

New palynological information from the subsurface Copo, Caburé and Rincón formations (upper Lochkovian – Emsian), Salta Province, Argentina

SOL NOETINGER & MERCEDES DI PASQUO

NOETINGER, S. & DI PASQUO, M., 2013:04:26. New palynological information from the subsurface Copo, Caburé and Rincón formations (upper Lochkovian-Emsian), Salta Province, Argentina. *Memoirs of the Association of Australasian Palaeontologists* 44, 107-121. ISSN 0810-8889.

New palynological information recovered from cutting and core samples from the Puesto El Tigre x-1 well in northwestern Argentina is presented. The studied interval corresponds to the Copo, Caburé and Rincón formations. The assemblage comprises 41 spore and cryptospore species, 27 species of acritarchs together with prasinophycean and chlorophycean algae, and 12 chitinozoan species. The stratigraphic distribution of these taxa allow the definition of five associations, ranging in age from late Lochkovian to latest Emsian. These associations reflect palaeoenvironmental changes related to transgressive-regressive cycles occurring during this time span, which corroborates previous interpretations.

S. Noetinger (noetinger@macn.gov.ar), Museo Argentino de Ciencias Naturales “Bernardino Rivadavia”- CONICET, Angel Gallardo 470, Ciudad A. de Buenos Aires, C1405DJR, Argentina; M. di Pasquo (medipa@cicyttp.org.ar) CICyTTP – CONICET, Dr. Matteri and España S/N, Diamante (E3105BWA), Entre Ríos, Argentina. Received 25 October 2012.

Keywords: Palynology, biostratigraphy, palaeoenvironment, Early Devonian, Argentina

THE DEVONIAN rocks in northwestern Argentina are exposed in the Eastern Range, and the western Subandean and Santa Barbara ranges, totaling more than 2000 metres in thickness and extending into the subsurface of the eastern Subandean Range and the Chaco-Salteño Plain. These rocks are part of the Tarija Basin that includes central and southern Bolivia, and the northwest of Paraguay (Fig. 1). This basin was connected to other neighbouring basins like the Arizaro Basin, which extends into northern Chile and the Argentinean Puna, the Madre de Dios Basin in northern Bolivia and southern Peru, and other basins in western Brazil, based on common palaeontological records (see Grahn 2005). In northwestern Argentina, Devonian facies composed of sandstones and mudstones with minor conglomerates were mainly deposited in shallow marine environments alternating with more continental periods (see Starck 1999; Albariño *et al.* 2002).

This study presents a complete palynological survey of an assemblage from the Puesto El Tigre x-1 (PET x-1) borehole, formerly investigated by Volkheimer *et al.* (1986), who published only the chitinozoans. The stratigraphic distribution of the palynomorph species is analysed and compared with their global ranges to assess the age and correlation of the associations defined herein. Palynofacies are also considered to better understand and corroborate previous palaeoenvironmental interpretations (Volkheimer *et al.* 1986; Albariño *et al.* 2002).

MATERIAL AND METHODS

The PET x-1 borehole (ca. S 22° 42' 2.42", W 63° 6' 6.08") is located in the Chaco-Salteño Plain (Fig. 1B), and was drilled to a total depth of 4320 metres. Volkheimer *et al.* (1986) analysed the chitinozoan content of 17 cutting

samples whereas our palynological study embraces a preliminary report of 37 samples within 2512-3422 metres depth presented by Noetinger & di Pasquo (2009) and new results from 16 samples (including six core samples) selected from the 2512-4243 metre depth interval (Fig. 2).

Standard palynological methods were used to obtain organic residues from the samples at the Laboratory of Palynostratigraphy and Paleobotany (Department of Geology, Natural and Pure Sciences Faculty, University of Buenos Aires) in 2008 and di Pasquo processed seven selected samples in 2009 to complete the set of studied samples. They were first crushed and then treated with hydrochloric and then with hydrofluoric acid to remove carbonate, silica, and silicates, respectively. The residues were then sieved through a 25 µm mesh and mounted on slides with glycerine jelly.

Palynofacies analysis was performed on the samples with eight types of dispersed organic matter and palynomorph groups recognised. These consist of amorphous organic matter (AOM); structured phytodebris (SP), characterised by identifiable cuticles and wood; unstructured phytodebris (USP), known as gelified matter; black phytodebris (BP) or opaque clasts; spores (SPO); phytoplankton (PHY), comprising acritarchs, prasinophycean and chlorophycean algae; chitinozoans (CHI); and cryptospores (CRY). This simplified classification scheme of organic components was adapted from Tyson (1995) and the palynomorphs found in the analysed assemblages were used to calculate relative percentages, and thus to define and identify the different palynofacies. A palynological marine index {PMI= [Marine Richness (Rm)/Terrestrial Richness (Rt) + 1] x 100; Helenes *et al.* 1998} was also calculated to support the interpretation of depositional environments. The values used are those

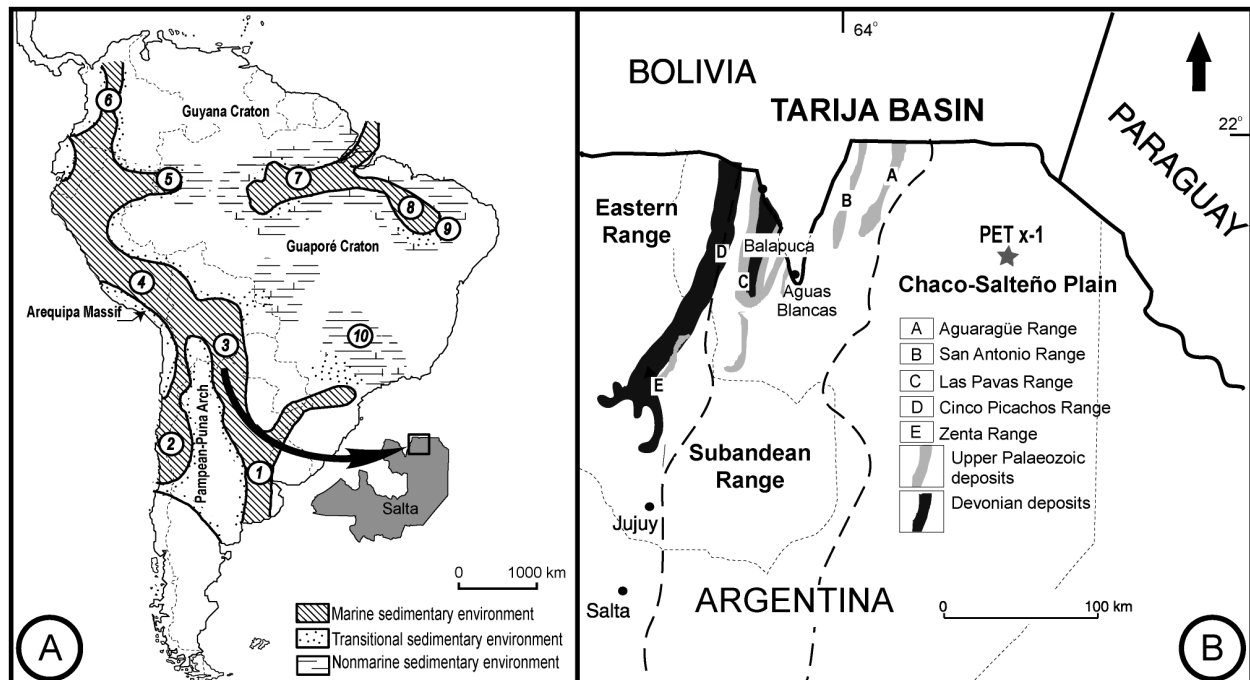


Figure 1. A, Palaeoenvironmental map of South America during the Lochkovian with the location of the basins of the area: 1, Chacoparaná; 2, Precordillera; 3, Tarija; 4, Madre de Dios; 5, Solimões; 6, Llanos Orientales; 7, Amazonas; 8, Parnaíba; 9, Jatobá; 10, Paraná (based on Melo 1989; Grahn 2003, 2005, Rubinstein *et al.* 2008, Grahn *et al.* 2010a; modified from di Pasquo & Noetinger 2008). B, Detail of the area and location of the studied well.

stipulated by de Araujo Carvalho *et al.* (2006), where the marine and terrestrial richness were expressed as number of genera per sample. Low values of PMI are interpreted as indicative of brackish-water influence, and higher PMI values are interpreted as indicative of marine conditions of deposition. Because the PMI is based on the palynomorph diversity of terrestrial and marine species, it is therefore used as a substitute for the typical terrestrial/marine ratio.

Identification and illustration of palynomorphs was undertaken at the Laboratory of Palynostratigraphy and Paleobotany (Department of Geology, Natural and Pure Sciences Faculty, University of Buenos Aires) using transmitted light microscopes with a digital video camera (*Leitz Orthoplan* and *Motic 2.0 MB*, *Nikon Eclipse 80i* (with DIC objectives) and *Pax-it 3.1 MB*). The position of illustrated specimens in the respective slides quoted with the CICYTTP-PI acronym (Repository), are based on England-Finder coordinates.

STRATIGRAPHY AND PALEONTOLOGICAL RECORDS

Late Silurian and Devonian stratigraphic units included between the Oclroyic and Chanic unconformities in northern Argentina and southern Bolivia (Tarija Basin), assigned to a first interval by Starck *et al.* (1993) and Starck (1995), comprise three supersequences: Cinco Picachos, Las Pavas and Aguaragüe (Fig. 3). They are characterised by stacked kilometric coarsening shale and sandstone facies, bounded by flooding surfaces of the first order. The second interval includes the Carboniferous, Permian and mostly Triassic and Jurassic deposits. In this study, the first two supersequences are briefly described together with the units involved (i.e., Copo, Caburé and Rincón formations).

The Cinco Picachos Supersequence is exposed in the Cinco Picachos Range along the boundary between the

Eastern and the Subandean ranges extending up to the Santa Bárbara System in Argentina (Fig. 1; Starck 1999). Further east, this Supersequence is represented in the subsurface by the Caburé Formation, defined in the El Caburé x-1 borehole of Santiago del Estero Province, as comprising mainly indurated fine-grained quartz-sandstones with a variable thickness between ca. 400 and 500 metres (Padula *et al.* 1967). It is recognised between two shaly units, the Copo (Silurian) and Rincón (mid-Devonian) formations in the subsurface of the Chaco-Salteño and Chacoparaná plains in Argentina (Chebli *et al.* 1999; Grahn & Gutiérrez 2001; Antonelli & Ottone 2006; Noetinger & di Pasquo 2009) and Uruguay (Grahn 2003). In the El Caburé x-1 borehole, Antonelli & Ottone (2006) assigned the Caburé Formation to the Emsian based on spores and acritarchs whilst Grahn (2003) indicated a Ludlow-Pridoli age for the upper Copo Formation based on the presence of the chitinozoans *Fungochitina kosovensis?* Paris & Kriz, *Angochitina* aff. *A. filosa* Eisenack, *Ancyrochitina* sp. and *Cingulochitina* aff. *C. serrata* Taugourdeau & de Jekhowsky. *F. kosovensis?* and *A. aff. A. filosa* also occur in the lower Caburé Formation, and *Clathrochitina* sp. A and *Ancyrochitina* sp. are new species recorded by Grahn (2003) who suggested a Pridoli age for the assemblage. Milani & Zalán (1999) compared the Caburé Formation to the top of the Furnas Formation in the Paraná Basin (Fig. 3), the latter dated as no older than Lochkovian, and no younger than early Pragian based on the palynology (Loboziak *et al.* 1995; Grahn *et al.* 2010a).

The Las Pavas Supersequence crops out in the same ranges as the Cinco Picachos Supersequence, and further east in the subsurface of the Chaco-Salteño and Chacoparaná plains (Starck 1999), where it is represented by the Rincón and Michicola formations (Figs 1, 3). The Rincón Formation overlies the Caburé Formation and is composed of black laminated shales, which are partly fossiliferous

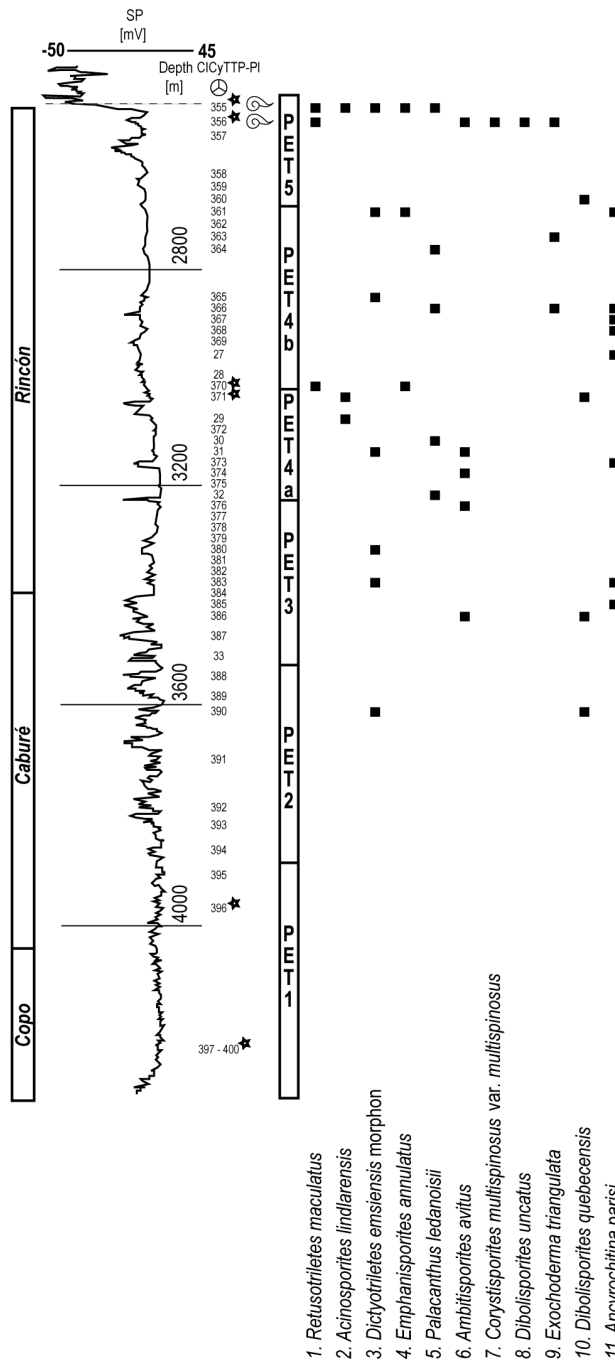


Figure 2. Electric log of the PET x-1 borehole with the location of the studied samples (CICyTTP-PI cores are marked with a star), stratigraphic distribution of selected species (in last occurrence order) and palynomorph associations recognised (PET1, 2, etc.). Position of bivalve and gastropod casts in top two cores indicated.

(Padula *et al.* 1967). These strata include macrofossils such as *Metacryphaeus* sp., *Calmonia subcesiva* Clarke and *Australocoelia tourtelotti* Boucot & Gill, among others. The palaeomicroplankton suggests an Emsian – Givetian age (Cuerda & Baldis 1971; Russo *et al.* 1979; Aceñolaza *et al.* 2000; Grahn & Gutiérrez 2001; Grahn 2003). Grahn & Gutiérrez (2001) and Grahn (2003) mentioned Middle Devonian chitinozoan species (*e.g.*, *Ancyrochitina langei*? Sommer & van Boekel, *Alpenachitina eisenacki* Dunn & Miller and *Ramochitina ramosi* Sommer & van Boekel) from the Rincón Formation in the Los Horcones-2 and El Caburé-1 wells. Antonelli & Ottone (2006) attributed a late Emsian – early Eifelian age to the Rincón Formation based on the presence of the miospores *Dibolisporites echinaceus* (Eisenack) Richardson, *Emphanisporites annulatus* McGregor, *Grandispora* spp., *Dictyotriletes emsiensis*

(Allen) McGregor and *Rhabdosporites langii* (Eisenack) Richardson. The Michicola Formation is considered a facies variation of the Rincón Formation by many authors; in the subsurface of the Chaco-Salteño Plain (see Aceñolaza *et al.* 2000), it comprises tens of metres of mainly silicified white-greyish quartz sandstone (Russo *et al.* 1979).

In the Puesto El Tigre x-1 borehole studied herein, Padula *et al.* (1967, p. 174) defined the Puesto El Tigre Formation (ca. 1800 metres thick) as consisting of three members: two dark, fissile shaly units at its top and base and a quartz-sandstone unit in the middle. The Puesto El Tigre Formation was rejected by Mingramm & Russo (1972) and Russo *et al.* (1979) because they considered that these members are equivalent to the Copo, Caburé, and Rincón formations respectively (Fig. 3). We agree with these authors and follow the stratigraphy proposed by them. Acevedo (1986)

Countries				ARGENTINA				BOLIVIA				BRAZIL				
Chronology				TARIJA						MADRE DE DIOS		PARANA	AMAZON	PARNAIBA		
Basin																
Geographic units				Supersequences (1)	Chaco-Salteño Plain (2)	Eastern Range	Southern Subandean (2)	Altiplano-Oriental Range (3)	Northern Subandean Range	(4)	(5)	(6)				
Period	Epoch	Stage	Ma													
DEVONIAN	UP	Fras.	385	Aguaragüe	Jollín Tonono	Los Monos	Iquiri Los Monos	Colpacucho	Tomachi	São Domingo	Barreirinha ?	Pimenteira				
		MID	Giv.	Las Pavas	"Puesto El Tigre"	Cerro Piedras	Huamampampa	Sica Sica		Furnas	Ereré					
	LOW	Eifel.	(Michicola) Rincón						Pescado		Icla	Belén	Ponta Grossa	Maecuru	Itaim	
		Ems.	Caburé						Porongal		Santa Rosa	Vila Vila	Tequeje	Manacapuru		?
		Prag.	Baritú						Tarabuco		Catavi	Rio Carrasco	?			
	SILURIAN	UP	Loch.	416	Cinco Picachos	Copo	Lipeón	Kirusillas								
Prid.			418									Jaicós				
Ludlo.			422									Pitinga	?			

Figure 3. Stratigraphic correlation of the local units with others from northern Argentina, southern Bolivia, Brazil and Uruguay. References: (1) Starck *et al.* 1993; (2) Starck 1999; (3) Suárez Soruco 2000; (4) Grahn *et al.* 2010a, 2010b; (5) Grahn & Melo 2003; Melo & Loboziak 2003 (6) Grahn *et al.* 2003; Breuer & Grahn 2011.

and Volkheimer *et al.* (1986), however, followed the first stratigraphic proposal for this borehole. Three chitinozoan zones were defined in the Puesto El Tigre Formation (Volkheimer *et al.* 1986): the *Urochitina lobo* Assemblage Zone (Lochkovian), the *Ramochitina magnifica* Assemblage Zone (Emsian), and the *Ancyrochitina parisi* Assemblage Zone (latest Emsian), which are recognised in this study, and further addressed in the text. Additionally, the latter authors referred to the presence at the top of the well, below the contact with the Cretaceous–Cenozoic succession, of two units, the Michicola and Tonono formations, without samples and therefore without any palaeontological information (ca. 100 metres). Unidentified bivalve and gastropod casts were recognised in two cores at the top of the section (see Fig. 2).

RESULTS

Composition, age and correlation

A variety of spores, acritarchs and chlorophycean algae, along with chitinozoans, were recovered, including many of the same taxa recognised by Volkheimer *et al.* (1986) (Figs 2, 4–6; see Taxa Identified section below). Even though the general preservation of the palynomorphs is very poor, with high thermal maturity (4– to 4) (Utting *et al.* in Utting & Wielens 1992), it was still possible to recognise key species that suggest an age range from late Lochkovian to latest Emsian.

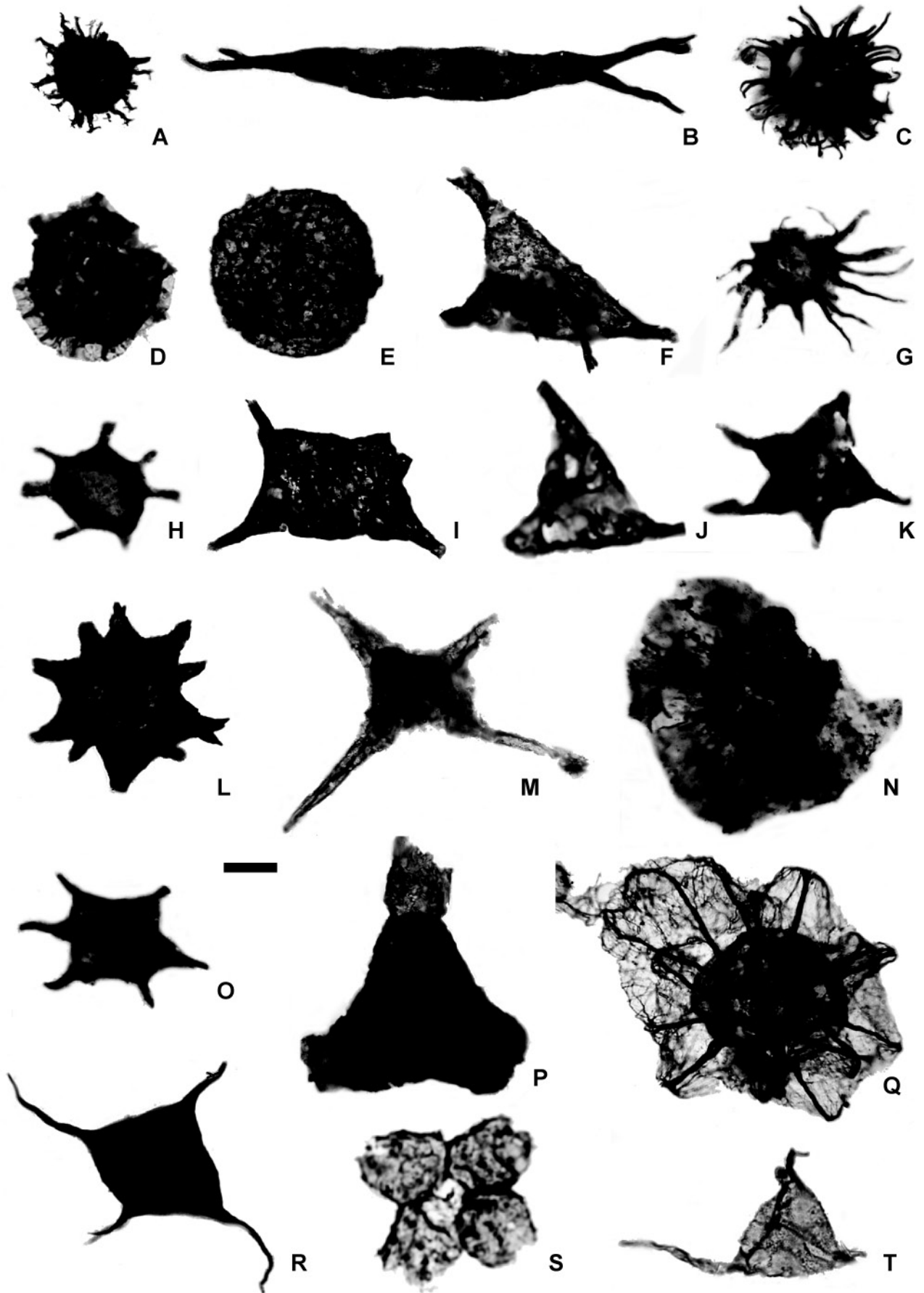
The palynomorph assemblage comprises 41 spore and cryptospore species, some of which are left in

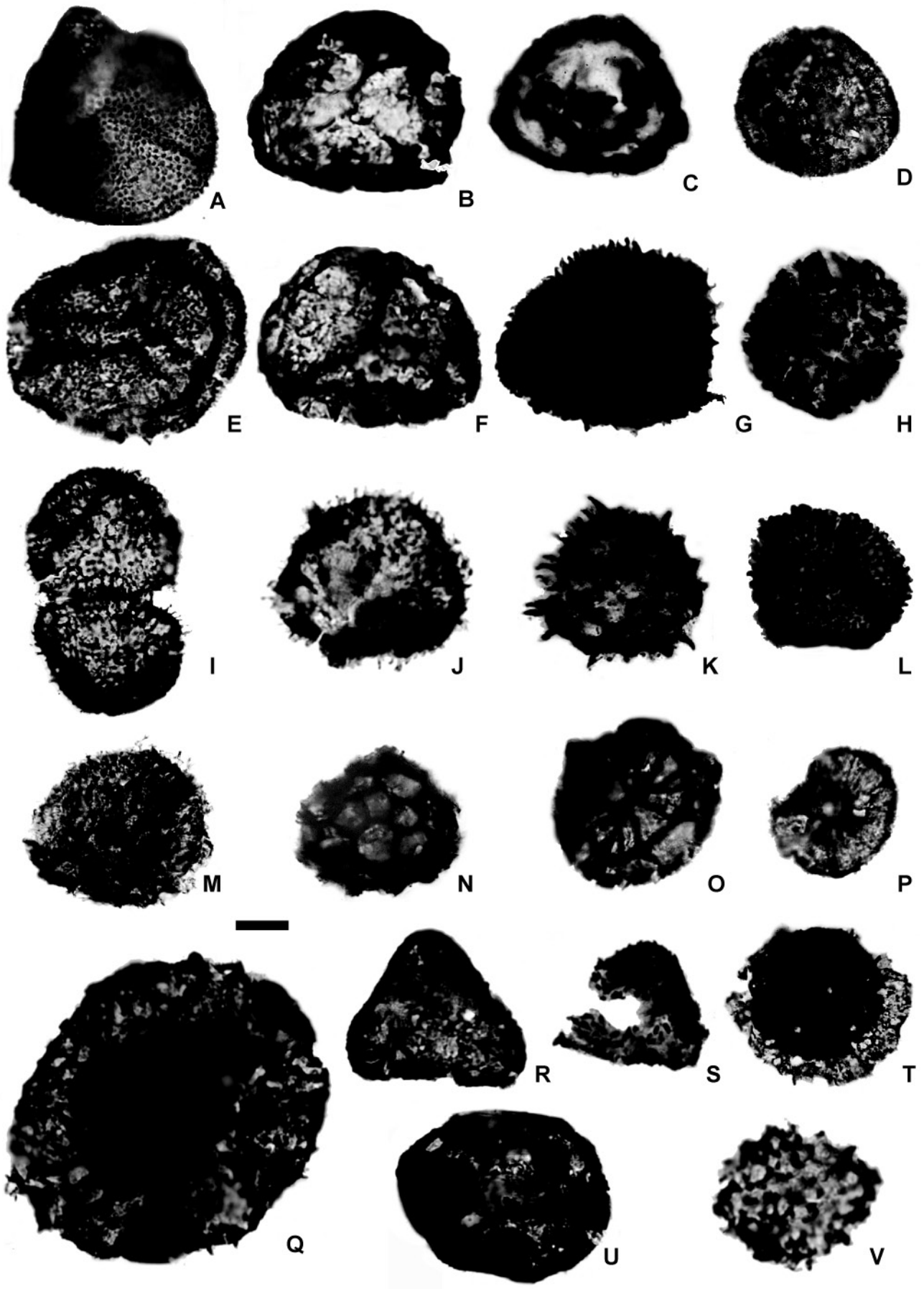
open nomenclature, as well as 27 species of acritarchs, prasinophycean and chlorophycean algae, and 12 species of chitinozoans. Most of the palynomorph species recorded herein are well known and adequately circumscribed in previous palynological literature; hence the taxa are listed (see below) and only the most stratigraphically representative species and those in open nomenclature are illustrated (Figs 4–6).

The stratigraphic distribution and the analysis of the global ranges of several key species (Figs 2, 7) support the definition of five assemblages and their ages. Although the last occurrence in cutting samples is considered the most accurate appearance of each taxon, to establish the boundaries of the assemblages here defined, we also considered the total ranges of important taxa within the succession in combination with the information provided by core samples, when available. Because mixtures of taxa with different stratigraphic ranges or other kinds of inconsistencies were not recognised, their stratigraphic distribution throughout the section (Fig. 2) seems to be trustworthy, although some subtle caving cannot be discounted.

PET1 Association (3872 – 4243 m). The presence of key species such as *Urochitina lobo* and *Sphaerochitina densibaculata*, along with several long-ranging species (e.g., *Cingulochitina* spp., *Onondagella asymmetrica*, *Archaeozonotrites chulus* var. *chulus* and *Verhyachium valiente*) characterise this assemblage. Volkheimer *et al.*

Figure 4 (opposite). **A**, *Ammonidium* sp., CICYTTP-PI 376 (1) B1/1. **B**, *Bimerga bensonii*, CICYTTP-PI 381 (1) J33/3. **C**, *Michrystidium* sp., CICYTTP-PI 394 (1) Z56/4. **D**, *Cymatiosphaera hermosa*, CICYTTP-PI 381 (1) S27. **E**, *Dictyotidium variatum*, CICYTTP-PI 396 (2) Z45/4. **F**, *Exochoderma irregulare*, CICYTTP-PI 366 (1) S28. **G**, *Michrystidium salopiense*, CICYTTP-PI 33 (2) X48/2. **H**, *Multiplicisphaeridium intonsurans*, CICYTTP-PI 33 (1) M45/1. **I**, ?*Neoverhyachium carminae*, CICYTTP-PI 380 (2) 20/101. **J**, *Onondagella asymmetrica*, CICYTTP-PI 374 (1) A54/1. **K**, *Palacanthus ledanoisii*, CICYTTP-PI 30 (1) D47/4. **L**, *Polyedryxium evolutum*, CICYTTP-PI 383 (1) E26/1. **M**, *Polyedryxium? tetraedroide*, CICYTTP-PI 33 (6) B48. **N**, *Pterospermella reticulata*, CICYTTP-PI 31 (3) S54. **O**, *Stellinium rabians*, CICYTTP-PI 27 (1) K49/2. **P**, *Triangulina aspera*, CICYTTP-PI 388 (1) Y39. **Q**, *Tunisphaeridium caudatum*, CICYTTP-PI 380 (1) W22. **R**, *Verhyachium (Tetraverhyachium) valiente*, CICYTTP-PI 376 (1) H29/3. **S**, *Quadrisporites granulatus*, CICYTTP-PI 356 (1) G27/1. **T**, *Verhyachium (Verhyachium) trispinosum*, CICYTTP-PI 378 (1) N48/1. Scale: A, B, E, F, M, P= 20 µm; C, D, G, I, J, L, N, Q-T= 15 µm; H, K, O= 10 µm.





(1986, p. 245) defined the *Urochitina lobo* Association Zone as “pre-Emsian” age in the same borehole based on the same chitinozoan species here recorded except that *Cingulochitina striata* Volkheimer *et al.* was not present in our samples. Le Hérisse *et al.* (1997) recorded *Urochitina* cf. *U. lobo* and *Cingulochitina serrata* from the Talacasto Formation in the Argentinian Precordillera. In Bolivia, Limachi *et al.* (1996) defined a biozone with *U. lobo* and *Sphaerochitina densibaculata* from the top of the Tarabuco and Santa Rosa formations, together with *Cingulochitina* sp. and *Hoegisphaera* sp., the last being absent in PET x-1. Finally, Grahn (2005) characterised the *Urochitina lobo* Interval Zone for western Gondwana, and restricted it to the upper Lochkovian based on the first appearance of the eponymous species up to the first appearance of *Ramochitina magnifica* in the ?uppermost Lochkovian. *Sphaerochitina densibaculata* is among the species included in this zone (see Grahn 2002, 2005). Melo (2005) established the range of *U. lobo* as upper to uppermost Lochkovian and that of *R. magnifica* as Pragian-lowest Emsian for Brazilian basins. Recently, a well preserved and diverse assemblage with both terrestrial and marine palynomorphs containing *Urochitina lobo* was identified in the Apillapampa section in Bolivia, and assigned to the upper Lochkovian (di Pasquo *et al.* 2009). In agreement with Grahn (2005), a late Lochkovian age is assigned to this assemblage (Figs 2, 7).

PET2 Association (3834 - 3454 m). This is characterised by the last occurrence of such long-ranging species as *Dictyotriletes emsiensis* morphon, *Dibolisporites quebecensis* and *Bimerga bensonii*, and the absence of *Urochitina lobo* and *Sphaerochitina densibaculata*. The first two species are recorded globally from the upper Lochkovian whilst the third species occurs after the Pragian (see Fig. 7; Melo 2005; di Pasquo *et al.* 2009 and its supplementary online information). Hence, an early Pragian age is attributed to this assemblage (Figs 2, 7).

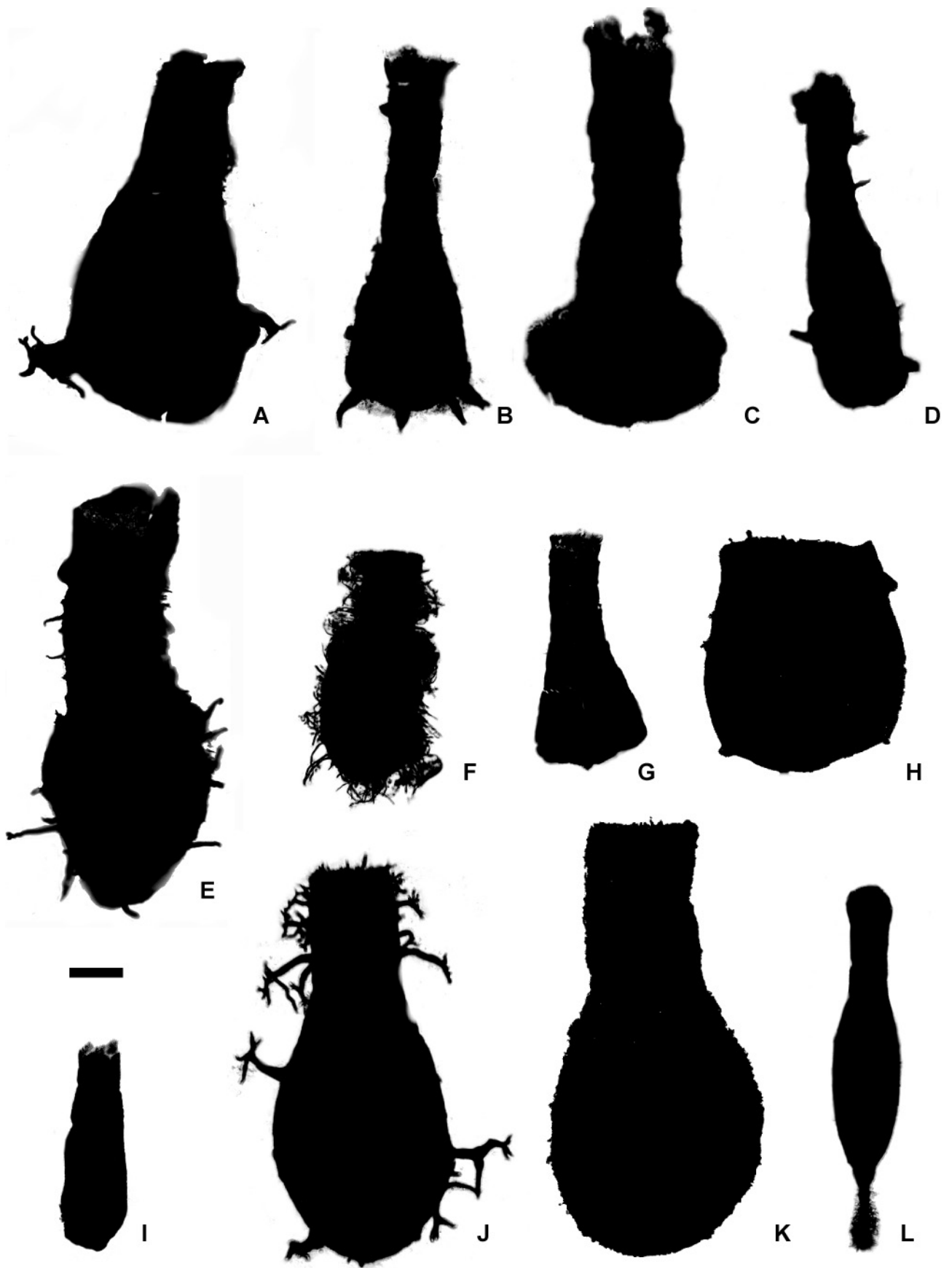
PET3 Association (3422 - 3304 m). This association is defined by the range (FOD-LOD occurrence) of *Ramochitina magnifica*. *Triangulina aspera* and *Ancyrochitina parisi* appear in CICYTTP-PI 385 and 33 respectively (Fig. 2) and a few long-ranging species also occur in this assemblage (*Ambitisporites avitus*, *Perotrilites caperatus?*, *Cymbohilates heteroverrucosus*, *Cymatiosphaera hermosa* and *Polyedryxium evolutum*). Grahn (2005) delimited the base of the *Ramochitina magnifica* Interval Zone at the first occurrence (FO) of the eponymous species and the top at the FO of *Ancyrochitina pachycerata*, in the Pragian. However, this biozone seems to have different ages depending on the locality. *Ramochitina magnifica* occurs in the basal Fox Bay Formation in the Falkland Islands and was listed as *Angochitina* sp. A. in the Horlick Formation of Antarctica

by Troth *et al.* (2011). It also appears in the Si Zone of the MN Zone, in the Paraná Basin (Rubinstein *et al.* 2005), as well as in the base of the Ponta Grossa Formation of late Pragian – early Emsian age (Grahn *et al.* 2010a).

In Paraguay, *Ramochitina magnifica* occurs in a spore association dated as Lochkovian – early Pragian in the Santa Elena Formation (Pereira 2000); in Bolivia, it is recorded together with Pragian spores (Vavrdová *et al.* 1996; Melo 2000), and in Uruguay it was recorded in the Cordobés Formation of Early Devonian age (see Daners & Verde 2008). Volkheimer *et al.* (1986) recorded this species above *Urochitina lobo* and it was selected to define the *Ramochitina magnifica* Association Zone of late Emsian age. Isolated occurrences of *Ancyrochitina parisi*, together with *Ramochitina magnifica*, were also noted by Volkheimer *et al.* (1986) in the PET x-1 well. Although the effect of caving cannot be discounted in this well, Grahn *et al.* (2010b) found *Ancyrochitina parisi* in the Pow (Su) Zone of Pragian – early Emsian age in Brazil. Hence, the Pragian - earliest Emsian range of *R. magnifica* (Melo 2005), together with *Perotrilites caperatus?* and *Triangulina aspera* from the Lochkovian - Emsian, and *Cymbohilates heteroverrucosus* from the Emsian of northwestern Gondwana, suggest an age range from the early Pragian to the late Pragian-?early Emsian (see Figs 2, 7).

PET4 Association (2712 – 3290 m). This thick interval is defined by a continuous record of *Ancyrochitina parisi* up to its appearance (FO) at a depth of 2,712 m (Fig. 2). This association is divided in two, the lower PET4a and upper PET4b based on the range (FO-LO) of *Dibolisporites eifeliensis*, which appears at the base of the PET4b in the core sample CICYTTP-PI 370 (3042 - 3048 m). PET4a is characterised by long-ranging species such as *Acinosporites lindlarensis*, *Ambitisporites avitus*, *Dibolisporites quebecensis* and *Palacanthus ledanoisi*, and by the first occurrence of *Onondagaella asymmetrica*, *Dibolisporites? nodosus* and *Archaeozonotriletes chulus* var. *chulus*. PET4b is also characterised by the appearance of *Retusotriletes maculatus* and *Emphanisporites annulatus* at the base, the continuous presence of *Emphanisporites epicautus* and the first occurrence of *Bimerga bensonii*. *Leiotriletes pagius*, *Lophotriletes devonicus* and *Grandispora douglstownense* are exclusively recorded at the top of this section with the first appearance of *?Perotrilites caperatus* and *Emphanisporites epicautus*. Grahn (2005) assigned the *Ancyrochitina parisi* Interval Range Zone to the late Emsian (possibly including late early Emsian and earliest Eifelian) for the upper Ponta Grossa - lowermost São Domingos formations, based on its FO. This assessment is supported by miospores (Loboziak & Melo 2000) and megafossils (Melo 1989). Grahn *et al.* (2010b) documented the FO of this species from the late Pragian - early Emsian *Ancyrochitina pachycerata* Zone

Figure 5. A, *Acinosporites lindlarensis*, CICYTTP-PI 371 (1) S57/4. B, *Ambitisporites avitus*, CICYTTP-PI 374 (1) A52/1. C, *Amicosporites streelii*, CICYTTP-PI 386 (1) H51/2. D, *Apiculiretusispora brandtii*, CICYTTP-PI 371 (1) F59. E, *Apiculiretusispora densiconata*, CICYTTP-PI 361 (1) L43/1. F, *Apiculiretusispora plicata*, CICYTTP-PI 355 (1) G52. G, *Corystisporites multispinosus* var. *multispinosus*, CICYTTP-PI 356 (1) A62/2. H, *Cymbohilates heteroverrucosus*, CICYTTP-PI 33 (6) E58/2. I, *Cymbohilates* sp., CICYTTP-PI 383 (1) C58/3. J, *Dibolisporites eifeliensis*, CICYTTP-PI 361 (1) B40/1. K, *Dibolisporites? nodosus*, CICYTTP-PI 33 (6) S59/1. L, *Dibolisporites quebecensis*, CICYTTP-PI 360 (1) A53/1. M, *Dibolisporites uncatus*, CICYTTP-PI 356 (2) Q38. N, *Dictyotriletes emsiensis* morphon, CICYTTP-PI 383 (1) U53/2. O, *Emphanisporites annulatus*, CICYTTP-PI 370 (1) V29. P, *Emphanisporites epicautus*, CICYTTP-PI 370 (1) N48/1. Q, *Grandispora douglstownense*, CICYTTP-PI 362 K27/3. R, *Leiotriletes* sp. cf. *L. bonitus*, CICYTTP-PI 359 (2) C51/3. S, *Lophotriletes devonicus*, CICYTTP-PI 361 (1) A52/2. T, *Perotrilites caperatus?*, CICYTTP-PI 381 (1) W48. U, *Retusotriletes maculatus*, CICYTTP-PI 356 (2) A33/1. V, *Verrucosisporites* sp. A, CICYTTP-PI 359 (1) D46/4. Scale: A, H-P, S-V = 15 µm; D, E, G, Q, R = 20 µm; B, C, F = 10 µm.



up to the early Eifelian (see also Melo 2005). On the other hand, *Emphanisporites annulatus* is recognised as a marker of the base of the Emsian especially in South America (Melo 2005; Troth *et al.* 2011). Hence, we suggest a latest Pragian to Emsian age for the whole assemblage (see Figs 2, 7).

PET5 Association (2512 – 2710 m). This association is characterised by the first appearance of *Ambitisporites avitus*, *Dictyotriletes emsiensis* morphon and *Emphanisporites annulatus*, and the exclusive appearance of *Corystisporites multispinosus* var. *multispinosus* and *Dibolisporites uncatus* in two core samples (see Fig. 2). The last two species are known from the late Emsian in the AP and DE Zones (Richardson & McGregor 1986, Streel *et al.* 1987), and *Dictyotriletes emsiensis* morphon is known to occur up to the late Emsian (Fig. 7). The Interval Zone *Grandispora/Samarisporites* spp. (GS) of late Emsian – early Eifelian age, defined for the Amazonas Basin by Melo & Loboziak (2003) share few species (*e.g.*, *Acinosporites lindlarensis*, *Emphanisporites annulatus*) with this assemblage. Moreover, the absence of *Ancyrochitina parisi* and *Alpenachitina eisenacki* Dunn & Miller and other key taxa of the Eifelian (*Grandispora* spp., *Acinosporites* spp., *Craspedispora* spp.), which are characteristic of the AD Pre-Lem zone (Europe) and Per (Brazil), support a late Emsian age for the top of this succession (see Figs 2, 7).

Palaeoenvironmental considerations

The palynofacies throughout the section seem to be homogeneous in character although the PMI index together with the variation in AOM (Fig. 8) allowed the recognition of palynofacial changes that are helpful in the environmental reconstruction of the succession. As a general rule, the sequence boundaries are recognised at intervals with upward-decreasing PMI values, whereas a maximum flooding surface (MFS) usually will be near the maximum values of PMI in each sequence (Helenes *et al.* 1998). There were four marine flooding episodes and four marine regression events, represented by third order cycles during the Devonian (see Fernández-Seveso *et al.* 2000), in several sectors of the Tarija Basin (Fig. 1), some of which are reflected by the palynological data (Fig. 8), presented here. According to Albariño *et al.* (2002), during the Lochkovian-Pragian and Pragian-Emsian transitions, there occurred transgressive events recognised herein as a set of peaks of PMI with the highest values of AOM mainly in the PET1-PET3 interval (Fig. 8). The samples CICyTTP-PI 358, 359 and 360 show high input of AOM, with low values of SPO as well as a low PMI index, likely product of the poor preservation of these particular samples. The samples CICyTTP-PI 355 and 356 at the end of the PET5 interval record the highest values of the relative percentage of spores (*e.g.*, the lowest values of PMI) and the lowest values of AOM (Fig. 8). These samples could reflect the sequence boundary (SB) recorded by Fernández-Seveso *et al.* (2000) at the end of the Emsian, and this is also supported by a high supply of terrigenous phytodebris and spores known from several localities of the Subandean Range and the Chaco-Salteño Plain (Noetinger 2010; Noetinger

& di Pasquo 2010, 2011). At the beginning of the Eifelian, Albariño *et al.* (2002) interpreted a new transgressive event; however, the lack of the remaining Devonian column in this borehole prevents a more accurate age for the top of PET5 association (Figs 2, 7), as well as its palaeoenvironmental evolution.

TAXA IDENTIFIED

The identified palynomorph taxa are reported by major groups and in alphabetical order. Only those previously not recorded or that merit particular comment are described below. The species described in open nomenclature are generally represented by few specimens, are poorly preserved, or have questionable affinity. Nevertheless, they are included in the stratigraphic distribution of the assemblages (Fig. 2), and some of them are illustrated in Figures 4-6. Note that taxon authors are not included in the References.

Microplankton and Incertae sedis

Ammonidium sp. (Fig. 4A) (5 specimens). Vesicle subspherical, psilate wall with numerous homomorphic subcylindrical processes that are in free communication with the vesicle, and regularly distributed across the vesicle surface. Tips of processes are variably digitate (bifurcate - quadrifurcate). Diameter: 25-30 µm. Processes: 5-10 µm long.

Bimerga bensonii Wood, 1995 (Fig. 4B)

Cymatiosphaera hermosa Cramer & Diez, 1976 (Fig. 4D)

Dictyotidium variatum Playford, 1977 (Fig. 4E)

Dorsennidium (Dorsennidium) minutum (Downie) Sarjeant & Stancliffe emend. Stancliffe & Sarjeant, 1996

Dorsennidium (Dorsennidium) raczii (Cramer) Sarjeant & Stancliffe, 1994

Estiastra sp.

Exochoderma irregulare Wicander, 1974 (Fig. 4F)

Exochoderma triangulata Wicander & Wood, 1981

Micrhystridium salopiense (Lister) Dorning, 1981 (Fig. 4G)

Micrhystridium sp. (Fig. 4C) (1 specimen). Spheroidal vesicle densely covered by thin, filiform, processes with expanded bases and of uniform length that is 1/3 the total diameter of the vesicle. Observations: *Comasphaeridium intonsum* (Loeblich & Wicander) Sarjeant & Stancliffe has spines that are 50% as long as the diameter of the vesicle. Diameter: 26 µm. Processes: 7-13 µm long. Bases: 1.6-2.4 µm wide.

Multiplicisphaeridium intonsum (Lister) Sarjeant & Stancliffe, 1994 (Fig. 4H) (1 specimen). Remarks: The processes are incomplete but their furcation is evident.

Multiplicisphaeridium ramusculosum Deflandre emend. Lister 1970

Neoveryhachium carminae? (Cramer) Cramer, 1970 (Fig. 4I)

Onondagaella asymmetrica (Deunff ex Deunff) Cramer emend. Playford, 1977 (Fig. 4J)

Palacanthus ledanoisii Deunff emend. Playford, 1977 (Fig. 4K)

Polydrixium evolutum Deunff, 1955 (Fig. 4L)

Polydrixium? tetraedroide (Cramer) Deunff, 1971 (Fig.

Figure 6. A, *Ancyrochitina* sp. cf. *A. asterigis*, CICyTTP-PI 370 (1) U31. B, *Ancyrochitina parisi*, CICyTTP-PI 27 (1) O33/3. C, *Saharochitina* sp., CICyTTP-PI 370 (1) Q57/2. D, *Ancyrochitina* sp., CICyTTP-PI 370 (1) X43. E, *Angochitina* sp. A, CICyTTP-PI 365 (2) P26. F, *Angochitina* sp. B, CICyTTP-PI 396 (2) W45/4. G, *Belonechitina* sp., CICyTTP-PI 366 (2) X43/3. H, *Cingulochitina* sp. CICyTTP-PI 396 (2) B45/1. I, *Conochitina* sp., CICyTTP-PI 366 (2) Y53/4. J, *Ramochitina magnifica*, CICyTTP-PI 381 (1) L54/1. K, *Sphaerochitina densibaculata*, CICyTTP-PI 396 (2) E45/1. L, *Urochitina loboii*, CICyTTP-PI 396 (1) C19. Scale: A, B, D, F, G, I, L = 35 µm; C, E, H, J, K = 20 µm.

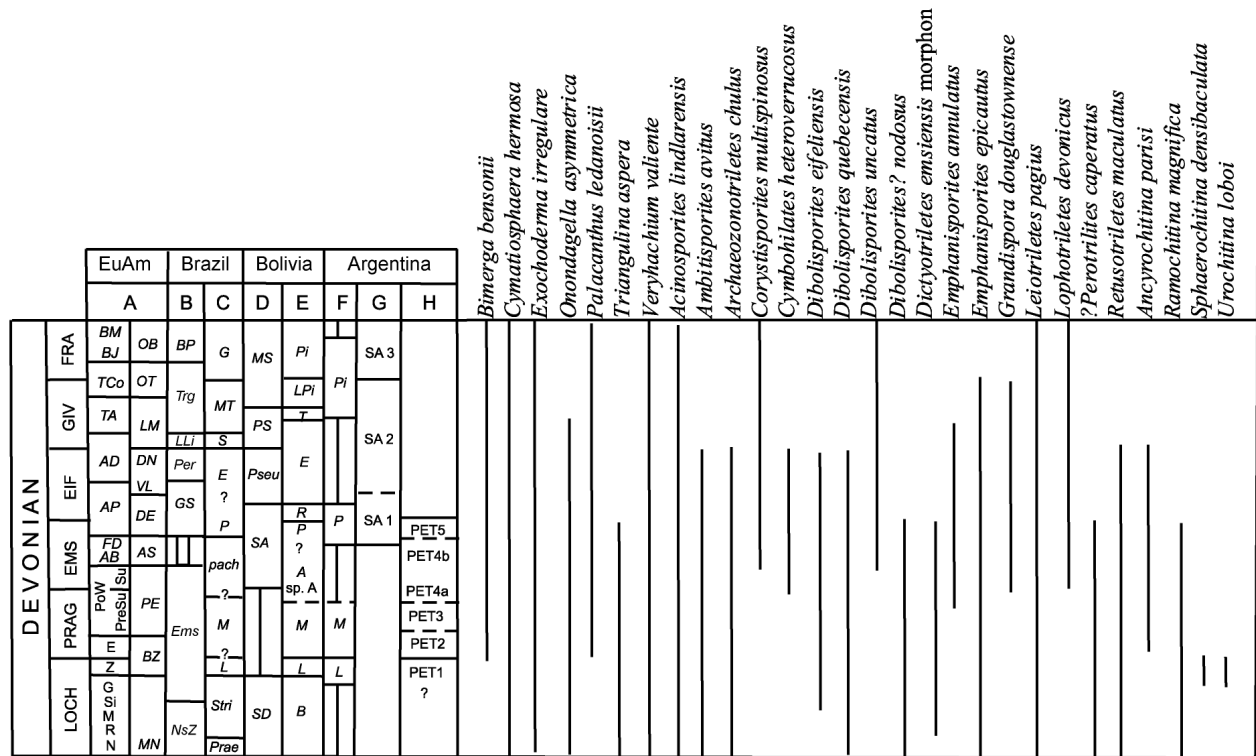


Figure 7. Biostratigraphic correlation of the PET x-1 assemblages with selected biostratigraphic schemes of the world and regional assemblages (A, Richardson & McGregor 1986, Streele *et al.* 1987, Steemans 1989; B, Melo & Loboziak 2003; C, Grahn 2005; D, Limachi *et al.* 1996; E, Grahn 2002; F, Volkheimer *et al.* 1986; G, Noetinger & di Pasquo 2011) and stratigraphic ranges of selected taxa (listed in main groups and in alphabetical order) based on selected literature: Achab *et al.* 1997; Al-Ghazi 2007; Antonelli & Ottone 2006; Bosetti *et al.* 2011; Breuer 2007 (and references therein); di Pasquo 2007 (and references therein); Ghavidel-Syooki 1995, 2003; Grahn 2002, 2005; Grahn *et al.* 2000, 2003, 2005, 2010a,b; Gaugris & Grahn 2006; Lazar 2008; Noetinger 2011 (and references therein); Rubinstein 1995, 2002; Servais *et al.* 2007; Spina & Vecoli 2009; Steemans *et al.* 2009; Ville de Goyet *et al.* 2007; Volkheimer *et al.* 1986; Zhu *et al.* 2008. Abbreviations: **Euamerica** (EuAm) (A): N, *S. newportensis*; R, *C. retorrída*; M, *E. microronatus* var. *microronatus*; Si, *E. zavallatus* var. *sinuosus*; G, *E. zavallatus* var. *gedin*; Z, *E. zavallatus* var. *zavallatus*; PoW, *V. polygonalis*–*D. wetteldorfensis*; AB, *E. annulatus*–*B. bellatulus*; FD, *E. foveolatus*–*V. dubia*; AP, *A. apiculatus*–*C. proteus*; AD, *A. acanthomammillatus*–*D. devonicus*; TA, *S. triangulatus*–*A. ancyrea* var. *ancyrea*; Tco, *S. triangulatus*–*C. concinna*; BJ, *V. bulliferus*–*C. jekhowskyi*; BM, *V. bulliferus*–*L. media*. MN, *E. microronatus*–*S. newportensis*; BZ, *B. breconensis*–*E. zavallatus*; PE, *V. polygonalis*–*D. emsiensis*; AS, *E. annulatus*–*C. sextantii*; DE, *G. douglstownense*–*A. eurypterota*; VL, *C. velatus*–*R. langii*; DN, *D. devonicus*–*G. naumovii*; LM, *G. lemurata*–*C. magnificus*; OT, *C. optivus*–*C. triangulatus*; OB, *A. ovalis*–*V. bulliferus*. **Brazil** (B): NsZ, *Non-spinose zonates*; Ems, *D. emsiensis*; GS, *Grandispora/Samarisporites* spp.; Per, *G. permulta*; LLi, *G. lemurata*–*C. ex gr. ligurata*; Trg, *S. triangulatus*; BP, *V. bulliferus*–*G. piliformis*. (C): Prae, *A. praedensibaculata*; Stri, *A. strigosa*; L, *U. loboi*; M, *R. magnifica*; pach, *A. pachycerata*; P, *A. parisi*; E, *A. eisenacki*; S, *R. stiphrospinata*; MT, *F. microspinosa*–*A. taouratinensis*; G, *H. glabra*. **Bolivia** (D): SD, *Dictyotriletes*–*S. saharica*/ *S. pilosa*; SA, *E. annulatus*/ *E. sommeri*; Pseu, *G. pseudoreticulata*; PS, *V. premmus*/ *V. scurrus*; MS, *Samarisporites*/ *M. brasiliensis*. (E): B, *E. cf. E. bohemia*; L, *U. loboi*; M, *R. magnifica*; A, *Ancyrochitina* sp. A.; P, *A. parisi*; R, *R. ramosi*; E, *A. eisenacki*; T, *A. taouratinensis*; LPI, *A. langei*–*F. pilosa*; Pi, *F. pilosa*. **Argentina** (F): L, *U. loboi*; M, *R. magnifica*; P, *A. parisi*; Pi, *F. pilosa*.

4M)

Pterospermella reticulata (Brito) Loeblich & Wicander, 1976 (Fig. 4N)

Quadrifurcatus granulatus (Cramer) Ströther 1991 (Fig. 4S)

Stellinium rabians (Cramer) Eisenack, Cramer & Diez, 1976 (Fig. 4O)

Triangulina aspera Pöthe de Baldi, 1977 (Fig. 4P)

Tunisphaeridium caudatum Deunff & Evitt, 1968 (Fig. 4Q)

Veryhachium (Tetravveryhachium) longispinosum Jardiné *et al.* emend. Stancliffe & Sarjeant, 1994

Veryhachium (Tetravveryhachium) valiente Cramer emend. Stancliffe & Sarjeant, 1994 (Fig. 4R)

Veryhachium (Veryhachium) centrigerum Deunff, 1957

Veryhachium (Veryhachium) trispinosum (Eisenack) Stockmans & Williére emend. Stancliffe & Sarjeant, 1994 (Fig. 4T)

Spores and cryptospores

Acinosporites lindlarensis Riégel, 1968 (Fig. 5A)

Ambitisporites avitus (Hoffmeister) Steemans, Le Hérisse & Bozdogan, 1996 (Fig. 5B)

Amicosporites streelii Steemans, 1989 (Fig. 5C)

Apiculiretusispora brandtii Streele, 1964 (Fig. 5D)

Apiculiretusispora densiconata Tiwari & Schaarschmidt, 1975 (Fig. 5E)

Apiculiretusispora plicata (Allen) Streele, 1967 (Fig. 5F)

Archaeozonotriletes chulus (Cramer) Richardson & Lister var. *chulus* Richardson & Lister, 1969

Biornatispora sp. cf. *B. salopiensis* (Richardson & Lister) Steemans, 1981

Camptotriletes sp. in McGregor, 1984

cf. *Dictyotriletes craticulus* Clayton & Graham, 1974

Corystisporites multispinosus Richardson var. *multispinosus* McGregor & Camfield 1982 (Fig. 5G)

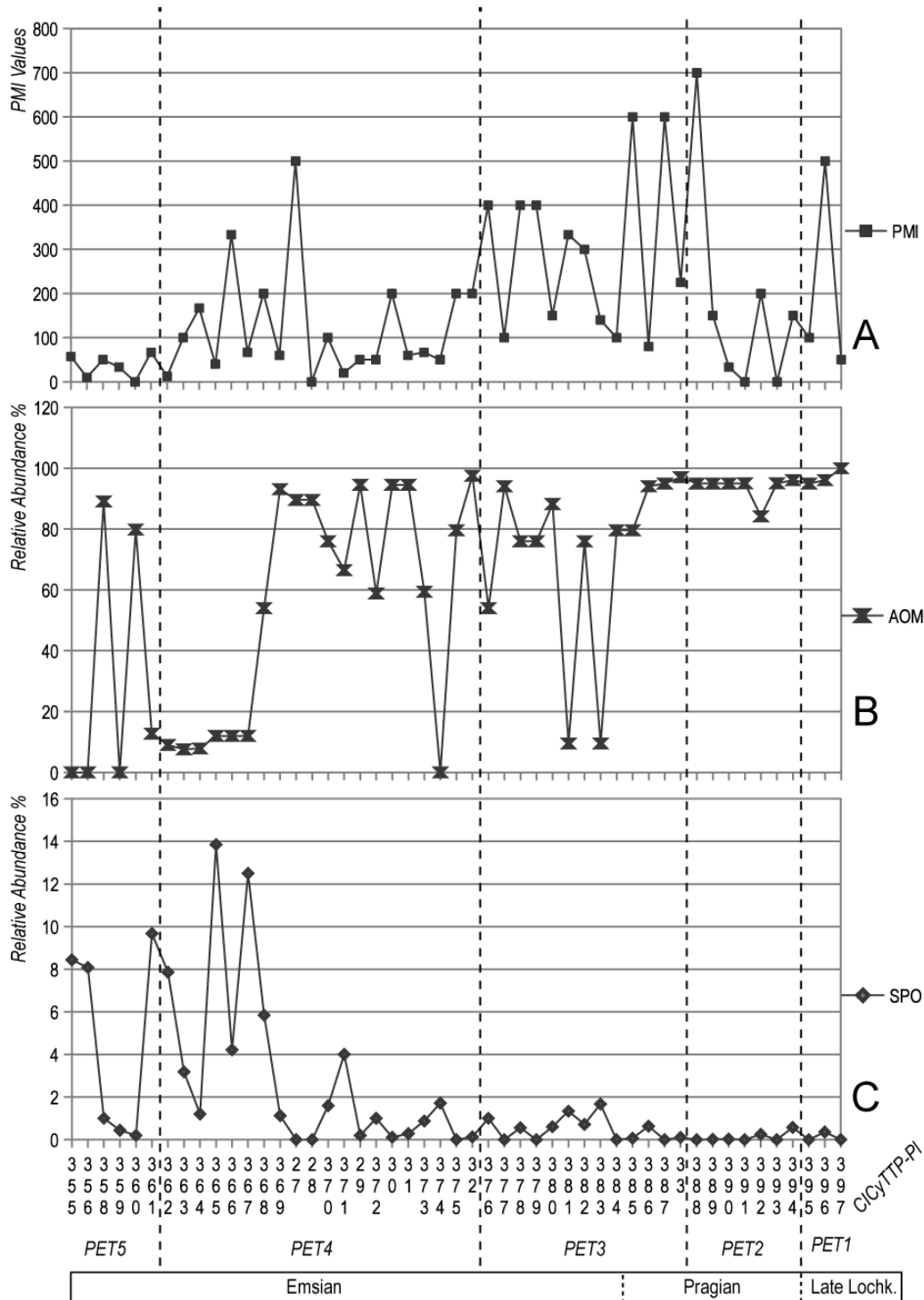


Figure 8. A, PMI values. B, Relative percentage abundance of AOM. C, Relative percentage abundance of spores. The relative percentage abundance is based on the total composition of the palynofacies.

?*Corystisporites* sp.
Cymbohilates heteroverrucosus Breuer, Al-Ghazi, Al-Ruwaili, Higgs, Steemans & Wellman, 2007 (Fig. 5H)
Cymbohilates sp. (Fig. 5I) (4 specimens). Cryptospore hilate proximally. Circular to subcircular amb. Exospore wall subequatorially and distally sculptured with grana, spines, verrucae, baculae or biform elements between 1 – 3 µm high, densely distributed, and which may or may not be

fused. Contact area sculptured as well, and delimited by a more or less circular scar. Remarks: The density of the ornamentation varies from specimen to specimen. Diameter of each monad: 39 - 56 µm.
Cymbosporites sp. McGregor, 1984
Dibolisporites eifeliensis (Lanning) McGregor, 1973 (Fig. 5J)
Dibolisporites? nodosus Turnau, 1986 (Fig. 5K)

- Dibolisporites quebecensis* McGregor, 1973 (Fig. 5L)
Dibolisporites sp. cf. *D. gibberosus* (Naumova) Richardson 1965 in McGregor, 1974
Dibolisporites uncatu (Naumova) McGregor & Camfield, 1982 (Fig. 5M)
Dictyotrilletes emsiensis morphon Rubinstein, Melo & Steemans, 2005 (Fig. 5N)
Dyadospora murusattenuata morphon Ströther & Traverse 1979 *sensu* Steemans, Le Hérisse & Bozdogan, 1996
Emphanisporites annulatus McGregor, 1961 (Fig. 5O)
Emphanisporites epicautus Richardson & Lister, 1969 (Fig. 5P)
Emphanisporites microratus Breuer, Stricanne & Steemans, 2005
Emphanisporites rotatus McGregor emend. McGregor, 1973
Gneudaspora divellomedia (Chibrikova) Balme 1988 var. *minor* Breuer, Al-Ghazi, Al-Ruwaili, Higgs, Steemans & Wellman, 2007
Grandispora douglastownense Loboziak, Streel & Burjack, 1989 (Fig. 5Q)
Leiotrilletes pagius Allen, 1965
Leiotrilletes sp. cf. *L. bonitus* Cramer, 1966 (Fig. 5R) (1 specimen). Trilete spore of triangular outline. Psilate exine which appears to be infragranulated due to the preservation. Straight to slightly sinuous trilete mark, accompanied by fine lips. Darkened zone along the margin of the distal face. Remarks: The specimen is larger than the one of Cramer (1966) and lacks the shaded areas along the mark. Diameter: 70 μ m.
Lophotrilletes devonicus (Naumova ex Chivrikova) McGregor & Camfield, 1982 (Fig. 5S)
Perotrilletes caperatus? (McGregor) Steemans, 1989 (Fig. 5T) (6 specimens). Spore with subcircular amb. Trilete mark not discernible. The exine forms a veil, with radial folds, that represents normally 10-20% of the central body. Distal face with verrucae or rugulae. Remarks: All of the recovered specimens are incomplete and very poorly preserved. Diameter: 52 - 78 μ m.
Phyllothecotrilletes densicorpus Tiwari & Schaarschmidt, 1975
Punctatisporites scabratus McGregor, 1960
Retusotrilletes maculatus McGregor & Camfield, 1976 (Fig. 5U)
Streelispora granulata Richardson & Lister, 1969
Synorisporites lybicus Richardson & Ioannides, 1973 in McGregor, 1984
Vermiverruspora sp.
Verruciretusispora sp.
Verrucosisporites sp.
Verrucosisporites sp. A (Fig. 5V) (2 specimens). Spore with indistinct trilete mark. Circular to subcircular amb. Ornamentation on distal face consists of verrucae and coni densely packed. Verrucae are 1.5 - 2 μ m in height forming rugulae. Diameter: 46 - 57 μ m.
- Chitinozoans**
Ancyrochitina parisi Volkheimer, Melendi & Salas 1986 (Fig. 6B)
Ancyrochitina sp. cf. *A. asterigis* Paris 1981 (Fig. 6A) (1 specimen). Ovoid vesicle. Cylindrical neck. Psilate wall. There are at least two broad processes emerging at the base of the vesicle, each with a base of ca. 20 μ m, which end up with several levels of branches. Remarks: The specimen is larger than the original species. Dimensions: Total length, 209 μ m; Maximum width, 97 μ m; Aperture, 36 μ m; Ratio neck/total length, 1/3.
Ancyrochitina sp. (Fig. 6D) (1 specimen). Ovoid vesicle. Cylindrical neck. Psilate wall. There are two, barely discernible, incomplete processes emerging at the base of the vesicle. Remarks: *Ancyrochitina* sp. resembles *Ancyrochitina* sp. C of Gaugis & Grahn (2006) but the poor preservation of the only specimen prevents a confident assignment. Dimensions: Total length, 263 μ m; Maximum width, 68 μ m; aperture, 36 μ m; ratio neck/total length, 1/2; length processes (incomplete), 12-14 μ m.
Angochitina sp. A (Fig. 6E) (1 specimen). Vesicle in the shape of an amphora, flexure and shoulder poorly defined. The neck expands briefly towards the aperture. The vesicle wall and neck are covered by strong simple spines 7-23 μ m long. Dimensions: Total length, 162 μ m; maximum width, 63 μ m; aperture, 41 μ m; ratio neck/total length, 1/2.
Angochitina sp. B (Fig. 6F) (1 specimen). Ovoid vesicle, flexure and shoulder poorly defined. Cylindrical neck. Wall of the vesicle and neck densely covered by strong simple spines 8-29 μ m long. Dimensions: Total length, 174 μ m; maximum width, 76 μ m; aperture, 41 μ m; ratio neck/total length, 1/3.
Belonechitina sp. (Fig. 6G)
Cingulochitina sp. (Fig. 6H)
Conochitina sp. (Fig. 6I)
Ramochitina magnifica Lange, 1967 (Fig. 6J)
Saharochitina sp. (Fig. 6C) (1 specimen). Lenticular vesicle. Cylindrical neck. Wall of the vesicle and neck glabrous. Dimensions: Total length, 154 μ m; maximum width, 80 μ m; aperture, 35 μ m; ratio neck/total length, 2/3.
Sphaerochitina densibaculata Volkheimer, Melendi & Salas, 1986 (Fig. 6K)
Urochitina lobo Volkheimer, Melendi & Salas, 1986 (Fig. 6L)
- CONCLUSION**
Despite the poor retrieval of palynomorph species due to the conspicuous thermal alteration shown throughout the section, it was nevertheless possible to recognise several elements, including spores, cryptospores, acritarchs, prasinophycean and chlorophycean algae in addition to the earlier published chitinozoan association. This allowed the erection of five assemblages ranging from late Lochkovian to latest Emsian in age. These associations reflect palaeoenvironmental changes related to transgressive-regressive cycles registered for the time span in agreement with previous studies. The assemblages suggest a late Lochkovian age for the upper? Copo and lower Caburé formations (PET1), a Pragian age for the Caburé Formation (PET2 and early PET3), and latest Pragian to late Emsian for the Rincón Formation (PET3-5).
- ACKNOWLEDGEMENTS**
We thank Lic. Cristina Vistalli (YPF) for providing the subsurface samples from the Puesto El Tigre x-1 well and the permission to publish the results, and Lic. Gustavo Holfeltz for processing samples. In addition we thank R. Wicander and an anonymous reviewer for making useful suggestions for the improvement of this paper. This study was supported with funds from the "Agencia Nacional de Promoción Científica y Tecnológica" (PICTR 00313/03), the "Consejo Nacional de Investigaciones Científicas y Técnicas" (PIP 5518 CONICET) and the University of Buenos Aires (UBACYT X 428). It is a contribution to IGCP 499.

REFERENCES

- ACEÑOLAZA, F.G., ACEÑOLAZA, G. & GARCÍA, G., 2000. El Silúrico-Devónico del Noroeste Argentino. 205-214 in Caminos, R. (ed.), *Geología Argentina*. Instituto de Geología y Recursos Minerales, Anales 29.
- ACEVEDO, O.M., 1986. El Precarbónico en la Provincia de Salta. *Boletín de Informaciones Petroleras*, 65- 72.
- ACHAB, A., ASSELIN, E., LAVOIE, D. & MUSSARD, J.M., 1997. Chitinozoan assemblages from the third-order transgressive-regressive cycles of the Upper Gaspé limestones (Lower Devonian) of eastern Canada. *Review of Palaeobotany and Palynology* 97, 155-175.
- AL-GHAZI, A., 2007. New evidence for the Early Devonian age of the Jauf Formation in northern Saudi Arabia. *Revue de Micropaléontologie* 50, 59-72.
- ALBARIÑO, L., DALENZ-FARJAT, A., ÁLVAREZ, L., HERNÁNDEZ, R. & PÉREZ LEYTON, M., 2002. Las secuencias sedimentarias del Devónico en el Subandino sur y el Chaco, Bolivia y Argentina. *5° Congreso de Exploración y Desarrollo de Hidrocarburos (Mar del Plata 2002)*, CD Trabajos Técnicos.
- ANTONELLI, J. & OTTONE, G., 2006. Palinología de coronas del Devónico y Carbonífero Superior del pozo YPF.SE.EC.X-1, El Caburé, provincia de Santiago del Estero, Argentina. *Revista del Museo de Ciencias Naturales* 8, 111- 117.
- ARAUJO CARVALHO DE, M., MENDOÇA FILHO, J.G. & RÊGO MENEZES, T., 2006. Paleoenvironmental reconstruction based on palynofacies analysis of the Aptian- Albian succession of the Sergipe Basin, northeastern Brazil. *Marine Micropaleontology* 59, 56- 81.
- BOSETTI, E., GRAHN, Y., HORODYSKI, R., MENDLOWICZ MAULLER, P., BREUER & P., ZABINI, C., 2011. An earliest Givetian “Lilliput Effect” in the Paraná Basin, and the collapse of the Malvinokaffric shelly fauna. *Paläontologische Zeitschrift* 85, 49-65.
- BREUER, P. 2007. *Devonian miospore palynology in Western Gondwana: an application to oil exploration*. Unpublished Ph.D. thesis, University of Liège, Liège.
- BREUER, P. & GRAHN, Y., 2011. Middle Devonian spore stratigraphy in the eastern outcrop belt of the Parnaíba Basin, northeastern Brazil. *Revista Española de Micropaleontología* 43, 19-38.
- CHEBLI, G.A., MOZETIC, M.E., ROSELLO, E.A. & BUHLER, M., 1999. Cuenca Sedimentaria de la Llanura Chacopampeana. 627- 644 in Caminos, R. (ed.), *Geología Argentina*. Instituto de Geología y Recursos Minerales, Anales 29.
- CUERDA, A.J. & BALDIS, B.A., 1971. Silúrico-Devónico de la Argentina. *Ameghiniana* 8, 128-164.
- DANERS, G. & VERDE, M., 2008. Fósiles microscópicos. 1-47 in Perea, D. (ed.), *Fósiles de Uruguay, Cap. 4*. Dirac Facultad de Ciencias.
- DI PASQUO, M.M., 2007. Asociaciones palinológicas en las formaciones Los Monos (Devónico) e Itacua (Carbonífero Inferior) en Balapuca (cuenca Tarija), sur de Bolivia. Parte 1. Formación Los Monos. *Revista Geológica de Chile* 34, 97-137.
- DI PASQUO, M.M. & NOETINGER, S., 2008. First record of Early Devonian (Lochkovian) flora from the Santa Rosa Formation-Alarache, Southern Bolivia. *Geologica Acta* 6, 191-210.
- DI PASQUO, M.M., AMENÁBAR, C.R. & NOETINGER, S., 2009. Middle Devonian microfloras and megaflores from western Argentina and southern Bolivia: Their importance in the palaeobiogeographical and palaeoclimatic evolution of western Gondwana. 193–213 in Königshof, P. (ed.), *Devonian Change: case studies in palaeogeography and palaeoecology*. The Geological Society, London, Special Publications 314.
- FERNÁNDEZ SEVESO, F., VISTALLI, M.C. & VIÑES, R.F., 2000. Correlación de reservorios en la cuenca silúrica-devónica del Chaco: Una revisión integrada previa a la adquisición de bloques exploratorios en Bolivia. *Boletín de Informaciones Petroleras, REPSOL-YPF*, marzo, 152- 166.
- GHAVIDEL-SYOOKI, M., 1995. Palynostratigraphy and palaeogeography of a Palaeozoic sequence in the Hassanakdar area, central Alborz Range, northern Iran. *Review of Palaeobotany and Palynology* 86, 91-109
- GHAVIDEL-SYOOKI, M., 2003. Palynostratigraphy of Devonian sediments in the Zagros Basin, southern Iran. *Review of Palaeobotany and Palynology* 127, 241-268.
- GRAHN, Y., 2002. Upper Silurian and Devonian Chitinozoa from central and southern Bolivia, central Andes. *Journal of South American Earth Sciences* 15, 315-326.
- GRAHN, Y., 2003. Silurian and Devonian chitinozoan assemblages from the Chaco-Paraná Basin, northeastern Argentina and central Uruguay. *Revista Española de Micropaleontología* 35, 1-8.
- GRAHN, Y., 2005. Devonian chitinozoan biozones of western Gondwana. *Acta Geologica Polonica* 55, 211-227.
- GRAHN, Y. & GUTIÉRREZ, P.R., 2001. Silurian and Middle Devonian Chitinozoa from the Zapla and Santa Bárbara ranges, Tarija Basin, northwestern Argentina. *Ameghiniana* 38, 35-50.
- GRAHN, Y. & MELO, J.H.G., 2003. Silurian-Devonian chitinozoan biostratigraphy along the Urubu, Uatuma and Abacate rivers in the western part of the Amazonas Basin, northern Brazil. *Bulletin of Geosciences* 78, 373-391.
- GRAHN, Y., PEREIRA, E. & BERGAMASCHI, S., 2000. Silurian and Lower Devonian Chitinozoan biostratigraphy of the Paraná Basin in Brazil and Paraguay. *Palynology* 24, 147-176.
- GRAHN, Y., LOBOZIAK, S. & MELO, J.H.G., 2003. Integrated correlation of late Silurian (Prídoli s.l.)– Devonian chitinozoans and miospores in the Solimões Basin, northern Brazil. *Acta Geologica Polonica* 53, 283- 300.
- GRAHN, Y., MELO, J.H.G., STEEMANS, P., 2005. Integrated chitinozoan and miospore zonation of the Serra Grande Group (Silurian-Lower Devonian), Parnaíba Basin, northeast Brazil. *Revista Española de Micropaleontología* 37, 183-204.
- GRAHN, Y., MENDLOWICZ MAULLER, P., BREUER, P., BOSETTI, E.P., BERGAMASCHI, S. & PEREIRA, E., 2010a. The Furnas/Ponta Grossa contact and the age of the lowermost Ponta Grossa Formation in the Apucarana Sub-Basin (Paraná Basin, Brazil): Integrated palynological age determination. *Revista Brasileira de Paleontologia* 13, 89-102.
- GRAHN, Y., MENDLOWICZ MAULLER, P., PEREIRA, E., LOBOZIAK, S., 2010b. Palynostratigraphy of the Chapada Group and its significance in the Devonian stratigraphy of the Paraná Basin, south Brazil. *Journal of South American Earth Sciences* 29, 354- 370.
- GAUGRIS, K.A. & GRAHN, Y., 2006. New chitinozoan species from the Devonian of the Paraná Basin, south Brazil, and their biostratigraphic significance. *Ameghiniana* 43, 293–310.
- HELENES, J., DE-GUERRA, C. & VÁSQUEZ, J., 1998. Palynology and chronostratigraphy of the Upper Cretaceous in the subsurface of the Barinas area, western Venezuela. *American Association of Petroleum Geologists Bulletin* 82, 1308–1328.
- LAZAR, A., 2008. Stratigraphical distribution and palynological correlation between Devonian formations from north Dobrogea and East European Platform. *Acta Palaeontologica Romaniaae* 6, 173-180.
- LE HÉRISSE, A., RUBINSTEIN, C. & STEEMANS, P., 1997. Lower Devonian palynomorphs from the Talcasto Formation, Cerro del Fuerte Section, San Juan Precordillera, Argentina. 497-515 in Fatka, O. & Servais, T. (eds), *Acritarcha in Praha 1996*. Acta Universitatis Carolinae Geologica 40.
- LIMACHI, R., GOITIA, V.H., SARMIENTO, D., ARISPE, O., MONTECINOS, R., DÍAZ MARTÍNEZ, E., DALENZ FARJAT, A., LIACHENCO, N., PÉREZ

- LEYTON, M. & AGUILERA, E., 1996. Estratigrafía, geoquímica, correlaciones, ambientes sedimentarios y bioestratigrafía del Silúrico-Devónico de Bolivia. 183-197 in *12° Congreso Geológico de Bolivia (Tarija 1996), Memorias 12*.
- LOBOZIAK, S. & MELO, J.H.G., 2000. Miospore events from late Early to Late Devonian strata of western Gondwana. *Géobios* 33, 399-407.
- LOBOZIAK, S., MELO, J.H.G., STEEMANS, P. & BARRILARI, I., 1995. Miospore evidence for pre-Emsian and latest Famennian sedimentation in the Devonian of the Paraná Basin, south Brazil. *Anais da Academia Brasileira de Ciências* 67, 391-392.
- MELO, J.H.G., 1989. The Malvinokaffric Realm in the Devonian of Brazil. 669-703 in McMillan, N.J., Embry, A. F. & Glass, D.J. (eds), *Devonian of the World*. Canadian Society of Petroleum Geologists, Memoir 14.
- MELO, J.H.G., 2000. Palynological evaluation of some Silurian-Devonian sections of southern Bolivia. 136-141 in *14° Congreso Geológico Boliviano (La Paz 2000), Memorias*.
- MELO, J.H.G., 2005. Selected Devonian palynological biohorizons in Brazilian Paleozoic basins: state of the art. 249 in *Gondwana 12 (Mendoza 2005)*, Abstracts.
- MELO, J.H.G. & LOBOZIAK, S., 2003. Devonian - Early Carboniferous miospore biostratigraphy of the Amazon Basin, northern Brazil. *Review of Palaeobotany and Palynology* 124, 131-202.
- MILANI, E.J. & ZALÁN, P.V., 1999. An outline of the geology and petroleum systems of the Paleozoic interior basins of South America. *Episodes* 22, 199-205.
- MINGRAMM, A. & RUSSO, A., 1972. Sierras Subandinas y Chaco Salteño. 185-235 in Leanza, A. F. (ed.), *Geología Regional Argentina*. Academia Nacional de Ciencias de Córdoba.
- NOETINGER, S., 2010. Middle-Upper Devonian palynoflora from the Tonono X-1 borehole, Salta Province, northwestern Argentina. *Ameghiniana* 47, 165-184.
- NOETINGER, S., 2011. *Estudios de asociaciones micro y megafloísticas del Devónico en la porción Sur de la Cuenca Tarija, noroeste argentino y Sur de Bolivia: edad, correlación y ambiente de sedimentación*. Unpublished Ph.D. thesis, University of Buenos Aires, Buenos Aires, 318 p.
- NOETINGER, S. & DI PASQUO, M.M., 2009. Nuevos datos palinológicos de la Formación Rincón en la Provincia de Salta, Argentina. 2 in *14° Simposio Argentino de Paleobotánica y Palinología, (Mar del Plata 2009), Resúmenes*.
- NOETINGER, S. & DI PASQUO, M.M., 2010. Palynomorphs from Abra Limite, Zenta Range, Eastern Cordillera, northwestern Argentina. *Revista Brasileira de Paleontologia* 13 (1), 13-20.
- NOETINGER S. & DI PASQUO M.M., 2011. Devonian palynofloras of the San Antonio x-1 borehole from the Tarija Basin, northwestern Argentina. *Geologica Acta* 9, 199-216.
- PADULA, E., ROLLERI, E., MINGRAMM, A.R., CRIADO ROQUE, P., FLORES, M.A. & BALDIS, B., 1967. Devonian of Argentina. 165-199 in Oswald, D.H. (ed.), *International Symposium on the Devonian System, Volume 2*. Alberta Society of Petroleum Geologists, Calgary.
- PEREIRA, E., 2000. *Evolução Tectono-Sedimentar do Intervalo Ordoviciano-Devoniano da Bacia do Paraná com ênfase na sub-bacia de Alto Garças e no Paraguai Oriental*. Unpublished D.Sc. thesis, University of São Paulo, São Paulo, 277 p.
- RICHARDSON, J.B. & MCGREGOR, D.C. 1986. Silurian and Devonian spore zones of the Old Red Sandstone continent and adjacent regions. *Geological Survey of Canada, Bulletin* 364, 1-79.
- RUBINSTEIN, C.V., 1995. Acritarchs from the upper Silurian of Argentina: their relationship with Gondwana. *Journal of South American Earth Sciences* 8, 103-115.
- RUBINSTEIN, C.V., 2002. Bioestratigrafía, paleogeografía y paleoambientes basados en palinóforos en cuencas ordovícicas, silúricas y devónicas de la Argentina. 209-213 in Trombotta, D. & Villalba, R. (eds). *INAGLIA, 30 años de investigación básica y aplicada en Ciencias Ambientales*. Mendoza.
- RUBINSTEIN, C.V., MELO, J.H.G. & STEEMANS, P., 2005. Lochkovian (earliest Devonian) miospores from the Solimões Basin, northwestern Brazil. *Review of Palaeobotany and Palynology* 133, 91-113.
- RUBINSTEIN, C.V., LE HÉRISSE, A. & STEEMANS, P., 2008. Lochkovian (Early Devonian) acritarchs and prasinophytes from the Solimões Basin, northwestern Brazil. *Neues Jahrbuch für Geologie und Paläontologie – Abhandlungen* 249, 167-184.
- RUSSO, A., FERELLO, R. & CHEBLI, G., 1979. Llanura Chaco Pampeana. 139-183 in *2° Simposio de Geología Regional Argentina (Córdoba, 1979)*. Academia Nacional de Ciencias de Córdoba 1.
- SERVAIS, T., VECOLI, M., LI, J., MOLYNEUX, S.G., RAEVSKAYA, E. & RUBINSTEIN, C., 2007. The acritarch genus *Verhachium* Deunf 1954: taxonomic evaluation and first appearance. *Palynology* 31, 191-203.
- SPINA, A. & VECOLI, M., 2009. Palynostratigraphy and vegetational changes in the Siluro-Devonian of the Ghadamis Basin, North Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology* 282, 1-18.
- STARCK, D., 1995. Silurian-Jurassic stratigraphy and basin evolution of northwestern Argentina. 251-267 in Tankard, A.J., Suárez Soruco, R. & Welsink, H.J. (eds), *Petroleum basins of South America*. American Association of Petroleum Geologists, Memoir 62.
- STARCK, D., 1999. Facies continentales en el Siluro-Devónico de la cuenca del Noroeste. Provincia de Salta, Argentina. *Boletín de Informaciones Petroleras* 16, 99-107.
- STARCK, D., GALLARDO, E. & SCHULZ, A., 1993. The pre-Carboniferous unconformity in the Argentine portion of the Tarija Basin. 373-384 in *12° International Congress of Carboniferous-Permian (Buenos Aires 1991), Comptes Rendus* 2. Buenos Aires.
- STEEMANS, P., 1989. Etude palynostratigraphique du Dévonien inférieur dans l'ouest de l'Europe. *Mémoires pour servir à l'Explications des Cartes Géologiques et Minières de la Belgique* 27, 1-453.
- STEEMANS, P., JAVAUX, E.J., BREUER, P., LE HÉRISSE, A., MARSHALL, C.P. & DE VILLE DE GOYET, F., 2009. Description and microscale analysis of some enigmatic palynomorphs from the Middle Devonian (Givetian) of Libya. *Palynology* 33, 101-112.
- STREEL, M., HIGGS, K., LOBOZIAK, S., RIÉGEL, W. & STEEMANS, P., 1987. Spore stratigraphy and correlation with faunas and floras in the type marine Devonian of the Ardenne-Rhenish regions. *Review of Palaeobotany and Palynology* 50, 211-229.
- SUÁREZ SORUCO, R., 2000. Compendio de Geología de Bolivia. *Revista Técnica Yacimientos Petrolíferos Fiscales Bolivianos* 18, 1-213.
- TROTH, I., MARSHALL, J.E.A., RACEY, A. & BECKER, R.T., 2011. Devonian sea-level change in Bolivia: a high palaeolatitude biostratigraphical calibration of the global sea-level curve. *Palaeogeography, Palaeoclimatology, Palaeoecology* 304, 3-20.
- TYSON, R.V., 1995. *Sedimentary organic matter: Organic facies and palynofacies*. Chapman & Hall, London, 615 p.
- UTTING, J. & WIELENS, H., 1992. Organic petrology, thermal maturity, geology, and petroleum source rock potential of Lower Permian coal, Karoo Supersystem, Zambia. *Energy Sources* 14, 337-354.
- VAVRDOVÁ, M., BEK, J., DUFKA, P. & ISAACSON, P.E., 1996. Palynology of the Devonian (Lochkovian to Tournaisian) sequence, Madre de Dios Basin, northern Bolivia. *Vestník Českého geologického ústavu* 71, 333-349.

- VILLE DE GOYET, F.D., BREUER, P., GERRIENNE, P., PRESTIANNI, C., STREEL, M. & STEEMANS, P., 2007. Middle Devonian (Givetian) megaspores from Belgium (Ronquières) and Libya (A1-69 borehole). Abstract 11 in Steemans P. & Javaux E. (eds), *Recent advances in palynology*. Carnets de Géologie / Notebooks on Geology, Brest, Memoir 2007/01.
- VOLKHEIMER, W., MELENDI, D.L. & SALAS, A., 1986. Devonian chitinozoans from northwestern Argentina. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 173, 229- 251.
- ZHU, H., WICANDER, R. & MARSHALL, J.E.A., 2008. Biostratigraphic and paleogeographic significance of a palynological assemblage from the Middle Devonian Ulusubasite Formation, eastern Junggar Basin, Xinjiang, China. *Review of Palaeobotany and Palynology* 152, 141-157.

