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Ordovician and Silurian chitinozoan biozones of western Gondwana

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Abstract – A formal Ordovician–Silurian chitinozoan biozonation for western Gondwana is proposed. This palaeogeographic province includes South America, and was located in medium to high latitudes during Ordovician and Silurian times. Ordovician chitinozoans are known from northern Argentina, southern Bolivia, and Brazil. Silurian chitinozoans occur in Brazil, northern Argentina, southern Bolivia and southern Peru. No published information is available about Ordovician–Silurian chitinozoans from Ecuador, Colombia or Venezuela. Altogether more than 150 localities (including wells and outcrops) are included in this study, and 154 species have been encountered. A biozonation based on the first occurrence of critical chitinozoan species is introduced. Five biozones are defined in the Ordovician (zones of *Desmochitina* sp. gr. *minor*, *Conochitina decipiens*, *Eremochitina brevis*, *Lagenochitina obeligis* and *Tanuchitina anticostiensis*), and nine in the Silurian (zones of *Belonechitina postrobusta*, *Spinachitina harringtoni*, *Pogonochitina djalmai*, *Margachitina margaritana–Salopochitina monterrosae*, *Angochitina echinata*, *Eisenackitina granulata*, *Fungochitina kosovensis* and the subzones of *Sphaerochitina solutidina* and *Desmochitina* cf. *D. densa*). These biozones are compared with known graptolite, conodont, acritarch and spore zones from the same area, and chitinozoan zones on a global basis.

Keywords: Gondwana, Ordovician, Silurian, Chitinozoa, biozonation.

1. Introduction

Graptolites and/or shelly fossils from Ordovician and Silurian strata in the intracratonic basins of western Gondwana (Fig. 1) are present in northern Argentina, southern Bolivia and southern Peru. In Brazil and eastern Paraguay these fossils are limited to specific levels in the stratigraphic column, and therefore are only of restricted biostratigraphic value. Recent investigations on chitinozoans, acritarchs and spores have made possible a more detailed dating of the Silurian rocks. It should be noted that such an important microfossil group as conodonts is, except for the Ordovician in northern Argentina, Llandovery in southern Peru, early Wenlock in southern Bolivia, and Caradoc strata in eastern Paraguay (*Acontiodus* sp. reworked with other shelly fossils into Aeronian Vargas Peña shales: unpub. data), unknown from Ordovician and Silurian rocks of southern Bolivia, Brazil and eastern Paraguay. Acritarchs and spores have been applied in biostratigraphy only on a limited scale. However, local Silurian chitinozoan biozonations have been suggested for the Parnaíba (Grahn, Melo & Steemans, 2005) and Paraná (Grahn, Pereira & Bergamaschi, 2000; Grahn, 2005*b*) basins. The latter scheme has also been applied to lower Silurian strata in the Tarija Basin (northern Argentina) by Grahn & Gutiérrez (2001). These local biozones are not easily applied on a regional, and even less so on a global, scale. The purpose of this paper is to present an Ordovician–Silurian chitinozoan biozonation applicable for the intracratonic basins of western Gondwana, and to compare this biozonation with other zonations in well-known areas on a global scale.

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2. Previous chitinozoan studies in the Ordovician and Silurian of western Gondwana

Ordovician and Silurian chitinozoans from Brazil and Paraguay have been discussed in a series of internal reports from PETROBRAS and UERJ (Universidade do Estado do Rio de Janeiro) by H. Müller (Internal report, PETROBRAS, Salvador, 1962), R. F. Daemon (Internal report, PETROBRAS, Salvador, 1964), Y. Grahn (Internal reports, PETROBRAS, Rio de Janeiro, 1988a–d, 1989a–c, 1992c–f, and Internal reports, UERJ, Rio de Janeiro, 1997, 1998) and Y. Grahn & J. H. G. Melo (Internal report, PETROBRAS, Rio de Janeiro, 1990), and they have also been the subject in two doctoral theses (N. M. Costa, unpub. Ph.D. thesis, Univ. de São Paulo, 1972; L. P. Quadros, unpub. Ph.D. thesis, Univ. Federal do Rio de Janeiro, 1985) and one Masters thesis (P. Mendlowicz Mauller, unpub. M.Sc. thesis, Univ. do Estado do Rio de Janeiro, 2004). Only in the latter thesis has a formal biozonation (*sensu* Grahn, Pereira & Bergamaschi, 2000) been used. Since the papers by Lange (1967), Sommer & van Boekel

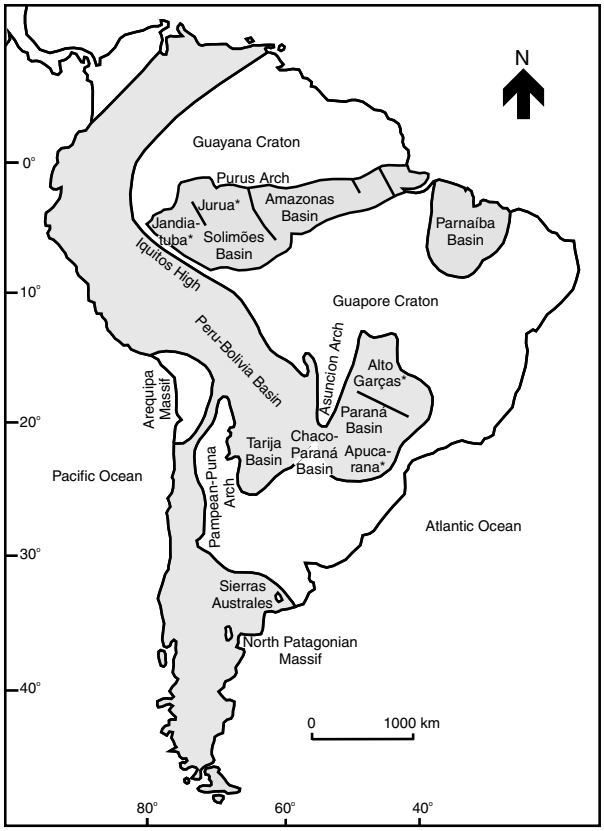

Figure 1. Silurian sedimentary basins in South America. Based on Rubinstein, 1997. Asterisk symbolizes a sub-basin.

(1963, 1965), Costa (1970, 1971*a*,*b*, 1974), Quadros (1982, 1988), Wood & Miller (1991), Gray *et al.* (1992), Grahn (1992*a*,*b*) and Grahn & Paris (1992), new geological information has been published about Silurian Chitinozoa from Brazil and Paraguay (Grahn 2005*a*,*b*; Grahn & Melo, 2003; Grahn, Pereira & Bergamaschi, 2000; Grahn, Loboziak & Melo, 2001, 2003; Grahn, Melo & Steemans, 2005; Le Hérissé *et al.* 2001; Azevedo-Soares & Grahn, 2005). In Grahn, Pereira & Bergamaschi (2000) a regional chitinozoan biozonation was suggested for the Silurian of eastern Paraguay, which was also applied to the lower Silurian in northern Argentina (Grahn & Gutiérrez, 2001), and in Grahn (2005*b*) the Silurian chitinozoans of the Paraná Basin in Brazil are compared with those from eastern Paraguay. Grahn, Melo & Steemans (2005) also introduced a chitinozoan biozonation for the Silurian Tianguá Formation in the Parnaíba Basin. A formal biozonation for the Solimões and Amazonas basins has hitherto not been proposed. Chitinozoans of Ordovician and/or Silurian age have also been described or discussed from southern Bolivia (Cramer, Díez & Cuerda, 1974; Suárez-Riglos, 1975; Liachenko, 1994; Heuse, Grahn & Erdtmann, 1999; Melo, 2000; Grahn, 2002), southern Peru (Dávila & Ponce de León, 1971) and northern Argentina (Volkheimer, Melendi & Acesolaza, 1980; Ottone, Toro & Waisfeld, 1992; Grahn & Gutiérrez, 2001; Grahn, 2003).

3. Notes on the Ordovician and Silurian palaeogeography and palaeoenvironment of western Gondwana

South America was a part of Gondwana and located in medium to high latitudes during Ordovician and Silurian times. The Late Ordovician (Hirnantian) glaciation was centred in North Africa, and can be traced in coeval sediments as ice-striated quartz grains in the continental (glacial outwash) sedimentation of the Amazonas and Parnaíba basins (Caputo, 1998). No glaciation took place in the area despite a geographic position near the South Pole (Grahn & Caputo, 1992). The Hirnantian glaciation can also be traced in the Paraná Basin in connection with a glacial centre in the Cape Basin (Grahn & Caputo, 1992). During Llandovery times, three glacial events (upper Rhuddanian–lower Aeronian, uppermost Aeronian–lower Telychian and upper Telychian–lower Sheinwoodian) took place, which are reflected in the Nhamundá (Amazonas Basin), Ipú (Parnaíba Basin) and Vila Maria (Paraná Basin) sediments as levels with diamictites (Grahn & Caputo, 1992). During deglaciation periods the intracratonic basins were in contact with the Iapetus Ocean. The diamictite levels can also be found in eastern Paraguay (Eusebio Ayala Formation), northern Argentina (Zapla Formation), southern Bolivia (Cancañiri Formation) and southern Peru (San Gabán Formation). The geographic South Pole was situated in central Brazil in Early Silurian times. During the Late Silurian, western Gondwana was still situated in the polar region, and the climate continued to be cool, as indicated by the palaeogeographic position, lack of carbonate sediments and the presence of organisms with an Afro-South American/Malvinokaffric affinity.

4. Chitinozoan biostratigraphy

During the study I felt obliged to redetermine many of the previous chitinozoan determinations. The new exact names are shown in Appendix 1. A list of chitinozoan species reported from western Gondwana and cited in text and figures is presented in Appendix 2, and a list of chitinozoan species not reported from western Gondwana but cited in the text is shown in Appendix 3.

4.a. Southern Peru

Dávila & Ponce de León (1971) mentioned a find of *Rhabdochitina* sp. (possibly *Conochitina proboscifera*) from the San Gabán Formation in the Punco Punco section northeast of Ayaviri. If correct, it indicates a correlation of the San Gabán Formation with the Cancañiri and Zapla formations in southern Bolivia and northern Argentina, respectively (Díaz-Martínez *et al.* 2001).

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4.b. Southern Bolivia

Ordovician and Silurian chitinozoans from 15 localities in the East Precordillera and Subandean Belt of Bolivia have been described in the literature. From the East Precordillera north and northeast of Culpina, and at Cementario and Estancia Savinga Mayu, Heuse, Grahn & Erdtmann (1999) described upper Tremadocian chitinozoans (*Desmochitina* sp. gr. *minor*) from the upper Cienguillas and Obispo formations, and lower Arenigian species (*Conochitina decipiens*, *Conochitina* cf. *C. havliceki* and *Conochitina* sp.) from the base of the Agua y Toro Formation. No chitinozoans have been reported from younger Ordovician beds in Bolivia. Near the pass of La Cumbre, about 20 km northeast of La Paz, the Cancañiri Formation yields *Belonechitina* sp., *Conochitina* sp. and *Cyathochitina* sp. B, indicating an Early Silurian age (Díaz-Martínez & Grahn, 2004). Late Silurian (Ludlow–Pridoli) chitinozoan assemblages are known from the Subandean Belt (Peru–Bolivia Basin), where they have been described from the Kirusillas Formation (Cramer, Díez & Cuerda, 1974) at Cochabamba (Appendix 1). Grahn (2002) described chitinozoans from the Kirusillas and Tarabuco formations in the Rio Pilaya, Sella, Sobo-Sobo and Tarabuco sections. Liachenko (1994) discussed Upper Silurian and Lower Lochkovian chitinozoans from three sections in the Kirusillas and Tarabuco formations along Rio Chimoré. However, the quality of her illustrations does not allow reliable determinations (Appendix 1). The chitinozoans have a Gondwanan affinity in the Silurian.

4.c. Northern Argentina

Ordovician and Silurian chitinozoans from eight localities in the Tarija (=Peru–Bolivia Basin) and Chaco–Paraná basins are known from the literature. From Cajas and Los Colorados in the Tarija Basin, Ottone, Toro & Waisfeld (1992) described an assemblage in the lower and upper part of the Acoite Formation of early–middle Arenigian age (Appendix 1). Sequences at Arroyo Colorado (Cachipunco Formation), Arroyo Matos (Zapla and Lipeón formations), Rio Capillas (Zapla and Lipeón formations), and 9 de Octubre Mine (Lipeón Formation) yielded middle Llandovery–early Wenlock chitinozoans; at Angosto Los Pereyras (upper Cachipunco Formation) occur Ludlow–Pridoli chitinozoans (Grahn & Gutiérrez, 2001), and one core (El Caburé-1) in the Chaco-Paraná Basin yielded Late Silurian chitinozoans from the Copo and Caburé formations (Grahn, 2003). Volkheimer, Melendi & Acesolaza (1980) mentioned the finds of chitinozoan fragments in the Mojotoro Formation of probable Early Ordovician age. The Arenigian chitinozoans have a mixed Gondwana–Laurentian affinity, while the Silurian assemblages display a Gondwanan affinity.

4.d. Eastern Paraguay

Silurian chitinozoans are known from nine localities in eastern Paraguay, all of them in the Itacurubi Group. Grahn, Pereira & Bergamaschi (2000) described chitinozoan assemblages from the Shell-Pecten Asuncion 1 well and the Anschutz Minerals RD 115 and RD 116 wells, and the Minas Cué outcrop was described by Grahn (2005*b*). Two shallow borings (269-R3 and 269-R4) yielding *Cyathochitina* sp. B, *Cingulochitina* cf. *C. serrata* (=*C.* aff. *C. serrata*), *Ancyrochitina* sp. and *Angochitina* sp. were mentioned by Gray *et al.* (1992). Two additional shallow borings (269-R1 and 269-R2), yielding essentially the same fauna as described by Grahn, Pereira & Bergamaschi (2000), were discussed by P. Mendlowicz Mauller (unpub. M.Sc. thesis, Univ. do Estado do Rio de Janeiro, 2004). Wood & Miller (1991) described a chitinozoan fauna (*Plectochitina paraguayensis*, *Eisenackitina bejui* and *Pterochitina* n.sp. = *Pterochitina deichaii*) from the type locality of the Vargas Peña Formation. An additional assemblage was discussed by Wood & Miller (1997).

4.e. Brazil

Ordovician and Silurian chitinozoans from Brazil are well known and described from the Solimões, Amazonas, Parnaíba and Paraná basins. Published information is available from more than one hundred localities. In the Solimões Basin, Ordovician chitinozoans from the Benjamin Constant Formation have been reported by Grahn (1992*b*) in three deep drillings (PETROBRAS 2-BT-1-AM, 1-JD-1-AM and 1-JT-2-AM wells), and Silurian chitinozoans from the lower Jutaí Formation in PETROBRAS 1-JD-1-AM well reported by Grahn, Loboziak & Melo (2003). The Ordovician–Silurian chitinozoan assemblages are well documented from the Amazonas Basin. An Ashgill (Rawtheyan) fauna was described from the upper Autás-Mirim Formation in PETROBRAS 1-AM-1-AM well by Grahn (1992*a*,*b*). Silurian chitinozoans illustrated from nearly 70 localities in the Pitinga and lower part of the Manacapuru formations by Lange (1967) have subsequently been described by Grahn & Melo (2003), and in 33 additional localities by Grahn (2005*b*) and Azevedo-Soares & Grahn (2005). Sommer & van Boekel (1963, 1965) described chitinozoans from the shallow well Bom Jardim 56 at Itaituba (Appendix 1). Costa (1970, 1971*a*) described chitinozoans from Igarapé da Rainha (sample 4-65-68 of Grahn, 2005*a*), a tributary of Rio Tapajós (Appendix 1). Costa (1974) investigated Early Silurian chitinozoans from Madame Island below the Viramundo waterfall. Chitinozoans from this locality, designated as AM 76 by PETROBRAS, were also described by Grahn (2005*a*). The Silurian chitinozoans of the Trombetas Group (Pitinga and lower part of the Manacapuru formations) were also discussed by Grahn & Paris (1992). In the Parnaíba Basin, Silurian chitinozoans are known from 13 localities in the upper

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Ipú, Tianguá and lower part of the Jaicós formations (Grahn, Loboziak & Melo, 2001). Quadros (1982) discussed Silurian Chitinozoa (Appendix 1) from three of these localities (PETROBRAS 1-MA-1-PI, 2-SL-1-MA and 2-PM-1-MA wells). Additional species were described by Grahn *in* Le Hérissé *et al.* (2001), and commented upon by Grahn, Loboziak & Melo (2001). A complete list of Silurian chitinozoans from the Parnaíba Basin is published by Grahn, Melo & Steemans (2005). Silurian chitinozoans from the Paraná Basin are restricted to the shales of the Vila Maria Formation, and only known from one locality for certain (Grahn, 1992*a*, 2005*b*). The chitinozoan fauna was described by Grahn, Pereira & Bergamaschi (2000) and Grahn (2005*b*).

5. Ordovician and Silurian chitinozoan zones of western Gondwana

It should be noted that no published information about Ordovician and Silurian Chitinozoa is available from Ecuador, Colombia and Venezuela. The proposed biozones are in general interval range zones defined from the first occurrence biohorizon (FOB) of the index species to the first occurrence of the index species in the following zone. Altogether, 154 species have been encountered, of which 16 are in the Ordovician sequences. No global chitinozoan biozonation has been suggested for the Ordovician, but good biostratigraphic schemes exist for the Welsh Borderland (Jenkins, 1967), North Gondwana (Paris, 1990), Québec and western Newfoundland (Achab, 1989), Baltoscandia (Nõlvak & Grahn, 1993; Nõlvak, 1999), Brabant Massif (Samuelsson & Verniers, 2000) and mid-continental U.S.A. (Grahn & Bergström, 1984). Some regional biostratigraphic schemes have been published for the Silurian, such as Baltoscandia (Laufeld, 1974; Nestor, 1994), Ukraine (Laufeld, 1971; Nestor, 1994; Paris & Grahn, 1996), Brabant Massif (Verniers, 1982), North Africa (Jardiné & Yapaudjian, 1968), Bohemia (Dufka, 1992; Kriz *et al.* 1986), Spain (Schweineberg, 1987), Saudi-Arabia (Paris *et al.* 1995; Al-Hajri & Paris, 1998), Québec (Asselin, Achab & Bourque, 1989; Soufiane & Achab, 2000), China (Geng *et al.* 1997), Welsh Borderland (Sutherland, 1994; Verniers, 1999; Mullins & Loydell, 2001) and mid-continental U.S.A. (Grahn, 1985; Grahn & Bergström, 1985). A global chitinozoan biozonation for the Silurian was proposed by Verniers *et al.* (1995).

6. Ordovician chitinozoan biozonation of western Gondwana

The Ordovician biozonation and its correlation within western Gondwana are shown in Figure 2. A correlation with the global zonation is demonstrated in Figure 3.

6.a. *Desmochitina* sp. gr. *minor* Range Zone

Zone base definition: FOB of *Desmochitina* sp. gr. *minor* (Fig. 4a).

Characterization of zone: No other chitinozoan species are present.

Reference section for zone base: In the Dique section near Culpina in southern Bolivia, the zone base is defined in the top of Cieneguillas Formation, ~ 5 m below the base of the overlying Obispo Formation.

Representative occurrences of zone: Obispo Formation, Sama Anticline (Bolivia) and top of the Cieneguillas Formation and the base of the Obispo Formation, area near Culpina (Bolivia).

Lithostratigraphic distribution: Top of Cieneguillas Formation and Obispo Formation in Bolivia.

Age range: Late Tremadocian–earliest Arenigian (*Aorograptus victoriae–Tetragraptus phyllograptoides* graptolite zones) (Figs 2, 3).

Remarks: *Desmochitina* sp. gr. *minor* was first described from the conglomeratic series at Miedzygorz in the Holy Cross Mountains (Poland) by Szaniawski *in* Chlebowski & Szaniawski (1974). It has also been described from the Leetse and lower Toila formations in the Suhkrumägi section at Tallinn, Estonia (Grahn, 1984). All these occurrences are from the lower Arenigian (*Cyathochitina primitiva* Zone) in Baltoscandia (Nõlvak & Grahn, 1993).

6.b. *Conochitina decipiens* Interval Zone

Zone base definition: FOB of *Conochitina decipiens* (Fig. 5a).

Characterization of zone: The co-occurrence of *C. decipiens* and *Conochitina* cf. *C. havliceki*.

Reference section for zone base: The west flank of the Sama Anticline at Estancia Savinga Mayu in southern Bolivia. The base is situated about 50 m above the base of the Agua y Toro Formation.

Representative occurrences of zone: Agua y Toro Formation, Sama Anticline, Bolivia.

Lithostratigraphic distribution: Agua y Toro Formation in Bolivia.

Age range: Early Arenigian (*Expansograptus protobalticus–Baltograptus minutus* graptolite zones) (Figs 2, 3).

Remarks: *Conochitina decipiens* range from lower to uppermost Arenigian. Only the lower part of its stratigraphic range is represented in this zone.

6.c. *Eremochitina brevis* Range Zone

Zone base definition: FOB of *Eremochitina brevis* (Fig. 4b).

Characterization of zone: The co-occurrence of *Eremochitina brevis* and *Conochitina ordinaria*.

Reference section for zone base: Section at Los Colorados Creek, about 30 km west of Tilcara in the Tumbaya Department, Jujuy Province, northwest

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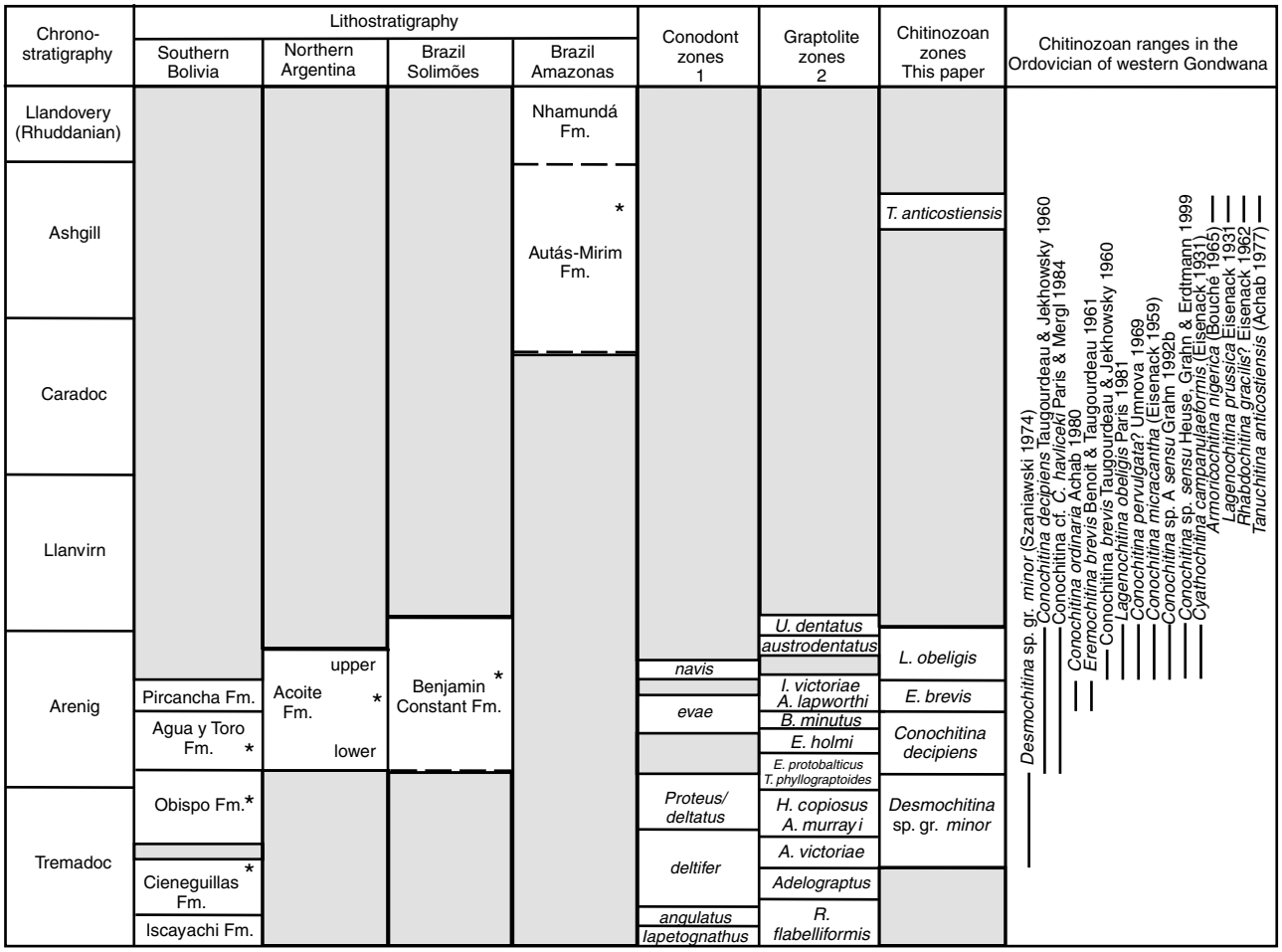

Figure 2. Correlation between Ordovician graptolite, conodont, and chitinozoan biozones in western Gondwana. 1 – Albanesi & Ortega, 2002. 2 – Albanesi & Ortega, 2002; Egenhoff, Maletz & Erdtmann, 2004. Asterisk symbolizes occurrence of chitinozoans.

Argentina. The base is situated about 500 m above the base of the Acoite Formation.

Representative occurrences of zone: See reference section for the base.

Lithostratigraphic distribution: Lower part of the Acoite Formation in Argentina.

Age range: Middle Arenigian (*Azygograptus lapworthi*–lower *Isograptus victoriae* graptolite zones) (Figs 2, 3).

Remarks: *Eremochitina brevis* is restricted to middle Arenig strata.

The biozone was originally defined from the subsurface of western Sahara by Paris (1990), where the index species occurs together with *L. esthonica*, *L. obeligis* and *Velatachitina veligera* in the upper part of the *E. brevis* Zone (Appendix 3).

6.d. *Lagenochitina obeligis* Interval Zone

Zone base definition: FOB of *Lagenochitina obeligis* (Fig. 5b).

Characterization of zone: The co-occurrence of *Lagenochitina obeligis* and *Conochitina brevis*. Other species present are *Conochitina pervulgata*?, *C. micracantha*, *C.* sp. A *sensu* Grahn, 1992*b* and *C.* sp. *sensu* Heuse, Grahn & Erdtmann, 1999.

Reference section for zone base: PETROBRAS 1-JD-1-AM well at level 2594 m, which is 31 m above the base of the Benjamin Constant Formation and the pre-Cambrian basement of the Solimões Basin. No outcrop sections of the Benjamin Constant Formation are known.

Representative occurrences of zone: Upper part of the Acoite Formation, at Los Colorados Creek in northwest Argentina (see Section 6.c) and the Benjamin Constant Formation in the Solimões Basin (PETROBRAS 1-JD-1-AM and 2-BT-1-AM wells).

Lithostratigraphic distribution: Benjamin Constant Formation in Brazil and upper part of the Acoite Formation in northern Argentina.

Age range: Late Arenigian (upper *Isograptus victoriae–Undulograptus dentatus* graptolite zones) (Figs 2, 3).

Remarks: *Lagenochitina obeligis* ranges from middle Arenig to lower Llanvirn. Based on acritarchs (e.g. *Arkonia virgata*), Quadros (1988) dated the Benjamin Constant Formation as Arenigian/Llanvirn.

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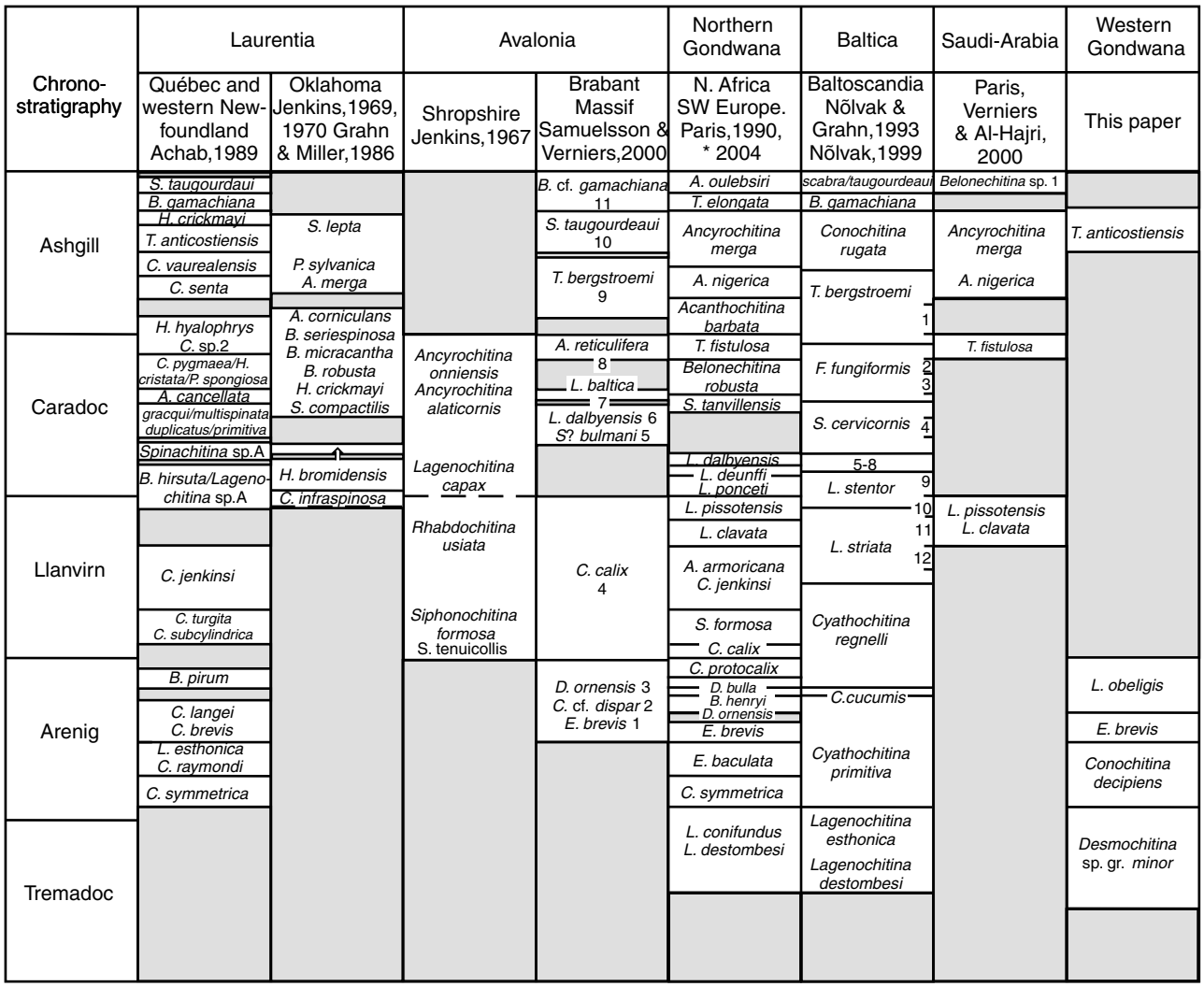

Figure 3. Correlation between Ordovician chitinozoan biozones in western Gondwana and other areas on a global scale. *2004 – Webby *et al.* (2004).

6.e. *Tanuchitina anticostiensis* Interval Zone

Zone base definition: FOB of *Tanuchitina anticostiensis* (Fig. 5c).

Characterization of zone: The co-occurrence of the index species, *Armoricochitina nigerica*, *Lagenochitina prussica* and *Rhabdochitina* aff. *gracilis*.

Reference section for zone base: PETROBRAS 1-AM-1-AM well level 2091 m, Amazonas Basin, northern Brazil. No outcrop sections of the Autás-Mirim Formation are known.

Representative occurrences of zone: Upper part of the Autás-Mirim Formation.

Lithostratigraphic distribution: Upper part of the Autás-Mirim Formation in northern Brazil.

Age range: Upper Ashgill (Figs 2, 3).

Remarks: *Tanuchitina anticostiensis* is restricted to upper Ashgillian (Rawtheyan) strata.

In Québec, *Tanuchitina anticostiensis* and *Hercochitina crickmayi* zones roughly correspond to the *T. anticostiensis* Zone in western Gondwana. In this interval, many different *Hercochitina* species occur together with *Conochitina concava*, *Conochitina armifera* and *Ancyrochitina longispina* (Appendix 3) (Achab, 1989).

7. Silurian chitinozoan biozonation of western Gondwana

The Silurian biozonation and its correlation within western Gondwana are shown in Figures 6–8 and 11. A correlation with the global zonation is demonstrated in Figures 9 and 10.

7.a. *Belonechitina postrobusta* Range Zone

Zone base definition: FOB of *Belonechitina postrobusta* (Fig. 5d) has not been defined in western Gondwana. The last occurrence is in the top Rhuddanian strata in eastern Paraguay (Grahn, Pereira & Bergamaschi, 2000).

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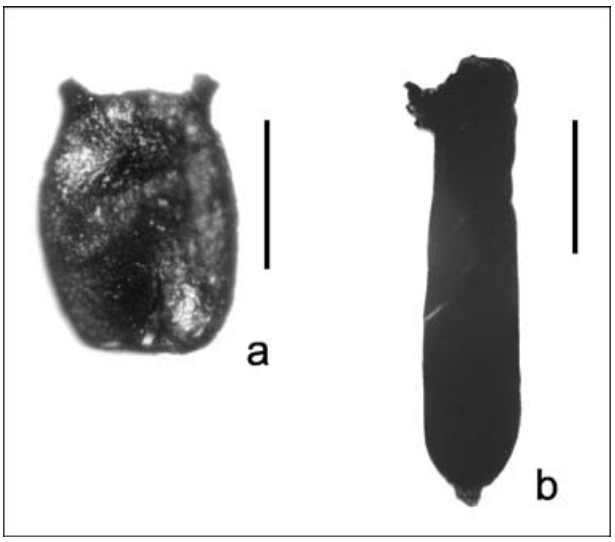

Figure 4. Ordovician chitinozoan index species from western Gondwana. The scale bars represent 100 μm. (a) *Desmochitina* sp. gr. *minor* (Szaniawski *in* Chlebowski & Szaniawski, 1974). Dique Section near Culpina, base of the Obispo Formation. By courtesy of Dr Thomas Heuse (Jena, Germany). (b) *Eremochitina brevis* Benoit & Taugourdeau, 1961. Los Colorado Creek, lower part of the Acoite Formation. By courtesy of Dr Eduardo Guillermo Ottone (Buenos Aires, Argentina).

Characterization of zone: In the uppermost part, *Spinachitina wolfarti*, *Sphaerochitina palestinaense* and *Ancyrochitina ancyrea* appear.

Reference section for zone base: No section known.

Representative occurrences of zone: Anschutz Minerals RD-116 well, lowermost part of the Vargas Peña Fm?, Paraná Basin, eastern Paraguay. The upper part of the *B. postrobusta* Zone is also present in the ELETRONORTE shallow borehole SM 1017, lowermost part of the Pitinga Formation, Amazonas Basin, northern Brazil (Grahn, 2005*a*).

Lithostratigraphic distribution: See representative occurrences of zone above.

Age range: Early Llandovery (Rhuddanian) (Figs 6, 8–11).

Remarks: *Belonechitina postrobusta* is restricted to lower Llandovery (Rhuddanian) strata.

In the global zonation (Verniers *et al.* 1995) the Rhuddanian includes the *Spinachitina fragilis*, *Belonechitina postrobusta*, *Conochitina electa* and lowermost *Spinachitina maennili* zones. Other important species in this interval include *Ancyrochitina laevaensis*, *Belonechitina aspera*, *Plectochitina nodifera*, *Angochitina seurati*, *Euconochitina iklaensis*, *Plectochitina paraguayensis* and *Pterochitina deichaii* (Appendix 3).

7.b. *Spinachitina harringtoni* Range Zone

Zone base definition: FOB of *Spinachitina harringtoni* (Fig. 5e).

Characterization of zone: In the upper part is a subzone with *Sphaerochitina solutidina* defined (see Section 7.c). Besides the index species are other diagnostic species *Plectochitina* sp. A, *Sphaerochitina silurica*, *Spinachitina* sp. A, *Conochitina* sp. A *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000, *Plectochitina* sp. C *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000 and *Sphaerochitina* sp. C *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000.

Reference section for zone base: Outcrop Minas Cué (Grahn, 2005*b*), lower part of the Vargas Peña Formation, Paraná Basin, eastern Paraguay.

Representative occurrences of zone: Lower part of the Vargas Peña Formation in the Paraná Basin, eastern Paraguay.

Lithostratigraphic distribution: See representative occurrencies of zone.

Age range: Middle Llandovery (Aeronian) (Figs 6, 8–11).

Remarks: *Spinachitina harringtoni* is restricted to middle Llandovery (Aeronian) strata.

In the global zonation (Verniers *et al.* 1995) the Aeronian includes the *Spinachitina maennili* and *Conochitina alargada* zones. Other important species in this interval include *Ancyrochitina convexa*, *Conochitina vitrea* and, in the uppermost part (of the *C. alargada* Zone), *Plectochitina saharica* and *Plectochitina pseudoagglutinans* (Appendix 3).

7.c. *Sphaerochitina solutidina* Range Subzone

Zone base definition: FOB of *Sphaerochitina solutidina* (Fig. 5f).

Characterization of zone: Besides the index species are other diagnostic species such as *Conochitina* sp. A *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000, *Plectochitina* sp. C *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000 and *Sphaerochitina* sp. C *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000.

Reference section for zone base: Anschutz Minerals RD-116 well, level 300 m, lower part of the Vargas Peña Formation, Paraná Basin, eastern Paraguay.

Representative occurrences of zone: Lower part of the Vargas Peña Formation in the Paraná Basin, eastern Paraguay.

Lithostratigraphic distribution: See representative occurrences of zone above.

Age range: Middle Llandovery (Aeronian) (Figs 6, 8–11).

Remarks: *Sphaerochitina solutidina* is restricted to upper middle Llandovery (upper Aeronian) strata.

In the global zonation (Verniers *et al.* 1995) this subzone corresponds to the upper *Conochitina alargada* zone. Other important species in this interval are *Plectochitina saharica* and *Plectochitina pseudoagglutinans*.

7.d. *Pogonochitina djalmai* Interval Zone

Zone base definition: FOB of *Pogonochitina djalmai* (Fig. 5g).

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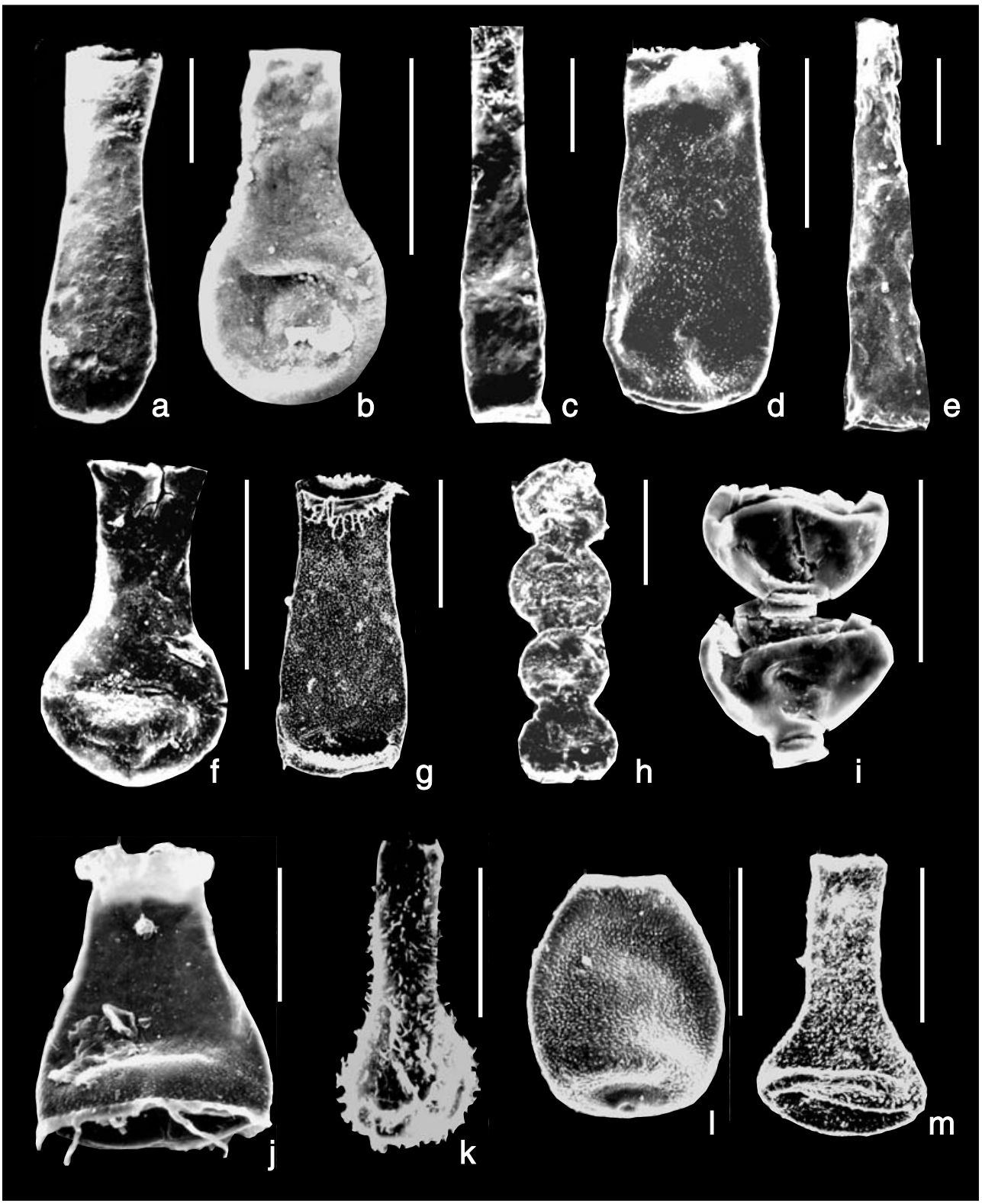

Figure 5. Ordovician and Silurian chitinozoan index species from western Gondwana. The scale bars represent 100 μm. (a) *Conochitina decipiens* Taugourdeau & Jekhowsky, 1960. PETROBRAS 1-JD-1-AM well level 2590 m, Benjamin Constant Fm. (b) *Lagenochitina obeligis* Paris, 1981. PETROBRAS 1-JD-1-AM well, core 18 (1096 m), Benjamin Constant Fm. (c) *Tanuchitina anticostiensis* (Achab, 1977). PETROBRAS 1-AM-1-AM well, level 2091 m, Autás-Mirim Fm. (d) *Belonechitina postrobusta* (Nestor, 1980). Anschutz Minerals RD-116 well, level 400.95 m, Vargas Peña Fm. (e) *Spinachitina harringtoni* Grahn *in* Grahn, Pereira & Bergamaschi, 2000. Anschutz Minerals RD-115 well, level 141.77 m, Vargas Peña Fm. (f) *Sphaerochitina solutidina* Paris, 1988. Anschutz Minerals RD-116 well, level 280.70 m, Vargas Peña Fm. (g) *Pogonochitina djalmai* (Sommer & van Boekel, 1965). Outcrop Igarapé da Rainha 4-65-68, Pitinga Fm. (lower part). (h) *Desmochitina* cf. *D. densa* Eisenack, 1962. Anschutz Minerals RD-116 well, level 222.60 m, Vargas Peña Fm. (i) *Margachitina margaritana* (Eisenack, 1937). PETROBRAS 1-AM-1-AM well, cuttings 1746–1749 m, Pitinga

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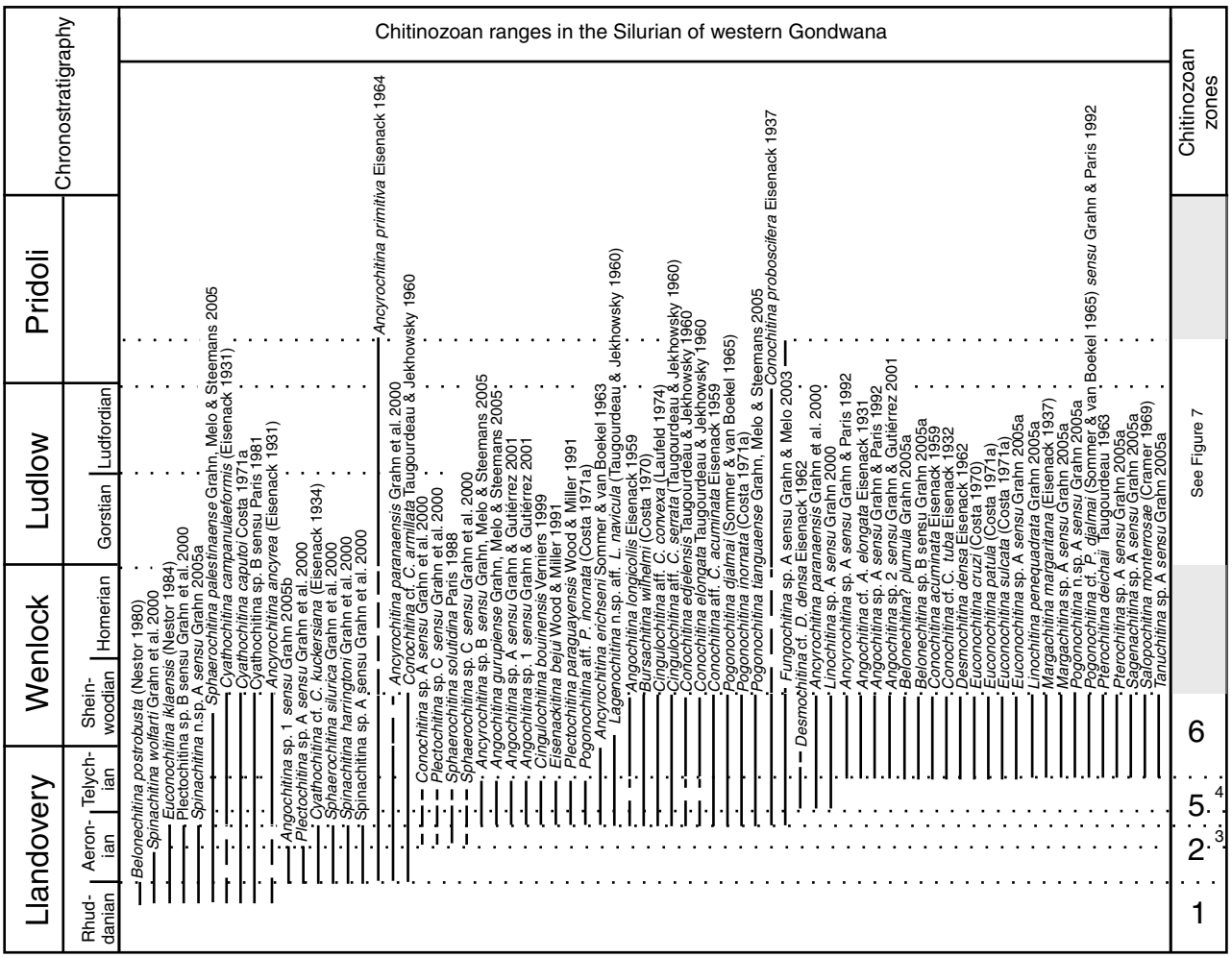

Figure 6. Chronostratigraphy and chitinozoan ranges in the Early Silurian of western Gondwana. Chitinozoan Zone 1 – *Belonechitina postrobusta*, 2 – *Spinachitina harringtoni*, 3 – *Sphaerochitina solutidina*, 4 – *Desmochitina* cf. *D. densa*, 5 – *Pogonochitina djalmai*, and 6 – *Margachitina margaritana–Salopochitina monterrosae*.

Characterization of zone: In the upper part is a subzone with *Desmochitina* cf. *D. densa* defined (see Section 7.e). Besides the index species are other diagnostic species such as *Angochitina gurupiense*, *Cingulochitina bouinensis*, *Eisenackitina bejui*, *Plectochitina paraguayensis*, *Ancyrochitina erichseni*, *Angochitina longicollis*, *Pogonochitina inornata* and *Pogonochitina tianguaense*.

Reference section for zone base: PETROBRAS 1-AM-1-AM well, level 1755 m, Amazonas Basin, northern Brazil. No outcrop section with the base of the *P. djalmai* Zone is known.

Representative occurrences of zone: Several localities within the lower part of the Pitinga Formation in the Amazonas Basin and the Tianguá Formation in the Parnaíba Basin, northern Brazil.

Lithostratigraphic distribution: See representative occurrences of zone above.

Age range: Late middle Llandovery (Aeronian) to late Llandovery (Telychian) (*Monograptus turriculatus* graptolite Zone in the lower part) (Figs 6, 8–11).

Remarks: *Pogonochitina djalmai* range from upper middle Llandovery (uppermost Aeronian) to lower Wenlock (lower Sheinwoodian) strata.

Pogonochitina djalmai occur together with Telychian graptolites in the Bové Basin (Guinea) (Paris *in* Villeneuve *et al.* 1989). In the global zonation (Verniers *et al.* 1995) this zone can be correlated with the Zone of *Eisenackitina dolioliformis*. Other important species in this interval include *Pterochitina deichaii*, *Conochitina vitrea*, *Plectochitina pseudoagglutinans*,

Fm. (lower part). (j) *Salopochitina monterrosae* (Cramer, 1969). PETROBRAS 1-AM-1-AM well, cuttings 1746–1749 m, Pitinga Fm. (lower part). (k) *Angochitina echinata* Eisenack, 1931. PETROBRAS 1-AM-1-AM well, core 46 (1607.00–1613 m), Pitinga Fm. (upper part). (l) *Eisenackitina granulata* (Cramer, 1964). PETROBRAS 1-AM-1-AM well, core 46 (1607.00–1613 m), Pitinga Fm. (upper part). (m) *Fungochitina kosovensis* Paris, 1981. PETROBRAS 1-AM-1-AM well, core 46 (1607.00–1613 m), Pitinga Fm. (upper part).

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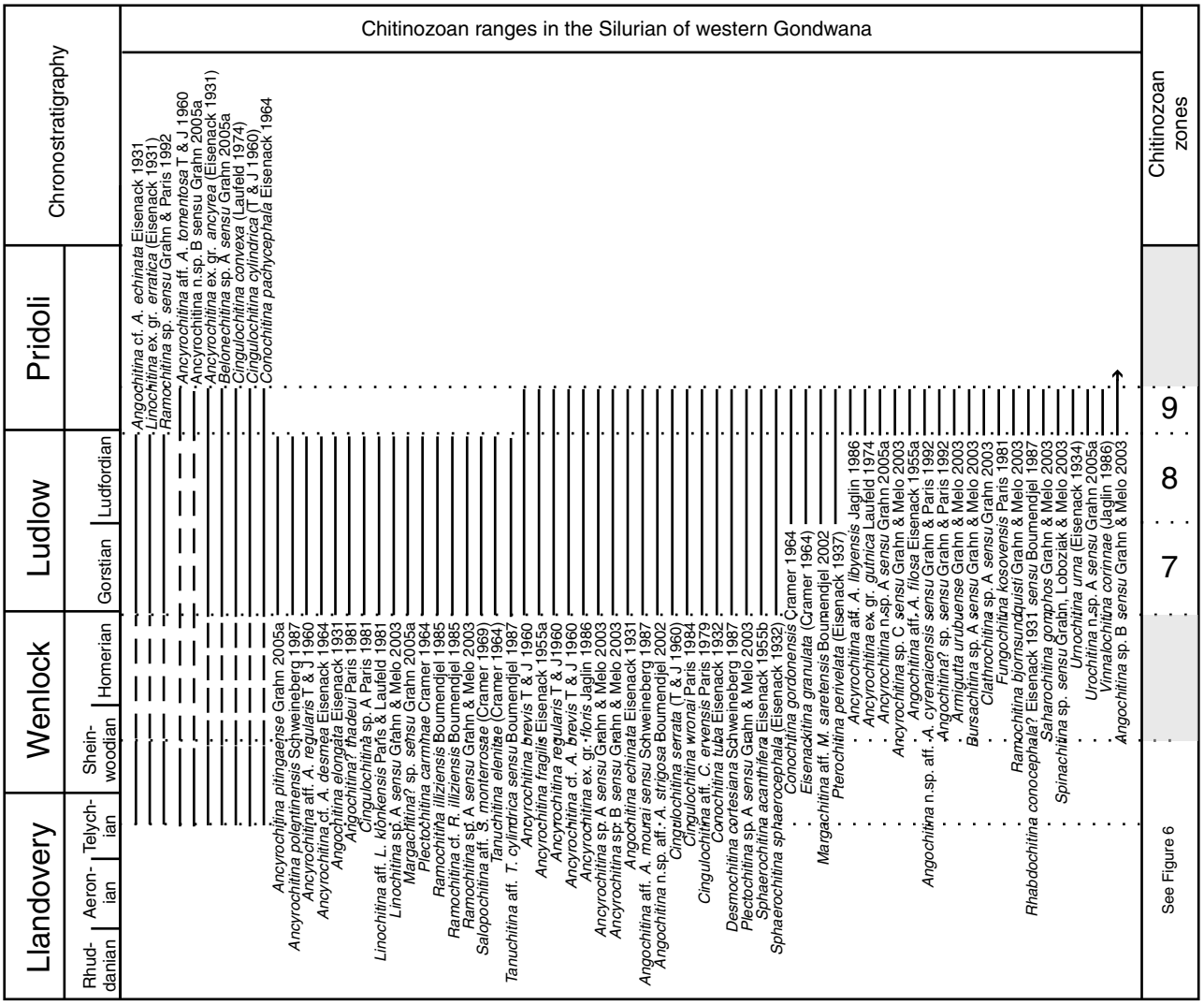

Figure 7. Chronostratigraphy and chitinozoan ranges in the Late Silurian of western Gondwana. Chitinozoan Zone 6 – *Angochitina echinata*, 7 – *Eisenackitina granulata*, and 8 – *Fungochitina kosovensis*. T & J 1960 – Taugourdeau & Jekhowsky (1960).

Plectochitina saharica, *Conochitina edjelensis* and *Conochitina emmastensis* (Appendix 3).

7.e. *Desmochitina* cf. *D. densa* Range Subzone

Zone base definition: FOB of *Desmochitina* cf. *D. densa* (Fig. 5h).

Characterization of zone: Besides the index species, other diagnostic species are *Pogonochitina inornata*. *Ancyrochitina paranaensis* and *Linochitina* sp. A *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000, have their first appearance in this subzone, and *Conochitina elongata* disappears in its topmost part.

Reference section for zone base: Anschutz Minerals RD-116 well, level 230 m, upper part of the Vargas Peña Formation, Paraná Basin, eastern Paraguay. No outcrop section with the base of the *Desmochitina* cf. *D. densa* Subzone is known.

Representative occurrences of zone: Upper Vargas Peña Formation in the Paraná Basin, eastern Paraguay.

Lithostratigraphic distribution: See representative occurrences of zone.

Age range: Early late Llandovery (early Telychian) (*Monograptus turriculatus* graptolite Zone in the lower part) (Figs 6, 8–11).

Remarks: *Desmochitina* cf. *D. densa* is restricted to lower upper Llandovery (lower Telychian) strata.

In the global zonation (Verniers *et al.* 1995) the *Desmochitina* cf. *D. densa* subzone is coeval with the upper *Eisenackitina dolioliformis* Zone. See above for characteristic chitinozoan species in this zone (see Section 7.d).

7.f. *Margachitina margaritana–Salopochitina monterrosae* Range Zone

Zone base definition: FOB of *Margachitina margaritana* (Fig. 5i) or *Salopochitina monterrosae* (Fig. 5j).

Characterization of zone: In addition to the index species, other diagnostic species are *Angochitina* sp. A *sensu* Grahn & Paris, 1992, *Belonechitina*?

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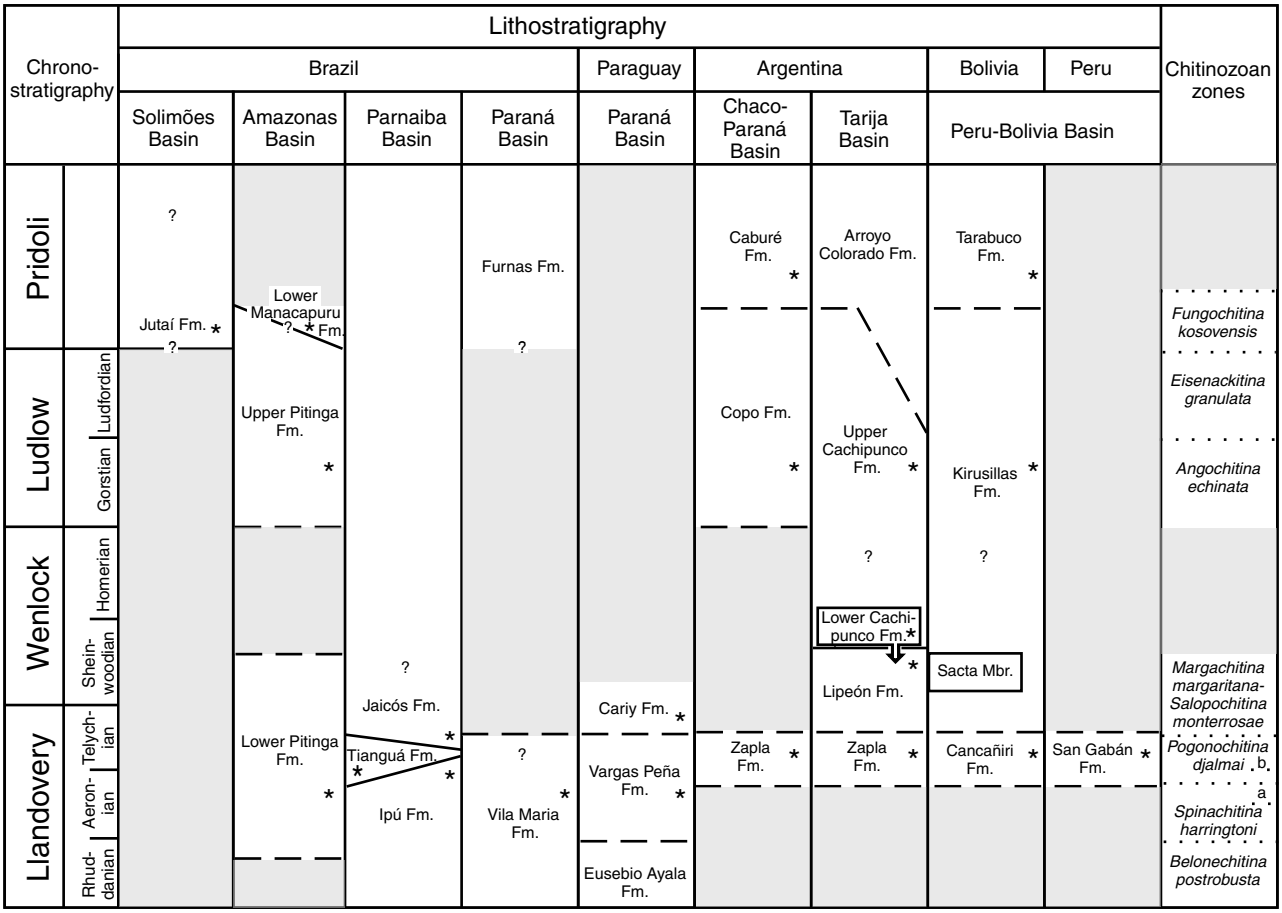

Figure 8. Correlation between Silurian lithostratigraphic units in western Gondwana. a – Chitinozoan Subzone of *Sphaerochitina solutidina* and b – Subzone of *Desmochitina* cf. *D. densa*. Asterisk symbolizes occurrence of chitinozoans.

plumula, *Conochitina acuminata*, *Desmochitina densa*, *Euconochitina cruzi*, *Linochitina penequadrata*, *Pogonochitina* cf. *P. djalmai*, *Pterochitina deichaii* and others (Fig. 3).

Reference section for zone base: PETROBRAS 1-AM-1-AM well, level 1752 m, lower part of the Pitinga Formation, Amazonas Basin, northern Brazil. No outcrop section with the base of the *M. margaritana–S. monterrosae* Zone is known.

Representative occurrencies of zone: Several localities within the lower part of the Pitinga Formation in the Amazonas Basin, northern Brazil.

Lithostratigraphic distribution: See representative occurrences of zone.

Age range: Latest Llandovery (late Telychian) to early Wenlock (Sheinwoodian) (Figs 6, 8–11).

Remarks: *Margachitina margaritana* and *Salopochitina monterrosae* range from uppermost Llandovery (upper Telychian) to lower Wenlock (lower Sheinwoodian) strata.

In the global zonation (Verniers *et al.* 1995) this zone can be correlated with the *Angochitina longicollis* and lower *Margachitina margaritana* zones. Other important species in this interval include *Eisenackitina dolioliformis*, *Conochitina emmastensis*, *Desmochitina densa*, *Conochitina acuminata*, *Conochitina proboscifera*, *Salopochitina monterrosae* and *Ramochitina corniculata* (Appendix 3).

7.g. *Angochitina echinata* Interval Zone

Zone base definition: FOB of *Angochitina echinata* (Fig. 5k).

Characterization of zone: An abundant and diverse chitinozoan fauna appears at the base of this zone (Fig. 6).

Reference section for zone base: Outcrop at Cochabamba (Cramer, Díez & Cuerda, 1974), Peru–Bolivia Basin, southern Bolivia.

Representative occurrences of zone: Several localities within the upper part of the Pitinga Formation in the Amazonas Basin, northern Brazil. Localities with the upper part of the Kirusillas Formation in southern Bolivia.

Lithostratigraphic distribution: Upper part of the Pitinga Formation in the Amazonas Basin, northern Brazil, upper part of the Kirusillas Formation, Peru–Bolivia Basin, southern Bolivia and upper part of the Cachipunco Formation, Tarija Basin, northern Argentina.

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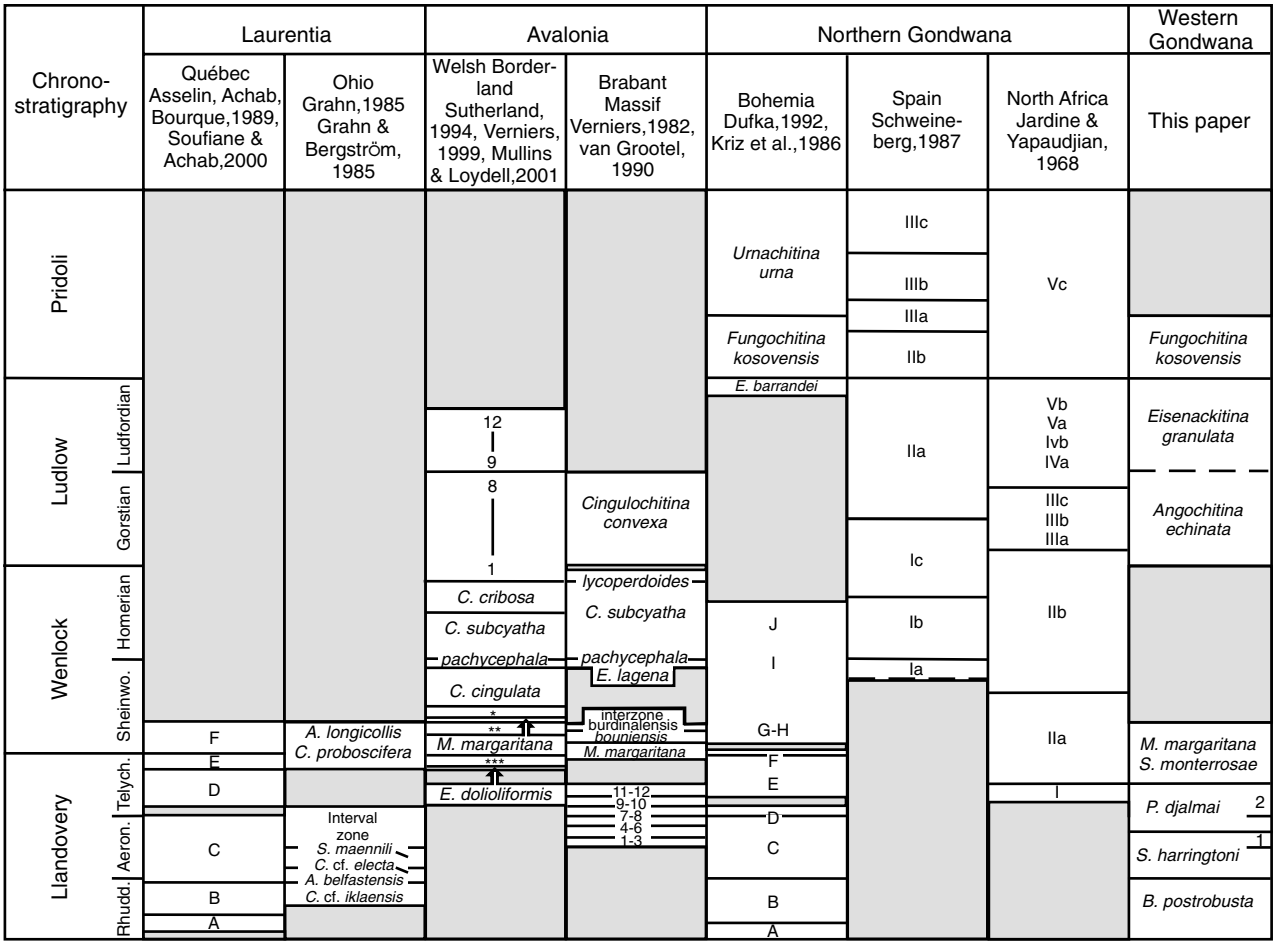

Figure 9. Correlation between Silurian chitinozoan biozones in western Gondwana and other areas on a global scale. 1 – Chitinozoan Subzone of *Sphaerochitina solutidina* and 2 – Subzone of *Desmochitina* cf. *D. densa*. Zones defined by Mullins & Loydell. *** – zones with *Angochitina longicollis*, *Conochitina acuminata*, and *Margachitina banwyensis*. ** – Zone with *Cingulochitina bouniensis*. * – Zone with *Salopochitina bella* = *S. monterrosae*. 'van Grootel, 1990' – G. van Grootel, unpub. Ph.D. thesis, Ghent University, 1990.

Age range: Early Ludlow (*Neodiversograptus nilssoni–Saetograptus scanicus* graptolite zones) (Figs 7–11).

Remarks: *Angochitina echinata* ranges from Ludlow to lower Pridoli strata.

In the global zonation (Verniers *et al.* 1995) the lower part of *Angochitina elongata* Zone can be correlated with the Zone of *Angochitina echinata*. Other important species in this interval include *Conochitina pachycephala*, *Ancyrochitina desmea*, *Belonechitina latifrons* and *Cingulochitina convexa* (Appendix 3).

7.h. *Eisenackitina granulata* Interval Zone

Zone base definition: FOB of *Eisenackitina granulata* (Fig. 5l).

Characterization of zone: The co-occurrence of the index species, *Conochitina gordonensis*, *Margachitina* aff. *M. saretensis* and *Pterochitina perivelata* together with an abundant and diverse chitinozoan fauna ranging from the underlying lower Ludlow strata (Fig. 7).

Reference section for zone base: Outcrop AGS 542 at Urubu River (Grahn & Melo, 2003), upper part of the Pitinga Formation, Amazonas Basin, northern Brazil.

Representative occurrences of zone: Several localities within the upper part of the Pitinga or lowermost part of the Manacapuru formations in the Amazonas Basin, northern Brazil.

Lithostratigraphic distribution: Upper part of the Pitinga and possibly lowermost part of the Manacapuru formations in the Amazonas Basin, northern Brazil.

Age range: Late Ludlow (*Saetograptus leintwardinensis* graptolite Zone in the lower part) (Figs 7–11).

Remarks: *Eisenackitina granulata* ranges from upper Ludlow to lower Pridoli strata.

In the global zonation (Verniers *et al.* 1995) the upper part of the *Angochitina elongata*, *Eisenackitina philipi* and *Eisenackitina barrendei* zones can be correlated with the Zone of *Eisenackitina granulata*. Other important species in this interval include *Eisenackitina lagenomorpha*, *Eisenackitina granosa* and *Sphaerochitina sphaerocephala* (Appendix 3).

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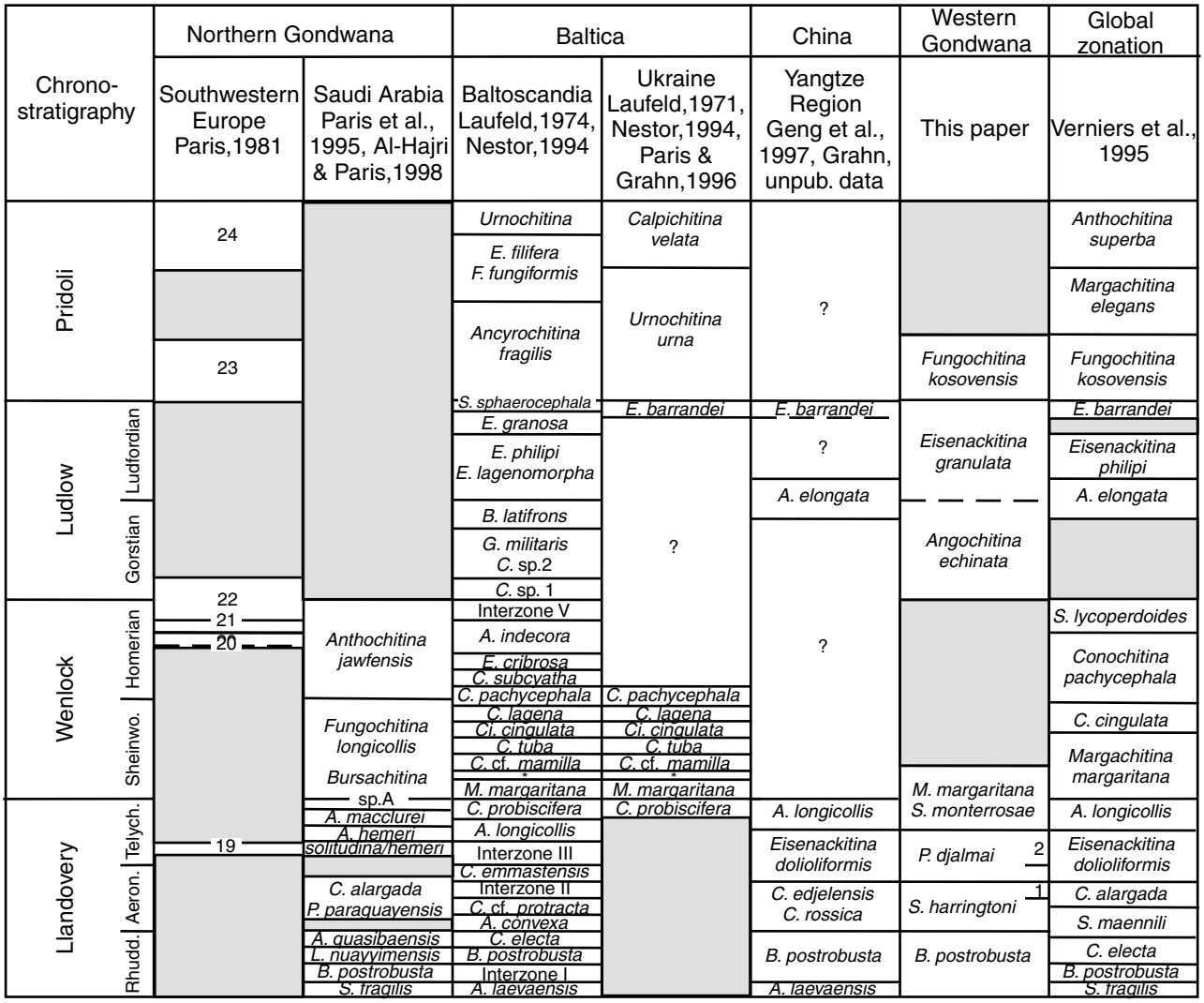

Figure 10. Correlation between Silurian chitinozoan biozones in western Gondwana and other areas on a global scale. 1 – Chitinozoan Subzone of *Sphaerochitina solutidina* and 2 – Subzone of *Desmochitina* cf. D. *densa*.

7.i. *Fungochitina kosovensis* Range Zone

Zone base definition: FOB of *Fungochitina kosovensis* (Fig. 5m).

Characterization of zone: The co-occurrence of the index species, *Ancyrochitina* aff. *A. libyensis*, *Angochitina* n.sp. aff. *A. cyrenaicensis*, *Angochitina*? sp. *sensu* Grahn & Paris, 1992, *Armigutta urubuense*, *Clathrochitina* sp. A *sensu* Grahn, 2003, *Ramochitina bjornsundquisti*, *Rhabdochitina conocephala*, *Saharochitina gomphos*, *Urnochitina urna*, *Urochitina* n.sp. A *sensu* Grahn, 2005*a*, *Vinnalochitina corinnae* and others.

Reference section for zone base: PETROBRAS 1-AM-1-AM well, core 46 (1613 m), uppermost part of the Pitinga Formation, Amazonas Basin, northern Brazil. No outcrop section with the base of *F. kosovensis* Zone is known.

Representative occurrences of zone: Several localities within the uppermost part of the Pitinga and/or lowermost part of the Manacapuru formations in the Amazonas Basin, northern Brazil.

Lithostratigraphic distribution: Uppermost part of the Pitinga and lowermost part of the Manacapuru formations in the Amazonas Basin, northern Brazil and Kirusillas Formation, Peru–Bolivia Basin, southern Bolivia.

Age range: Early Pridoli (Figs 7–11).

Remarks: *Fungochitina kosovensis* is restricted to lower Pridoli strata.

Paris & Kriz (1984) defined the *F. kosovensis* Zone in Bohemia, and the accompanying species include *Calpichitina gregaria*, *Pterochitina perivelata*, *Eisenackitina* cf. *intermedia*, *Urnochitina urna* and others. In the global zonation (Verniers *et al.* 1995) the *Fungochitina kosovensis* Zone is coeval with this zone in western Gondwana. Other important species in this interval include *Eisenackitina intermedia* and *Eisenackitina lagenomorpha* (Appendix 3).

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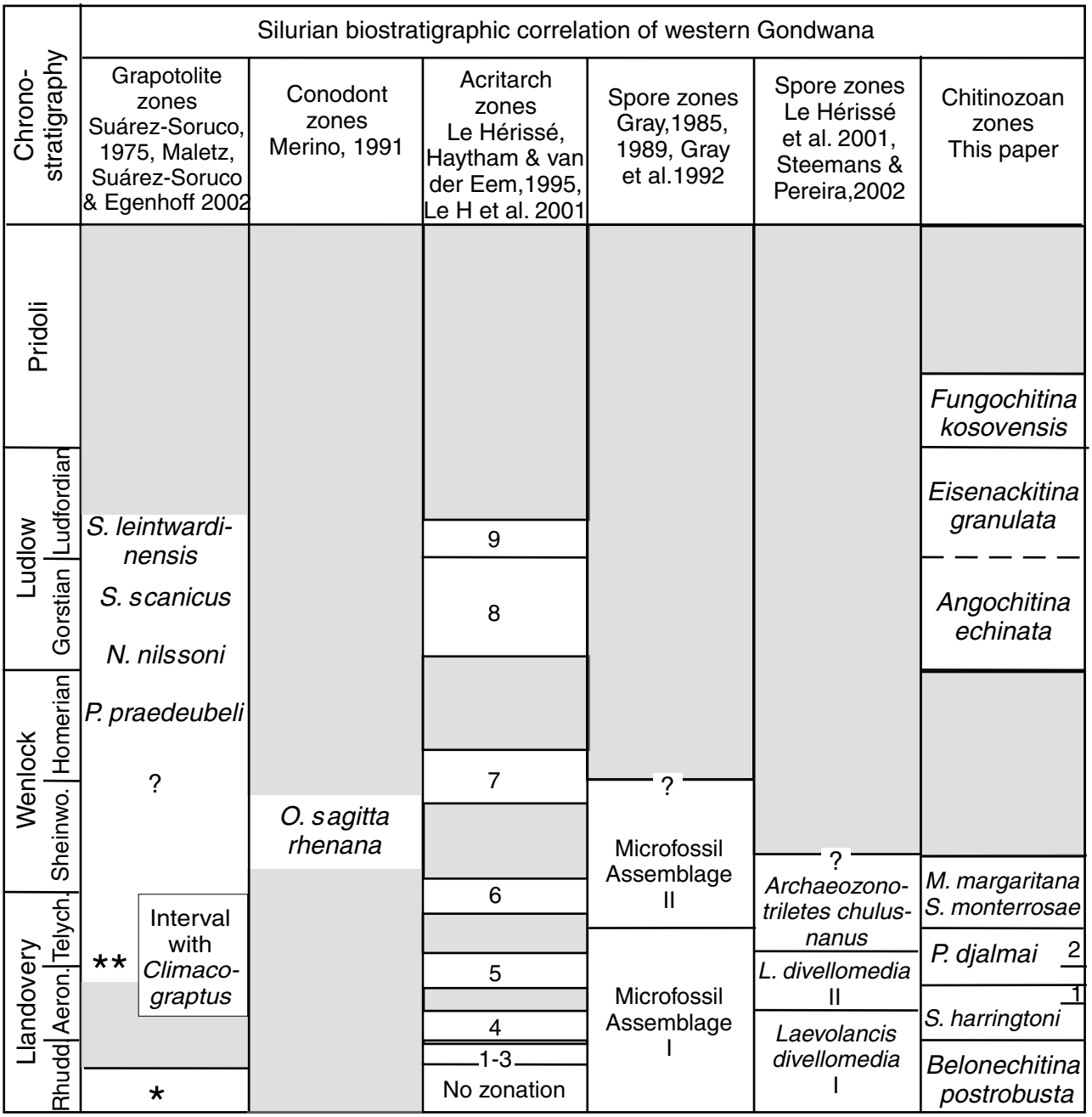

Figure 11. Correlation between Silurian graptolite, conodont, acritarch, spore and chitinozoan biozones in western Gondwana. 1 – Chitinozoan Subzone of *Sphaerochitina solutidina* and 2 – Subzone of *Desmochitina* cf. *D. densa*. * Based on graptolites, Rickards *et al.* (2002), considered the lowermost part of the Lipeón Formation as early Rhuddanian (*acuminatus–atavus* zones). Acritarchs (Bultynck & Martin, 1982; Rubinstein, 1997) and chitinozoans (Grahn & Gutiérrez, 2001), however, suggest a Telychian–Sheinwoodian age for that part. Interval with *Climacograptus* indicate finds of *Monograptus* cf. *gregarius* and *Climacograptus innotatus brasiliensis* in the Amazonas Basin (Jaeger, 1976) and *Climacograptus scalaris scalaris* in the Parnaíba Basin (H. Jaeger, pers. comm. 1992). ** – *Monograptus turriculatus* Zone is present at the base of the Kirusillas Formation (Ahlfeld & Branisa, 1960; Suárez-Soruco, 1975).

8. Conclusions

This erection of the chitinozoan biozonation for the Ordovician and Silurian of western Gondwana (South America) is hampered by the scattered Ordovician information available. Future information from Ecuador, Colombia and Venezuela and complementary information from the investigated areas will alter and refine this biozonation, especially for the Ordovician. It is clear that the Ordovician chitinozoan assemblages have a mixed provinciality with elements from both Laurentia, Baltica and Gondwana. The Silurian chitinozoan assemblages display a more distinct Gondwana affinity. South America was in a polar to circumpolar

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position during the Ordovician and Silurian, and the chitinozoan assemblages therefore should reflect a cold water fauna. As pointed out by Grahn & Bergström (1984), chitinozoan cold water assemblages seem to be more diverse and abundant than tropical assemblages. This is also true for western Gondwana (cf. contemporary tropical faunas in Baltica and Laurentia). The nature of the sampling (mostly oil company borings and isolated outcrops) have prevented a more dense sampling, which undoubtedly could reveal a more detailed chitinozoan biozonation for western Gondwana. Altogether five chitinozoan zones are defined in the Ordovician (zones of *Desmochitina* sp. gr. *minor*, *Conochitina decipiens*, *Eremochitina brevis*, *Lagenochitina obeligis* and *Tanuchitina anticostiensis*), and nine in the Silurian (zones of *Belonechitina postrobusta*, *Spinachitina harringtoni*, *Pogonochitina djalmai*, *Margachitina margaritana–Salopochitina monterrosae*, *Angochitina echinata*, *Eisenackitina granulata*, *Fungochitina kosovensis* and the subzones of *Sphaerochitina solutidina* and *Desmochitina* cf. *D. densa*). These biozones can be correlated with other areas on a global scale.

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Appendix 1. Revised chitinozoan species

Southern Bolivia

Cramer, Díez & Cuerda (1974)
Ancyrochitina ancyrea Bolivian variant = *Ancyrochitina* n.sp. A *sensu* Grahn, 2005*a*
Angochitina sp. 2 = *Angochitina echinata* Eisenack, 1931
Angochitina sp. 1 = *Angochitina* sp.
Linochitina erratica …. *L. cingulata* = *Cingulochitina convexa* (Laufeld, 1974) and *Cingulochitina wronai* Paris, 1984
Conochitina proboscifera = *Conochitina tuba* Eisenack, 1932
Pterochitina perivelata (Eisenack, 1937)
Desmochitina urna = *Urnochitina urna* (Eisenack, 1934)

Liachenko (1994)
Ancyrochitina cf. *ancyrea*, *Fungochitina* sp. A, *Gotlandochitina* sp. 1, and *Ancyrochitina* sp. = Ancyrochitina spp.
Angochitina cf. *echinata* and *Angochitina* sp. A–E = *Angochitina echinata* Eisenack, 1931
Sphaerochitina sp. 1 = *Angochitina* sp.
Sphaerochitina sp. 1 (Pl. 2, fig. 9) = *Fungochitina kosovensis*? Paris, 1981
Cingulochitina aff. sp. *serrata* and *Cingulochitina serrata* = *Cingulochitina serrata* (Taugourdeau & Jekhowsky, 1960)
Conochitina proboscifera and *Conochitina* sp. A = *Conochitina gordonensis* (Cramer, 1964)
Conochitina sp. C = *Conochitina probiscifera* Eisenack, 1937
Conochitina sp. B = *Conochitina tuba*? Eisenack, 1932
Eisenackitina? sp. = *Eisenackitina granulata* (Cramer, 1964)
Margachitina sp. 1 and *Calpichitina* (*Densichitina*) sp. 1 = *Margachitina catenaria* Obut, 1973
Pterochitina perivelata (Eisenack, 1937)

Northern Argentina

Ottone, Toro & Waisfeld (1992)
Conochitina sp. A = *Eremochitina brevis* Benoit & Taugourdeau, 1961
Spathachitina sp. A = *Conochitina ordinaria* Achab, 1980
Spathachitina sp. B and *Lagenochitina* sp. A = *Conochitina brevis* Taugourdeau & Jekhowsky, 1960

Eastern Paraguay

Wood & Miller (1997)
Ancyrochitina sp. 5 = *Ancyrochitina paranaensis* Grahn *in* Grahn, Pereira & Bergamaschi, 2000
Desmochitina cf. *D. densa* Eisenack, 1962
Conochitina sp. (Pl. 16, fig. 5) = *Conochitina probiscifera*? Eisenack, 1937
Conochitina sp. (Pl. 16, fig. 6) = *Conochitina* sp. A *sensu* Grahn, Pereira & Bergamaschi, 2000
Eisenackitina cf. *E. bejui* Wood & Miller, 1991
Linochitina sp. = *Linochitina* sp. A *sensu* Grahn, Pereira & Bergamaschi, 2000

Brazil

Sommer & van Boekel (1963, 1965)
Ancyrochitina erichseni Sommer & van Boekel, 1963
Conochitina djalmai = *Pogonochitina djalmai* Sommer & van Boekel, 1965
Sphaerochitina lucianoi = *Sphaerochitina palestinaense* Grahn, Melo & Steemans, 2005

Costa (1970, 1971*a*)
Pallachitina wilhelmi and *Pallachitina depressa* = *Bursachitina wilhelmi* (Costa, 1970)
Spathachitina cruzi, Spathachitina clarindoi, Spathachitina reticulata, and *Spathachitina tenuis* = *Euconochitina cruzi* (Costa, 1970)
Spathachitina magalhaesi and *Spathachitina raihensis* in Costa, 1970, and in Costa, 1971*a* *Conochitina acuminata* (Pl. 1, fig. 1), *Conochitina decipiens* (Pl. 1, fig. 5), *Conochitina flavioi* (Pl. 2, figs 4–5), *Conochitina pedunculosa* (Pl. 3, figs 1–6, Pl. 4, figs 1–2), *Conochitina simplex* (Pl. 4, fig. 3), *Conochitina turris* (Pl. 4, fig. 5), *Spathachitina raihensis* (Pl. 7, fig. 4), *Spathachitina magalhaesi* (Pl. 7, figs 5–6), *Tanuchitina ontariensis* (Pl. 8, figs 1–4), *Tanuchitina proeminentis* (Pl. 8, figs 5–6), *Tanuchitina paraensis* (Pl. 9, figs 1–7), *Illichitina multiplex* (Pl. 12, fig. 5), *Pogonochitina grandis* (Pl. 13, figs 3, 5), *Cyathochitina brasilica* (Pl. 15, figs 1–3), *Cyathochitina conica* (Pl. 16, fig. 1), *Cyathochitina dispar verrucata* (Pl. 16, figs 2–3), *Cyathochitina campanulaeformis* (Pl. 16, fig. 5), *Cyathochitina caputoi* (Pl. 16, fig. 6), *Cyathochitina elinitae* (Pl. 17, figs 1–4), and *Cyathochitina* cf. *granulata* (Pl. 17, fig. 7) = *Pogonochitina djalmai* Sommer & van Boekel, 1965
Cyathochitina hymenophora nigerica (Pl. 17, figs 5–6) = *Salopochitina monterrosae* (Cramer, 1969)
Conochitina latifrons (Pl. 2, fig. 3), *Pogonochitina grandi* (Pl. 12, fig. 7, Pl. 13, figs 1–2, 4, 6), and *Pogonochitina spinifera* (Pl. 14, fig. 1) = *Pogonochitina* aff. *P. inornata* (Costa, 1971*a*)
Pogonochitina spinifera inornata (Pl. 14, figs 2–4) = *Pogonochitina inornata* (Costa, 1971*a*)
Conochitina intermedia (Pl. 2, figs 1–2) = *Pogonochitina* cf. *P. djalmai* Sommer & van Boekel, 1965
Desmochitina cingulata (Pl. 18, fig. 3), *Desmochitina cingulata serrata* (Pl. 18, figs 4–7), and *Hoegisphaera complanata* (Pl. 18, fig. 8) = *Cingulochitina* ex. gr. *serrata* (Taugourdeau & Jekhowsky, 1960)
Desmochitina erratica (Pl. 18, figs 1–2) = *Linochitina* ex. gr. *erratica* Eisenack, 1931
Conochitina vasculiformis (Pl. 4, fig. 6), *Spathachitina cruzi* (Pl. 6, figs 1–2), *Spathachitina clarindoi* (Pl. 6, figs 3–5), *Spathachitina reticulata* (Pl. 7, figs 1–3), and *Spathachitina tenuis* (Pl. 7, fig. 7) = *Euconochitina cruzi* (Costa, 1970)
*Ancyrochitina spino*sa (Pl. 11, figs 1–2) = *Angochitina* sp. A *sensu* Grahn & Paris, 1992
Pallachitina wilhelmi (Pl. 5, fig. 1), *Pallachitina rotunda* (Pl. 5, fig. 2), and *Pallachitina depressa* (Pl. 5, fig. 3) = *Bursachitina wilhelmi* (Costa, 1970)
Angochitina amazonica (Pl. 11, fig. 6), *Angochitina crumena* (Pl. 11, figs 7–8), *Lagenochitina sommeri* (Pl. 14, figs 5–8), and *Lagenochitina ovoidea* (Pl. 14, figs 9–10) = *Lagenochitina* sp. aff. *L. navicula* Taugourdeau & Jekhowsky, 1960
Cyathochitina caputoi (Pl. 15, figs 6–7) = *Cyathochitina* sp. B *sensu* Paris, 1981
Ancyrochitina ancyrea (Pl. 10, figs 2–4), *Ancyrochitina megastyla* (Pl. 10, fig. 5?), and *Ancyrochitina primitiva* (Pl. 10, figs 6–8) = *Ancyrochitina primitiva*? Eisenack, 1964
Plectochitina saharica (Pl. 11, figs 3–5), *Sphaerochitina collinsoni* (Pl. 12, fig. 2), and *Cyathochitina campanulaeformis* (Pl. 15, figs 4–5) = *Ancyrochitina* sp. *A sensu* Grahn & Paris, 1992.

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Quadros (1982)
Desmochitina sp. = *Cingulochitina bouniensis* Verniers, 1999
Cyathochitina sp. = *Pogonochitina tianguaense* Grahn, Melo & Steemans, 2005
Conochitina dolosa = *Conochitina elongata* Taugourdeau & Jekhowsky, 1960

Appendix 2. List of chitinozoan species reported from western Gondwana and cited in text and figures

Ancyrochitina ancyrea (Eisenack, 1931)
Ancyrochitina brevis Taugourdeau & Jekhowsky, 1960
Ancyrochitina erichseni Sommer & van Boekel, 1963
Ancyrochitina fragilis Eisenack, 1955*a*
Ancyrochitina paranaensis Grahn *in* Grahn, Pereira & Bergamaschi, 2000
Ancyrochitina pitingaense Grahn, 2005*a*
Ancyrochitina polentinensis Schweineberg, 1987
Ancyrochitina primitiva Eisenack, 1964
Ancyrochitina regularis Taugourdeau & Jekhowsky, 1960
Ancyrochitina aff. *A. libyensis* Jaglin, 1986
Ancyrochitina aff. *A. regularis* Taugourdeau & Jekhowsky, 1960
Ancyrochitina aff. *A. tomentosa* Taugourdeau & Jekhowsky, 1960
Ancyrochitina cf. *A. brevis* Taugourdeau & Jekhowsky, 1960
Ancyrochitina cf. *A. desmea* Eisenack, 1964
Ancyrochitina sp. A *sensu* Grahn & Paris, 1992
Ancyrochitina sp. A. *sensu* Grahn & Melo, 2003
Ancyrochitina sp. B *sensu* Grahn & Melo, 2003
Ancyrochitina sp. B. *sensu* Grahn, Melo & Steemans, 2005
Ancyrochitina sp. C *sensu* Grahn & Melo, 2003
Ancyrochitina n. sp. A. *sensu* Grahn, 2005*a*
Ancyrochitina n. sp. B. *sensu* Grahn, 2005*a*
Ancyrochitina ex. gr. *ancyrea* (Eisenack, 1931)
Ancyrochitina ex. gr. *floris* Jaglin, 1986
Ancyrochitina ex. gr. *gutnica* Laufeld, 1974
Angochitina echinata Eisenack, 1931
Angochitina elongata Eisenack, 1931
Angochitina filosa Eisenack, 1955*a*
Angochitina gurupiense Grahn, Melo & Steemans, 2005
Angochitina longicollis Eisenack, 1959
Angochitina strigosa Boumendjel, 2002
Angochitina n. sp. aff. *A. cyrenaicensis sensu* Grahn & Paris, 1992
Angochitina aff. *filosa* Eisenack, 1955*a*
Angochitina sp. aff. *A. mourai non* Lange, 1952 *sensu* Schweineberg, 1987
Angochitina cf. *A. echinata* Eisenack,1931 *sensu* Grahn & Paris, 1992
Angochitina cf. *A. elongata* Eisenack, 1931
Angochitina sp. A *sensu* Grahn & Paris, 1992
Angochitina sp. A *sensu* Grahn & Gutiérrez, 2001
Angochitina sp. 1 *sensu* Grahn & Gutiérrez, 2001
Angochitina sp. 1. *sensu* Grahn, 2005*b*
Angochitina sp. 2 *sensu* Grahn & Gutiérrez, 2001
Angochitina sp. B. *sensu* Grahn & Melo, 2003
Angochitina? thadeui Paris, 1981
Angochitina? sp. *sensu* Grahn & Paris, 1992
Armigutta urubuense Grahn & Melo, 2003
Armoricochitina nigerica (Bouché, 1965)
Belonechitina? plumula n. sp. Grahn, 2005*a*
Belonechitina postrobusta (Nestor, 1980)
Belonechitina sp. A. *sensu* Grahn, 2005*a*
Belonechitina sp. B. *sensu* Grahn, 2005*a*
Bursachitina wilhelmi (Costa, 1970)
Bursachitina sp. A. *sensu* Grahn & Melo, 2003
Cingulochitina bouinensis Verniers, 1999
Cingulochitina convexa (Laufeld, 1974)
Cingulochitina cylindrica (Taugourdeau & Jekhowsky, 1960)
Cingulochitina serrata (Taugourdeau & Jekhowsky, 1960)
Cingulochitina wronai Paris, 1984
Cingulochitina aff. *C. convexa* (Laufeld, 1974)
Cingulochitina aff. *C. ervensis* (Paris *in* Babin *et al.*, 1979)
Cingulochitina aff. *C. serrata* (Taugourdeau & Jekhowsky, 1960)
Cingulochitina sp. A. Paris, 1981
Clathrochitina sp. A. *sensu* Grahn, 2003
Conochitina acuminata Eisenack, 1959
Conochitina brevis (Taugourdeau & Jekhowsky, 1960)
Conochitina decipiens (Taugourdeau & Jekhowsky, 1960)
Conochitina edjelensis (Taugourdeau & Jekhowsky, 1960)
Conochitina elongata (Taugourdeau & Jekhowsky, 1960)
Conochitina gordonensis Cramer, 1964
Conochitina micracantha (Eisenack, 1959)
Conochitina ordinaria Achab, 1980
Conochitina pachycephala Eisenack, 1964
Conochitina pervulgata? Umnova, 1969
Conochitina proboscifera Eisenack, 1937
Conochitina tuba Eisenack, 1932
Conochitina cf. *C. acuminata* Eisenack, 1959
Conochitina cf. *C. armillata* Taugourdeau & Jekhowsky, 1960
Conochitina cf. *C. havliceki* Paris & Mergl, 1984
Conochitina cf. *C. tuba* Eisenack, 1932
Conochitina sp. A *sensu* Grahn, 1992
Conochitina sp. A *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000
Conochitina sp. *sensu* Heuse, Grahn & Erdtmann, 1999
Cyathochitina campanulaeformis (Eisenack,1931)
Cyathochitina caputoi Costa, 1971*a*
Cyathochitina sp. B *sensu* Paris, 1981
Cyathochitina cf. *C. kuckersiana* (Eisenack, 1934)
Desmochitina cortesiana Schweineberg, 1987
Desmochitina densa Eisenack, 1962
Desmochitina sp. gr. *minor* (Szaniawski *in* Chlebowski & Szaniawski, 1974)
Desmochitina cf. *D. densa* Eisenack, 1962
Eisenackitina bejui Wood & Miller, 1991
Eisenackitina cf. *E. bejui* Wood & Miller, 1991
Eisenackitina granulata (Cramer, 1964)
Eremochitina brevis Benoit & Taugourdeau, 1961
Euconochitina cruzi (Costa, 1970)
Euconochitina iklaensis (Nestor, 1984)
Euconochitina patula (Costa, 1971*a*)
Euconochitina sulcata (Costa, 1971*a*)
Euconochitina sp. A. *sensu* Grahn, 2005*a*
Fungochitina kosovensis Paris, 1981
Fungochitina sp. A. *sensu* Grahn & Melo, 2003
Lagenochitina obeligis Paris, 1981
Lagenochitina prussica Eisenack, 1931
Lagenochitina aff. *L. navicula* Taugourdeau & Jekhowsky, 1960
Linochitina penequadrata n. sp. Grahn, 2005*a*
Linochitina aff. *L. klonkensis* Paris, Laufeld & Chlupáè, 1981
Linochitina ex. gr. *erratica* (Eisenack, 1931)
Linochitina sp. A *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000
Linochitina sp. A *sensu* Grahn & Melo, 2003

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Margachitina margaritana (Eisenack, 1937)
Margachitina aff. *M. saretensis* Boumendjel, 2002
Margachitina sp. A. *sensu* Grahn, 2005*a*
Margachitina? sp. *sensu* Grahn, 2005*a*
Plectochitina carminae Cramer, 1964
Plectochitina paraguayensis Wood & Miller, 1991
Plectochitina n. sp. A. *sensu* Grahn, 2005*a*
Plectochitina sp. A. *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000
Plectochitina sp. A. *sensu* Grahn & Melo, 2003
Plectochitina sp. C. *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000
Pogonochitina djalmai (Sommer & van Boekel, 1965)
Pogonochitina inornata (Costa, 1971*a*)
Pogonochitina tianguaense Grahn, Melo & Steemans, 2005
Pogonochitina cf. *P. djalmai* (Sommer & van Boekel, 1965) *sensu* Grahn & Paris, 1992
Pogonochitina aff. *P. inornata* (Costa, 1971*a*)
Pogonochitina n. n. sp. A. *sensu* Grahn, 2005*a*
Pterochitina deichaii Taugourdeau, 1963
Pterochitina perivelata (Eisenack, 1937)
Pterochitina sp. A. *sensu* Grahn, 2005*a*
Ramochitina bjornsundquisti Grahn & Melo, 2003
Ramochitina illiziensis Boumendjel, 1985
Ramochitina cf. *R. illiziensis* Boumendjel, 1985
Ramochitina sp. *sensu* Grahn & Paris, 1992
Ramochitina sp. A. *sensu* Grahn & Melo, 2003
Rhabdochitina conocephala? Eisenack, 1931 *sensu* Boumendjel (K. Boumendjel, unpub. Ph.D. thesis, Univ. de Rennes, 1987)
Rhabdochitina gracilis? Eisenack, 1962
Sagenachitina sp. A. *sensu* Grahn, 2005*a*
Saharochitina gomphos Grahn & Melo, 2003
Salopochitina monterrosae (Cramer, 1969)
Salopochitina aff. *S. monterrosae* (Cramer, 1969)
Sphaerochitina acanthifera Eisenack, 1955b
Sphaerochitina palestinaense Grahn, Melo & Steemans, 2005
Sphaerochitina silurica Grahn *in* Grahn, Pereira & Bergamaschi, 2000
Sphaerochitina solutidina Paris, 1988
Sphaerochitina sphaerocephala (Eisenack, 1932)
Sphaerochitina sp. C *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000
Spinachitina harringtoni Grahn *in* Grahn, Pereira & Bergamaschi, 2000
Spinachitina wolfarti Grahn *in* Grahn, Pereira & Bergamaschi, 2000
Spinachitina n. sp. A. *sensu* Grahn, 2005*a*
Spinachitina sp. A. *sensu* Grahn *in* Grahn, Pereira & Bergamaschi, 2000
Spinachitina sp. *sensu* Grahn, Loboziak & Melo, 2003
Tanuchitina anticostiensis (Achab, 1977)
Tanuchitina elenitae (Cramer, 1964)
Tanuchitina aff. *T. cylindrica* (Taugourdeau & Jekhowsky, 1960) *sensu* Boumendjel (K. Boumendjel, unpub. Ph.D. thesis, Univ. de Rennes, 1987)
Tanuchitina sp. A. *sensu* Grahn, 2005*a*
Urnochitina urna (Eisenack, 1934)
Urochitina n. sp. A. Grahn, 2005*a*
Vinnalochitina corinnae (Jaglin, 1986)

Appendix 3. List of chitinozoan species not reported from western Gondwana but cited in text

Ancyrochitina convexa Nestor, 1980
Ancyrochitina laevaensis Nestor, 1980
Ancyrochitina longispina Achab, 1978
Angochitina seurati Paris, 1988
Belonechitina aspera (Nestor, 1980)
Belonechitina latifrons (Laufeld, 1974)
Calpichitina gregaria Paris & Kriz, 1984
Conochitina alagarda (Cramer, 1967)
Conochitina armifera Achab, 1977
Conochitina concava Achab, 1978
Conochitina electa Nestor, 1980
Conochitina emmastensis (Nestor, 1982)
Conochitina vitrea (Taugourdeau, 1962)
Cyathochitina primitiva Szaniawski *in* Chlebowski & Szaniawski, 1974
Eisenackitina dolioliformis Umnova, 1976
Eisenackitina granosa (Laufeld, 1974)
Eisenackitina intermedia (Eisenack, 1955*a*)
Eisenackitina cf. *intermedia* (Eisenack, 1955*a*)
Eisenackitina lagenomorpha (Eisenack, 1931)
Eisenackitina philipi (Laufeld, 1974)
Hercochitina crickmayi Jansonius, 1964
Lagenochitina esthonica Eisenack, 1955b
Plectochitina nodifer (Nestor, 1980)
Plectochitina pseudoagglutinans (Taugourdeau, 1963)
Plectochitina saharica (Taugourdeau, 1962)
Ramochitina corniculata (Laufeld, 1974)
Spinachitina fragilis (Nestor, 1980)
Spinachitina maennili (Nestor, 1980)
Velatachitina veligera Poumot, 1968

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