Silurian species on a global basis. The presence of *Cingulochitina convexa* (LAUFELD 1974) (Pl. 2, Fig. 8) is in agreement with a Přídolí age. *Spinachitina* sp. (Pl. 2, Fig. 7) is another species present.

KNOWN OCCURRENCES OUTSIDE THE SOLIMÕES BASIN: *Ancyrochitina ancyrea* is a latest Ordovician – Silurian species with a global distribution. *Ancyrochitina libyensis* is known from the Přídolí of Libya (JAGLIN 1986) and Bolivia (GRAHN 2002).

REMARKS: This biozone is also questionably recognized in wells 2-BT-1-AM (1023-1075 m) and 2-EP-1-AM (1152-1177 m). It is not possible to compare this biozone with the global Silurian chitinozoan zonation by VERNIERS & *al*. (1995).

Angochitina filosa Interval range Zone

DEFINITION: This biozone is defined by the partial range of *Angochitina filosa*, and extends vertically from the first occurrence of *Cingulochitina ervensis* and

Cingulochitina serrata, in the lower part of the Jutaí Formation, to the first occurrence of *Urochitina loboi* and *Ramochitina jutaiense*.

TYPE INTERVAL AND LOCALITY: The type interval for the zone is defined in the lower Jutaí Formation (early Lochkovian). Type locality is well 1-JD-1-AM between ca. 2470 and 2502 m (Text-fig. 2).

CHARACTERISTIC CHITINOZOANS: The interval between the Přídolí strata and characteristic upper Lochkovian strata is dominated by long-ranging species known globally from Přídolí – Lochkovian strata, i.e. *Angochitina filosa* EISENACK 1955, *Ancyrochitina fragilis* EISENACK 1955, *Cingulochitina ervensis* PARIS 1981b (Pl. 2, Figs 1-2), and *Cingulochitina serrata* (TAUGOURDEAU & JEKHOWSKY 1960) (Pl. 2, Figs 3-4). However, rare occurrences of *Angochitina strigosa* BOUMENDJEL 2002 (Pl. 1, Fig. 4), *Eisenackitina bohemica* (EISENACK 1934) (Pl. 1, Fig. 2), and *Ancyrochitina* cf. *asterigis* PARIS 1981b (Pl. 4, Fig. 4) indicate an early Lochkovian age for this interval.

KNOWN OCCURRENCES OUTSIDE THE SOLIMÕES BASIN: *Angochitina filosa* is a common Přídolí – Lochkovian species on a global basis (EISENACK 1955, BOUMENDJEL 1987).

REMARKS: This biozone is also present in well 2-EP-1-AM (cuttings 1160 m), 2-JA-1-AM (cuttings 1780 m), 1-JT-2-AM (cuttings 2496 m), and 1-RBI-1-AM (cuttings 1857 m). This zone corresponds to the early Lochkovian *Eisenackitina bohemica* Interval Range Zone of PARIS & *al*. (2000).

Urochitina loboi **and** ***Ramochitina jutaiense*** **Concurrent range Zone**

DEFINITION: This biozone is defined by the co-occurrence of the two index species. It extends vertically from the first occurrence of the index species in the upper part of the Jutaí Formation to the first occurrence of *Ancyrochitina arirambaense* and *Alpenachitina eisenacki* in the Jandiatuba and or Uerê formations.

TYPE INTERVAL AND LOCALITY: The type interval for the zone is defined in the upper Jutaí Formation (late Lochkovian). Type locality is well 1-JD-1-AM between 2423 m and ca. 2470 (Text-fig. 2).

CHARACTERISTIC CHITINOZOANS: The uppermost part of the Jutaí Formation contains a characteristic chitinozoan assemblage of Lochkovian age. The presence of *Margachitina saretensis* BOUMENDJEL 2002 (Pl. 2, Figs 5, 11), *Ramochitina jutaiense* sp. nov. (Pl. 1, Fig. 11; Pl. 3, Fig. 9; Pl. 5, Fig. 9) and *Urochitina loboi* VOLKHEIMER & *al*. 1986 (Pl. 2, Fig. 9; Pl. 3, Fig. 2) suggests a late Lochkovian age, which is supported by spore data (MELO & LOBOZIAK 2003). Other important species are *Angochitina filosa* (Pl. 3, Figs 4-5), *Ancyrochitna fragilis* EISENACK 1955 (Pl. 5, Figs 3-4), *Cingulochitina ervensis* PARIS 1981b, *Cingulochitina serrata* (TAUGOURDEAU & JEKHOWSKY 1960) (Pl. 2, Figs 3-4), *Margachitina catenaria* OBUT 1973 (Pl. 2, Fig. 6), and *Pterochitina megavelata* BOUMENDJEL 2002 (Pl. 4, Fig. 1). Species present that might have biostratigraphic potential are *Sphaerochitina* cf. *S. patula* JAGLIN 1986 (Pl. 3, Fig. 1), *Ancyrochitina* cf. *A. batidoriformis* SCHWEINEBERG 1987 (Pl. 5, Fig. 2), *Ancyrochitina* sp. A (Pl. 4, Fig. 7), *Plectochitina* sp. (Pl. 5, Figs 5-6), and *Urochitina* cf. *loboi* VOLKHEIMER & *al*. 1986 (Pl. 2, Fig. 10; Pl. 3, Fig. 3).

KNOWN OCCURRENCES OUTSIDE THE SOLIMÕES BASIN: *Urochitina loboi* is also known from contemporaneous strata in Argentina (VOLKHEIMER & *al*., 1986) and Bolivia (GRAHN 2002).

REMARKS: This biozone is also recognized in all Solimões wells penetrating the Jutaí Formation (Text-fig. 3). *Urochitina* is not reported from strata older than late Lochkovian, and the zone should therefore correspond to the late Lochkovian *Urochitina simplex* Total Range Zone of PARIS & *al*. (2000).

Ancyrochitina arirambaense **and** ***Alpenachitina eisenacki*** **Concurrent range Zone**

DEFINITION: This biozone is defined by the co-occurrence of the two index species. It extends vertically from the first occurrence of the index species in the lower part of the Jandiatuba and Uerê formations to the first occurrence of *Angochitina mourai* in the same formations. QUADROS (1988) reported *Alpenachitina eisenacki* between 2442-2514 m in well 1-JD-1-AM. This depth interval is within the Jutaí Formation, so these finds of *A. eisenacki* most probably result from caving contaminations.

TYPE INTERVAL AND LOCALITY: The type interval for the zone is defined in the lower Jandiatuba Formation (Eifelian *s.l.* – early Givetian). Type locality is well 1-JD-1-AM between ca. 2370 and 2423 m (Text-fig. 2).

CHARACTERISTIC CHITINOZOANS: The chitinozoan species with oldest known stratigraphic inceptions indicate an Eifelian *s.l.* – early Givetian age, such as *Alpenachitina eisenacki* DUNN & MILLER 1964 (Pl. 4, Figs 8-9), *Ancyrochitina arirambaense* GRAHN & MELO in press

(Pl. 4, Fig. 3), and *Ramochitina ramosi* SOMMER & VAN BOEKEL 1964 (Pl. 1, Fig. 10). Other species restricted to this interval in the Solimões Basin are *Alpenachitina*? sp. (Pl. 4, Fig. 10), *Hoegisphaera* cf. *H. glabra* STAPLIN 1961 (Pl. 1, Fig. 1), *Ramochitina* sp.1 (Pl. 3, Fig. 7), and *Ramochitina* sp. 2 (Pl. 3, Fig. 10). *Fungochitina pilosa* (COLLINSON & SCOTT 1958) has its first occurrence in this interval. *Ancyrochitina langei* SOMMER & VAN BOEKEL 1964 (Pl. 4, Fig. 5; Pl. 5, Fig. 7) and *Spinachitina* aff. *biconstricta* (LANGE 1949) (Pl. 1, Fig. 7) occur in the upper part of the zone, of early Givetian age.

KNOWN OCCURRENCES OUTSIDE THE SOLIMÕES BASIN: *Ancyrochitina arirambaense* and *Alpenachitina eisenacki* are common Eifelian – early Givetian species in the intracratonic basins of Brazil. The latter is also known globally from coeval strata (see GRAHN & MELO in press).

REMARKS: This biozone is also recognized in wells 2-EP-1-AM (cuttings 1095, 1104 m), 2-FB-1-AM (core 41 between 2206 and 2207 m), 1-JT-2-AM (cuttings 2364, 2382, and 2403 m), 2-JT-1-AM (core 14 between 1549 and 1551 m), and 2-SR-1-AM (cuttings 1534 m). The chitinozoans in this zone correspond to the Eifelian – early Givetian *Alpenachitina eisenacki*, *Eisenackitina aranea* and *Ancyrochitina cornigera* Interval Range zones of PARIS & *al*. (2000).

***Angochitina mourai* Interval range Zone**

DEFINITION: This biozone is defined by the partial range of *Angochitina mourai* in the Solimões Basin. It extends vertically from the first occurrence of the index species in the upper part of the Jandiatuba and Uerê formations to the first occurrence of *Fungochitina ultima* PARIS & BOUMENDJEL 2000 *in* PARIS & *al*. 2000 (Pl. 1, Fig. 6).

TYPE INTERVAL AND LOCALITY: The type interval for the zone is defined in the upper Jandiatuba Formation (Frasnian – middle Famennian). Type locality is well 1-JD-1-AM between 2247 and ca. 2370 m (Text-fig. 2).

CHARACTERISTIC CHITINOZOANS: This chitinozoan assemblage, of Frasnian – middle Famennian age, yields *Angochitina mourai* LANGE 1952 (Pl. 3, Fig. 6), *Angochitina* cf. *katzeri* GRAHN & MELO 2002 (Pl. 1, Figs 8-9), *Angochitina rathbuni* GRAHN & MELO 2002 (Pl. 1, Fig. 5), and *Ramochitina* sp. 3 (Pl. 4, Fig. 2).

KNOWN OCCURRENCES OUTSIDE THE SOLIMÕES BASIN: *Angochitina mourai* is a common Late Devonian species in the intracratonic basins of Brazil (Y.G. own observations).

REMARKS: This biozone is also recognized in wells 2-FB-1-AM (core 40), 2-JA-1-AM (core 22), and 1-SOJ-1-AM (cuttings 2787 m). The zone corresponds to the Frasnian – middle Famennian *Hoegisphaera glabra*, *Angochitina hispida* and *Angochitina avelinoi* Interval Range zones of PARIS & *al*. (2000).

***Fungochitina ultima* Total range Zone**

DEFINITION: This biozone is defined by the total range of *Fungochitina ultima* in the Solimões Basin. It extends vertically from the first to the last occurrence of the index species in the upper part of the Jandiatuba and Uerê formations.

TYPE INTERVAL AND LOCALITY: The type interval for the zone is defined within the upper Jandiatuba Formation (late Famennian). Type locality is well 1-JD-1-AM core 2 (2241-2247 m) (Text-fig. 2).

CHARACTERISTIC CHITINOZOANS: In addition to the eponymous species, this chitinozoan assemblage, of late Famennian age, yields rare specimens of *Angochitina mourai* and *Fungochitina pilosa* (COLLINSON & SCOTT 1958) (Pl. 1, Fig. 3; Pl. 5, Fig. 8)

KNOWN OCCURRENCES OUTSIDE THE SOLIMÕES BASIN: *Fungochitina ultima* is also described from latest Famennian strata in Algeria and Libya (PARIS & *al*. 2000).

REMARKS: This biozone does not correspond to the *F. ultima* Total Range Biozone in PARIS & *al*. (2000). In its type area in SW Algerian Sahara, the species occurs together with the miospore *Retispora lepidophyta* in the latest Famennian. The first occurrence of *F. ultima* in the Solimões Basin clearly predates the latest Famennian (Text-fig. 4) or "Strunian"; as it corresponds to the VH miospore Zone. *Fungochitina fenestrata* (TAUGOURDEAU & JEKHOWSKY 1960), the index species for the biozone below, is known from the same level in North Africa, and from the VCo miospore zone in the Amazonas Basin of Brazil (MELO & *al*. 1996). The specimens of *F. ultima* are somewhat bigger in the Solimões Basin as compared to those from North Africa.

MIOSPORE BIOSTRATIGRAPHY

In the Solimões Basin, due to a high level of coalification, the organic matter is often very poorly preserved.

Miospores, when present, are generally too dark, opaque, and partly or strongly corroded. For this reason, the determination of several miospore taxa is doubtful and in many cases the biostratigraphic conclusions based on these microfossils requires some caution. Despite these problems, some positive results have been obtained, and the following miospore zones or zonal intervals could be identified in the Solimões Basin Devonian (in descending stratigraphic order):

Undifferentiated *Retispora lepidophyta – Hymenozonotriletes explanatus* (LE) and *Retispora lepidophyta – Verrucosisporites nitidus* (LN) Interval zones

The following samples have yielded several identifiable miospore species: well 1-BV-1-AM (cuttings 3153 m), well 2-EP-1-AM (core 10 between 1091.0 and 1092.3 m), well 2-FB-1-AM (core 38 between 2084.0 and 2084.2 m), well 1-JR-1-AM (core 3 between 2778.3 and 2780.5 m), and well 1-RBB-1-AM (core 1 betwenn 2041.0 and 2054.5 m). Among these species is *Retispora lepidophyta* (KEDO) PLAYDORD 1976 (Pl. 6, Fig. 4), a globally distributed index species for the latest Famennian. Its total range, in the type "Strunian" of the Ardenne-Rhenish regions, is currently subdivided into three interval zones (MAZIANE & *al*. 1999), each of them being defined by the inception of a diagnostic species, in ascending stratigraphic order: *Knoxisporites literatus* (LL Zone), *Indotriradites explanatus* (LE Zone) and *Verrucosisporites nitidus* (LN Zone).

None of these index species has been recovered in any of the Solimões samples investigated. However, this study has recorded the presence, in several samples, of *Spelaeotriletes* cf. *obtusus* HIGGS 1975 (Pl. 6, Fig. 25) (well 2-FB-1-AM core 38, well 1-JR-1-AM core 3, well 1-RBB-1-AM core 1), *Cordylosporites spathulatus* (WINSLOW) PLAYFORD & SATTERTHWAIT 1985 (Pl. 6, Fig. 10) (well 1-BV-1-AM cuttings 3153 m), *Tumulispora rarituberculata* (LUBER) POTONIÉ 1966 (Pl. 6, Fig. 17) (well 2-EP-1-AM core 10), *Vallatisporites* cf. *vallatus* HACQUEBARD 1957 (Pl. 6, Fig. 1) (well 2-FB-1-AM core 38) and *Convolutispora major* (KEDO) TURNAU 1978 (Pl. 6, Fig. 15) (well 1-BV-1-AM). This palynoflora suggests that such sections belong to the highest part of the *Retispora lepidophyta* range. They can therefore be regarded as coeval with similar deposits in the Amazonas and Parnaíba Basins in which the LL Zone, i.e. the pre-*explanatus* part of the *Retispora lepidophyta* total range, has not been individualised, and might be entirely missing (LOBOZIAK & MELO 2002; MELO & LOBOZIAK 2003). Because of the scarcity or absence of *Verrucosisporites nitidus* PLAYFORD 1964 in most of the investigated sections bearing *Retispora lepidophyta*, an undifferentiated LE - LN zonal attribution has been proposed for all of them. However, as noted in LOBOZIAK & *al*. (2000), it is not unlikely that current identifications of the LE - LN zonal range in northern Brazil may turn out to be local impoverished variants of the more ubiquitous LN palynofloras.

A similar LE-LN zonal range is suggested for the samples here analyzed, and therefore for the main glacial event in the Solimões Basin. This corresponds to the *R. lepidophyta* (Rle) – *V. vallatus* (LVa) zonal range in the recently defined Devonian – Carboniferous miospore biozonation for the Brazilian basins (MELO & LOBOZIAK 2003). Coeval strata in Western Europe are within the *praesulcata* conodont (STREEL & LOBOZIAK 1996, text-fig. 3) zone. However, glaciogenic strata of Tournaisian age also occur in the Juruá Sub-basin (LOBOZIAK & *al*. 1994 a-b).

Other taxa recorded in the "Strunian" fossiliferous samples of the Solimões Basin include: *Cristatisporites* sp. (Pl. 6, Fig. 12), *Cymbosporites minutus* (KEDO) AVKHIMOVITCH & *al*. 1988 (Pl. 6, Fig. 14), *Cymbosporites* sp. *sensu* LOBOZIAK & STREEL 1992 (i.e. pl. 2, fig. 15) (Pl. 6, Fig. 2), *Diaphanospora rugosa* (NAUMOVA) BYSHEVA 1985 (pl. 6, fig. 16), *Densosporites* cf. *spitsbergensis* PLAYFORD 1963 (Pl. 6, Fig. 5), *Densosporites* sp., *Knoxisporites* cf. *hederatus* (ISHCHENKO) PLAYFORD 1963 (Pl. 6, Fig. 13), *Vallatisporites* cf. *verrucosus* HACQUEBARD 1957 (Pl. 6, Fig. 3), and *Verrucosisporites* sp. *sensu* LOBOZIAK & STREEL 1992 (i.e. pl. 3, fig. 14) (Pl. 6, Fig. 11). Their presence is consistent with the proposed age assignment.

***Apiculiretusispora verrucosa – Vallatisporites hystricosus* (VH) Interval Zone**

Late Famennian (uppermost Fa2c) miospores are present in well 1-JD-1-AM (core 2 between 2241 and 2251 m). Several miospore species have been identified from this sample, e.g. *Cymbosporites* sp. (Pl. 6, Fig. 22), *Vallatisporites hystricosus* (WINSLOW) BYSHEVA 1985 (Pl. 6, Figs. 18, 21), *Hystricosporites* sp. (Pl. 6, Fig. 20), *Ancyrospora langii* (TAUGOURDEAU-LANTZ) ALLEN 1965 (Pl. 6, Fig. 19), *Aurospora pseudocrista* AHMED 1980 (Pl. 6, Fig. 24), *Teichertospora torquata* (HIGGS) MCGREGOR & PLAYFORD 1990 (Pl. 6, Fig. 23) and *Rugospora radiata* (JUSHKO) BYSHEVA 1985. Among them, *V. hystricosus* is the most significant taxon, for it is a zonal species in the Ardenne-Rhenish regional biozonation (MAZINE & *al*. 1999). Its first occurrence there defines the base of the *A verrucosa – Vallatisporites hystricosus* (VH) Oppel Zone within the middle *expansa* conodont Zone. The absence of *Retispora lepidophyta* and other miospores characteristic for the LL – LE – LN zones is another diagnostic feature of this biozone. The interval corresponds to the *Vallatisporites hystricosus* (Hys) Interval Zone, recently defined in the Brazilian Devonian basins (MELO & LOBOZIAK 2003).

Acinosporites apiculatus – Grandispora protea (AP) Oppel Zone or younger Middle Devonian interval

Middle Devonian miospores occur in well 1-BV-1-AM (core 3 at 3331 m). Some miospore species have been doubtfully identified from this sample, e.g., *Acinosporites apiculatus* (STREEL) STREEL 1967 (Pl. 6, Fig. 8), *Aneurospora goensis* STREEL 1964 (Pl. 6, Fig. 7), *Biornatispora reticulata* LELE & STREEL 1969, *Dibolisporites echinaceus* (EISENACK) RICHARDSON 1965 (Pl. 6, Fig. 9), and *Emphanisporites rotatus* MCGREGOR 1961 (Pl. 6, Fig. 6). Among them, *A. apiculatus* is the most significant taxon because it is a zonal species in the Ardenne-Rhenish regional biozonation (STREEL & *al*. 1987). Its first occurrence there characterizes the base of the *A. apiculatus – G. protea* (AP) Oppel Zone within the *costatus – patulus* conodont Zone (STREEL & LOBOZIAK 1996). In the case of the Solimões sections studied here, the scarcity and extremely poor preservation of the recovered palynofloras do not allow any accurate biozonal assignment of the investigated sample. Thus an AP+ attribution (Text-fig. 4), and therefore a latest Emsian – early Eifelian minimum age, is here suggested. This corresponds to a stratigraphic interval not older than the *Grandispora* / *Samarisporites* spp. (GS) Interval Zone, recently defined in the Brazilian Devonian basins (MELO & LOBOZIAK 2003).

CONCLUSIONS

Some of the main problems found during the present work in the Solimões Basin involve the very poor preservation of the palynomorphs in most of the studied sections, the scarcity of miospores in the most distal marine facies (Middle Devonian and Frasnian strata), and the very low availability of *in situ* sampling (cores) at critical intervals. The palynological results allowed the first recognition of Western European Devonian miospore zones in the basin. Miospore evidence confirms a latest Devonian (latest Famennian or "Strunian") age of the main glacial event in the Solimões Basin, which is recorded by widespread diamictites over much of the basin. These can be regarded as coeval with similar deposits in the Amazonas (Curiri Formation) and Parnaíba ("Cabeças" Formation) basins. Nevertheless, Tournasian diamictites are also recorded in the Juruá Sub-basin (LOBOZIAK & *al*. 1994 aa-b). Biostratigraphic information in this paper was provided by chitinozoans mainly in those marine sequences where miospores are rare, absent or otherwise of little assistance. This holds particularly true for Frasnian and older Devonian/Silurian strata. The chitinozoan assemblages show great similarity to those known from other Paleozoic intracratonic basins in Brazil. The presence in the Solimões Basin, of *Urochitina loboi* (VOLKHEIMER & *al*. 1986), formerly considered as an endemic species of the Chaco-Paraná Basin in northwest Argentina, now demonstrates that a marine connection between this basin, the Peru-Bolivia Basin (GRAHN 2002) and the Solimões Basin was effective during the Early Devonian. Similar connections of the Solimões region with other Brazilian Paleozoic basins (Amazonas, Parnaíba, Paraná) during the Middle and Late Devonian are also evidenced by the chitinozoan data.

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APPENDIX Sample levels and chitinozoans from additional wells in the Solimões Basin

Well and coordinates	Sample level	Formation	Chitinozoan species
2-BT-1-AM 4^{o} 23’ 45” S, 69^{o} 56’ 55” W	1011 m	Jutaí	Angochitina filosa
	1017 m		Angochitina filosa, Urochitina loboi
	1023 m		Ancyrochitina fragilis, Cingulochitina serrata, Plectochitina sp., Urochitina cf. U. loboi
2-EP-1-AM 6^{o} 41’ 36.8” S, 69^{o} 48’ 7.8” W	1095 m	Jandiatuba	Fungochitina pilosa
	1104 m		Alpenachitina? sp., Fungochitina pilosa
	1113 m	Jutaí	Sphaerochitina cf. S. patula
	core 11 (1112.8 - 1115.8 m)		Angochitina filosa, Sphaerochitina cf. S. patula, Cingulochitina serrata, Eisenackitina bohemica, Pterochitina megavelata
	1146 m		Angochitina filosa
	1150 m		Angochitina filosa
	1160 m		Angochitina filosa
2-FB-1-AM 3^{o} 31’ 3” S, 66^{o} 4’ 51” W	core 40 (2131 - 2137 m)	Uerê	Angochitina mourai, Fungochitina pilosa
	core 41 (2206 - 2207 m)		Ramochitina sp.2
2-JA-1-AM 5^{o} 32’ 55.8” S, 67^{o} 28’ 57” W	core 22 (1725 - 1727 m)	Uerê	Angochitina mourai, Angochitina cf. A. katzeri, Fungochitina pilosa, Ramochitina sp.3
	1735 m	Jutaí	Ancyrochitina sp.A, Plectochitina sp.
	1745 m		Ancyrochitina sp.A, Angochitina filosa, Ramochitina jutaiense n.sp.
	1748 m		Angochitina filosa
	1751 m		Ramochitina jutaiense n.sp.
	1780 m		Angochitina filosa
1-JT-2-AM 5^{o} 25’ 50” S, 69^{o} 3’ 0” W	2364 m	Uerê	Ancyrochitina arirambaense
	2382 m		Alpenachitina eisenacki
	2403 m		Ancyrochitina arirambaense, Alpenachitina eisenacki
	2424 m	Jutaí	Cingulochitina ervensis, Urochitina loboi
	2445 m		Ramochitina jutaiense n.sp.
	2496 m		Ancyrochitina cf. A. asterigis
2-JT-1-AM 4^{o}17’ 20.2” S, 67^{o} 55’ 19.7” W	core 14 (1549 - 1551 m)	Uerê	Ancyrochitina arirambaense, Ancyrochitina langei, Hoegisphaera cf. H. glabra Reworked from Jutaí Fm: Angochitina filosa,Cingulochitina serrata, Margachitina catenaria, Ramochitina jutaiense n.sp.
1-RBI-1-AM 5^{o} 30’ 30” S, 68^{o} 0’ 35” W	1824 m	Jutaí Biá Mbr.	Ramochitina jutaiense n.sp.
	1839 m		Margachitina saretensis
	1851 m		Angochitina filosa, Cingulochitina ervensis
	1857 m		Eisenackitina bohemica
1-SOJ-1-AM 4^{o} 53’ 6.2” S, 66^{o} 25’ 14.7” W	2787 m	Uerê	Angochitina mourai
2-SR-1-AM 3^{o} 0’ 25” S, 65^{o} 56’ 44.8” W	1534 m	Uerê	Ancyrochitina sp., Alpenachitina eisenacki, Fungochitina pilosa
1-UE-1-AM 5^{o} 2’ 51” S, 67^{o} 2’ 25” W	2112 m	Jutaí Biá Mbr.	Ancyrochiina cf. A. batidoriformis, Cingulochitina ervensis, Margachitina saretensis,Plectochitina sp., Ramochitina jutaiense n.sp. Contamination from the Uerê Fm: Ancyrochitina langei

PLATES 1-6

PLATE 1

Chitinozoans from the Solimões Basin

1 – *Hoegisphaera* cf. *glabra* STAPLIN 1961; Well 2-JT-1-AM, Uerê Fm., core 14 (1549-1551 m).
2 – *Eisenackitina bohemica* (EISENACK 1934); Well 1-RBI-1-AM, Jutaí Formation (Biá Member), cuttings 1857 m.
3 – *Fungochitina pilosa* (COLLINSON & SCOTT 1958); Well 1-JD-1-AM, Jandiatuba Formation, core 3 (2353.5-2355.5 m).
4 – *Angochitina strigosa* BOUMENDJEL 2002; Well 1-JD-1-AM, Jutaí Formation, cuttings 2490 m.
5 – *Angochitina rathbuni* GRAHN & MELO 2002; Well 1-JD-1-AM, Jandiatuba Formation, core 3 (2353.5-2355.5 m).
6 – *Fungochitina ultima* PARIS & BOUMENDJEL in PARIS & *al*. 2000; Well 1-JD-1-AM, Jandiatuba Formation, core 2 (2241-2242 m).
7 – *Spinachitina* aff. *biconstricta* (LANGE 1949); Well 1-JD-1-AM, contamination in the Jutaí Formation, cuttings 2530 m.
8 – *Angochitina* cf. *katzeri* GRAHN & MELO 2002; Well 1-JD-1-AM, Jandiatuba Formation, core 3 (2353-2354 m).
9 – *Angochitina* cf. *katzeri* GRAHN & MELO 2002. Well 2-JA-1-AM, Jandiatuba Formation, core 22 (1725-1727 m).
10 – *Ramochitina ramosi* SOMMER & VAN BOEKEL 1964; Well 1-JD-1-AM, Jandiatuba Formation, cuttings 2424 m.
11 – *Ramochitina jutaiense* sp. nov.; Well 1-JD-1-AM, Jutaí Formation, cuttings 2424 m.

The scale bars represent 100 μm

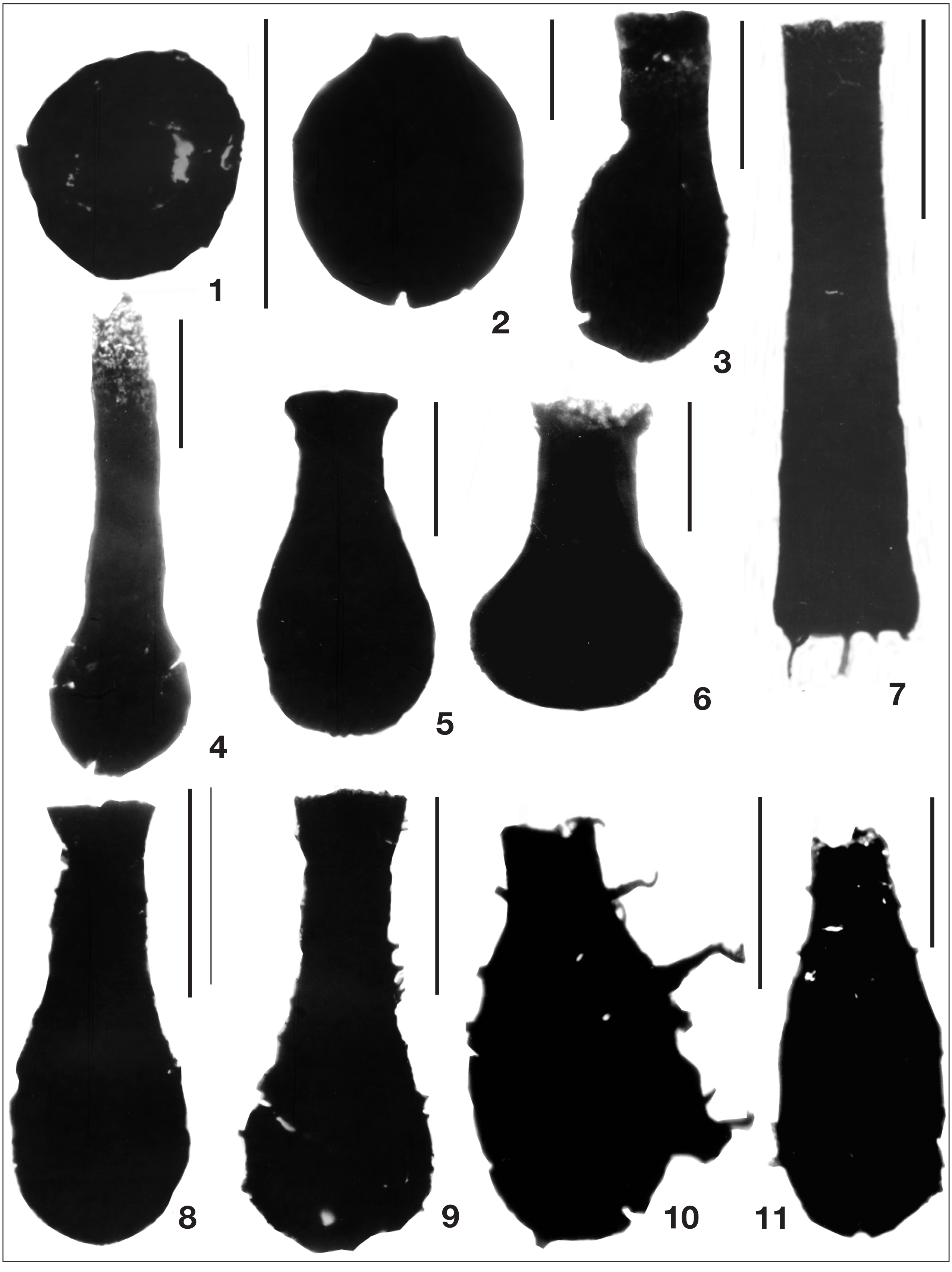
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PLATE 2

Chitinozoans from the Solimões Basin

1 – *Cingulochitina ervensis* PARIS 1981b. Well 1-JD-1-AM, Jutaí Formation, cuttings 2481 m.

2 – *Cingulochitina ervensis* PARIS 1981b. Well 1-RBI-1-AM, Jutaí Formation (Biá Member), cuttings 2481 m.

3 – *Cingulochitina serrata* (TAUGOURDEAU & JEKHOWSKY 1960). Well 2-EP-1-AM, Jutaí Formation, core 11 (1112.8-1151.8 m).

4 – *Cingulochitina serrata* (TAUGOURDEAU & JEKHOWSKY 1960). Well 1-JD-1-AM, Jutaí Formation, core 4 (2428-2446 m).

5 – *Margachitina saretensis* BOUMENDJEL 2002. Detail of number 11. Well 1-UE-1-AM, Jutaí Formation (Biá Member), cuttings 2112 m.

6 – *Margachitina catenaria* OBUT 1973. Reworked in the Uerê Formation. Well 2-JT-1-AM, core 14 (1549-1551 m).

7 – *Spinachitina* sp. Well 1-JD-1-AM, Jutaí Formation, cuttings 2514 m.

8 – *Cingulochitina convexa* (LAUFELD 1974). Well 1-JD-1-AM, Jutaí Formation, cuttings 2520 m.

9 – *Urochitina loboi* VOLKHEIMER & *al*. 1986. Detail of base (see also plate 3, fig. 2). Well 2-BT-1-AM, Jutaí Formation, cuttings 1023 m.

10 – *Urochitina* cf. *loboi* VOLKHEIMER & *al*. 1986. Detail of base (see also plate 3, fig. 3). Well 2-BT-1-AM, Jutaí Formation, cuttings 1023 m.

11 – *Margachitina saretensis* BOUMENDJEL 2002. Well 1-UE-1-AM, Jutaí Formation (Biá Member), cuttings 2112 m.

The scale bars for figures 9 and 10 represents 50 μm; all other figures 100 μm

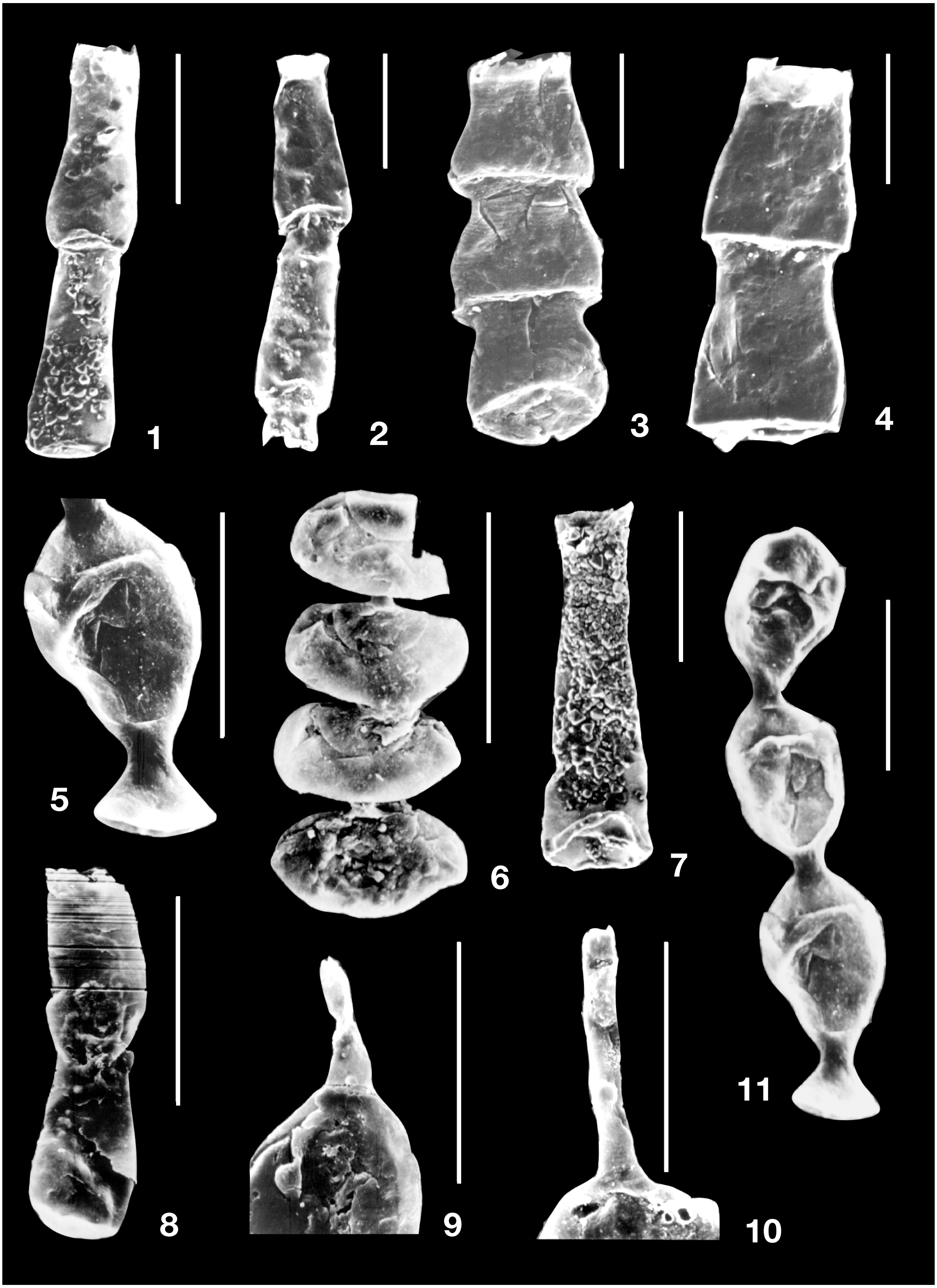
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PLATE 3

Chitinozoans from the Solimões Basin

1 – *Sphaerochitina* cf. *patula* JAGLIN 1986. Well 2-EP-1-AM, Jutaí Formation, cuttings 1113 m.
2 – *Urochitina loboi* VOLKHEIMER & *al*. 1986. Well 2-BT-1-AM, Jutaí Formation, cuttings 1017 m.
3 – *Urochitina* cf. *loboi* VOLKHEIMER & *al*. 1986. Well 2-BT-1-AM, Jutaí Formation, cuttings 1023 m.
4 – *Angochitina filosa* EISENACK 1955. Well 2-EP-1-AM, Jutaí Formation, core 11 (1112,8-1151,8 m).
5 – *Angochitina filosa* EISENACK 1955. Well 1-JD-1-AM, Jutaí Formation, core 4 (2428-2446 m).
6 – *Angochitina mourai* LANGE 1952. Well 1-SOJ-1-AM, Uerê Formation, cuttings 2787 m.
7 – *Ramochitina* sp. 1. Well 1-JD-1-AM, Jandiatuba Formation, cuttings 2376 m.
8 – *Angochitina* cf. *echinata* EISENACK 1931. Well 1-JD-1-AM, Jutaí Formation, cuttings 2520 m.
9 – *Ramochitina jutaiense* sp. nov. Holotype. Well 1-UE-1-AM, Jutaí Formation (Biá Member), cuttings 2112 m.
10 – *Ramochitina* sp. 2. Well 2-FB-1-AM, Uerê Formation, core 41 (2206-2207 m).

The scale bars represent 100 μm

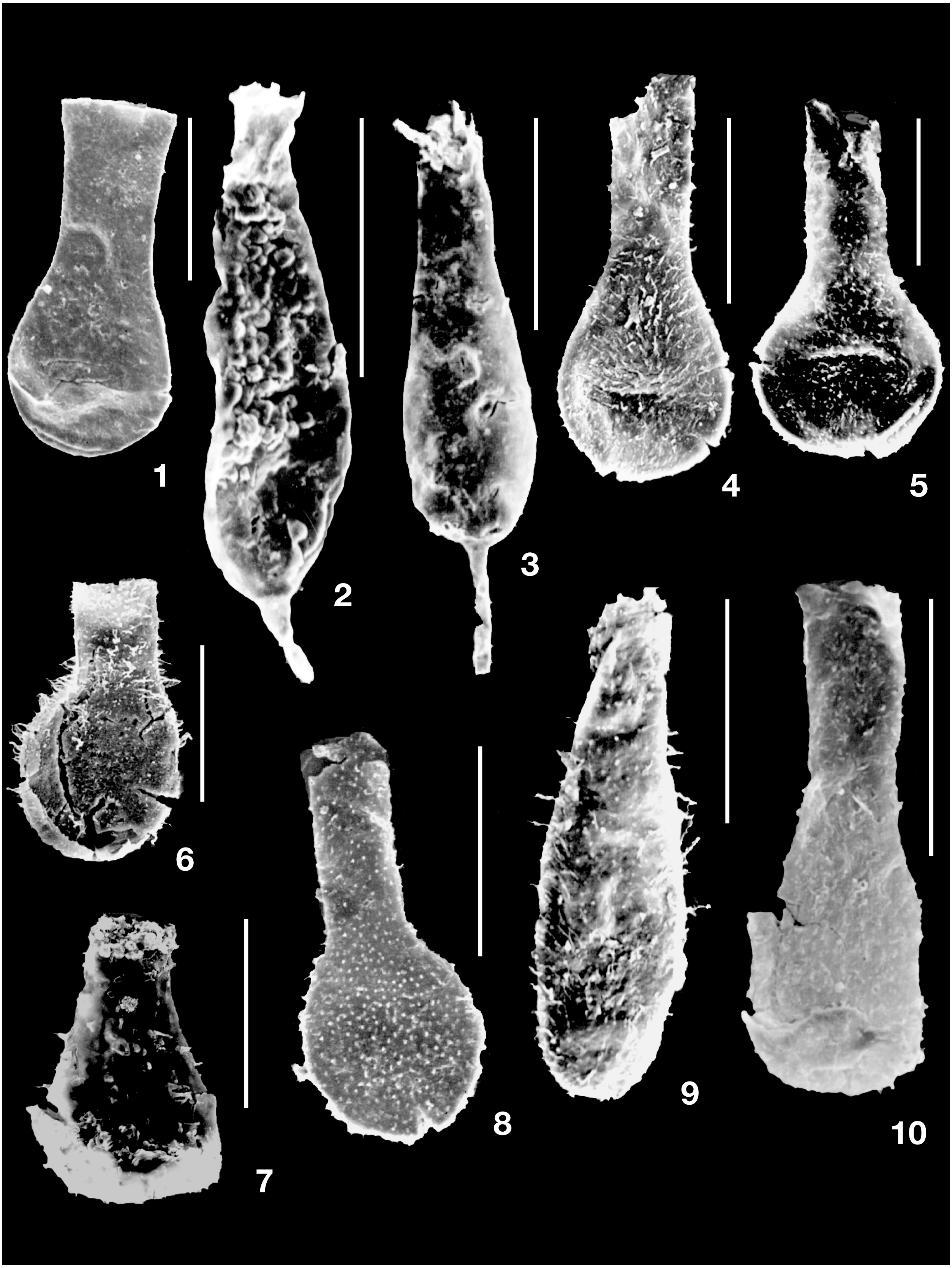
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PLATE 4

Chitinozoans from the Solimões Basin

1 – *Pterochitina megavelata* BOUMENDJEL 2002. Well 1-JD-1-AM, Jutaí Formation, core 4 (2430-2431 m).

2 – *Ramochitina* sp. 3. Well 2-JA-1-AM, Uerê Formation, core 22 (1726-1727 m).

3 – *Ancyrochitina arirambaense* GRAHN & MELO in press. Well 1-JT-2-AM, Uerê Formation, cuttings 2364 m.

4 – *Ancyrochitina* cf. *asterigis* PARIS 1981b. Well 1-JT-2-AM, Jutaí Formation, cuttings 2496 m.

5 – *Ancyrochitina langei* SOMMER & VAN BOEKEL 1964. Well 2-JT-1-AM, Uerê Formation, core 14 (1549-1551 m).

6 – *Ancyrochitina* aff. *libyensis* JAGLIN 1986. Well 1-JD-1-AM, Jutaí Formation, cuttings 2530 m.

7 – *Ancyrochitina* sp. A. Well 2-JA-1-AM, Jutaí Formation, cuttings 1735 m.

8 – *Alpenachitina eisenacki* DUNN & MILLER 1964. Well 2-SR-1-AM, Uerê Formation, cuttings 1534 m.

9 – *Alpenachitina eisenacki* DUNN & MILLER 1964. Well 1-JT-2-AM, Uerê Formation, cuttings 2382 m.

10 – *Alpenachitina*? sp. Well 2-EP-1-AM, Jandiatuba Formation, cuttings 1104 m.

The scale bars represent 100 μm

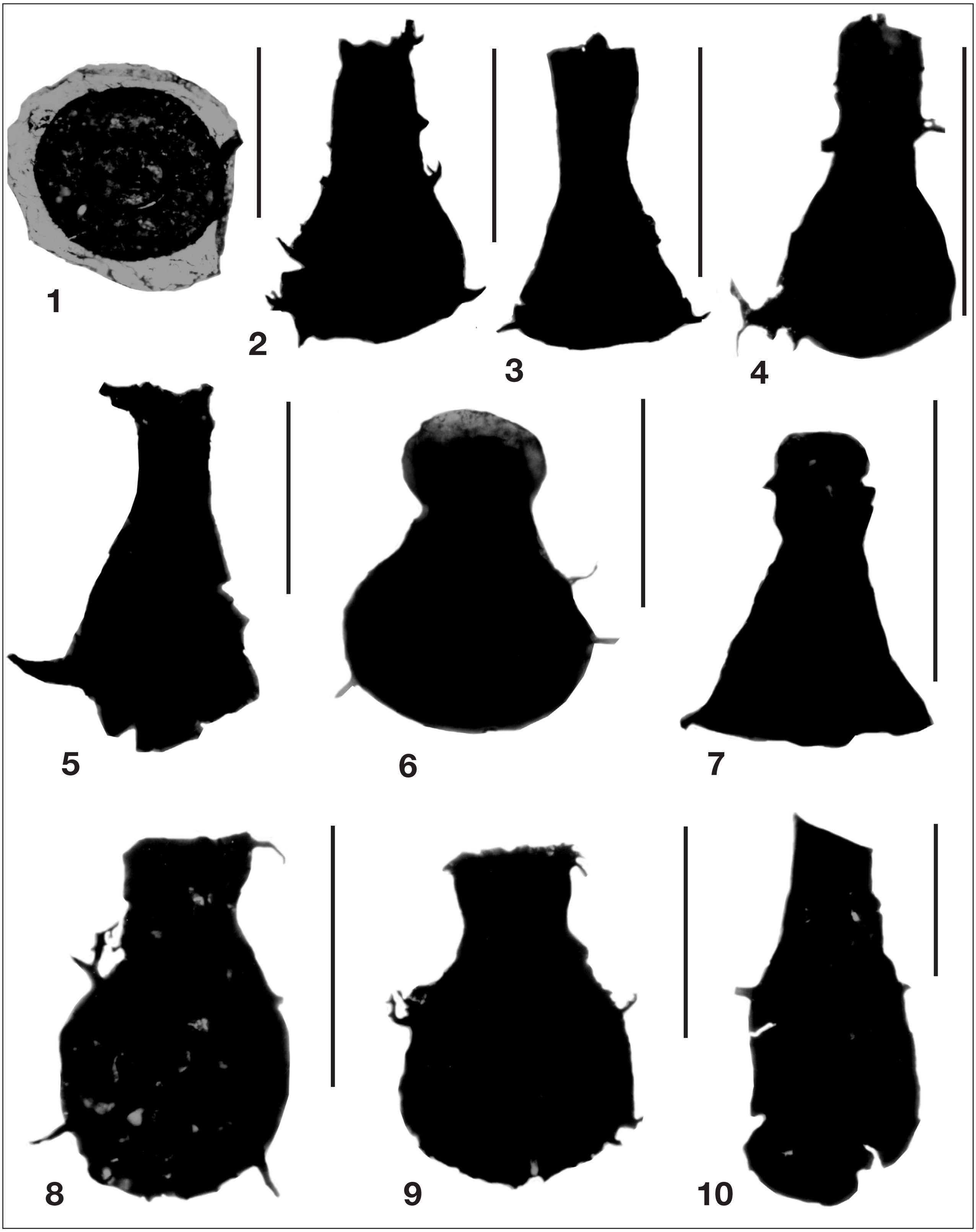
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PLATE 5

Chitinozoans from the Solimões Basin

1 – *Ancyrochitina ancyrea* (EISENACK 1931). Well 1-JD-1-AM, Jutaí Formation, cuttings 2508 m.

2 – *Ancyrochitina* cf. *batidoriformis* SCHWEINEBERG 1987. Well 1-UE-1-AM, Jutaí Formation (Biá Member), cuttings 2112 m.

3 – *Ancyrochitina fragilis* EISENACK 1955. Well 1-JD-1-AM, Jutaí Formation, core 4 (2445-2446 m).

4 – *Ancyrochitina fragilis* EISENACK 1955. Well 1-JD-1-AM, Jutaí Formation, core 4 (2428-2446 m).

5 – *Plectochitina* sp. Well 1-UE-1-AM, Jutaí Formation (Biá Member), cuttings 2112 m.

6 – *Plectochitina* sp. Well 2-BT-1-AM, Jutaí Formation, cuttings 1023 m.

7 – *Ancyrochitina langei* SOMMER & VAN BOEKEL 1964. Caving in the Jutaí Formation (Biá Member), Well 1-UE-1-AM, cuttings 2112 m.

8 – *Fungochitina pilosa* (COLLINSON & SCOTT 1958). Well 1-JD-1-AM, Jandiatuba Formation, core 3 (2349,5-2357,5 m).

9 – *Ramochitina jutaiense* sp. nov. Well 1-JD-1-AM, reworked in late Famennian (VH Zone) beds (Jandiatuba Formation), core 2 (2241-2247 m).

The scale bars represent 100 μm

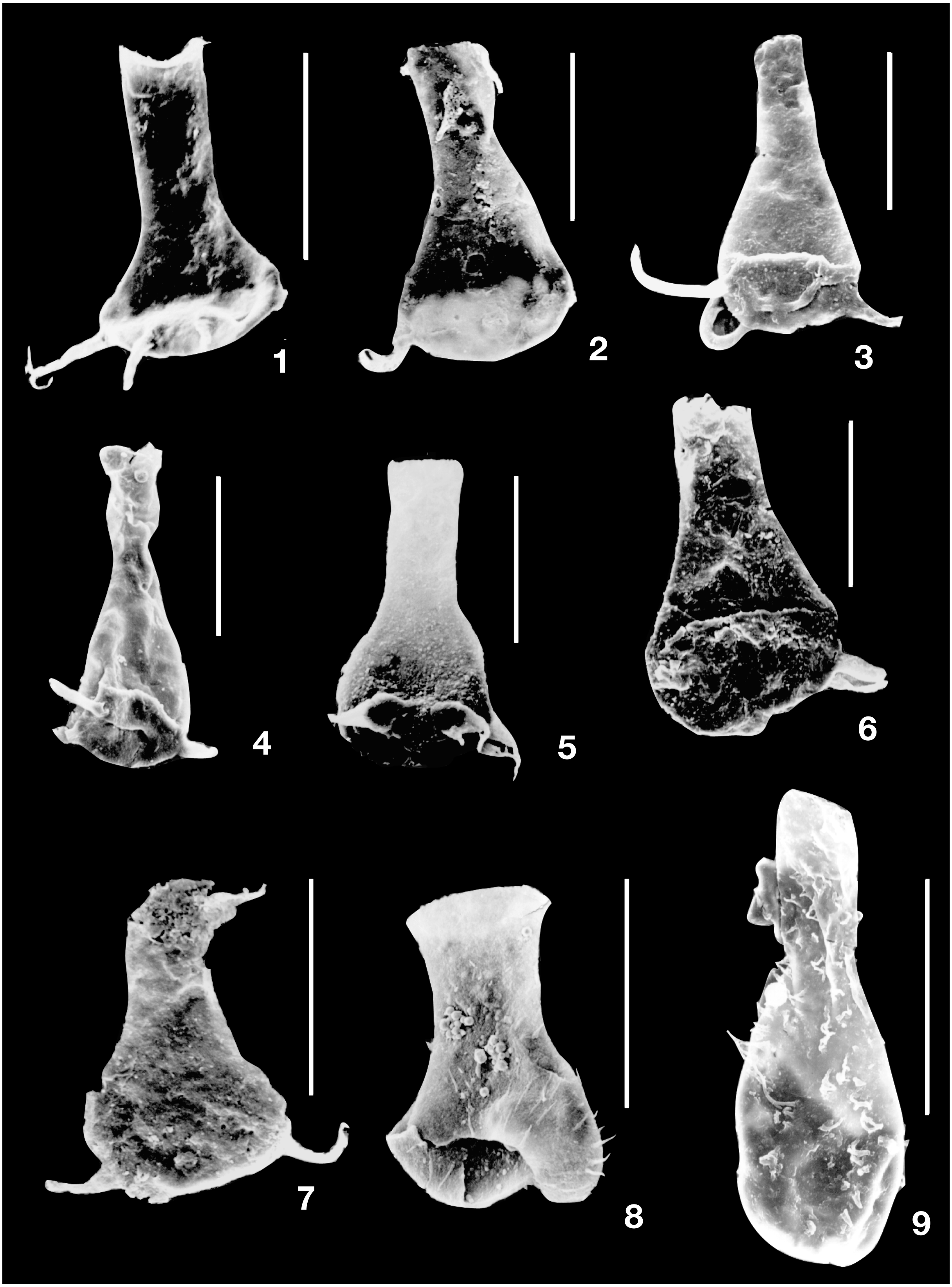
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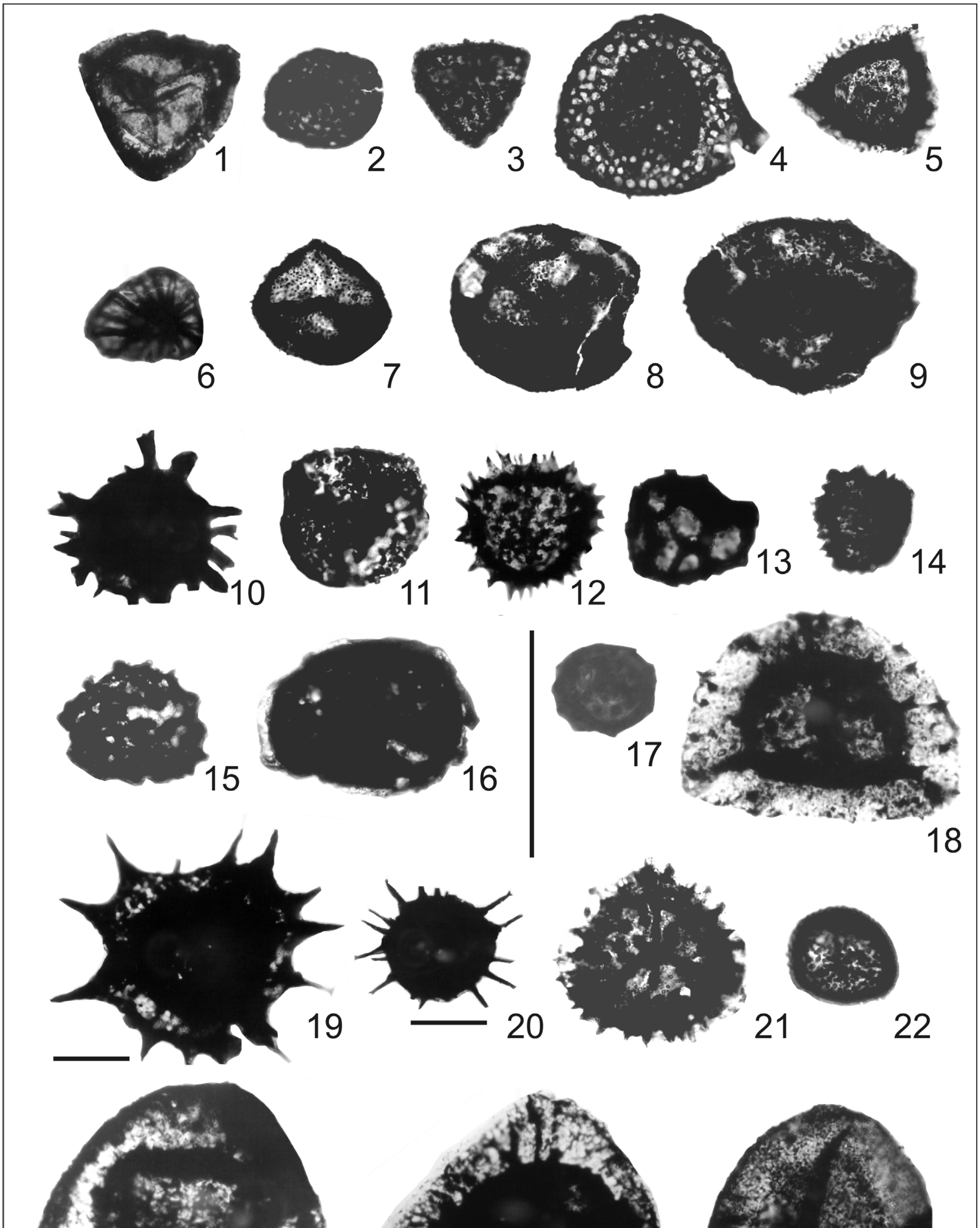
PLATE 6

Miospores from the Solimões Basin

1 – *Vallisporites* cf. *vallatus* HACQUEBARD 1957. Well 2-FB-1-AM, Uerê Formation, core 38 (2084.20 m).
2 – *Cymbosporites* sp. *sensu* LOBOAZIAK & STREEL 1992. Well 2-FB-1-AM, Uerê Formation, core 38 (2084.15 m).
3 – *Vallatisporites* cf. *verrucosus* HACQUEBARD 1957. Well 2-FB-1-AM, Uerê Formation, core 38 (2084.15 m).
4 – *Retispora lepidophyta* (KEDO) PLAYFORD 1976. Well 2-FB-1-AM, Uerê Formation, core 38 (2084.20 m).
5 – *Densosporites* cf. *spitsbergensis* PLAYFORD 1963. Well 2-FB-1-AM, Uerê Formation, core 38 (2084.20 m).
6 – *Emphanisporites rotatus* MCGREGOR 1961. Well 1-BV-1-AM, Jandiatuba Formation, cuttings 3331 m.
7 – *Aneurospora goensis* STREEL 1964. Well 1-BV-1-AM, Jandiatuba Formation, cuttings 3331 m.
8 – *Acinosporites apiculatus* (STREEL) STREEL 1967. Well 1-BV-1-AM, Jandiatuba Formation, cuttings 3331 m.
9 – *Dibolisporites echinaceus* (EISENACK) RICHARDSON 1965. Well 1-BV-1-AM, Jandiatuba Formation, cuttings 3331 m.
10 – *Cordylosporites spathulatus* (WINSLOW) PLAYFORD & SATTERTHWAIT 1985. Well 1-BV-1-AM, Jandiatuba Formation, cuttings 3331 m.
11 – *Verrucosisporites* sp. *sensu* LOBOZIAK & STREEL 1992. Well 1-JR-1-AM, Uerê Formation, core 3 (2778.3 m).
12 – *Cristatisporites* sp., Well 1-JR-1-AM, Uerê Formation, core 3 (2778.3 m).
13 – *Knoxisporites* cf. *hederatus* (ISHCHENKO) PLAYFORD 1963. Well 1-JR-1-AM, Uerê Formation, core 3 (2778.3 m).
14 – *Cymbosporites minutus* (KEDO) AVKHIMOVITCH & *al*. 1988. Well 1-JR-1-AM, Uerê Formation, core 3 (2778.3 m).
15 – *Convolutispora major* (KEDO) TURNAU 1978. Well 1-BV-1-AM, Jandiatuba Formation (Jaraqui Mbr.), cuttings 3153 m.
16 – *Diaphanospora rugosa* (NAUMOVA) BYSHEVA 1985. Well 1-BV-1-AM, Jandiatuba Formation, cuttings 3153 m.
17 – *Tumulispora rarituberculata* (LUBER) POTONIÉ 1966. Well 2-EP-1-AM, Jandiatuba Formation, core 10 (1091.00-1092.23 m).
18 – *Vallatisporites hystricosus* (WINSLOW) BYSHEVA 1985. Well 1-JD-1-AM, Jandiatuba Formation, core 2 (2241-2242 m).
19 – *Ancyrospora langii* (TAUGOURDEAU-LANTZ) ALLEN 1965. 1-JD-1-AM, Jandiatuba Formation, core 2 (2246-2247 m).
20 – *Hystricosporites* sp. 1-JD-1-AM, Jandiatuba Formation, core 2 (2243-2244 m).
21 – *Vallatisporites hystricosus* (WINSLOW) BYSHEVA 1985. 1-JD-1-AM, Jandiatuba Formation, core 2 (2250-2251 m).
22 – *Cymbosporites* sp. 1-JD-1-AM, Jandiatuba Formation, core 2 (2241-2242 m).
23 – *Teichertospora torquata* (HIGGS) MCGREGOR & PLAYFORD 1990. 1-JD-1-AM, Jandiatuba Formation, core 2 (2241-2242 m).
24 – *Auroraspora pseudocrista* AHMED 1980. 1-JD-1-AM, Jandiatuba Formation, core 2 (2241-2242 m).
25 – *Spelaeotriletes* cf. *obtusus* HIGGS 1975. Well 1-RBB-1-AM, Jandiatuba Formation, core 1 (2041.00-2054.50 m).

The scale bars represent 50 μm (The scale bar in the lower right corner is representative for figures 1-16, 18 and 21-25)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