SILURIAN AND LOWER DEVONIAN CHITINOZOAN BIOSTRATIGRAPHY OF THE PARANÁ BASIN IN BRAZIL AND PARAGUAY

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Abstract

The taxonomy and distribution of Chitinozoa from Silurian (Llandovery) and Lower Devonian strata are reported from the Paraná Basin in southern Brazil and eastern Paraguay. The pre-Carboniferous sequences of the Paraná Basin in this area are present in three sub-basins viz., the Alto Garças (north) and Apucarana (south) sub-basins in Brazil, and the "East Paraguay Sub-basin" in east Paraguay. There is more similarity in the lithology between the Alto Garças and "East Paraguay" sub-basins, than between the former and the Apucarana sub-basin. Llandoverian and Lochkovian to Pragian beds are present in all sub-basins. So far, no Emsian beds have been found in outcrops from the north–northwest margin of the Alto Garças Sub-basin, and no early Emsian beds in the outcrops on the northeast margin. Furthermore, Emsian beds could not be identified from the "East Paraguay Sub-basin" in the present study. The Early Devonian sequence is more complete in the Apucarana Sub-basin. It seems that the Apucarana Sub-basin endured a different evolution compared to the two other sub-basins during the Ordovician, Silurian and lower Devonian. Of the 39 chitinozoan species encountered, 24 species are left in open nomenclature, and the following five species are newly described: *Ancyrochitina paranaensis*, *Angochitina daemoni*, *Sphaerochitina silurica*, *Spinachitina harringtoni*, and *Spinachitina wolfarti*. A chitinozoan biozonation, with five zones and three subzones, is proposed for the investigated interval, and compared with the spore zonation. In addition we infer that the Furnas Formation could correspond to two chitinozoan zones found in Bolivia and Argentina (zones of *Urochitina loboi* and *Angochitina* aff. *A. comosa*), ranging in age from late Lochkovian to earliest Pragian. The zones are, from oldest to youngest: total range zone of *Belonechitina postrobusta* (upper Rhuddanian); total range zone of *Conochitina elongata* (Aeronian); concurrent range subzone of *Spinachitina wolfarti* n. sp. and *Plectochitina* sp. A (lower Aeronian); concurrent range subzone of *Conochitina proboscifera* and *Spinachitina harringtoni* n. sp. (upper Aeronian *s.l.*); concurrent range subzone of *Conochitina proboscifera* and *Desmochitina* cf. *D. densa* (lower Telychian *s.l.*); concurrent range zone of *Salopochitina monterrosae* and *Conochitina proboscifera* (upper Telychian–lower Sheinwoodian); total range zone of *Urochitina loboi* (upper Lochkovian); total range zone of *Angochitina* aff. *A. comosa* (lowermost Pragian); total range zone of *Ramochitina magnifica* (Pragian *s.l.*), and total range zone of *Ancyrochitina parisi* (upper Emsian).

INTRODUCTION

Silurian rocks of the Paraná Basin in Paraguay and Brazil have been extensively studied since the pioneering works by Harrington (1950), Wolfart (1961), Faria and Reis Neto (1978), Faria (1982), and Andrade and Camarço (1980). The fossiliferous basal Silurian shales in east Paraguay were formerly named the Vargas Peña Shale by Wolfart (1961), who assigned to these shales an early Silurian age, based on a presence of *Climacograptus*. Other fossil groups have subsequently been described from the Vargas Peña type locality (for references, see Wood and Miller, 1991). The Vargas Peña Shale overlies the Eusebio Ayala Formation and underlies the Cariy Formation. Fossils from these predominantly arenaceous sequences are poorly known,

Palynology, 24 (2000): 147–176

ISSN 0191-6122

but they are in general considered as Silurian *s.l.* Together with the Vargas Peña Shale they form the Itacurubí Group. The stratigraphic concept of the Silurian of the Paraná Basin has only changed slightly since Wolfart (1961) and Burjack and Popp (1981). Gray et al. (1985) found tetrahedral tetrads, prasinophytes and acritarchs in the Vila Maria Formation at Três Barras Farm in the State of Goiás, and interpreted the age of the section as early Llandovery. The Vargas Peña Formation in east Paraguay, or the Vila Maria Formation and its equivalents in south Brazil, are now generally considered as Llandovery *s.l.* in age (Wood and Miller, 1991; 1997; Grahn, 1992; Gray et al., 1992; Borghi et al., 1997).

The Lower Devonian stratigraphy of the Paraná Basin has undergone more extensive changes since the reviews of Lange and Petri (1967), Melo (1988) and Grahn (1992). Early Devonian rocks have been known from the Paraná Basin in south Brazil since the pioneering works by Ammon (1893), Derby (1896) and Clarke (1913). Lange and Petri (1967) considered all Early Devonian rocks to be of Emsian age. Early Devonian rocks in east Paraguay were first described by Beder and Windhausen (1918), but they are still poorly known (González and Muff, 1995; Wiens, 1995). Spore investigations by Dino and Rodrigues (1990) and Loboziak et al. (1995) have also shown that late Lochkovian to Pragian beds are present in the Paraná Basin. For a historical review of studies of the Paraná Basin of Brazil prior to 1992, references are made to Grahn (1992). Pereira et al. (1998) presented a recent synopsis of the Ordovician, Silurian and Devonian sedimentary evolution in the region.

GEOLOGIC SETTING AND BIOSTRATIGRAPHY

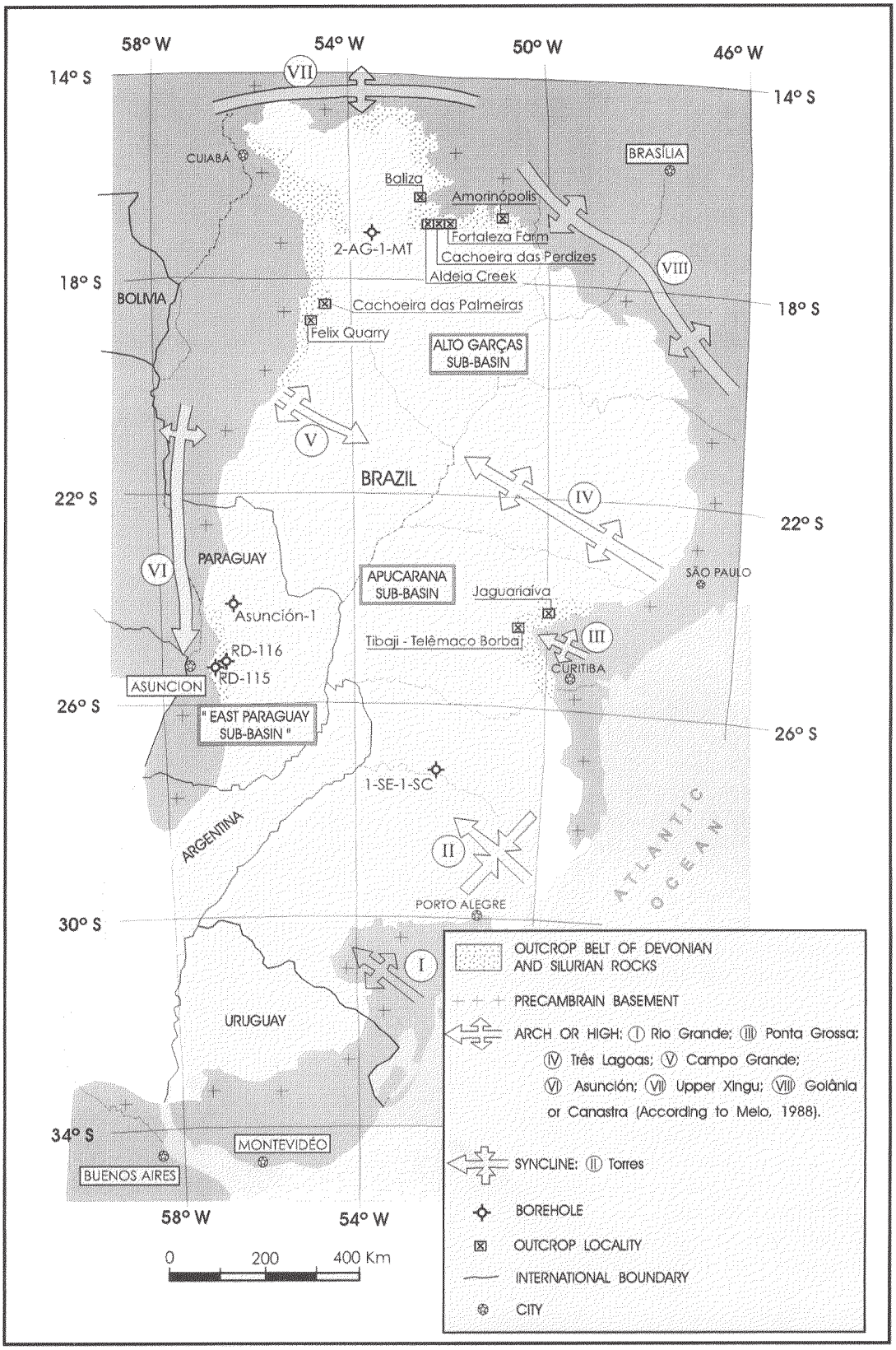
The Paraná Basin covers an area of approximately 1,600,000 km^2; in south Brazil (1,000,000 km^2), east Paraguay (100,000 km^2), central Uruguay (100,000 km^2), and northeast Argentina (400,000 km^2). It is the largest sedimentary basin in South America. The Paraná Basin in Brazil is subdivided into two sub-basins; the Alto Garças Sub-basin in the north, and the Apucarana Sub-basin in the south (Text-Figure 1). As indicated by Northfleet et al. (1969), Ramos (1970), Melo (1988), and Pereira and Bergamaschi (1996), the Alto Garças Sub-basin had a sedimentological evolution different from that of the Apucarana Sub-basin during the Ordovician, Silurian and most of the Devonian. This is evident when comparing the Pragian through Eifelian sequence (D2–D3 by Lange, 1967a), which is much more arenaceous and incomplete in the Alto Garças Sub-basin. The basal Devonian sandstone (D1 by Lange, 1967a) is lithologically similar in both sub-basins, but displays a different paleocurrent pattern in the northern part of the Paraná Basin as compared to that of the southern portion (Melo, 1988). Marine communication between the two sub-basins was not established until Givetian time (Melo, 1988; Pereira and Bergamaschi, 1996). There are also more lithological similarities between the Alto Garças and "East Paraguay" sub-basins, than between the former and the Apucarana Sub-basin. Silurian and Early Devonian rocks crop out in narrow belts east and southeast of Asunción in east Paraguay, on the east margin of the Apucarana Sub-basin, and on the north–northwestern and northeastern margins of the Alto Garças Sub-basin (Text-Figure 1). The predominant lithologies are sandstones and shales with minor amounts of siltstones. The Silurian of the Apucarana Sub-basin is also more arenaceous than in the other two sub-basins. It has not been possible to identify any fossils of early Emsian or early Eifelian age in the Paraná Basin of Brazil and Paraguay. The three sub-basins will be treated separately in the following discussions.

Apucarana Sub-basin

The classical early Devonian formations of the Paraná Basin were defined by Oliveira (1912) in the east outcrop belt of the Apucarana Sub-basin. The sub-basin is delimited by the Campo Grande and Três Lagoas Highs to the north (Text-Figure 1).

Vila Maria equivalents. Beds contemporary to the Vila Maria Formation in the Alto Garças Sub-basin have been identified in the deep drill hole 1-SE-1-SC (Text-Figure 1), in the southern part of the Apucarana Sub-basin. It is still uncertain if the Iapó Formation (Maack, 1947) constitutes the equivalent of the lower part of the Vila Maria Formation. Both formations yield glaciogenic deposits. In the Vila Maria equivalents the glaciogenic beds are overlain by shales and sandstones.

Furnas Formation. The Furnas Formation was proposed for a basal sandstone unit in Serra das Furnas, State of Paraná. The sandstone is locally rich in ichnofossils including *Didymaulichnus furnai* and *Palaeophycus* sp. The marine influence increases toward the top of the formation, and in its uppermost part occur rhyniophyte-bearing siltstones yielding spores and phytoplankton indicative of the Lochkovian–Pragian transition (Dino and Rodrigues, 1990; Loboziak et al., 1995). The maximum thickness of this unit is about 250 m. The base of the Furnas Formation could still be of Lochkovian age, and coeval with the base of the Puesto el Tigre (Volkheimer et al., 1986) and Talacasto formations (Le Hérissé et al., 1996) in Argentina, and the Tequeje (Vavrdová et al., 1996) and



Text-Figure 1. Location map of outcrops and wells in the Paraná Basin of Brazil and Paraguay investigated in the study.

Santa Rosa Formations in Bolivia (Rachebaeuf et al., 1993). No chitinozoans have been recovered from the Furnas Formation.

Ponta Grossa Formation. The Ponta Grossa Formation, as defined by Oliveira (1912), is restricted to the lower richly fossiliferous shales in the Apucarana Sub-basin. The lithology is dominated by gray shales with subordinate interbeds of siltstone and sandstone, and the maximum thickness is estimated at about 250 m. The invertebrate fauna (for further references, see Grahn, 1992) was chiefly described by Clarke (1913), and partly revised by Melo (1985, 1988). Lange (1967a) and Daemon et al. (1967) considered the Ponta Grossa Formation *s.s.* (their Jaguariaíva Member of the Ponta Grossa Formation) to be entirely of Emsian age. From the work of Daemon *et al*. (1967), it is clearly demonstrated that Emsian rocks are missing in the lower part of the sequence. Only in beds corresponding to unit D2b and D3 by Lange (1967a) does *Emphanisporites* cf. *erraticus* (= *Emphanisporites annulatus*) appear, which is a stratigraphically important spore to establish the presence of Emsian or younger beds. The chitinozoans indicate the presence of the *Ramochitina magnifica* Zone of Pragian age in the lower part of the Ponta Grossa Formation *s.s.*, and the *Ancyrochitina parisi* Zone of late Emsian age in the uppermost part.

The Tibaji Member of the Ponta Grossa Formation. This unit was defined by Oliveira (1912) for a micaceous, silty tempestitic sandstone exposed along São Domingos Creek. It pinches out basinwards and reaches a maximum thickness of about 35 m (Melo 1988). The fossil content is similar to that in the upper part of the Ponta Grossa Formation *s.s.*, and thus of late Emsian age. The Tibaji is here considered as a member of the Ponta Grossa Formation *sensu* Oliveira (1912). The lowermost part of the São Domingos Formation, as defined by Maack (1947) at the same type locality as for the Tibaji Member, is considered late Emsian. Lithologically this interval consists of alternating shale and siltstone layers.

Alto Garças Sub-basin

The Alto Garças Sub-basin is delimited by the Upper Xingu High to the north, and the Goiânia High to the northeast (Text-Figure 1). Evans (1894) assigned the rocks in the State of Mato Grosso to the Chapada Series and named Chapada dos Guimarães as the type area. This designation separated them from the Devonian rocks described from the State of Paraná (Apucarana Sub-basin) by Derby (1878). Ever since, it has been a controversial question if the stratigraphic nomenclature from the Apucarana Sub-basin can also be applied in the Alto Garças Sub-basin. In this paper we refer to the chronostratigraphic equivalents of the formations in the Apucarana Sub-basin.

Vila Maria Formation. The Vila Maria Formation was defined by Andrade and Camarço (1980), however, Faria (1982), formally described the rocks lithologically and designated a type locality for the unit. The formation consists of three parts. The lower comprises glaciogenic deposits, which are overlain by a middle shale sequence that contains fossils. The upper part consists of shallow marine sandstones yielding ichnofossils (*Arthrophycus alleghaniensis* and *Palaeophycus* sp.)

Furnas Equivalents. Sandstones underlying shales and siltstones of Ponta Grossa equivalents are contemporary to the Furnas Formation in the south part of the Paraná Basin (Apucarana Sub-basin). The Furnas Formation is here considered as possibly Lochkovian at the base, and earliest Pragian in the uppermost part. No chitinozoans have been found in this formation.

Ponta Grossa and Tibaji Equivalents. The Ponta Grossa Formation, as originally defined by Oliveira (1912) in the Apucarana Sub-Basin, contains gray shales with subordinate interbeds of siltstone and sandstone. In the Alto Garças Sub-Basin the content of sandstones is comparatively higher, and in the upper part the shales are replaced by siltstones. The chitinozoan assemblages show a striking similarity between the two sub-basins. The lower part with dark shales is of Pragian age, as evidenced by the presence of *Ramochitina magnifica*. Siltstones belonging to beds equivalent to the upper part of the Ponta Grossa Formation and the Tibaji Member, yield *Ancyrochitina* sp. A and *Ancyrochitina parisi*, the latter species being characteristic for the Tibaji Member and slightly younger beds in the Apucarana Sub-Basin. The Ponta Grossa equivalents are overlain by tempestitic sandstones that in the upper part are of late Eifelian age. The relations between the lower and upper part of the Ponta Grossa equivalents are difficult to discern. However, the siltstones of late Emsian age have not been found in the north–northwestern part of the Alto Garças Sub-Basin. This suggests the late Emsian transgression only reached the northeastern part of the sub-basin, and if so, there would be a gap in the sequence, corresponding to at least part of the Emsian in the north–northwestern part of the basin. In the northeastern part of the basin this gap includes the early Emsian.

"East Paraguay Sub-basin"

The "East Paraguay Sub-basin" is delimited by the Asunción High to the west (Text-Figure 1), and had a

marine connection to the Paraná Basin in Brazil, eastwards, through the Ordovician–early Devonian. Beds underlying the Itacurubí Group have been referred to Llanvirn–late Ashgill (Wiens, 1995), Ordovician *s.l.* (Wolfart, 1961; De Graff, 1987) or early Llandovery (Harrington, 1972). It should be noted that Caradocian shelly fossils have been found reworked into shales of Aeronian age in well Asunción-1 (Text-Figure 1).

Eusebio Ayala Formation. The type locality for this formation consists of road-cuts along Highway 2 between Eusebio Ayala and Itacurubí, from the outskirts of Eusebio Ayala to 5.5 km SE of the town. The total thickness of this unit is between 200–250 m (Harrington, 1972). Yellowish to brownish sandstones are the dominant lithologies, and shales and mudstone intercalations are present. Recently diamictites, sandstones and shales, attributed to a transgressive glacio–marine environment, were described by Borghi et al. (1997). Rare pelecypods, trilobites, brachiopods and orthoceratids in this sequence suggests a Silurian age.

Vargas Peña Formation. The Vargas Peña Shale is a kaolinite-rich, micaceous clay shale, that in weathered outcrops is mottled orange, yellow, brown and/or red. The total thickness of this unit is about 200 m. The fossils have been extensively described in the literature (see above for references). In its type section, at the homonymous clay pit, the Vargas Peña Formation is latest Aeronian or youngest Telychian in age, but in drillings and shale outcrops outside the type locality, the unit also contains early Aeronian chitinozoans. The authors therefore, refer shales of early Aeronian age, commonly defined as Vargas Peña shales, as the Vargas Peña Formation *s.l.*

Cariy Formation. The type locality for this formation comprises road-cuts and small quarries along Highway 2, close to Cariy Loma and Posta Primavera, 5–8 km SE of Itacurubí. The maximum thickness of this unit is estimated to be more than 100 m. Clay shale intercalations in predominantly yellowish to brownish and reddish sandstones have yielded a rich fauna of *Skolithus* sp., brachiopods, tentaculitids, favositids, graptolites, and trilobites. The chitinozoans suggest a late Telychian–early Sheinwoodian age. The Cariy Formation is unconformably overlain by late Famennian or younger glacial deposits or, locally, by early Devonian sandstones of the Santa Elena Formation.

Santa Elena Formation. The type area for the Santa Elena Formation includes outcrops near the town of Santa Elena. The formation was informally introduced by Gonzalez et al. (1994), and has been commonly used ever since. Its total thickness is estimated to be about 700 m. It consists of yellowish to brownish or reddish sandstones with grayish shale intercalations. The lower boundary is marked by a conglomerate above the regressive Cariy Formation. In the upper part of the formation the intercalating shales contain Pragian chitinozoans. Milani and Daemon (1992) have reported Emsian microfossils from this formation. The Santa Elena Formation is conformably overlain by sandstones of the informally designed Lima Formation.

PREVIOUS CHITINOZOAN RESEARCH IN THE PARANÁ BASIN

Devonian chitinozoans from the Paraná Basin are known only from a handful of papers. Lange (1949) described a chitinozoan species from the Emsian part of the Ponta Grossa Formation *s.s.*, which also is the first chitinozoan described and illustrated from Brazil. In his docent thesis, Sommer (1963) described chitinozoans from Aragarças in the State of Goiás, and Costa (1966, 1971), chitinozoans from Ribeirão do Monte, about 110 km southeast of Aragarças. A biozonation, mainly based on chitinozoans, was established for the Devonian of the Paraná Basin by Lange (1967a). Silurian chitinozoans from two shallow drillings in east Paraguay and from a well in the southern part of the Apucarana Sub-basin, were mentioned by Grahn in Gray et al. (1992). Wood and Miller (1991, 1997) described or illustrated chitinozoans, acritarchs and spores from the Vargas Peña type locality. Devonian chitinozoans have been reported from east Paraguay (Milani and Daemon, 1992), but the fauna is still undescribed.

MATERIALS AND METHODS

The localities of the outcrop sections investigated and the wells discussed in this paper are shown in Text-Figure 1. A total of 236 samples from the Alto Garças and Apucarana sub-basins in Brazil and the Paraná Basin in east Paraguay have been examined. The residues were studied for chitinozoans under a stereo light microscope and afterwards prepared for miospore and acritarch studies. Representative chitinozoan specimens were picked for analysis with a Scanning Electron Microscope performed in cooperation with Setor de Bioestratigrafia e Paleoecologia (SEBIPE) at Centro de Pesquisas e Desenvolvimento Leopoldo A. Miguez de Mello (CENPES), Petrobrás, in Rio de Janeiro. Sample processing and SEM preparations were carried out at the Geological Laboratory (LGPA) of the Geological Faculty at Universidade do Estado do Rio de Janeiro according to the techniques described by Laufeld (1974). Holotypes are stored in the evertebrate collections of Museo Nacional in Rio de Janeiro.

LOCALITIES AND CHITINOZOANS

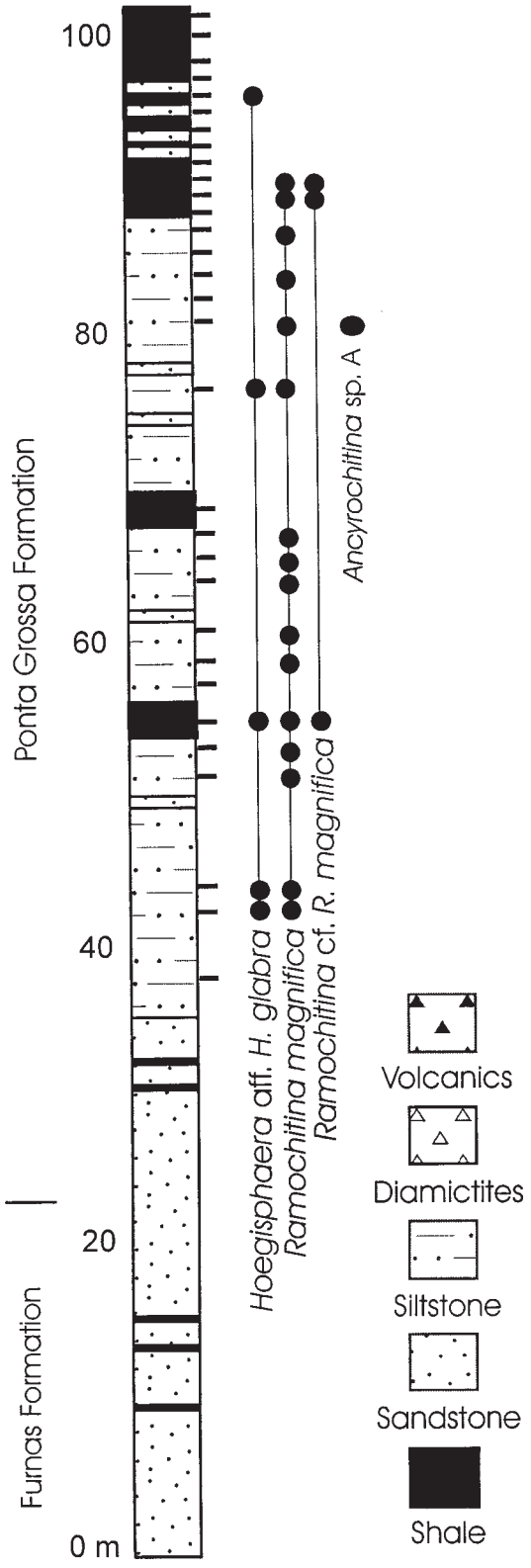
The localities (Text-Figure 1) are described in stratigraphical order for each sub-basin, and their geographic positions are given in co-ordinates determined by Geographic Positioning Satellites. The following discussion includes data from published and unpublished sources and the samples examined in our study.

Apucarana Sub-basin

Well 1-SE-1-SC. (27° 8' 36.4" S, 52° 17' 54.5" W). The well was drilled near the city of Seara in the State of Santa Catarina by Petrobrás during 1981–1982 (Text-Figure 1). Vila Maria Formation equivalents yield chitinozoans, e.g., *Ancyrochitina* spp., *Angochitina* spp., and *Cyathochitina* sp. B *sensu* Paris 1981, which confirms an Aeronian age.

Jaguariaíva. (24° 14' 12" S, 49° 42' 49" W–24° 14' 27" S, 49° 43' 54" W). The Jaguariaíva reference section is assigned to the Ponta Grossa Formation and is exposed along the railroad from Jaguariaíva to Arapoti from km 2.2 to km 6.6 (altitude 860 to 960 m). The lithology consists of gray shales with subordinate interbeds of siltstone and sandstone (Text-Figure 2). This section was previously believed to represent a complete sequence of the Ponta Grossa Formation. Lange and Petri (1967) considered it to be Emsian in age, and that the rocks only represented the lower part of the Ponta Grossa Formation. Therefore, they introduced the term Jaguariaíva Member of the Ponta Grossa Formation. However, from the original definition by Oliveira (1912), it is clear that his Ponta Grossa Shale corresponds to a transgressive shale section above the Furnas Formation and below a shaly and silty section referred to as São Domingos Shale by Maack (1947). These two units were lumped together as a single Ponta Grossa Formation by Oppenheim (1936), and this has been commonly accepted until recently. We consider the Jaguariaíva Member to be a junior synonym of the Ponta Grossa Formation *s.s.*

The Ponta Grossa Formation is of Pragian age at the type locality. The chitinozoan assemblage is dominated by *Ramochitina magnifica* and *Hoegisphaera* cf. *H. glabra*. A rare occurrence of *Ancyrochitina* sp. A (= *Cladochitina biconstricta* (Lange, 1949 *pars*) is also recorded. Strikingly similar chitinozoan faunas have been described from the lower Puesto el Tigre Formation in northwest Argentina (Volkheimer et al., 1986), and from the upper part of the Tequeje Formation in northern Bolivia (Vavrdová et al., 1996). In the latter area, Pragian spores also have been recovered from the same beds as the chitinozoans.



Text-Figure 2. Stratigraphic column and chitinozoan range chart for the Jaguariaíva type section.

Tibaji–Telêmaco Borba. (24° 30' 26" S, 50° 25' 12" W–24° 30' 10" S, 50° 26' 40" W). The Tibaji–Telêmaco Borba section is situated along road PR-340, from the outskirts of Tibaji and extending 15 km towards Telêmaco Borba (Text-Figure 3). The road was recently widened and a seemingly undisturbed sequence from the uppermost Furnas Formation into the lower São Domingos Formation is now exposed. The lowermost part of the section yields *Ramochitina magnifica* and *Hoegisphaera* cf. *H. glabra*, a characteristic Pragian chitinozoan assemblage. The first appearance of *Angochitina daemoni* n. sp. (= *Angochitina* cf. *A. capillata* by Lange 1967a) and *Ramochitina ramosi* indicates a late Emsian age. Other species in the Emsian part of the Tibaji–Telêmaco Borba section are *Angochitina* sp. B, *Ancyrochitina* sp. A (= *Cladochitina biconstricta* (Lange 1949 *pars*), *Ancyrochitina* sp. B, and *Ancyrochitina parisi*. The latter is a characteristic species for the late Emsian, and occurs within and immediately above the Tibaji Member of the Ponta Grossa Formation *s.s.*

Alto Garças Sub-basin

Aldeia Creek. (16° 26' 45" S, 52° 08' 36" W). The Aldeia Creek section according to M.L. Assine (written comm., 1997), differs in thickness and lithology from the paratype section for the Vila Maria Formation at Aldeia Creek by Faria (1982), and as illustrated by Gray et al. (1985) and Pereira (1992). Two of the samples (Text-Figure 4) yielded chitinozoans: *Ancyrochitina ancyrea*, *Ancyrochitina paranaensis* n. sp., *Sphaerochitina silurica* n. sp., and *Plectochitina* sp. C. The age of the Vila Maria shales at Aldeia Creek is late Aeronian (late middle Llandovery).

Cachoeira das Perdizes. (16° 22' 11" S, 52° 22' 34" W). This section was recognized by Faria (1982), and later described by, among others, Laranjeira et al. (1997) and Assine (1996). A sequence from the base of the Vila Maria (Iapó?) Formation into the Furnas Formation crops out at an 80 m high waterfall situated southeast of the town of Baliza in Goiás. Two samples from the Vila Maria shales yielded spores, acritarchs, and cryptospores (Laranjeira et al., 1997), but no chitinozoans were found by them. A similar palynoflora is present at the type locality for the Vila Maria Formation at Três Barras Farm in the State of Goiás (Gray et al., 1985).

Fortaleza Farm. (16° 24' 58" S, 52° 06' 48" W). The Vila Maria Formation exposed at the locality is not described in the literature. It is situated approximately 3 km east–northeast of the Aldeia Creek section. No chitinozoans were recovered.

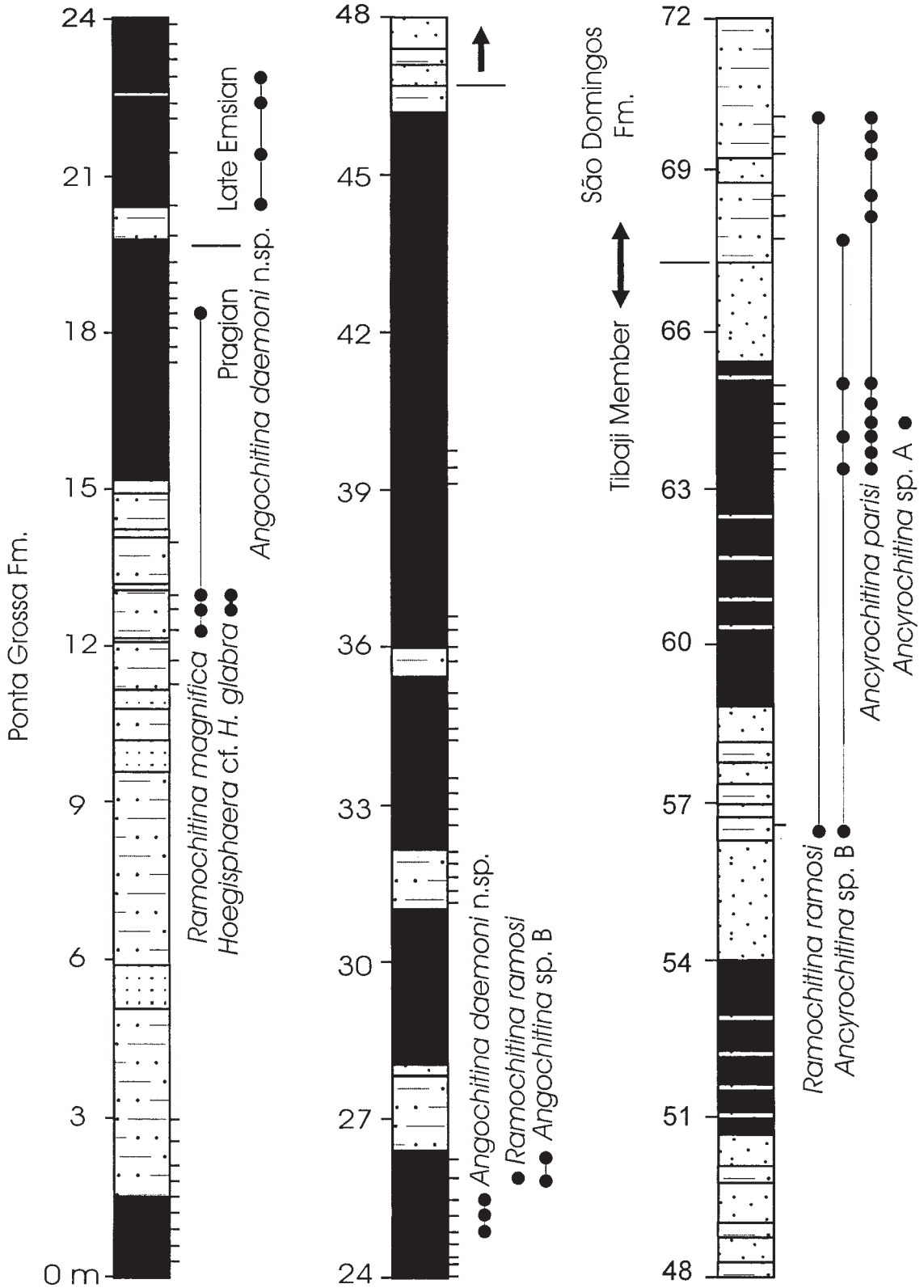
Amorinópolis. (16° 35' 27" S, 51° 05' 39" W). The Amorinópolis section is situated inside Amorinópolis town. The sample studied was collected from an argillaceous layer ca. 1 m above the basal Furnas Formation. A thin gravel bed marks the boundary between the Furnas and Ponta Grossa Formations at this locality. The sample yielded *Ramochitina* cf. *R. magnifica*, suggesting a Pragian age for the investigated layer.

Cachoeira das Palmeiras. (18° 21' 42" S, 54° 36' 43" W). The outcrop is situated in a little waterfall of the Rio Taquari, along the road between Coxim and Rondonópolis, and about 20 km outside Coxim. It has not been mentioned previously in the literature. The sampled rocks probably correspond to Ponta Grossa equivalents. No chitinozoans were recovered.

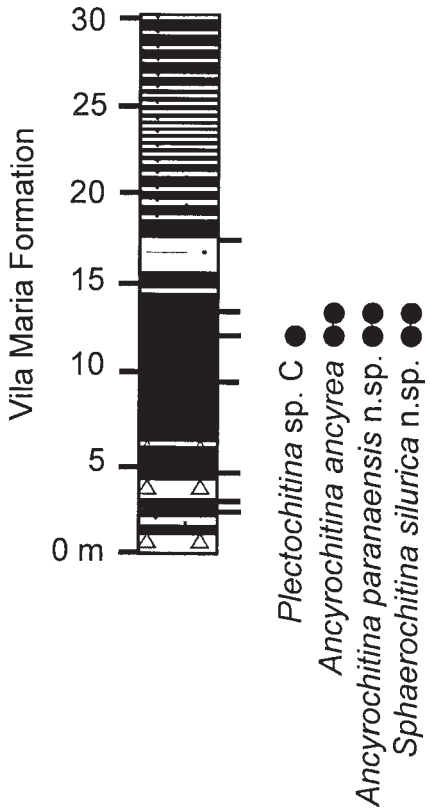
Felix Quarry. (18° 55' 57" S, 54° 50' 41" W). The Felix Quarry section (locally known as Barreiro da Prefeitura) is situated within the city of Rio Verde de Mato Grosso (Text-Figure 5), and close to route BR 163. Predominantly dark shales, belonging to Ponta Grossa equivalents, are here overlain by tempestitic sandstone of unknown age. The shales yield common *Ramochitina magnifica* indicating a Pragian age. No Emsian chitinozoan species were found.

Baliza. (16° 15' 50" S, 52° 31' 40" W). The Baliza section (Text-Figure 5) is situated along the road between Baliza and Doverlandia, and close to the bridge over Ribeirão das Perdizes. The lithology was discussed by Pereira (1992). The section consists of sandstones and siltstones corresponding to equivalents of the Ponta Grossa Formation. The chitinozoan species present, *Ancyrochitina parisi* and *Ancyrochitina* sp. A, indicate a late Emsian age.

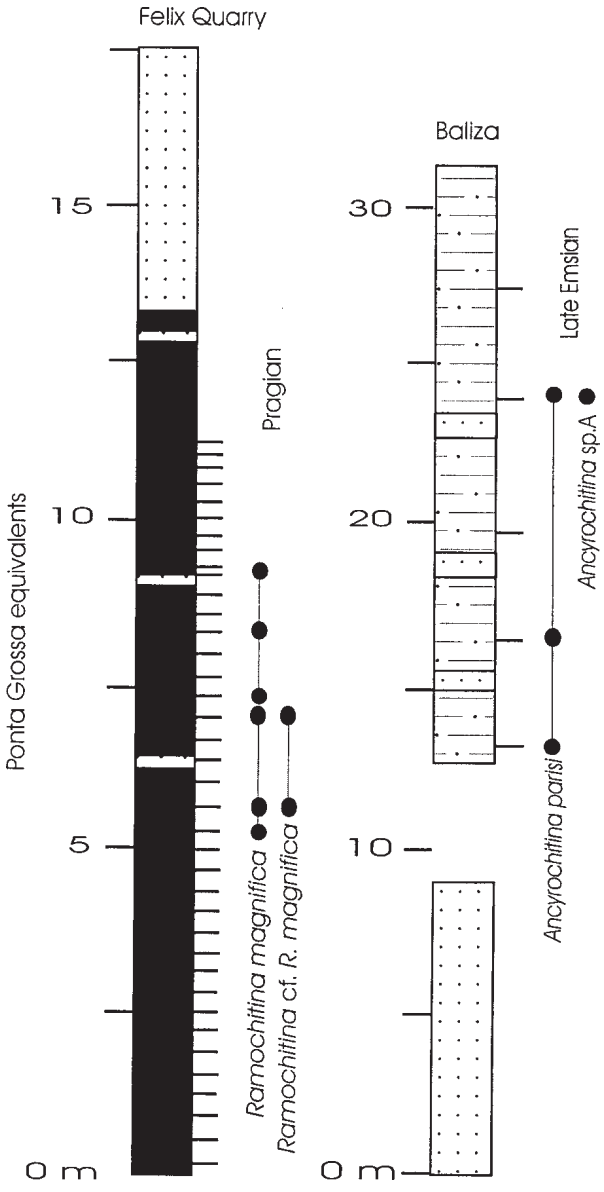
Well 2-AG-1-MT. (16° 57' 34.8" S, 53° 31' 26" W). This well was drilled in the northern part of the Alto Garças Sub-basin near Alto Garças in the State of Mato Grosso by Petrobrás in 1965, and it was made the standard reference section for the Paraná Basin Devonian by Lange (1967a). Faria (1982), using the well, subdivided the Furnas Formation *sensu* Lange, and introduced the Vila Maria Formation for the lower part. Zalán et al. (1987) further subdivided the sequence, and defined the Rio Ivaí Formation for the lowermost part of the Vila Maria Formation *sensu* Faria (1982). The pre-Ponta Grossa beds have also been discussed by Assine and Soares (1989), Assine et al. (1994), and Pereira (1992). Lange (1967a) found Early Devonian chitinozoans in two cores (Text-Figure 6). Core 18 yielded a characteristic Pragian assemblage containing *Ramochitina magnifica*. *Ramochitina ramosi*, a species that ranges from late Emsian to middle Givetian in the Paraná Basin, was recovered in core 17. Two other late Emsian species, *Ancyrochitina parisi* and *Ancyrochitina* sp. B, were recovered in cuttings below core 17. No chitinozoans were recovered from core 19.



Text-Figure 3. Stratigraphic column and chitinozoan range chart for the Lower Devonian in the Tibaji–Telêmaco Borba section. The arrows indicate the extension of the Tibaji Member of the Ponta Grossa Formation *s.s.*, and the base of the overlying São Domingos Formation. For legend, see Text-Figure 2.



Text-Figure 4. Stratigraphic column and chitinozoan range chart for the Aldeia Creek section. For legend, see Text-Figure 2.

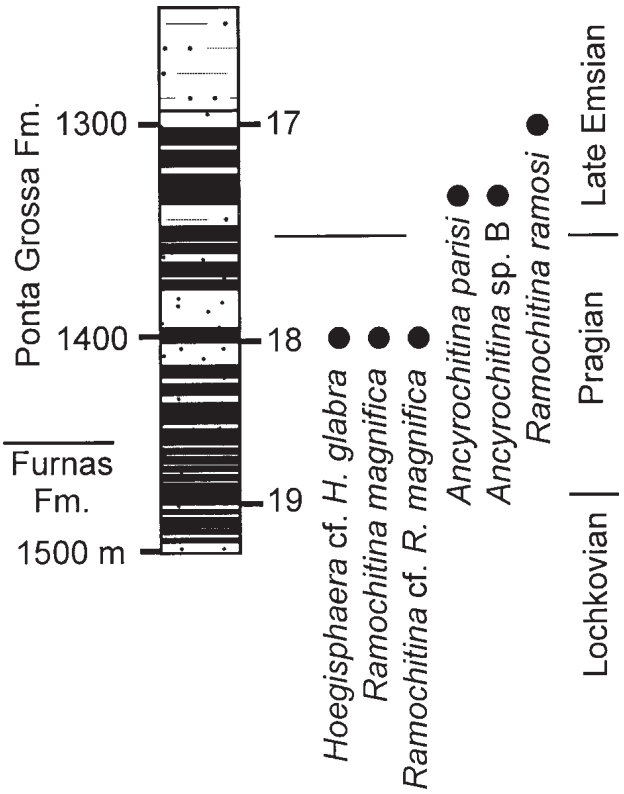


Text-Figure 5. Stratigraphic column and chitinozoan range chart for the Baliza and Felix Quarry sections. For legend, see Text-Figure 2.

"East Paraguay Sub-basin"

Well Asunción-1. (24° 4' 12.55" S, 56° 27' 12.42" W). Chitinozoans from this well were recovered by Milani and Daemon (1992) and Milani et al. (1996) from shales between 2,282.5–2,345 m and 2,790–2,820 m (Text-Figure 7). The well was drilled by Shell-Pecten in 1981 to a total depth of 3,385 m. From 2,282.5 m to 2,345 m, Milani and Daemon (1992) and Milani et al. (1996) mentioned a chitinozoan fauna, according to them characteristic for the lower Ponta Grossa Formation, but despite this they refer the sequence to the Vargas Peña Formation. Between 2,790 and 2,820 m chitinozoans typical for the Vargas Peña and Vila Maria Formations were found. The Vila Maria Formation is assigned a Silurian age, while the corresponding beds in Paraguay are placed at the base of the Tobati Formation, and considered to be of Caradocian and/or Ashgillian age. This very confusing picture is obviously due to an erroneous subdivision of the sequence into formations based only on lithology and without any biostratigraphic control. The shales between 2,282.5–2,345 m yield the characteristic Pragian chitinozoan species *Ramochitina magnifica*. The chitinozoan assemblage in the shaly interval between 2,790–2,820 m contains chitinozoan species characteristic for the early Aeronian, with such species as *Spinachitina wolfarti* n. sp. and *Spinachitina* sp. A.

Well RD-115. (56° 50' S, 25° 20' W). This well was drilled by Anschutz Minerals east of the city of Eusebio Ayala in 1980 to a total depth of 163 m. The shales contain



Text-Figure 6. Stratigraphic column and chitinozoan range chart for the Early Devonian in the 2-AG-1-MT well. For legend, see Text-Figure 2.

chitinozoans of Aeronian age, suggesting their assignment to the Vargas Peña Formation *s.l.* (Text-Figure 7). In the upper part occur e.g., *Conochitina* cf. *C. armillata* and *Cyathochitina* sp. B *sensu* Paris 1981, whereas in the lower part *Spinachitina harringtoni* n. sp., *Spinachitina wolfarti* n. sp. and *Spinachitina* sp. A are common species.

Well RD-116. (56° 40' S, 25° 18' W). This well was drilled by Anschutz Minerals northeast of the city of Santa Elena (Text-Figure 8) in 1980 to a total depth of 402.45 m. It was discussed by González and Muff (1995), who refer the upper 150 meters to the Santa Elena Formation, and the lower 250 m to the Cariy Formation. Milani and Daemon in González and Muff (1995) considered the lowermost 50 m to be Ludlovian, and the uppermost 60 m to be Pridolian–Lochkovian. From this investigation it is clear that the lower ca. 250 m in the well can be correlated with the Vargas Peña Formation, and possibly also the uppermost Eusebio Ayala Formation below 400 m (Text-Figure 8). The Cariy Formation is about 150 m thick and underlies ca. 50 m of glaciogenic deposits. The Cariy Formation is of late Telychian–early Sheinwoodian age, as evidenced by its characteristic chitinozoan fauna that includes *Conochitina proboscifera, Fungochitina* sp. A, *Margachitina* cf. *M. margaritana*, and *Salopochitina* (= *Pogonochitina*) *monterrosae*. This chitinozoan assemblage shows similarity to the fauna from the lower Pitinga Formation in Amazonas Basin (Grahn and Paris, 1992).

SPECIMEN REPOSITORY

Type specimens are housed in the Coleção de Paleoinvertebrados do Departamento de Geologia e Paleontologia do Museu Nacional, Rio de Janeiro, Brazil.

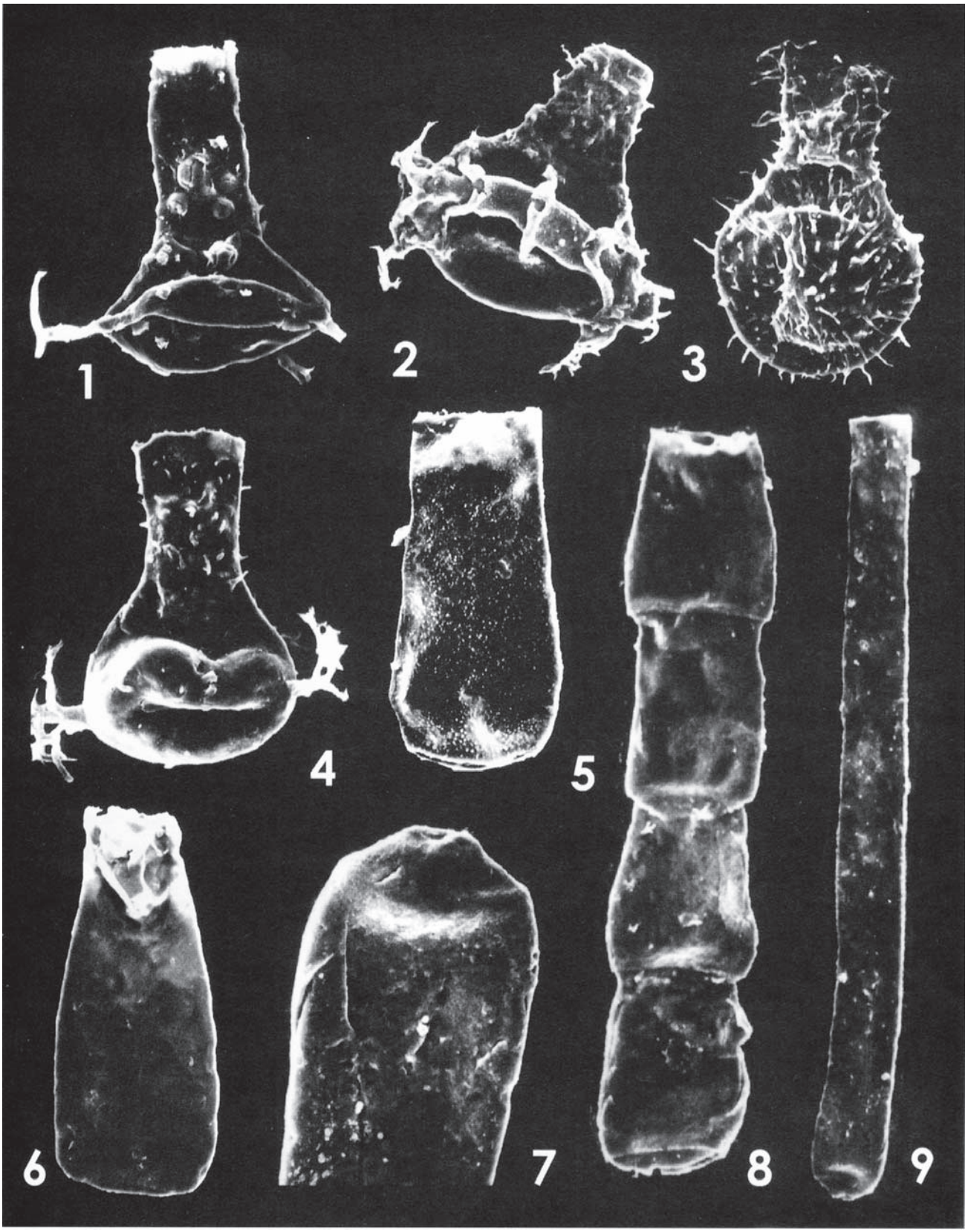
SYSTEMATIC PALEONTOLOGY (BY YNGVE GRAHN)

Thirty-nine species were identified in the present study. Their stratigraphic range is given in Text-Figures 9 and 10. Most of these species are poorly preserved and occur in low abundances. Only five species were present in at least five well-preserved specimens, and for this reason 24 species are left in open nomenclature in spite of their stratigraphic utility. For the coefficient value in the cor-

PLATE 1

Llandoverian Chitinozoa from the Paraná Basin. All specimens are from well RD-116.

1 *Ancyrochitina ancyrea* (Eisenack 1931), level 236.85 m, SEM x320.
2 *Ancyrochitina paranaensis* n. sp., Holotype, level 193.85 m, SEM x195.
3 *Angochitina* sp. A *sensu* Grahn and Paris 1992, level 177.40 m, SEM x365.
4 *Ancyrochitina paranaensis* n. sp., level 195.71 m, SEM x295.
5 *Belonechitina postrobusta* (Nestor 1980), level 400.95 m, SEM x285.
6 *Conochitina elongata* (Taugourdeau 1963), level 388.43 m, SEM x295.
7 *Conochitina proboscifera* Eisenack 1937, detail of the basal part of specimen in 9, SEM x400.
8 *Cingulochitina* cf. *C. serrata*, level 236.85 m, SEM x295.
9 *Conochitina proboscifera* Eisenack 1937, level 181.16 m, SEM x130.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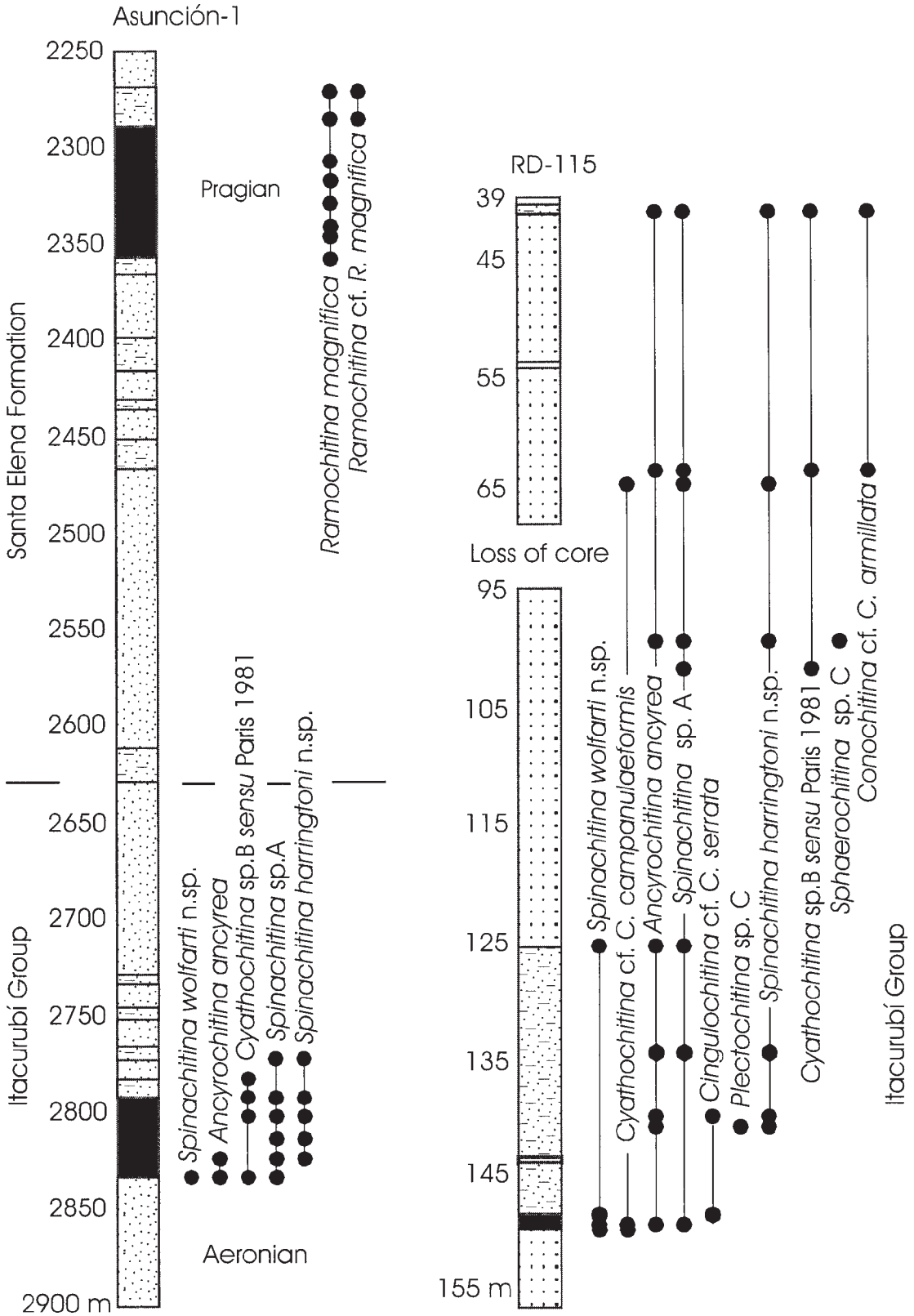
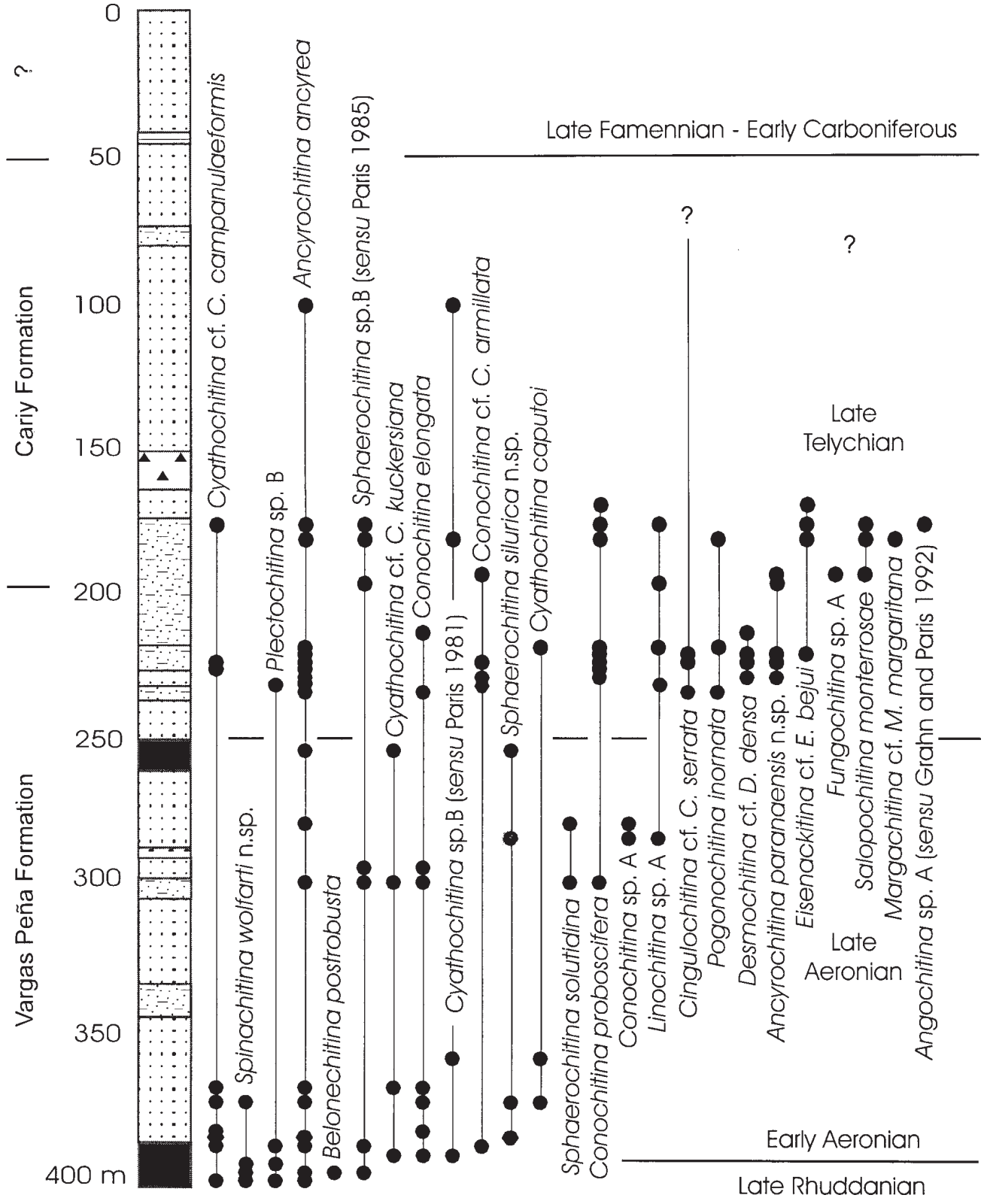
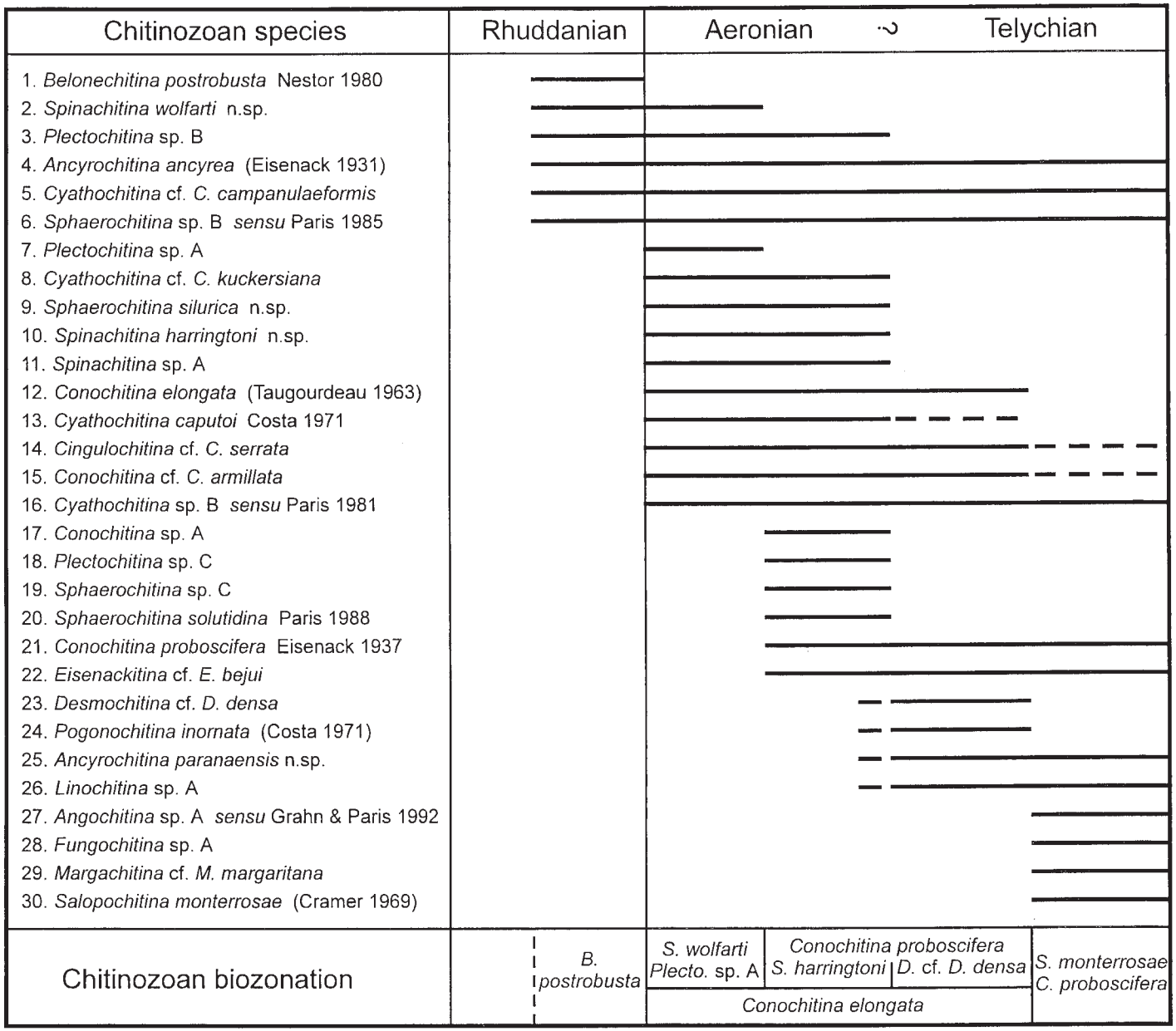


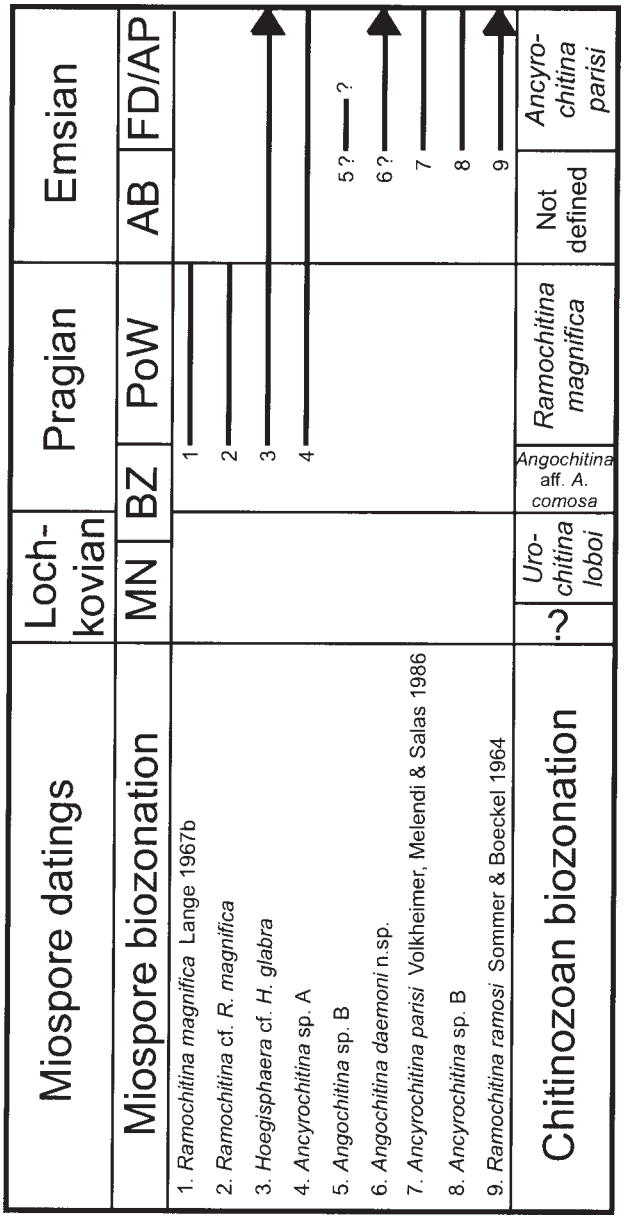
Text-Figure 7. Stratigraphic column and chitinozoan range chart for the Asunción-1 and RD-115 wells. For legend, see Text-Figure 2.



Text-Figure 8. Stratigraphic column and chitinozoan range chart for the RD-116 well. For legend, see Text-Figure 2.



Text-Figure 9. Lower Silurian chitinozoan, ranges and biozones in the Paraná Basin of Brazil and Paraguay.



Text-Figure 10. Lower Devonian chitinozoan, ranges and biozones in the Paraná Basin of Brazil and Paraguay. Spore zonation after Streel et al. (1987), Loboziak et al. (1995) and Stanislas Loboziak and José Henrique G. de Melo, personal communication (2000). The chitinozoan biozones of *Urochitina loboi* and *Angochitina* aff. *A. comosa* have only been found in adjacent basins from Bolivia and/or Argentina.

rected dimensions of the compressed chitinozoans, see discussion in Paris (1981). The taxonomy follows that of Paris et al. (1999).

Group CHITINOZOA Eisenack 1931
Order PROSOMATIFERA Eisenack 1972
Family CONOCHITINIDAE
Eisenack 1931 emend. Paris 1981
Subfamily SPINACHITININAE Paris 1981

Genus *Spinachitina* Schallreuter 1963

Spinachitina harringtoni n. sp.
Plate 4, figs. 3, 4

Derivation of Name. Latin, *harringtoni*, in honour of the late Dr. Horacio J. Harrington, pioneer in the studies of Paleozoic rocks in Paraguay.

Diagnosis. Uniformly elongated conical *Spinachitina* species with a crown of 10–12 short simple processes on the margin and a glabrous vesicle.

Holotype. Plate 4, fig. 3. Coleção de Paleoinvertebrados do Departamento de Geologia e Paleontologia do Museu Nacional. MN 7519-I.

Type Locality. Well RD-115, 141.77 m, Vargas Peña Formation, Paraguay.

Description. A *Spinachitina* species with an uniformly elongated conical vesicle. The margin is surrounded by a crown of 10–12 short simple processes. These are easily lost. Margin of vesicle wall is glabrous towards the aperture. Aperture is straight.

Corrected Dimensions (5 specimens, flattening corrected by a coefficient of 0.8). Total length: 357–543 μm (holotype 543 μm). Maximum width: 63–94 μm (holotype 82 μm). Aperture: 29–70 μm (holotype 42 μm), Length of appendices: ≤ 10 μm (holotype 10 μm).

Occurrence. *Spinachitina harringtoni* n. sp. ranges throughout the Aeronian in Paraguay.

Spinachitina wolfarti n. sp.
Plate 4, figs. 1–2

Derivation of Name. Latin, *wolfarti*, in honour of Dr. Reinhard Wolfart, the first geologist to correctly establish a Silurian age for the Itacurubí Group in Paraguay.

Diagnosis. *Spinachitina* species with a conical vesicle and a weakly developed flexure. Neck almost parallel towards a fimbriate aperture. A crown of 10–12 simple processes on the margin, and a glabrous vesicle.

Holotype. Plate 4, fig. 1. Coleção de Paleoinvertebrados do Departamento de Geologia e Paleontologia do Museu Nacional. MN 7520-I.

Type Locality. Well RD-115, 149.45 m, Vargas Peña Formation, Paraguay.

Description. A *Spinachitina* species with a conical vesicle that, after 1/3–1/2 of the total length aperturewards, displays a weakly developed flexure, whereafter the neck becomes more parallel towards a fimbriate aperture. The chamber margin is provided with a crown of 10–12 simple appendices. Margin of vesicle wall is glabrous towards the aperture.

Corrected Dimensions (8 specimens, flattening corrected by a coefficient of 0.8). Total length: 240–408 μm (holotype 313 μm). Maximum width: 64–110 μm (holotype 86 μm). Aperture: 35–61 μm (holotype 56 μm), Length of appendices: ≤ 38 μm (holotype 17 μm).

Occurrence. *Spinachitina wolfarti* n. sp. ranges from the latest Rhuddanian to the early Aeronian in Paraguay.

Family LAGENOCHITINIDAE
Eisenack 1931 emend. Paris 1981
Subfamily LAGENOCHITININAE Paris 1981

Genus *Sphaerochitina* Eisenack 1955a
emend. Paris et al.1999

Sphaerochitina silurica n. sp.
Plate 3, figs. 3, 11

Derivation of Name. Latin, *silurica*, referring to the age of the species.

Diagnosis. *Sphaerochitina* species with an almost spherical, glabrous body, and a cylindrical neck, comprising half the total length (± 10%).

Holotype. Plate 3, fig. 3. Coleção de Paleoinvertebrados do Departamento de Geologia e Paleontologia do Museu Nacional. MN 7521-I.

Type Locality. Well RD-116, 388.43 m, Vargas Peña Formation, Paraguay.

Description. A *Sphaerochitina* species with an almost spherical body and a cylindrical neck, comprising half the total length (± 10%). The neck might be slightly curved, as well as widened at the aperture. Vesicle wall is provided with tubercles.

Corrected Dimensions (12 specimens, flattening corrected by a coefficient of 0.8). Total length: 147–226 μm (holotype 208 μm). Maximum width: 48–75 μm (holotype 75 μm). Aperture: 18–37 μm (holotype 37 μm).

Occurrence. *Sphaerochitina silurica* n. sp. is a common species in the Aeronian, with an optimal abundance in the early Aeronian of the Paraná Basin.

Subfamily ANGOCHITININAE Paris 1981

Genus *Angochitina* Eisenack 1931

Angochitina daemoni n. sp.
Plate 5, fig. 6.

Derivation of Name. Latin, *daemoni*, in honour of the late Dr. Roberto Ferreira Daemon, palynologist and pioneer in Paraná Basin studies.

Diagnosis. *Angochitina* species with an ovoid body and a cylindrical neck comprising 1/3–1/2 of the total length. Aperture straight.

Holotype. Lange 1967a, pl. 1, fig. 11. Museu Nacional, Rio de Janeiro. Slide M.N. 4014-1.

Type Locality. Well 2-AG-1-MT, core 16, earliest Givetian, Alto Garças Sub-basin, Brazil.

Description. An *Angochitina* species with an ovoid body, and a cylindrical neck comprising 1/3–1/2 of the total length. Flexure distinct and aperture straight. The vesicle is covered by thin, hairy and randomly distributed simple spines. Multirooted spines may occur at the base.

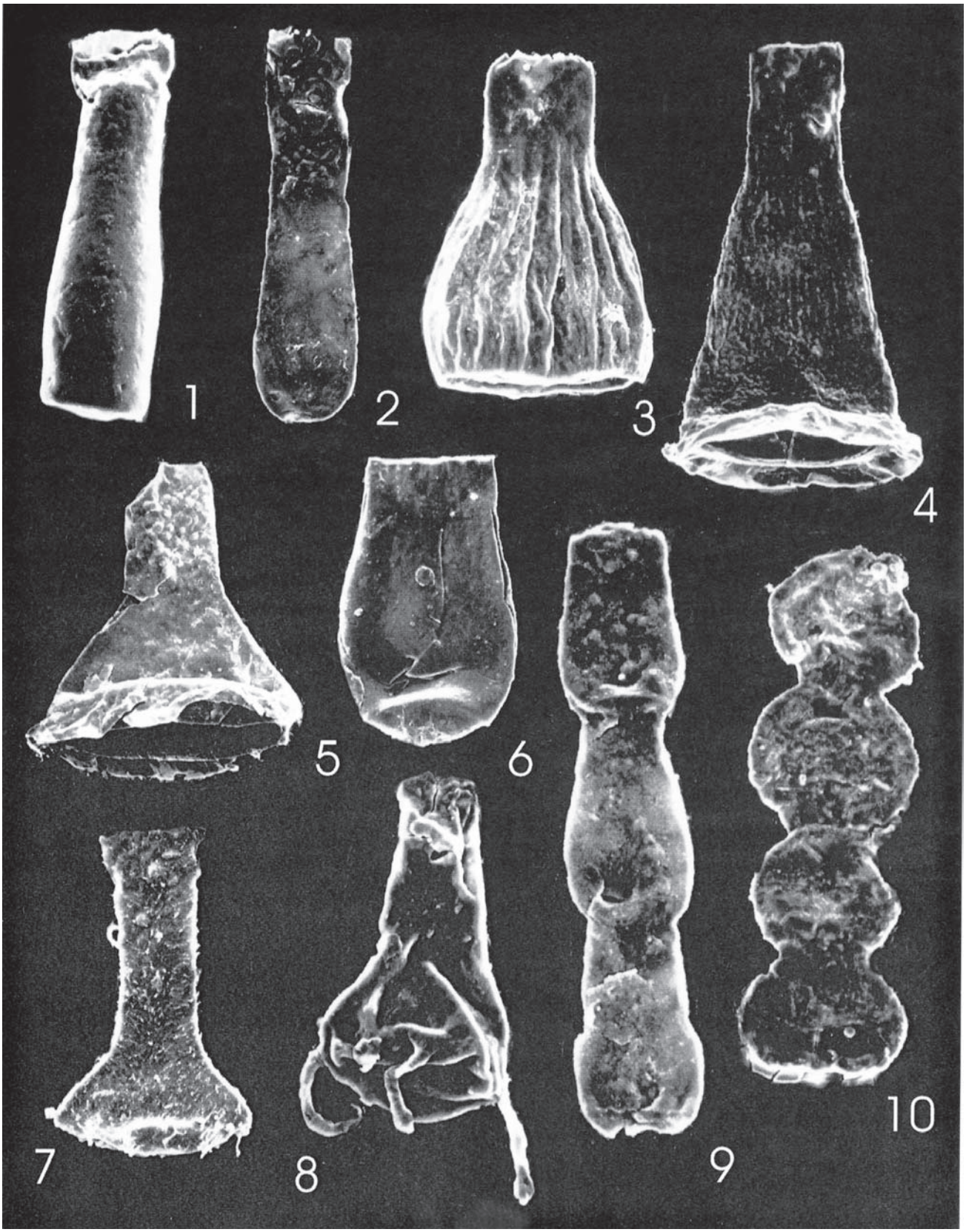
Corrected Dimensions (10 specimens, flattening corrected by a coefficient of 0.8). Total length: 152–280 μm (holotype 208 μm). Maximum width: 54–85 μm (holotype 67 μm). Aperture: 30–53 μm (holotype 36 μm).

Occurrence. According to Lange (1967a, text-fig. 3) this common species range from Eifelian to early Givetian

PLATE 2

Llandoverian Chitinozoa from the Paraná Basin. All specimens are from well RD-116.

1 *Conochitina* cf. *C. armillata*, level 235.85 m, SEM x260.
2 *Conochitina* sp. A, level 280.70 m, SEM x180.
3 *Cyathochitina caputoi* Costa 1971, level 217.65 m, SEM x235.
4 *Cyathochitina* cf. *C. campanulaeformis*, level 388.43 m, SEM x175.
5 *Cyathochitina* cf. *C. kuckersiana*, level 300.39 m, SEM x165.
6 *Eisenackitina* cf. *E. bejui*, level 222.60 m, SEM x170.
7 *Fungochitina* sp. A, level 193.85 m, SEM x280.
8 *Plectochitina* sp. B, level 388.45 m, SEM x345.
9 *Linochitina* sp. A, level 177.40 m, SEM x350.
10 *Desmochitina* cf. *D. densa*, level 222.60 m, SEM x300.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(D3–D4b by Lange, 1967a, p. 71–72, pl. 1, figs. 10–13, as *Angochitina* cf. *A. capillata*). However, in outcrops from the Apucarana Sub-basin in Brazil, it occurs in Emsian (late Emsian?) rocks as well. Its total range in the Paraná Basin is from Emsian to latest early Givetian (top of AD Lem spore Zone *sensu* Streel et al., 1987).

Subfamily ANCYROCHITININAE Paris 1981

Genus *Ancyrochitina* Eisenack 1955a

Ancyrochitina paranaensis n. sp.
Plate 1, figs. 2, 4

Derivation of Name. Latin, *paranaensis*, from Paraná, the basin from which this species is described.

Diagnosis. *Ancyrochitina* species with a crown of eight processes at the margin. These are branching up to five times towards the aperature. Each branch may be further divided one or two times. The vesicle wall is covered by simple spines, which are more densely distributed on the neck, which comprises 1/3–1/2 of the total length.

Holotype. Plate 1, fig. 2. Coleção de Paleoinvertebrados do Departamento de Geologia e Paleontologia do Museu Nacional. MN 7522-I.

Type Locality. Well RD-116, 193.85 m, lower Cariy Formation, Late Telychian, Paraguay.

Description. An *Ancyrochitina* species with a convex base and convex flanks. The neck, comprises 1/3–1/2 of the total length, slightly widens towards a straight aperture. The margin is provided with a crown of eight processes branching up to five times towards the aperature. Each branch may be further divided one or two times. The vesicle, except for the base, is covered by simple spines, which are more densely distributed on the neck.

Corrected Dimensions. (7 specimens, flattening corrected by a coefficient of 0.8). Total length: 130–195 μm (holotype 193 μm). Maximum width: 64–120 μm (holotype 96 μm). Aperture: 32–55 μm (holotype 55 μm). Length of processes: ≤ 70 μm (holotype 55 μm).

Occurrence. *Ancyrochitina paranaensis* n. sp. ranges from late Aeronian (middle Llandovery) to late Telychian (late Llandovery). Miller (1996; pl. 3, fig. 1) and Wood and Miller (1997; pl. 15, figs. 5, 6) reported it as *Ancyrochitina* sp. and *Ancyrochitina* sp. 5, respectively, from an undefined level within the late Aeronian to early Telychian Vargas Peña Formation at the Vargas Peña type locality.

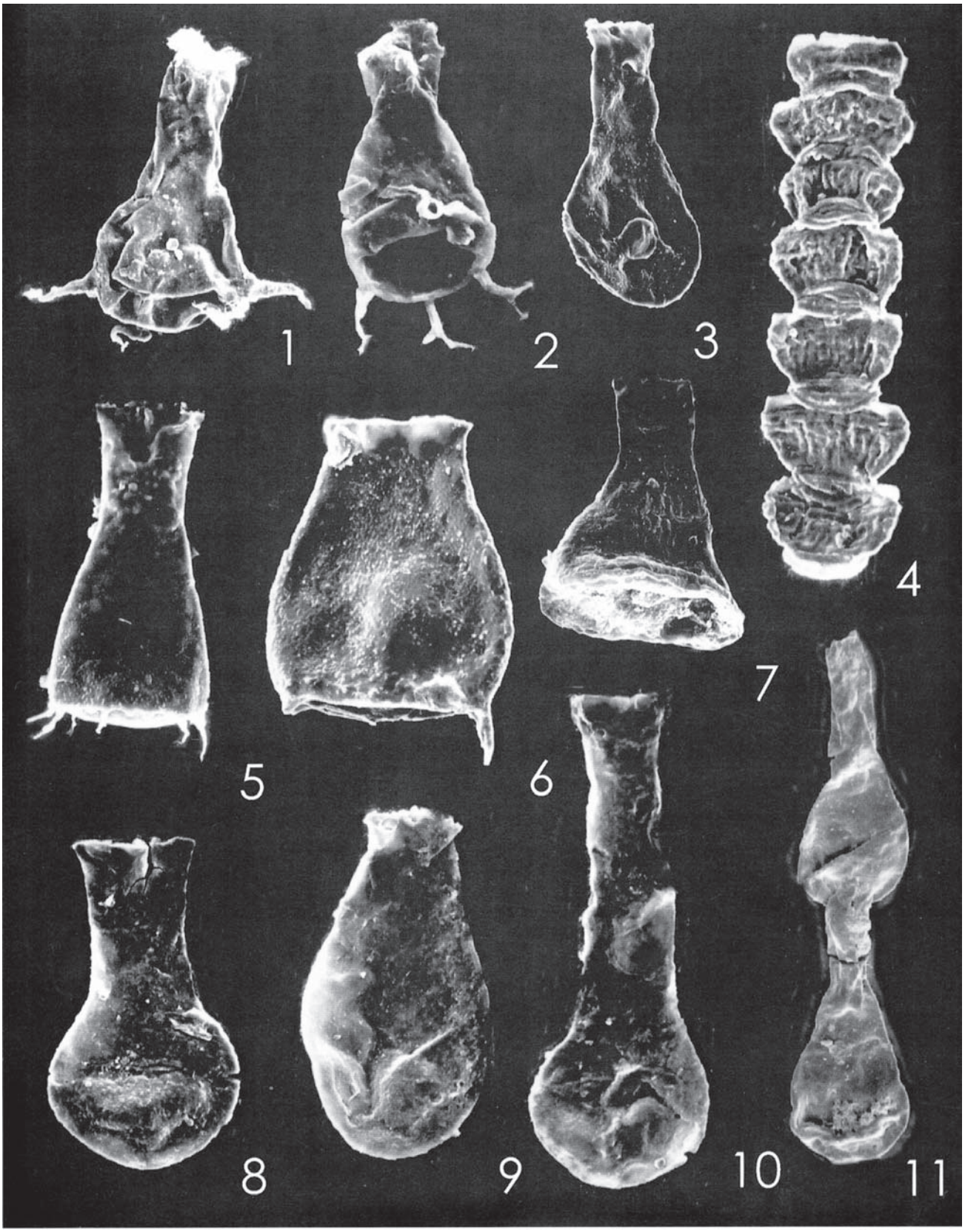
CHITINOZOAN BIOSTRATIGRAPHY

The Early Silurian and Early Devonian chitinozoans of the Paraná Basin in Brazil and Paraguay can be used to recognize seven zones and three subzones. The bulk of the Devonian Furnas Formation and its equivalents, and the lower Santa Elena Formation, are barren of body fossils, but are here considered as partly coeval with the total range zone of *Urochitina loboi* of late Lochkovian age. This zone is defined in the lower Puesto El Tigre Formation (Volkheimer et al., 1986) and further recognized in the Talacasto Formation (Le Hérissé et al., 1996) from Argentina, and in the lower Tequeje and Santa Rosa Formations from Bolivia (Vavrdová et al. 1996; Rachebaeuf et al., 1993). The zone is also present in the Solimões Basin, north Brazil (Grahn, 1992). The uppermost part of the Furnas Formation and its equivalents, and the lower Santa Elena Formation are referred to the *Angochitina* aff. *A. comosa* Zone of earliest Pragian age. This species is common in the lowermost Icla Formation of the Subandean of Bolivia (Rachebaeuf et al., 1993), where it stratigraphically is

PLATE 3

Llandoverian Chitinozoa from the Paraná Basin.

1 *Plectochitina* sp. A, Well RD-115, level 141.77 m, SEM x315.
2 *Plectochitina* sp. C, Aldeia Creek, ca. 12 m, SEM x240.
3 *Sphaerochitina silurica* n. sp., Holotype, Well RD-116, level 388.43 m, SEM x240.
4 *Margachitina* cf. *M. margaritana*, Well RD-116, level 181.16 m, SEM x240.
5 *Pogonochitina inornata* (Costa 1971), Well RD-116, level 181.16 m, SEM x240.
6 *Salopochitina monterrosae* (Cramer 1969), Well RD-116, level 177.40 m, SEM x290.
7 *Cyathochitina* sp. B *sensu* Paris 1981, Well RD-115, level 40.15 m, SEM x155.
8 *Sphaerochitina* solutidina Paris 1988, Well RD-116, level 280.70 m, SEM x345.
9 *Sphaerochitina* sp. C, Well RD-115, level 99.20 m, SEM x340.
10 *Sphaerochitina* sp. B *sensu* Paris 1985 (in Hill et al. 1985), Well RD-116, level 296.57 m, SEM x310.
11 *Sphaerochitina silurica* n. sp., unknown locality in east Paraguay, SEM x285.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followed by *Ramochitina magnifica* (YG personal observations).

Total Range Zone of *Belonechitina postrobusta*

Definition. This total range zone corresponds to the total range of *Belonechitina postrobusta* (Nestor 1980), below the first occurrence of *Conochitina elongata* (Taugourdeau 1963), as shown in Text-Figure 9.

Type Interval and Locality. The holotype of the eponymous species was described from the Öhne Formation, Juuru Stage (early Llandovery), in the Ikla boring (515.7 m), south Estonia (Nestor, 1980). As the type interval and locality for the total range zone of *Belonechitina postrobusta* in the Paraná Basin, the lowermost Vargas Peña Formation *s.l.* in well RD-116, below 400 m, is suggested (see Text-Figure 8).

Characteristic Chitinozoans. *Ancyrochitina ancyrea* (Plate 1, fig. 1) and *Cyathochitina* cf. *C. campanulaeformis* (Plate 2, fig. 4) are common species, and *Spinachitina wolfarti* n. sp. (Plate 4, figs. 1, 2), *Plectochitina* sp. B (Plate 2, fig. 8), and *Sphaerochitina* sp. B (Plate 3, fig. 10) have their first occurrence within the zone.

Known Occurrences Outside the Paraná Basin. *Belonechitina postrobusta* is a common Rhuddanian species. It has been also reported from Sweden (Grahn, 1995, 1998); Estonia and north Latvia (Nestor, 1980, 1994); Belgium (Martin, 1974); Bohemia (Dufka, 1992; Dufka and Fatka, 1993); Saudi Arabia, Tunisia, southwest Algeria (Verniers et al., 1995; Paris et al., 1995); Canada, Quebec, Gaspé (Asselin et al.,1989), and south China (Geng and Cai, 1988; Geng et al., 1997).

Remarks . In the Paraná Basin the total range zone of *Belonechitina postrobusta* is restricted to the uppermost Rhuddanian (lower Llandovery). In Sweden (Grahn, 1998) the total range zone corresponds to an interval from the upper part of the *Parakidograptus acuminatus* Zone to the base of the *Coronograptus gregarius* Zone (Rhuddanian). In Estonia and north Latvia the *B. postrobusta* Zone is defined as a partial range zone corresponding to the *Cystograptus vesiculosus* Zone (Nestor, 1994). A similar definition of the *B. postrobusta* Zone was made by Verniers et al. (1995) in their global Silurian biozonation, and Geng et al. (1997) defined a *B. postrobusta* Zone for the same interval in the Yangtze Region of south China.

Total Range Zone of *Conochitina elongata*

Definition. This total range zone corresponds to the total range of *Conochitina elongata* (Taugourdeau 1963). It extends from the first occurrence of the nominal species (Text-Figure 9) to the first occurrence of *Salopochitina monterrosae* (Cramer 1969).

Type Interval and Locality. The holotype was described as *Conochitina edjelensis elongata* from "middle–late" Llandovery shales in the Edjelé area, Algerian Sahara (Taugourdeau, 1963). As the type interval and locality for the total range zone of *C. elongata* (Plate 1, fig. 6) in the Paraná Basin, the Vargas Peña Formation *s.l.* in well RD-116, between 195 and 400 m, is suggested (Text-Figure 8).

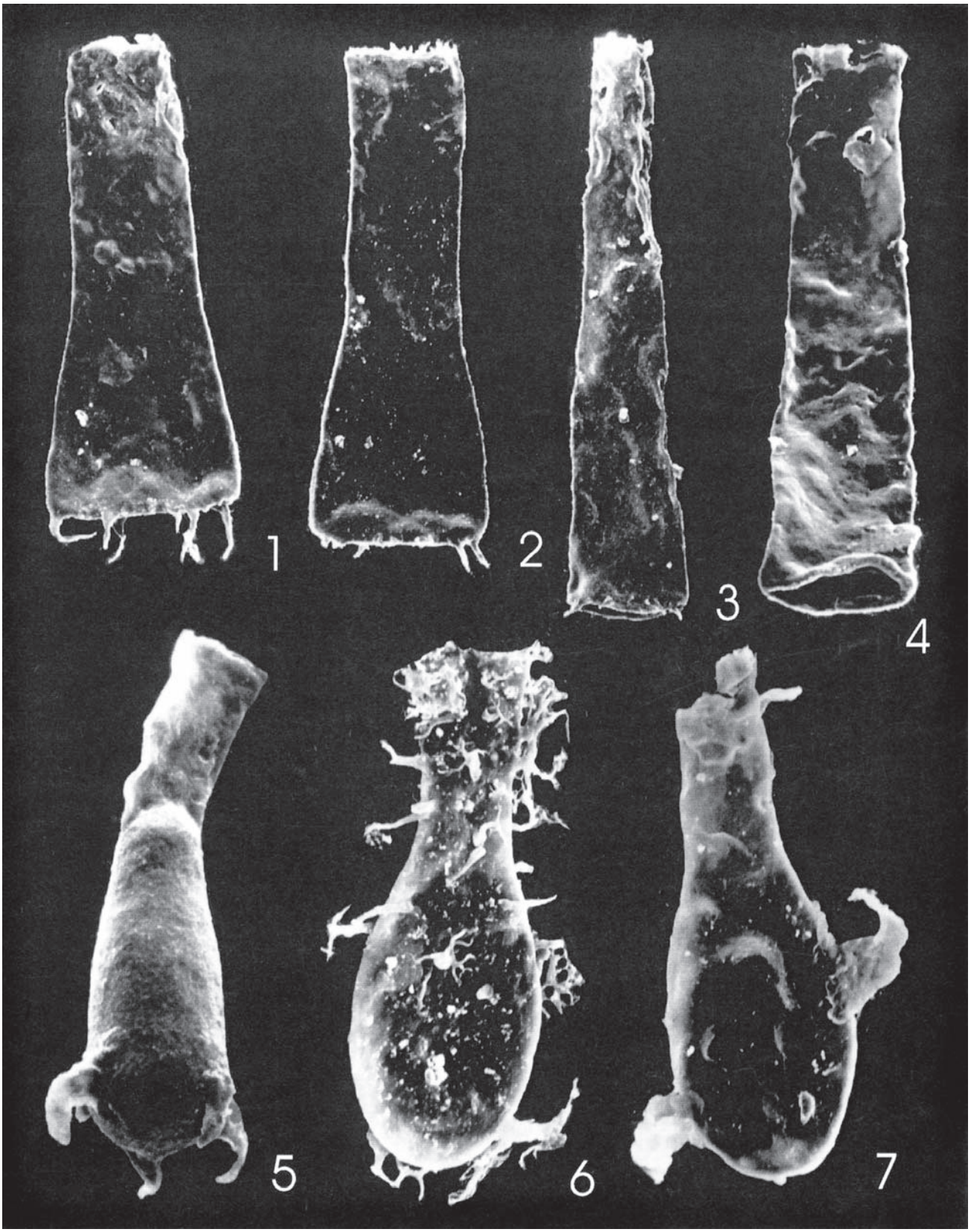
Characteristic Chitinozoans. *Conochitina elongata* and *Cyathochitina* spp. (Plate 2, figs. 3–5) are also common. Other species characteristic for the zone are *Sphaerochitina solutidina* Paris 1988 (Plate 3, fig. 8), *Sphaerochitina* sp. B (Plate 3, fig. 10) *sensu* Paris 1985 (*in* Hill et al., 1985), *Sphaerochitina silurica* n. sp., and *Spinachitina harringtoni* n. sp. are usually present (Text-Figure 10).

Known Occurrences Outside the Paraná Basin. *Conochitina elongata* has also been reported from subsurface "middle–late" Llandovery shales in the Edjelé area, Algeria (Taugourdeau, 1963); the Llandoverian Formigoso Formation in NW Spain (Cramer, 1967); middle to upper Llandovery in members MB2A and MB2B, Mehaigne area in the Brabant Massif, Belgium (Verniers, 1982);

PLATE 4

Llandoverian and early Devonian Chitinozoa from the Paraná Basin.

1 *Spinachitina wolfarti* n. sp., Holotype, Well RD-115, level 149.43 m, SEM x265.
2 *Spinachitina wolfarti* n. sp., Well RD-115, level 149.43 m, SEM x270.
3 *Spinachitina harringtoni* n. sp., Holotype, Well RD-115, level 141.77 m, SEM x200.
4 *Spinachitina harringtoni*? n. sp., Well RD-116, level 401.50 m, SEM x230.
5 *Ancyrochitina* sp. A (= *Cladochitina biconstricta* (Lange 1949 *pars*), Jaguariaíva section, ca. 81 m, SEM x335.
6 *Ramochitina magnifica* Lange 1967a, Well 2-AG-1-MT, core 18, SEM x300.
7 *Ramochitina* cf. *R. magnifica*, Well 2-AG-1-MT, core 18, SEM x320.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Stimulograptus sedgwickii to *Spirograptus turriculatus* zones (upper Areonian–lower Telychian) in the subsurface of NE Libya (Hill et al., 1985); middle Rhuddanian to lower Telychian, Prague Basin, Bohemia (Dufka, 1992); upper Aeronian–lower Telychian in central Saudi Arabia (Paris et al., 1995), and the upper Solvik and lower Rytteraker Formations (Aeronian) in the Oslo Region, Norway (Nestor, pers. comm., 1998). It also occurs in the lower part of the Pitinga Formation in the Amazonas Basin, Brazil (Y.G. unpublished observations).

Remarks. In the Paraná Basin the total range zone of *C. elongata* is restricted to the Aeronian and early Telychian (middle–late Llandovery).

Concurrent Range Subzone of *Spinachitina wolfarti* n. sp. and *Plectochitina* sp. A

Definition. This concurrent range subzone corresponds to the partial range of *Spinachitina wolfarti* n. sp. and the total range of *Plectochitina* sp. A (Plate 3, fig.1). It extends from the first occurrence of *Plectochitina* sp. A and *Conochitina elongata* (Taugourdeau 1963) to the first occurrence of *Conochitina proboscifera* Eisenack 1937 (Plate 1, fig. 7).

Type Interval and Locality. The holotype of *Spinachitina wolfarti* n. sp. is from well RD-115, 149.45 m, Vargas Peña Formation, Paraguay. As the type locality and type interval for the concurrent range zone of *Spinachitina wolfarti* n. sp. and *Plectochitina* sp. A, well RD-116, between ca. 400 m and 300.50 m, is suggested (Text-Figure 8).

Characteristic Chitinozoans. The concurrent range subzone of *Spinachitina wolfarti* n. sp. and *Plectochitina* sp. A constitute the lower part of the total range zone of *Conochitina elongata*. It is characterized by the coexistence of its two index species, and by the absence of typical species of the overlying units, i.e., the concurrent range subzones of *Conochitina proboscifera* and *Spinachitina harringtoni* n. sp. and *Conochitina proboscifera* and *Desmochitina* cf. *D. densa* (Plate 2, fig. 10, see below).

Known Occurrences Outside the Paraná Basin. *Spinachitina wolfarti* n. sp. and *Plectochitina* sp. A have not yet been reported outside the Paraná Basin.

Remarks. In the Paraná Basin the concurrent range subzone of *Spinachitina wolfarti* n. sp. and *Plectochitina* sp. A is restricted to the lower Aeronian.

Concurrent Range Subzone of *Conochitina proboscifera* and *Spinachitina harringtoni* n. sp.

Definition. This concurrent range subzone corresponds to the partial range of *Conochitina proboscifera* Eisenack 1937 and *Spinachitina harringtoni* n. sp. The subzone extends from the first occurrence of *Conochitina proboscifera* Eisenack 1937 to the first occurrence of *Desmochitina* cf. *D. densa*.

Type Interval and Locality. The holotype of *Conochitina proboscifera* was described from Baltic erratics of uncertain age by Eisenack (1937). The well RD-116, between 300.50 m–235 m, is defined as the type interval and locality for the concurrent range subzone of *Conochitina proboscifera* and *Spinachitina harringtoni* n. sp. (Text-Figure 8).

Characteristic Chitinozoans. The concurrent range subzone of *Conochitina proboscifera* and *Spinachitina harringtoni* n. sp. corresponds to the middle part of the total range zone of *Conochitina elongata*, and it is easily distinguished through the co-occurrence of *Conochitina proboscifera*, *Cyathochitina* cf. *C. kuckersiana* (Plate 2, fig. 5), *Sphaerochitina silurica* n. sp., and *Sphaerochitina solutidina* (Plate 3, fig. 8). In the uppermost part of the zone is the first occurrence of *Cingulochitina* cf. *C. serrata* (Plate 1, fig. 8) and *Pogonochitina inornata* (Plate 3, fig. 5), two species that appear in the Aeronian–Telychian transition. *Conochitina* sp. A (Plate 2, fig. 2), *Plectochitina* sp. C (Plate 3, fig. 2), and *Sphaerochitina* sp. C (Plate 3, fig. 9) are

PLATE 5

Llandoverian and early Devonian Chitinozoa from the Paraná Basin.

1 *Ancyrochitina* sp. B, Tibaji–Telêmaco Borba section, level ca. 63.5 m, SEM x345.

2 *Ancyrochitina parisi* Volkheimer, Melendi and Salas 1986, Tibaji–Telêmaco Borba section, level ca. 64.5 m, SEM x370.

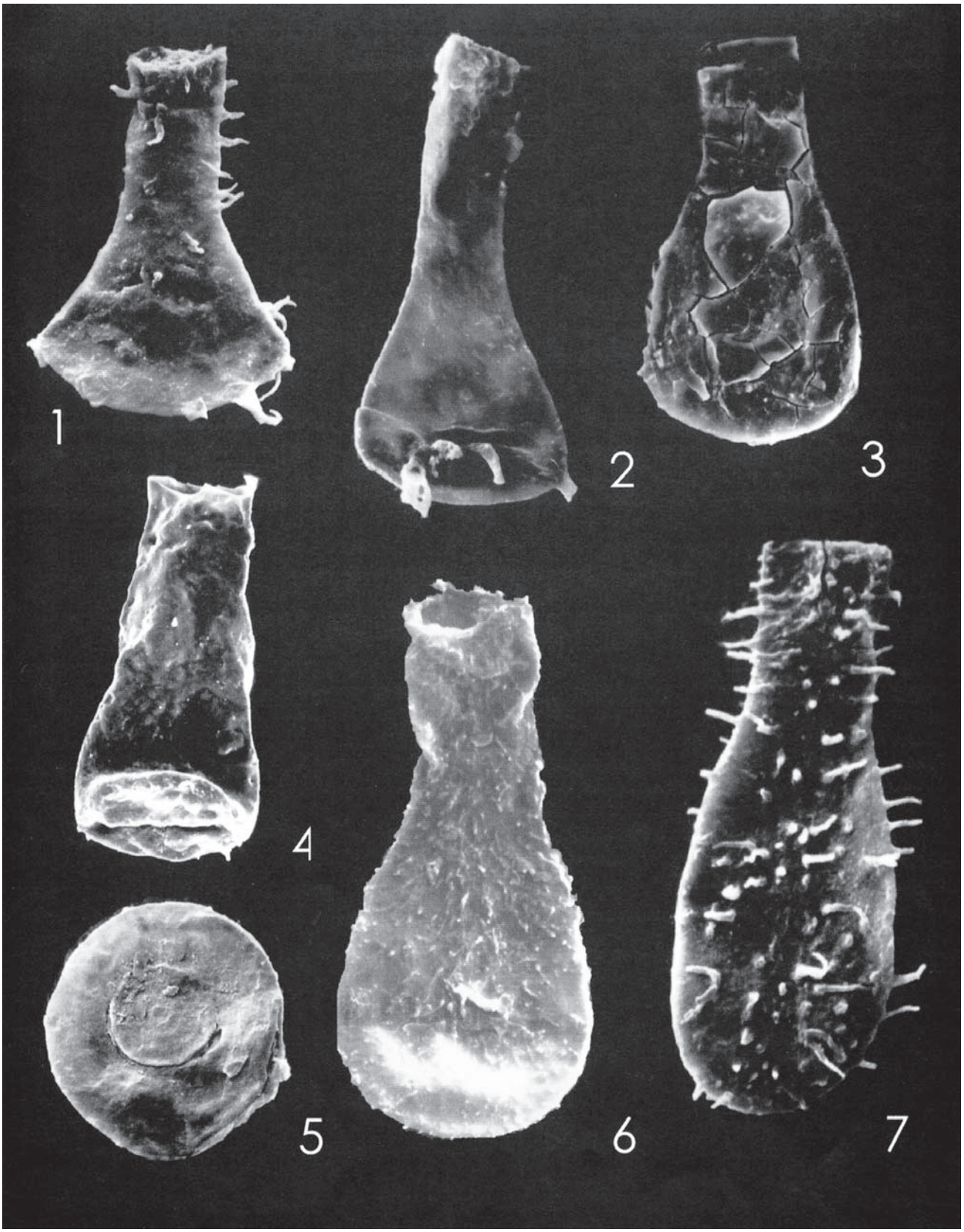
3 *Angochitina* sp. B, Tibaji–Telêmaco Borba section, level ca. 26 m, SEM x335.

4 *Spinachitina* sp. A, Well Asuncion-1, level 2810 m, SEM x295.

5 *Hoegisphaera* cf. *H. glabra*, Well 2-AG-1-MT, core 18, SEM x400.

6 *Angochitina daemoni* n. sp., Tibaji–Telêmaco Borba section, level ca. 22.5 m, SEM x385.

7 *Ramochitina ramosi* Sommer and Boeckel 1964, Tibaji–Telêmaco Borba section, level ca. 63.5 m, SEM x440.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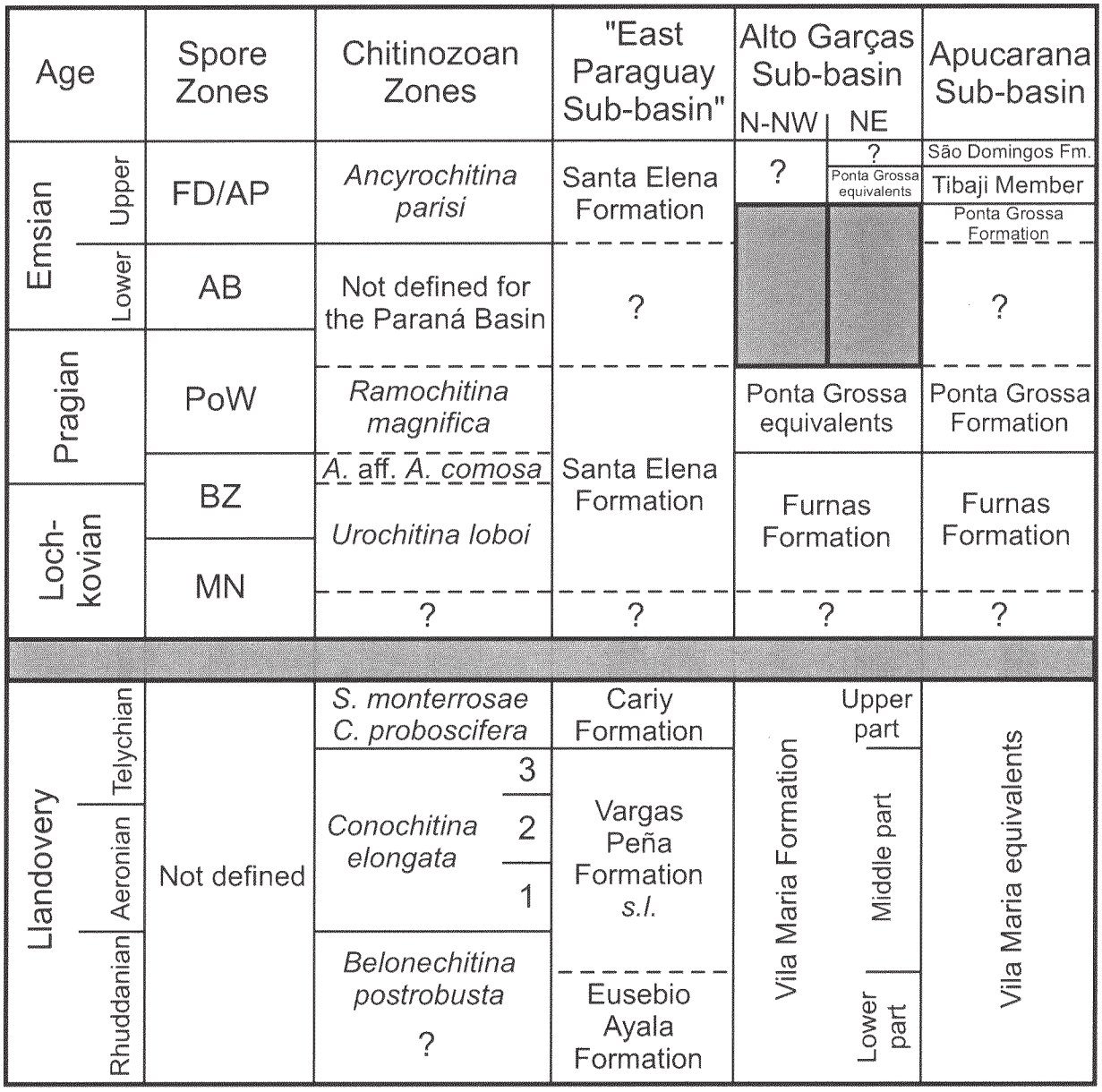

Text-Figure 11. Silurian and Lower Devonian correlation chart of the Paraná Basin of Brazil and Paraguay. 1. Concurrent subzone of *Spinachitina wolfarti* n. sp. and *Plectochitina* sp. A. 2. Concurrent subzone of *Conochitina proboscifera* and *Spinachitina harringtoni* n. sp. 3. Concurrent subzone of *Conochitina proboscifera* and *Desmochitina* cf. *D. densa*. After Grahn (1999). Spore zonation after Streel et al. (1987), Loboziak et al. (1995) and Stanislas Loboziak and José Henrique G. de Melo, personal communication (2000). The chitinozoan biozones of *Urochitina loboi* and *Angochitina* aff. *A. comosa* have only been found in adjacent basins from Bolivia and/or Argentina.

restricted to the concurrent range subzone of *C. proboscifera* and *S. harringtoni* n. sp.

Known Occurrences Outside the Paraná Basin. *Conochitina proboscifera* is a widespread and common Telychian to Sheinwoodian species. However, its first occurrence is of a diachronous nature. In Brazil, *C. proboscifera* is known from late Aeronian?–early Telychian shales of the lower Pitinga Formation (Grahn and Paris, 1992). In Sweden (Grahn, 1995; 1998), its first occurrence is in an unnamed formation of subsurface Gotland (*Stimulograptus sedgwickii* Zone, late Aeronian) where it ranges into the Sheinwoodian Högklint Beds. In

Estonia and west Latvia (Nestor, 1994) it ranges from the upper Velise Formation (Adavere Stage, *Monoclimacis griestoniensis* Zone, late Aeronian) to the uppermost Tôlla and Mustjala Members of the Jaani Stage (early Sheinwoodian), and in Jiangsu, south China (Geng et al., 1987; Geng et al., 1997) it is reported from the upper Kaochiapien Formation (*Stimulograptus sedgwickii* Zone, late Aeronian). Verniers (1982) and Verniers et al. (1995) have reported *Conochitina proboscifera* at different levels in the Telychian of Brabant Massif and Condoz Ridge, Belgium, from the top of Member MB3E to Member MB4 (Llandovery–Wenlock transition). The species is also recorded in the Vik, Ek, Skinnebukta, and Bruflat Formations (Telychian) of the Oslo Region, Norway (Nestor, pers. comm., 1998); Estill Shale (Llandovery–Wenlock transition), of Ohio and northern Kentucky in the U.S.A. (Grahn, 1985); Hughley Shales (Telychian) to the Buildwas and lower Coalbrookdale Formations (Sheinwoodian) in the Welsh Borderland (Dorning, 1981); Lande Mureé Formation (Telychian), of Brittany, France (Paris, 1981); NE Libya (Telychian) (Hill et al., 1985; Paris, 1988); Prague Basin (Sheinwoodian), Bohemia (Dufka, 1992); Pierre-Loiselle Formation (Telychian) of Gaspé, Quebec, Canada (Asselin et al., 1989); Jupiter and Chicotte Formations (Telychian), of Anticosti Island, Canada (Achab, 1981), and Restevo Beds (Telychian) of Podolia, Ukraine (Laufeld, 1971).

Remarks. In the Paraná Basin the concurrent range subzone of *Conochitina proboscifera* and *Spinachitina harringtoni* n. sp. range from the upper Aeronian to the Aeronian–Telychian transition.

Concurrent Range Subzone of *Conochitina proboscifera* and *Desmochitina* cf. *D. densa*

Definition. This concurrent range subzone corresponds to the partial range of *Conochitina proboscifera* Eisenack 1937 and the total range of *Desmochitina* cf. *D. densa* (Plate 2, fig. 10). The subzone extends from the first occurrence of *Desmochitina* cf. *D. densa* to the first occurrence of *Salopochitina monterrosae* (Cramer 1969).

Type Interval and Locality. The holotype of *Conochitina proboscifera* was described from Baltic erratics of uncertain age by Eisenack (1937). As the type interval and locality for the concurrent range subzone of *Conochitina proboscifera* and *Desmochitina* cf. *D. densa* the well RD-116, between 235 m–195 m, is suggested (Text-Figure 8).

Characteristic Chitinozoans. The concurrent range subzone of *Conochitina proboscifera* and *Desmochitina* cf. *D. densa* corresponds to the upper part of the total range zone of *Conochitina elongata*, and it is easily distinguished through the co-occurrence of *Ancyrochitina paranaensis* n. sp., *Conochitina proboscifera*, *Desmochitina* cf. *D. densa*, *Eisenackitina* cf. *E. bejui* (Plate 2, fig. 6), and *Pogonochitina inornata*.

Known Occurrences Outside the Paraná Basin. *Conochitina proboscifera* is a widespread and common late Llandovery to Sheinwoodian species (see above).

Remarks. In the Paraná Basin the concurrent range subzone of *Conochitina proboscifera* and *Desmochitina* cf. *D. densa* range from the Aeronian–Telychian transition to the lower Telychian. Wood and Miller (1991) reported *Plectochitina paraguayensis* from this subzone, and Paris *et al*. (1995) from the Rhuddanian–Aeronian of Saudi Arabia. The Vargas Peña type locality, and the fossiliferous shales of the Vila Maria Formation and lateral equivalents, are all biostratigraphically situated within this subzone.

Concurrent Range Zone of *Salopochitina monterrosae* and *Conochitina proboscifera*

Definition. This concurrent range zone corresponds to the total range of *Salopochitina monterrosae* (Cramer 1969) and the partial range of *Conochitina proboscifera* Eisenack 1937. The base of the zone is defined at the first occurrence of *Salopochitina monterrosae* (Plate 3, fig. 6). The top of the zone is erosionally truncated by the pre-Furnas unconformity in the Paraná Basin.

Type Interval and Locality. The holotype of *Salopochitina monterrosae* was described from the upper Llandovery in Pennsylvania, U.S.A as *Conochitina*? *monterrosae* by Cramer (1969). As the type interval and locality for the concurrent range zone of *Salopochitina monterosae* and *Conochitina proboscifera* in the Paraná Basin, the section assigned to the Cariy Formation in well RD-116, between 50 m and 195 m, is suggested (Text-Figure 8).

Characteristic Chitinozoans. The zone is characterized by the co-occurrence of the two index species. Other important species include *Fungochitina* sp. A (Plate 2, fig. 7), *Margachitina* cf. *M. margaritana*, *Eisenackitina* cf. *E. bejui*, and others (Text-Figure 10).

Known Occurrences Outside the Paraná Basin. *Salopochitina monterrosae* has also been reported from the late Llandovery Rose Hill and Tuscarora Formations in Pennsylvania, U.S.A (Cramer, 1969); the Sheinwoodian Buildwas Formation in the Lower Hill Farm borehole, Shropshire, England as *Salopochitina bella* by Swire (1990); and late Llandovery strata in the Bové Basin, Guinea, and the Amazonas Basin of Brazil, as *Pogonochitina monterrosae* by Grahn and Paris (1992), and unnamed from the latter basin by Lange (1967b). Tekbali and Wood

(1991) described it as "*Conochitina filifera*" from the Silurian of the Ghadãmis Basin in nortwest Libya. For occurrences of *Conochitina proboscifera*, see above mentioned concurrent range subzone of *Conochitina proboscifera* and *Spinachitina harringtoni* n. sp.

Remarks. In the Paraná Basin the concurrent range zone of *Salopochitina monterosae* and *Conochitina proboscifera* is restricted to the upper Telychian (upper Llandovery)–earliest Sheinwoodian (lower Wenlock).

Total Range Zone of *Ramochitina magnifica*

Definition. This total range zone corresponds to the total range of *Ramochitina magnifica* Lange 1967a *pars* (specimens with the same type of ornamentation as the holotype).

Type Interval and Locality. The holotype of *Ramochitina magnifica* was described from the lower Ponta Grossa Formation *s.s.* in well 1-CT-2-PR (Apucarana Sub-basin), level 156.00 m. The type interval and locality is the entire Ponta Grossa Formation in the Jaguariaíva railway section (Text-Figure 2).

Characteristic Chitinozoans. *Ramochitina magnifica* (Plate 4, fig. 6) is the most common species in this zone. *Ramochitina* cf. *R. magnifica* (= *Ramochitina magnifica* Lange 1967a *pars*) (Plate 4, fig. 7), *Hoegisphaera* cf. *H. glabra* (Plate 5, fig. 5), and *Ancyrochitina* sp. A (= *Cladochitina biconstricta* Lange 1967a *pars*) (Plate 4, fig. 5) also occur within the *R. magnifica* Zone.

Known Occurrences Outside the Paraná Basin. *Ramochitina magnifica* has also been reported from Pragian beds in the middle Puesto El Tigre Formation, northwest Argentina (Volkheimer et al., 1986), and the upper Tequeje Formation, Madre de Díos Basin, north Bolivia (Vavrdová et al., 1996). It also occurs in the subsurface of Uruguay (Cordobés Formation), where it had been mistakenly recorded by Oliveira and Veroslavsky (1994) as *Alpenachitina eisenacki* (J.H.G. Melo, pers. comm., 1998).

Remarks. In the Paraná Basin the total range zone of *Ramochitina magnifica* is of Pragian age (although not earliest or latest Pragian). It is restricted to the lower Ponta Grossa Formation *s.s.* in the Apucarana Sub-basin and its northern equivalents in the Alto Garças Sub-basin, and to the lower–middle part of the Santa Elena Formation in the "East Paraguay Sub-basin."

Total Range Zone of *Ancyrochitina parisi*

Definition. This total range zone corresponds to the total range of *Ancyrochitina parisi* Volkheimer et al. 1986.

Type Interval and Locality. The holotype was described from the upper Puesto El Tigre Formation in northwest Argentina (Volkheimer et al., 1986). The type interval and locality for the total range zone of *A. parisi* in the Paraná Basin is defined as the interval comprising the upper Ponta Grossa Formation *s.s.*, the Tibaji Member of the Ponta Grossa Formation *s.s.*, and the lowermost São Domingos Formation in the Tibaji–Telêmaco Borba section, between ca. 20 m and ca. 70 m, is suggested (Text-Figure 3).

Characteristic Chitinozoans. Besides *Ancyrochitina parisi* (Plate 5, fig. 2), *Ancyrochitina* sp. B (Plate 5, fig. 1) is another characteristic species of the total range zone of *A. parisi*. *Ramochitina ramosi* (Plate 5, fig. 7) has its first occurrence within the zone. It is uncertain whether *Angochitina daemoni* n. sp. first occurs earlier in the Emsian or just at the base of this zone.

Known Occurrences Outside the Paraná Basin. *Ancyrochitina parisi* has also been reported from the upper Puesto El Tigre Formation in northwest Argentina (Volkheimer et al., 1986).

Remarks. In the Paraná Basin, the total range zone of *A. parisi* is seemingly restricted to the upper Emsian, but could also include late early Emsian strata in its base.

CONCLUSIONS

The chitinozoan faunas in the shales of the Vila Maria Formation and its equivalents have species in common with the middle to upper Llandovery Vargas Peña Formation in Paraguay. It is suggested that the Vila Maria Formation and its equivalents are of Llandovery age and contemporary with the Itacurubí Group in east Paraguay.

Based on paleogeographic considerations the age of the lower Furnas Formation is possibly Lochkovian. The upper Furnas Formation is possibly situated within the earliest Pragian, as suggested by Dino and Rodrigues (1990) and Loboziak et al. (1995).

In its type section the Ponta Grossa Formation (Jaguariaíva Member by Lange and Petri, 1967) is of Pragian age. This part corresponds to unit D2a by Lange (1967a). Dark shales in the Alto Garças Sub-basin are of same age. Late Emsian siltstones apparently are missing in the north–northwestern part of that sub-basin, and a gap in the sequence corresponding to at least the early Emsian is identified in the Alto Garças Sub-basin.

In the "East Paraguay Sub-basin," the base of the Santa Elena Formation is probably contemporary with the base of the Furnas Formation and its equivalents. The Pragian age of the upper part of Santa Elena Formation suggests a correlation with the Ponta Grossa Formation *s.s.* and its equivalents. The upper part of the Ponta Grossa Formation

s.s.(= Unit D2b by Lange 1967a) is late Emsian in age. Rocks of this age remain unrecorded in east Paraguay.

The tempestitic sandstones of the Tibaji Member of the Ponta Grossa Formation *s.s.* in the Apucarana Sub-Basin are of late Emsian age as well, and have no known contemporary equivalents dated by fossils in the Alto Garças Sub-Basin. The Tibaji Member of Lange (his unit D3) probably corresponds to an interval with predominantly sandstones within the lower part of the São Domingos Formation and its equivalents. In the Apucarana Sub-basin, the lowermost part of the São Domingos Formation is still considered late Emsian.

The lower Silurian and Lower Devonian of the Paraná Basin in Paraguay and Brazil can be subdivided into seven chitinozoan zones and three subzones. These are: total range zone of *Belonechitina postrobusta* (upper Rhuddanian); total range zone of *Conochitina elongata* (Aeronian); concurrent range subzone of *Spinachitina wolfarti* n. sp. and *Plectochitina* sp. A (lower Aeronian); concurrent range subzone of *Conochitina proboscifera* and *Spinachitina harringtoni* n. sp. (upper Aeronian to the Aeronian–Telychian transition); concurrent range subzone of *Conochitina proboscifera* and *Desmochitina* cf. *D. densa* (Aeronian–Telychian transition to the lower Telychian); concurrent range zone of *Salopochitina monterrosae* and *Conochitina proboscifera* (upper Telychian–early Sheinwoodian); total range zone of *Urochitina loboi* (upper Lochkovian); total range zone of *Angochitina* aff. *A. comosa* (lowermost Pragian), total range zone of *Ramochitina magnifica* (Pragian *s.l.*), and total range zone of *Ancyrochitina parisi* (upper Emsian). Of the 39 chitinozoan species encountered, 24 are left in open nomenclature due to their poor preservation and low abundances.

ACKNOWLEDGMENTS

We are indebted to Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ), which made the work of the senior author possible through a grant (Universidade do Estado do Rio de Janeiro – Programa de Ampoio ao Desenvolvimento to Cientifico e Tecnologia / Financadora de Estudos e Projetos Convention nr. 65.91.0373.00). Thanks are also due to the Faculty of Geology at Universidade do Estado do Rio de Janeiro, and to Profa. Maria Antonieta Rodrigues, head of the post-graduation program at the Faculty of Geology at Universidade do Estado do Rio de Janeiro enthusiastic encouragement and for the working facilities. Through the courtesy of Dr. Eduardo A.M. Kousoukos, head of Setor Bioestratigrafia e Paleoecologia at Centro de Pesquisas e Desenvolvimento Leopoldo A. Miguez de Mello (Petrobrás, Rio de Janeiro), we had access to a Scanning Electron Microscope, and geologist José Henrique G. de Melo at the same department discussed the geology and reviewed the manuscript. Dr. Gordon Wood (Amoco, Houston) is acknowledged for a linguistic check of the manuscript. All technical help from Jorge Louiz dos Santos and Maria Rosalva Campos Coelho at Universidade do Estado do Rio de Janeiro and Rogério da Silva Martins da Costa at Centro de Pesquisas e Desenvolvimento Leopoldo A. Miguez de Mello is acknowledged. Our sincere thanks to all.

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