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Middle-Upper Devonian palynoflora from the Tonono x-1 borehole, Salta Province, northwestern Argentina

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Abstract. The surveyed microflora was recovered from six cores from the Tonono x-1 well in northwestern Argentina. Most of the studied interval corresponds to the Tonono Formation, *i.e.*, the upper part to the Jollín Member and the basal part of the interval may be related to the Michicola Formation. The microflora totals 73 species represented by trilete spores (35 species), microplankton (30 species) including prasinophycean, acritarch and chlorophycean algae and chitinozoans (8 species). The stratigraphic distribution of these species allowed the definition of three associations. The palynoassemblage To1 (3946,5 - 3638,5 m) is characterized by species such as *Grandispora douglastownense* Mc Gregor, *Dibolisporites eifeliensis* (Lanninger) McGregor, *Verrucosisporites* sp. cf. *V. loboziakii* Marshall and Fletcher, *Alpenachitina matogrossensis* Burjack and Paris, *Alpenachitina* sp. cf. *A. eisenacki* Dunn and Miller and *Ancyrochitina simplex* Grahn, Bergamaschi and Pereira suggesting a late Eifelian to earliest Givetian age. Based on the presence of *Geminospora lemurata* Balme, *Aneurospora greggsii* (McGregor) Streel, *Biharisporites parviornatus* Richardson, *Raistrickia aratra* Allen and *Leiotriletes balapucencis* di Pasquo a Givetian age is proposed for palynoassemblage To2 (3367,35 - 3285 m). Palynoassemblage To3 (3073,2 - 3137,5 m) is predominantly composed of marine elements together with AOM. Few key species are recognized; however the presence of *Acinosporites* sp. cf. *A. eumammillatus* Loboziak, Streel and Burjack together with the chitinozoans *Angochitina katzeri* Grahn and Melo and *Angochitina mourai* Lange support an early Frasnian age. The distinctive increase of marine elements and AOM between To2 and To3 suggests that a maximum flooding event would have occurred there during this period.

Resumen. Palinoflora del Devónico Medio-Superior del pozo Tonono x-1, provincia de Salta, noroeste de Argentina. Se presenta el estudio de seis coronas del pozo Tonono x-1 ubicado en el noroeste Argentino. La mayor parte del intervalo estudiado corresponde a la Formación Tonono; la porción superior al Miembro Jollín y la porción basal podría relacionarse con la Formación Michicola. La microflora recuperada se compone de 73 especies representadas por diversos grupos palinológicos como esporas trilete (35 especies), microplancton incluyendo prasinofitas, acritarcas, algas clorofitas (30 especies) y quitinozoos (8 especies). La distribución estratigráfica de las especies permite distinguir tres asociaciones, la asociación To1 (3946,5 - 3638,5 m), caracterizada por *Grandispora douglastownense* Mc Gregor, *Dibolisporites eifeliensis* (Lanninger) McGregor, *Verrucosisporites* sp. cf. *V. loboziakii* Marshall y Fletcher, *Alpenachitina matogrossensis* Burjack y Paris, *Alpenachitina* sp. cf. *A. eisenacki* Dunn y Miller y *Ancyrochitina simplex* Grahn, Bergamaschi y Pereira sugieren una edad eifeliana tardía–givetiana temprana. Debido a la presencia de *Geminospora lemurata* Balme, *Aneurospora greggsii* (McGregor) Streel, *Biharisporites parviornatus* Richardson, *Raistrickia aratra* Allen y *Leiotriletes balapucencis* di Pasquo se propone una edad givetiana para la asociación To2 (3367,35 - 3285 m). La asociación To3 (3073,2 - 3137,5 m) comprende predominantemente elementos marinos incluyendo MOA. Se reconocen las siguientes especies clave *Acinosporites* sp. cf. *A. eumammillatus* Loboziak, Streel y Burjack junto a los quitinozoos *Angochitina katzeri* Grahn y Melo y *Angochitina mourai* Lange las cuales sugieren una edad frasniana temprana. El notable incremento de material de origen marino y MOA entre To2 y To3 sugiere que un evento de máxima inundación podría haber ocurrido allí durante este período.

Key words. Palynostratigraphy. Mid–Late Devonian. Tonono Formation. Salta. Argentina.

Palabras clave. Palinoestratirgrafía. Devónico Medio–Tardío. Formación Tonono. Salta. Argentina.

Introduction

The Tarija basin comprises sedimentary rocks of Silurian to Recent age, which were deposited during several sedimentary cycles. In northwestern Argentina, the Silurian-Devonian unit occurs along an East-West axis and is represented in subsurface mostly by shale and sandstone facies that were mainly deposited in a shallow marine environment. These shales and sandstones increases to over 2000 meters in thickness in the Subandean area and the *Chaco-Salteño* Plain. Towards the south, these sediments become more continental in character (Disalvo, 2002). Many multidisciplinary works based on subsurface and surface information have been carried out by different oil companies, although, published accounts are less numerous (*e.g.*, Suárez Soruco 2000;

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Dalenz Farjat *et al*., 2002; Albariño *et al*. 2002; Álvarez *et al*., 2003; Vistalli *et al*., 2005). The *Chaco-Salteño* Plain was geophysically surveyed as part of an oil exploration programme. This resulted in the discovery of small, oil/ gas hydrocarbon, fields. The Tonono Field (figure 1A) was discovered in 1969 and holds over 100,000 m3 of condensate (Disalvo, 2002).

This contribution presents a detailed palynological survey of a Devonian palynoflora (microspores, megaspores and microplankton) recovered from six cores of the 3945-3077 m interval in Tonono x-1 borehole. The stratigraphic distribution of the species is analysed and compared with their global ranges to assess the age and correlation of the assemblages defined in this interval. Palynofacies are also considered in order to better understand previous palaeoenvironmental interpretations.

Summary of the stratigraphy and paleontology

The stratigraphic units of the Late Silurian to Devonian rocks from northern Argentina and southern Bolivia have been assigned to supersequence hierarchies by Starck (1995, 1999). This includes a Silurian-Jurassic tectonic-stratigraphic interval that is divided into two units separated by a regional unconformity at the end of the Devonian. In the first Silurian-Devonian unit, the Cinco Picachos, Las Pavas and Aguaragüe Supersequences are characterized by stacked, kilometer scale, coarsening-upward shale and sandstone facies bounded by first order flooding surfaces. In this scheme, on the Chaco-Salteño Plain, the Tonono Formation is part of the Aguaragüe Supersequence, conformably overlying the Michicola and Rincón Formations, which in turn are part of the Las Pavas Supersequence (Starck, 1995) (figure 1B). Lithologies in the subsurface Rincón Formation include shales containing macrofossils such as *Metacryphaeus* sp., *Calmonia subcesiva*, *Australocoelia tourtelotti* and palaeomicroplankton suggesting a time range from the Emsian to the Givetian (Cuerda and Baldis, 1971; Russo *et al*., 1979, Aceñolaza *et al*., 2000, Grahn and Gutierrez, 2001, Grahn, 2003, Antonelli and Ottone, 2006). The Michicola Formation comprises a dozen meters of whitish-grey mostly silicified quartzites (Russo *et al*., 1979) and is considered, by some authors a facies variant of the Rincón Formation (see Aceñolaza *et al*., 2000). The Michicola Formation is correlated with the quartzites of Cerro León in Paraguay, which are supposed to be Silurian (Padula *et al*., 1967).

The subsurface Tonono Formation shows a sucession of dark grey to black, laminated and fissile, very micaceous, bituminous and carbonaceous shales with variable sand or silt content. Grey to whitish sandstones appear in very thin individual layers. Its thickness varies between 710 and 1960 meters; such variation is due to erosion during the Chanic orogenic phase. The uppermost part of this formation is dominated by quartz sandstones; it is known as the Jollín Sandstone Member (Padula *et al*., 1967) and is correlated with the lower part of the Bolivian Iquiri Formation dated as Frasnian (Dávila and Rodríguez, 1967). Several unpublished accounts assign an Emsian-Eifelian to Givetian-Frasnian age for the Tonono Formation based on its palaeontological content, which includes the remains of cf. *Cyclostigma* sp. and an undescribed trilobite (see Padula *et al*., 1967; Böttcher *et al*., 1984). Azcuy and Laffitte (1981) described the "association 0" from an unidentified sample from the Tonono x-1 containing several chitinozoans and other microplankton such as acritarchs, chlorophycean algae (*e.g*., *Chomotriletes* sp.), prasinophytes (*e.g*., *Maranhites* spp.) and scant scolecodonts. Within this assemblage there are spores such as *Emphanisporites* sp. cf. *E. rotatus* and *Grandispora pseudoreticulata* among others. This group is recognized as Upper Devonian. Barreda (1986) studied a complete Givetian–Frasnian assemblage from the Tonono Formation on the northeastern Chaco–Salteño Plain -including microplankton, spores and chitinozoans- but only published the acritarch association. Volkheimer *et al.* (1986) also studied the Tonono Formation from three samples from the Ramos x-1 borehole and one from the Tonono x-1, where species such as *Sphaerochitina* sp., *Sphaerochitina* sp. cf. *S. schwalbi* and *Gotlandochitina* sp. occur, assigning a Middle Devonian for the upper level of the formation. Later on, di Pasquo (2003) recognized the Macharetí Group unconformably overlying the Tonono Formation in this borehole and assigned it an early Pennsylvanian age based on palynology.

Materials and methods

The Tonono x-1 (To) well (c.a. 63º 38′ W, 22º 17′ S) is located in the Chaco-Salteño Plain (figure 1.A). It was drilled to a total depth of 4032 meters (13228 feet). Forty-seven core samples were collected from several intervals. One sample from the Upper Devonian section was studied by Azcuy and Laffitte (1981) and Volkheimer *et al*. (1986). Di Pasquo (2003) studied in detail five core samples (2984 to 2656 m) that yielded diagnostic palynomorphs of the overlying RS and BC Biozones akin to the early Pennsylvanian. An abstract was presented by Noetinger and di Pasquo (2008a) of six core samples between 3073 m and 3945 m depth (figure 2). A detailed survey of these is the subject of this work.

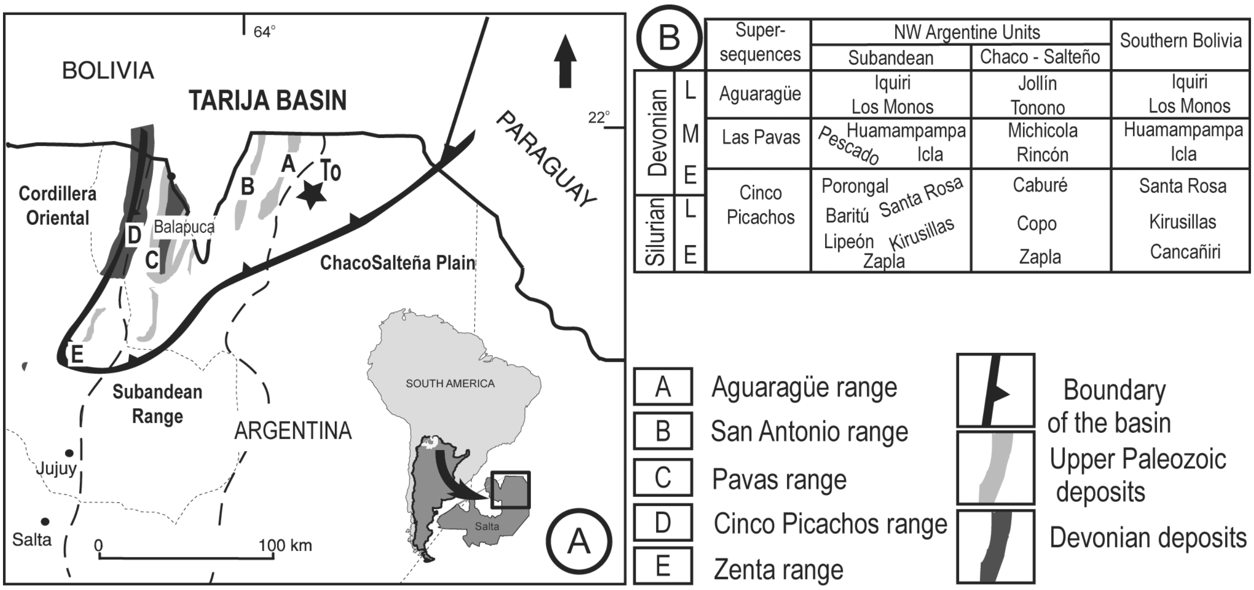


Figure 1. A, Distribution of Palaeozoic surface deposits in the Province of Salta, northern Argentina and location of the studied Tonono x-1 Borehole. **B,** Comparative stratigraphy of the study area modified from Starck (1999)./ ***A,*** *Distribución de los depósitos de superficie Paleozoicos en la provincia de Salta, al norte de Argentina y localización del pozo Tonono x-1.* ***B,*** *Estratigrafía comparada del área de estudio, modificada de Starck (1999).*

Standard palynological methods were performed to obtain organic residues from the core samples. These were crushed and then treated first with hydrochloric and then with hydrofluoric acid to remove carbonate, silica and silicates, respectively, sieved with a 25 μm mesh and finally mounted on slides with glycerine jelly.

Eight types of dispersed organic matter and palynomorph groups were identified in this study, including amorphous organic matter (AOM); structured phytodebris (SP), characterized by identifiable cuticles and wood; unstructured phytodebris (USP), known as gelified matter; black phytodebris (BP) or opaque clasts including charcoal; spores (SPO); phytoplankton (PHY) comprising acritarchs, prasinophycean and chlorophycean algae and chitinozoans (CHI). This is a simplified scheme adapted from Tyson (1995) for the types of organic components and palynomorphs found in the analysed assemblages used to calculate relative percentages allowing the definition of different palynofacies. Statistical analyses were also carried out to identify the subtle differences in the composition of the assemblages. A palynological marine index (PMI= (Marine Richness (R_m)/ Terrestrial Richness (R_t) + 1) 100, Helenes *et al.* 1998) was also calculated in order to support the interpretation of depositional environments. The values used are stipulated as in de Araujo Carvalho *et al.* (2006), where the marine and terrestrial richness were expressed as number of genera per sample. High values of PMI are interpreted as indicative of normal marine depositional conditions. As the PMI is based on the palynomorph diversity of terrestrial and marine palynomorph, it is therefore used as a substitute for terrestrial/marine ratio.

The identification of palynomorphs was undertaken using both *Leitz Orthoplan* and *Nikon Eclipse* 80*i* trinocular transmitted light microscopes, with x1000 maximum magnification. The photomicrographs were obtained with *Motic* (2.0 megapixels) and *Pax-it* (3.1 megapixels) videocameras and the illustrations are labelled with BAFC-Pl numbers followed by the England Finder reference. The studied samples are deposited at the Department of Geology of the Facultad de Ciencias Exactas, Físicas y Naturales (University of Buenos Aires).

Systematic paleontology

List of species

The identified palynomorph taxa are reported by major groups and in alphabetical order. Some specimens not illustrated are grouped at generic level because their poor preservation prevents a more specific assignment. Nevertheless, they are included in the stratigraphic distribution of the assemblages (figure 3), and some of them are figured together with the rest of the species as indicated in brackets (figures 4-8).

Trilete spores

Acinosporites acanthomammillatus Richardson 1965 (figure 4.1)

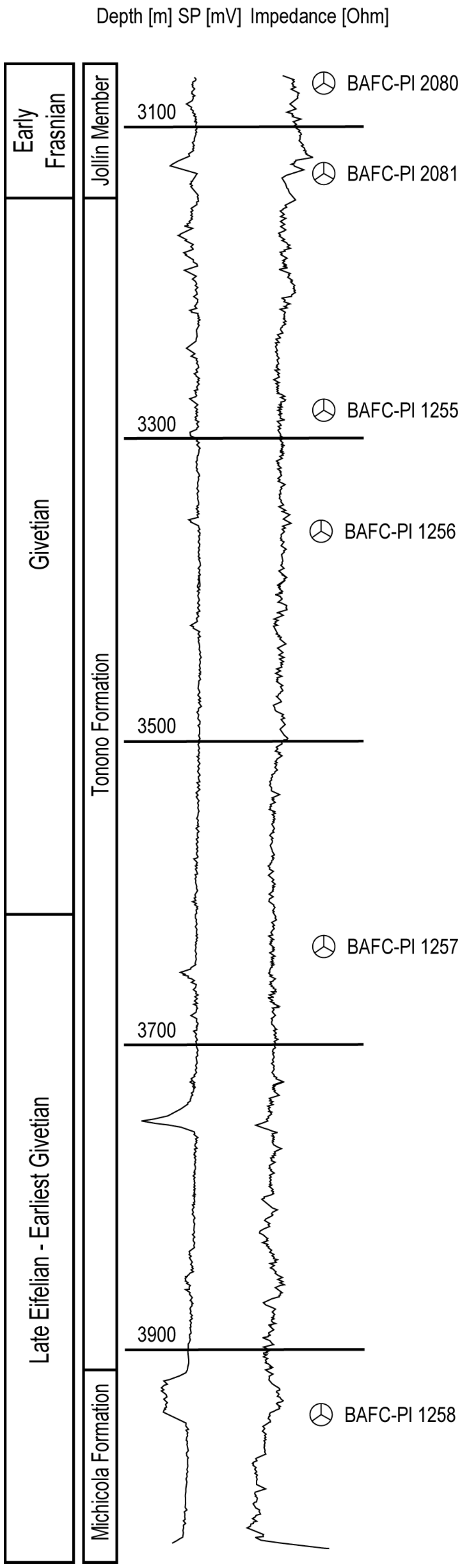


Figure 2. Lithostratigraphic scheme together with the wireline log of the Tonono x-1 well and the palynological sample depths / *esquema litoestratigráfico junto al perfil eléctrico del pozo Tonono x-1 y las profundidades de las muestras palinológicas.*

Acinosporites ledundae Ottone 1996 (figure 4.2)
Acinosporites lindlarensis Riegel 1968 (figure 4.3)
Acinosporites sp. cf. *A. eumammillatus* Loboziak, Streel and Burjack 1988 (figure 4.4)
Acinosporites sp. cf. *A. macrospinosus* Richardson 1965 (figure 4.5)
Aneurospora greggsii (McGregor) Streel in Becker, Bless, Streel and Thorez 1974 (figure 4.6)
Apiculatasporites microconus (Richardson) McGregor and Camfield 1982 (figure 4.7)
Apiculiretusispora plicata (Allen) Streel 1967 (figure 4.8)
Biharisporites parviornatus Richardson 1965 (figure 4.9)
Cymbosporites catillus Allen 1965 (figure 4.10)
Dibolisporites echinaceus (Eisenack) Richardson 1965 (figure 4.11)
Dibolisporites eifeliensis (Lanninger) McGregor 1973 (figure 4.12)
Dibolisporites quebecensis McGregor 1973 (figure 4.13)
Dibolisporites uncatus (Naumova) McGregor and Camfield 1982 (figure 4.14)
Dibolisporites spp.
Emphanisporites epicautus Richardson and Lister 1969 (figure 4.15)
Emphanisporites rotatus McGregor emend. McGregor 1973 (figure 4.16)
Geminospora lemurata Balme 1962 (figure 4.17)
Grandispora brevizonata (Menéndez and Pöthe de Baldis) di Pasquo 2007a (figure 5.1)
Grandispora daemonii Loboziak, Streel and Burjack 1988 (figure 5.2)
Grandispora douglastownense McGregor 1973 (figure 5.3)
Grandispora mammillata Owens 1971 (figure 5.4)
Grandispora permulta (Daemon) Loboziak, Streel and Melo 1999 (figure 5.5)
Grandispora pseudoreticulata (Menéndez and Pöthe de Baldis) Ottone 1996 (figure 5.6)
Grandispora spp.
Granulatisporites muninensis Allen 1965 (figure 5.7)
Leiotriletes balapucensis di Pasquo 2007a (figure 5.8)
Leiotriletes spp.
Lophotriletes devonicus (Naumova *ex* Chibrikova) McGregor and Camfield 1982 (figure 5.9)
Punctatisporites spp. (figure 5.10)
Raistrickia aratra Allen 1965 (figure 5.11)
Retusotriletes spp. (figure 5.12)
Verruciretusispora dubia (Eisenack) Richardson and Rasul 1978 (figure 5.13)
Verruciretusispora ornata (Menéndez and Pöthe de Baldis) Pérez Leyton *ex* di Pasquo 2007a (figure 5.14)

Figure 3. Stratigraphic distribution of the species recorded in the Tonono x-1 well / *distribución estratigráfica de las especies en el pozo Tonono x-1.*

Taxa	Palynoassemblages					
	To1		To2		To3	
	Depth [m]					
	3945 - 3946,5	3638,5 - 3640,5	3365,5 - 3367,35	3285 - 3289,5	3133 - 3137,5	3073,2 - 3077
	Samples BAFC-Pl					
	1258	1257	1256	1255	2081	2080
Emphanisporites rotatus	■	■	■	■	■	
Dibolisporites eifeliensis	■	■				
Apiculatasporites microconus	■		■			
Alpenachitina sp. cf. *A. eisenacki*	■					
Apiculiretusispora sp.	■				■	
Gorgonisphaeridium sp.	■			■	■	■
Leiosphaeridia sp.	■			■	■	■
Retusotriletes sp.	■		■			
Acinosporites acanthomammillatus		■	■	■		
Apiculatasporites sp.		■	■			■
Apiculiretusispora plicata		■	■			
Dibolisporites echinaceus		■	■			
Grandispora douglastownense						
Grandispora permulta		■	■	■		
Verruciretusispora ornata						
Verrucosisporites sp.		■	■		■	■
Acinosporites lindlarensis		■				
Acinosporites sp. cf. *A. macrospinosus*		■				
Alpenachitina matogrossensis		■				
Ancyrochitina sp.		■				
Ancyrochitina simplex		■				
Angochitina sp.		■				
Dibolisporites quebecensis		■				
Dibolisporites uncatus		■				■
Lophotriletes devonicus		■				
Ramochitina sp. cf. *R. ramosi*		■				
Verrucosisporites sp. cf. *V. loboziakii*		■				
Acinosporites sp.			■			
Aneurospora greggsii			■	■		
Biharisporites parviornatus			■			
Cymbosporites sp.			■			
Duvernaysphaera angelae			■	■	■	■
Emphanisporites epicautus			■			
Geminospora lemurata			■	■		
Grandispora brevizonata			■	■		
Grandispora mammillata			■	■		
Grandispora pseudoreticulata			■	■		
Grandispora sp.			■	■		
Granulatisporites muninensis			■			
Leiotriletes balapucencis			■	■		
Maranhites mosesii			■	■	■	■
Punctatisporites sp.			■	■	■	■
Quadrisporites granulatus			■	■		

Taxa	Palynoassemblages					
	To1		To2		To3	
	Depth [m]					
	3945 - 3946,5	3638,5 - 3640,5	3365,5 - 3367,35	3285 - 3289,5	3133 - 3137,5	3073,2 - 3077
	Samples BAFC-Pl					
	1258	1257	1256	1255	2081	2080
Verruciretusispora dubia			■			
Verrucosisporites scurrus			■	■	■	■
Verrucosisporites tumulentus			■	■	■	
Arkonites bilixus				■		
Acinosporites ledundae				■	■	■
Gorgonisphaeridium discissum				■	■	■
Hemiruptia legaultii				■	■	■
Polygonium barredae				■	■	■
Exochoderma arca				■	■	
Ammonidium garrasinoi				■		■
Exochoderma triangulata				■		■
Navifusa bacilla				■		■
Pterospermella pernambucensis				■		■
Crucidia camirense				■		
Dactylofusa fastidiona				■		
Duvernaysphaera tenuincingulata				■	■	■
Leiofusa sp.				■		
Maranhites sp.				■		
Multiplicisphaeridium ramispinosum				■		
Stellinium micropolygonale				■		
Raistrickia aratra				■		
Tetraveryhachium longispinosum				■		
Tunisphaeridium caudatum				■		
Cymbosporites catillus					■	■
Dibolisporites sp.					■	■
Grandispora daemonii					■	■
Haspidopalla exornata					■	■
Acinosporites sp. cf. *A. eumammillatus*					■	
Angochitina katzeri					■	
Angochitina mourai					■	
Fungochitina pilosa					■	
Leiotriletes sp.					■	
Papulogabata sp. *A.*					■	
Verrucosisporites premnus					■	
Fungochitina sp.					■	
Multiplicisphaeridium sp.						■
Dictyotidium munificum						■
Dorsennidium pastoris						■
Pterospermella capitana						■
Micrhystridium? spinoglobosum						■
Gorgonisphaeridium vesculum						■
Veryhachium trispinosum						■

Verrucosisporites premnus (Richardson) Richardson 1965 (figure 5.15)
Verrucosisporites scurrus (Naumova) McGregor and Camfield 1982 (figure 5.16, 17)
Verrucosisporites sp. cf. *V. loboziakii* Marshall and Fletcher 2002 (figure 5.18)
Verrucosisporites tumulentus Clayton and Graham 1974 (figure 5.19)
Verrucosisporites spp.

Phytoplankton

Ammonidium garrasinoi Ottone 1996 (figure 6.1)
Arkonites bilixus Legault 1973 (figure 6.2)
Crucidia camirense (Lobo Boneta) Ottone 1996 (figure 6.4)
Dactylofusa fastidiona (Cramer) Fensome, Williams, Barss, Freeman and Hill 1990 (figure 6.5)
Dictyotidium munificum (Wicander and Wood) R. Amenábar, di Pasquo, Carrizo and Azcuy 2006 (figure 6.6)
Dorsennidium pastoris (Deunff) Sarjeant and Stancliffe 1994 (figure 6.7)
Duvernaysphaera angelae Deunff 1964 (figure 6.8)
Duvernaysphaera tenuicingulata Staplin 1961 (figure 6.9)
Exochoderma arca Wicander and Wood 1981 (figure 6.10)
Exochoderma triangulata Wicander and Wood 1981 (figure 6.11)
Gorgonisphaeridium discissum Playford in Playford and Dring 1981 (figure 6.12)
Gorgonisphaeridium vesculum Playford in Playford and Dring 1981 (figure 6.13)
Gorgonisphaeridium spp.
Haspidopalla exornata (Deunff) Playford 1977 (figure 6.14)
Hemiruptia legaultii Ottone 1996 (figure 6.15)
Leiofusa sp. (figure 7.1)
Leiosphaeridia spp. (figure 7.2)
Maranhites mosesii (Sommer) Brito *emend*. Burjack and Oliveira *emend*. González 2009 (figure 7.3)
Maranhites spp.
Micrhystridium? *spinoglobosum* (Staplin) Sarjeant and Stancliffe 1994 (figure 7.4)
Multiplicisphaeridium ramispinosum (Staplin) Sarjeant and Vavrdová 1997 (figure 7.5)
Multiplicisphaeridium sp. (figure 6.3)
Navifusa bacilla (Deunff) Playford 1977 (figure 7.6)
Papulogabata sp. A (figure 7.7)
Polygonium barredae Ottone 1996 (figure 7.8)
Pterospermella capitana Wicander 1974 (figure 7.9)
Pterospermella pernambucensis (Brito) Eisenack, Cramer and Diez Rodriguez 1973 (figure 7.10)
Quadrisporites granulatus (Cramer) Ströther 1991 (figure 7.11)
Stellinium micropolygonale (Stockmans and Willière) Playford 1977 (figure 7.12)
Tunisphaeridium caudatum Deunff and Evitt 1968 (figure 7.13)
Veryhachium (*Tetraveryhachium*) *longispinosum* (Jardiné *et al*.) Stancliffe and Sarjeant 1994 (figure 7.14)
Veryhachium (*Veryhachium*) *trispinosum* (Deunff) Stancliffe and Sarjeant 1994 (figure 7.15)

Chitinozoans

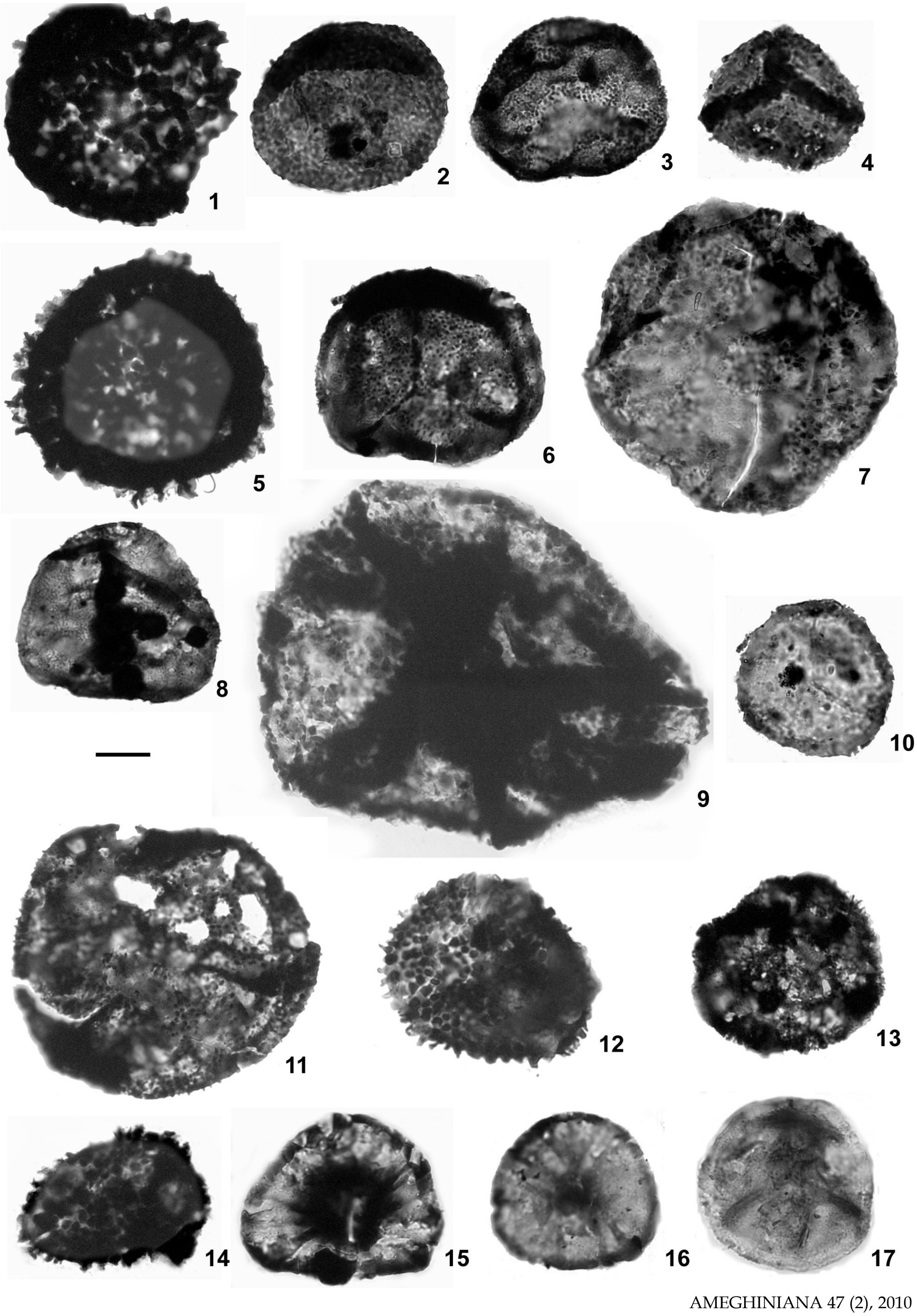
Alpenachitina matogrossensis Burjack and Paris 1989 (figure 8.1)
Alpenachitina sp. cf. *A. eisenacki* Dunn and Miller 1964 (figure 8.2)
Ancyrochitina simplex Grahn, Bergamaschi and Pereira 2002 (figure 8.3)
Ancyrochitina spp.
Angochitina katzeri Grahn and Melo 2002 (figure 8.4a,b)
Angochitina mourai Lange 1952 (figure 8.5a,b)
Angochitina spp.
Fungochitina pilosa Collinson and Scott 1958 (figure 8.7)
Fungochitina sp. (figure 8.6)
Ramochitina sp. cf. *R. ramosi* Sommer and Van Boekel 1964 (figure 8.8)

Systematic descriptions

Trilete spores

Anteturma Proximegerminantes Potonié

Figure 4. 1, ***Acinosporites acanthomammillatus*** Richardson BAFC-Pl 1257 (1) L34/2. **2,** ***Acinosporites ledundae*** Ottone BAFC-Pl 2081 (1) P43. **3,** ***Acinosporites lindlarensis*** Riegel BAFC-Pl 1257 (1) V42/3. **4,** ***Acinosporites*** sp. cf. ***A. eumammillatus*** Loboziak, Streel and Burjack BAFC-Pl 2081 (1) C38/1. **5,** ***Acinosporites*** sp. cf. ***A. macrospinosus*** Richardson BAFC-Pl 1257 (1) M38/4. **6,** ***Aneurospora greggsii*** (McGregor) Streel BAFC-Pl 1256 (1) Y56. **7,** ***Apiculatasporites microconus*** (Richardson) McGregor and Camfield BAFC-Pl 1258 (2) S18. **8,** ***Apiculiretusispora plicata*** (Allen) Streel BAFC-Pl 1257 (1) F28/3. **9,** ***Biharisporites parviornatus*** Richardson BAFC-Pl 1256 (1) U19. **10,** ***Cymbosporites catillus*** Allen BAFC-Pl 2080 (1) A46/2. **11,** ***Dibolisporites echinaceus*** (Eisenack) Richardson BAFC-Pl 1257 (1) Y24/1. **12,** ***Dibolisporites eifeliensis*** (Lanninger) McGregor BAFC-Pl 1257 (2) D49/3. **13,** ***Dibolisporites*** quebecensis McGregor BAFC-Pl 1257 (1) H32/2. **14,** ***Dibolisporites uncatus*** (Naumova) McGregor and Camfield BAFC-Pl 1257 (1) N45/4. **15,** ***Emphanisporites epicautus*** Richardson and Lister BAFC-Pl 1256 (2) U19. **16,** ***Emphanisporites rotatus*** McGregor emend. McGregor BAFC-Pl 1255 (1) C46/2. **17,** ***Geminospora lemurata*** Balme BAFC-Pl 1255 (1) D57/1. Scale bar/ *escala gráfica*: 1, 2, 3, 5, 6, 7, 9, 11= 15 ?m. 4, 8, 10, 12, 13, 14, 15, 16, 17= 10 µm.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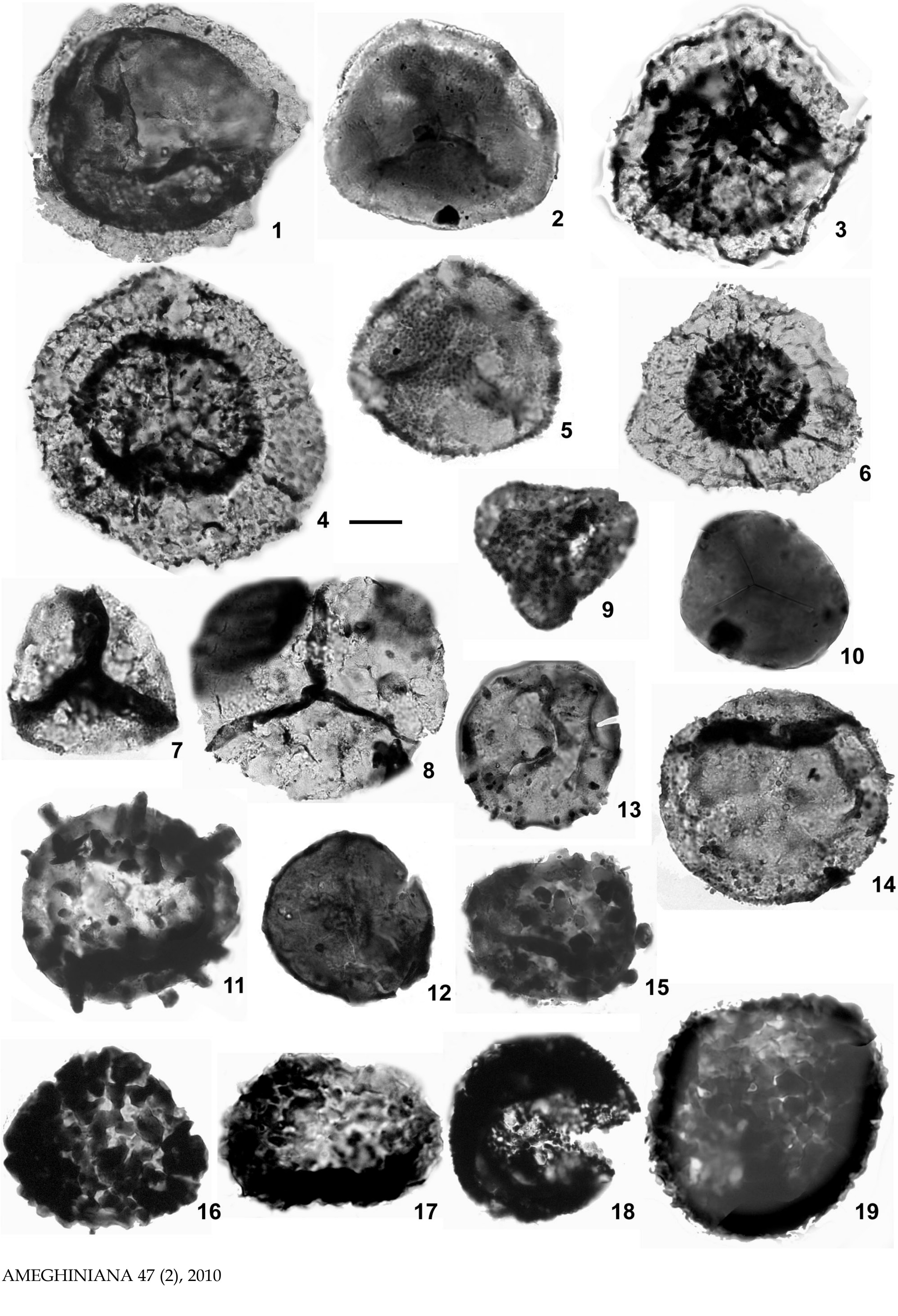
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Turma TRILETES Reinsch *emend*. Dettmann
Suprasubturma ACAVATITRILETES Dettmann
Subturma AZONOTRILETES Lüber *emend*. Dettmann
Infraturma LAEVIGATI (Bennie and Kidston) Potonié

Genus ***Leiotriletes*** (Naumova) Potonié and Kremp 1954

Type species. *L. sphaerotriangulus* (Loose) Potonié and Kremp 1954.

Leiotriletes balapucensis di Pasquo 2007a
Figure 5.8

Remarks. Of all the studied specimens in these samples, the better preserved one is the one illustrated herein. The lack of margin and exinal foldings, recurrent features in this species, offer a wide range of "apparent" ambs from subtriangular (see di Pasquo 2007a, p. 135, fig. 6. F-I) to round (see Amenábar *et al*. 2006, p. 354, fig. 5 E-J).

Infraturma MURORNATI Potonié and Kremp

Genus ***Acinosporites*** Richardson 1965

Type species. *A. acanthomammillatus* Richardson 1965.

Acinosporites lindlarensis Riegel 1968
Figure 4.3

Dimensions (6 specimens). 46- 64 μm.
Remarks. The mode for the size of the specimens from Tonono is slightly smaller than the original population.

Acinosporites sp. cf. ***A. eumammillatus*** Loboziak, Streel and Burjack 1988
Figure 4.4

Description. Trilete miospore with a subtriangular amb. Thickness of the exine 1.5 μm. Laesurae arms elevated, extending to the equator. Sculptural elements biform, consisting on a wide base surmonted by a small element, barely discernible.
Dimensions (1 specimen). 30 μm.
Remarks. The only specimen found, lacks a consistent thickening of the equatorial region; hence the *cf.* assignment.

Acinosporites sp. cf. ***A. macrospinosus*** Richardson 1965
Figure 4.5

Remarks. ***Acinosporites*** sp. cf. ***A. macrospinosus*** is slightly smaller and more rounded. The poor preservation prevents a more reliable identification.

Infraturma APICULATI Bennie and Kidston *emend*. Potonié
Subinfraturma VERRUCATI Dybová and Jachowicz

Genus ***Verrucosisporites*** Ibrahim *emend*. Smith 1971

Type species. *V. verrucosus* Ibrahim 1933.

Verrucosisporites sp. cf. ***V. loboziakii*** Marshall and Fletcher 2002
Figure 5.18

Description. Spore radial. Amb circular slighlty oval. Suturae not visible. Exine sculptured proximally and distally with verrucae of different sizes, which can be anastomosed.
Dimensions. 70 μm (one specimen).
Remarks. The poor preservation and the lack of additional specimens prevent a more precise assignment.

Paleomicroplankton

Group ACRITARCHA Evitt

Genus ***Multiplicisphaeridium*** Staplin *emend*. Sarjeant and Vavrdová 1997.

Type species. *M. ramispinosum* Staplin *emend*. Sarjeant and Vavrdová 1997.

Figure 5. 1, ***Grandispora brevizonata*** (Menéndez and Pöthe de Baldis) di Pasquo BAFC-Pl 1255 (2) G49/4. **2,** ***Grandispora daemonii*** Loboziak, Streel and Burjack BAFC-Pl 2081 (2) J19. **3,** ***Grandispora douglastownense*** McGregor BAFC-Pl 1256 (1) C21/3. **4,** ***Grandispora mammillata*** Owens BAFC-Pl 1256 (1) H49/2. **5,** ***Grandispora permulta*** (Daemon) Loboziak, Streel and Melo BAFC-Pl 1255 (1) F44. **6,** ***Grandispora pseudoreticulata*** (Menéndez and Pöthe de Baldis) Ottone BAFC-Pl 1256 (1) R33. **7,** ***Granulatisporites muninensis*** Allen BAFC-Pl 1256 (1) R31. **8,** ***Leiotriletes balapucensis*** di Pasquo BAFC-Pl 1255 (1) L61. **9,** ***Lophotriletes devonicus*** (Naumova ex Chibrikova) McGregor and Camfield BAFC-Pl 1257 (1) W20/2. **10,** ***Punctatisporites*** sp. BAFC-Pl 2081 (2) B22/3. **11,** ***Raistrickia aratra*** Allen BAFC-Pl 1255 (1) J59. **12,** ***Retusotriletes*** sp. BAFC-Pl 1258 (1) V43/1. **13,** ***Verruciretusispora dubia*** (Eisenack) Richardson and Rasul BAFC-Pl 1256 (1) Y22/4. **14,** ***Verruciretusispora ornata*** (Menéndez and Pöthe de Baldis) Pérez Leyton *ex* di Pasquo BAFC-Pl 1256 (1) U43/3. **15,** ***Verrucosisporites premnus*** (Richardson) Richardson BAFC-Pl 2081 (1) W35/1. **16, 17,** ***Verrucosisporites scurrus*** (Naumova) McGregor and Camfield BAFC-Pl 1256 (1) Y28/2, BAFC-Pl 2080 (1) G49/3. **18,** ***Verrucosisporites*** sp. cf. ***V. loboziakii*** Marshall and Fletcher BAFC-Pl 1257 (1) M24. **19,** ***Verrucosisporites tumulentus*** Clayton and Graham BAFC-Pl 1255 (1) C53/1. Scale bar/ *escala gráfica*: 1, 3, 4, 6, 8, 10, 11, 13= 20 μm. 2, 5, 7, 12, 15, 18= 15 μm. 9, 14, 16, 17, 19= 10 μm.

Multiplicisphaeridium sp.
Figure 6.3

Description. Vesicle spherical, psilate. Numerous processes, hollow, laevigate as well, homomorphic to slighltly heteromorphic, with circular bases proximally contacting the vesicle and acuminated distal extremities, free communicated with the vesicle.
Dimensions. Vesicle diameter: 40 µm; processes 9.5 µm long (one specimen).
Remarks. *Multiplicisphaeridium* sp. resembles *Baltisphaerosum* sp. in Ottone 1996 even though the former does not show any basal plug in the processes.

Genus ***Dorsennidium*** Wicander *emend*. Sarjeant and Stancliffe 1994

Type species. *D. patulum* Wicander 1974.

Dorsennidium pastoris (Deunff) Sarjeant and Stancliffe 1994
Figure 6.7

Remarks. This specimen resembles *Villosacapsula semipunctata* (Pöthe de Baldis) Sarjeant and Vavrdová 1997 but it has more processes and these are not ornamented.

Genus ***Leiofusa*** Eisenack *emend*. Eisenack *emend*. Combaz *et al*. *emend*. Cramer 1970

Type species. *Leiofusa fusiformis* Eisenack *ex* Eisenack 1938.

Leiofusa sp.
Figure 7.1

Remarks. *Leiofusa* sp. resembles *L. pyrena* Wicander and Wood 1981; however, the missing part of this single specimen prevents specific identification. *Leiofusa* sp. in Ottone (1996, Plate 7, figure 13) has a thiner wall and longer processes.

Genus ***Papulogabata*** Playford in Playford and Dring 1981

Type species. *P. annulata* Playford in Playford and Dring 1981.

Papulogabata sp. A
Figure 7.7

Diagnosis. Circular to subcircular vesicle; surface psilate. Wall presenting three radial thickenings, the one on the margin is 4 µm in width, the following one is 8 µm wide and the one closer to the center, surrounding the cyclopyle (11 µm), is 5 µm.
Comparisons and remarks. *Papulogabata annulata* Playford in Playford and Dring 1981 is smaller and has only one thickened ring. *P. persica* Ghavidel-Syooki (2003) is much bigger and the vesicle wall can be scabrated. Because only one specimen of *Papulogabata* sp. A was found it is placed in open nomenclature.

Chitinozoans

Group CHITINOZOA Eisenack
Order PROSOMATIFERA Eisenack
Family CONOCHITINIDAE Eisenack *emend*. Paris
Subfamily ANCYROCHITININAE Paris

Genus ***Alpenachitina*** Dunn and Miller 1964

Type species. *A. eisenacki* Dunn and Miller 1964.

Alpenachitina sp. cf. ***A. eisenacki*** Dunn and Miller 1964
Figure 8.2

Remarks. Despite the poor preservation, the specimen bears processes by the basal margin and by the shoulder, even though the missing collarette and the lack of further specimens prevent a more accurate assignment.

Family LAGENOCHITINIDAE Eisenack *emend*. Paris
Subfamily ANGOCHITININAE Paris

Genus ***Ramochitina*** Sommer and van Boekel *emend*. Paris *et al*. 1999

Type species. *R. ramosi* Sommer and van Boekel 1964.

Figure 6. 1, ***Ammonidium garrasinoi*** Ottone BAFC-Pl 2080 (1) R39. **2,** ***Arkonites bilixus*** Legault BAFC-Pl 1255 (2) B20. **3,** ***Multiplicisphaeridium*** sp. BAFC-Pl 2080 (1) F40. **4,** ***Crucidia camirense*** (Lobo Boneta) Ottone BAFC-Pl 1255 (1) D51. **5,** ***Dactylofusa fastidiona*** (Cramer) Fensome, Williams, Sedley Barss, Freeman, J and Hill BAFC-Pl 1255 (1) V57/3. **6,** ***Dictyotidium munificum*** (Wicander and Wood) R. Amenábar, di Pasquo, Carrizo and Azcuy BAFC-Pl 2080 (2) J29/1. **7,** ***Dorsennidium pastoris*** (Deunff) Sarjeant and Stancliffe BAFC-Pl 2080 (1) T37. **8,** ***Duvernaysphaera angelae*** Deunff BAFC-Pl 1256 (2) L43/4. **9,** ***Duvernaysphaera tenuincingulata*** Staplin BAFC-Pl 1255 (1) B54. **10,** ***Exochoderma arca*** Wicander and Wood BAFC-Pl 1255 (1) M45/4. **11,** ***Exochoderma triangulata*** Wicander and Wood BAFC-Pl 1255 (2) Y46/2. **12,** ***Gorgonisphaeridium discissum*** Playford in Playford and Dring BAFC-Pl 1255 (1) Z40/2. **13,** ***Gorgonisphaeridium vesculum*** Playford in Playford and Dring BAFC-Pl 2080 (1) T39/2. **14,** ***Haspidopalla exornata*** (Deunff) Playford BAFC-Pl 2080 (1) P25/1. **15,** ***Hemiruptia legaultii*** Ottone BAFC-Pl 2081 (1) L31. Scale bar / *escala gráfica*: 1, 3, 4, 5, 6, 14, 15= 15 µm. 2, 8, 9, 12, 13= 10 µm. 7, 10, 11= 20 µm.

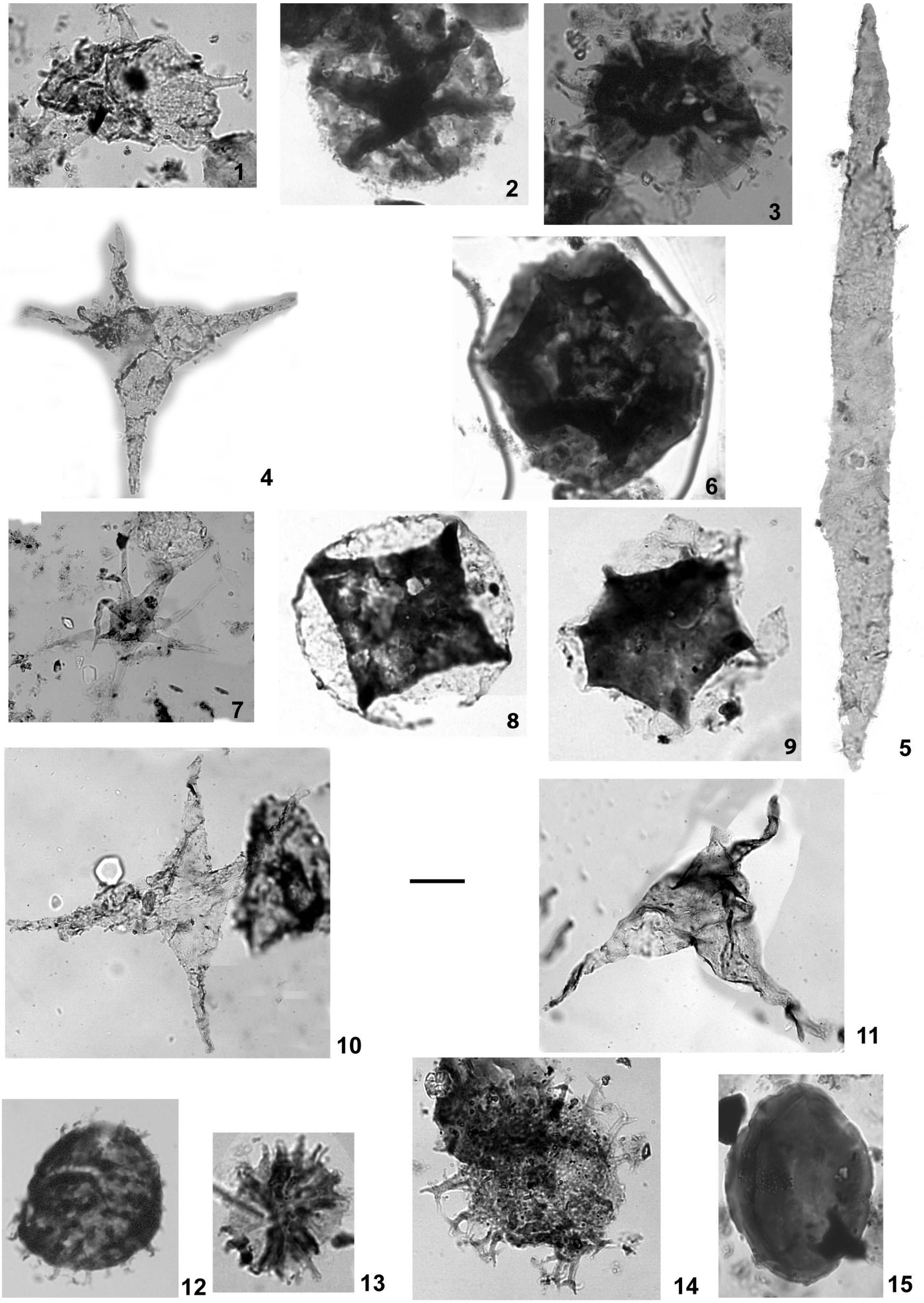
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Chart 1. Relative percentage of the phytoclasts and palynomorph groups and values of Palynologycal Marine Index (PMI) of the assemblages registered in the Tonono x-1 well / *porcentajes relativos de los fitoclastos y grupos de palinomorfos y valores del Indice Marino Palinológico (IMP) de las asociaciones registradas en el pozo Tonono x-1.*

PA	BAFC-Pl	PMI	AOM	SP	USP	BP	SPO	PHY	CHI
To1	1258	160	0	24.5	68.6	4.9	1	0.33	0.18
To1	1257	144	4.5	36	45	4.5	7.5	0	2.5
To2	1256	119	0	37.6	30	7.5	23.9	0.9	0
To2	1255	311	0	21	36	3	21.2	18.1	0
To3	2081	233	54	9	22.5	4.5	2.7	4.3	3
To3	2080	314	72	0	18	0	2.6	7	0

Ramochitina sp. cf. ***R. ramosi*** Sommer and Van Boekel 1964
Figure 8.8

Remarks. Because only a fragment of a specimen was found and despite its outstanding ornamentation, a more accurate identification is impossible.

Genus ***Fungochitina*** Taugourdeau 1966

Type species. *Conochitina fungiformis* Eisenack 1931.

Fungochitina sp.
Figure 8.6

Remarks. *Fungochitina* sp. resembles *Fungochitina* sp. cf. *F. pilosa* in Grahn and Melo 2002, but the shorter, robust spines, characteristic of this species are difficult to distinguish without a SEM image.

Composition of the assemblages and palaeoenvironmental considerations

The complete microflora recovered along the investigated interval of the Tonono x-1 Borehole comprises 73 relatively well-preserved species represented by diverse palynological groups such as trilete spores (35 species), microplankton including several prasinophycean and acritarch taxa together with chlorophycean algae such as *Quadrisporites* (30 species) and chitinozoans (8 species) (figures 3- 8). Thermal maturity (TAI) varies between 2 and 3 according to the scale of Utting *et al.* (in Utting and Wielens, 1992). Phytoclasts, such as tracheids and cuticular fragments, are frequent.

In order to characterize the palynofacies, a matrix was constructed with the relative percentages of the palynomorphs and the PMI, as explained previously (chart 1).

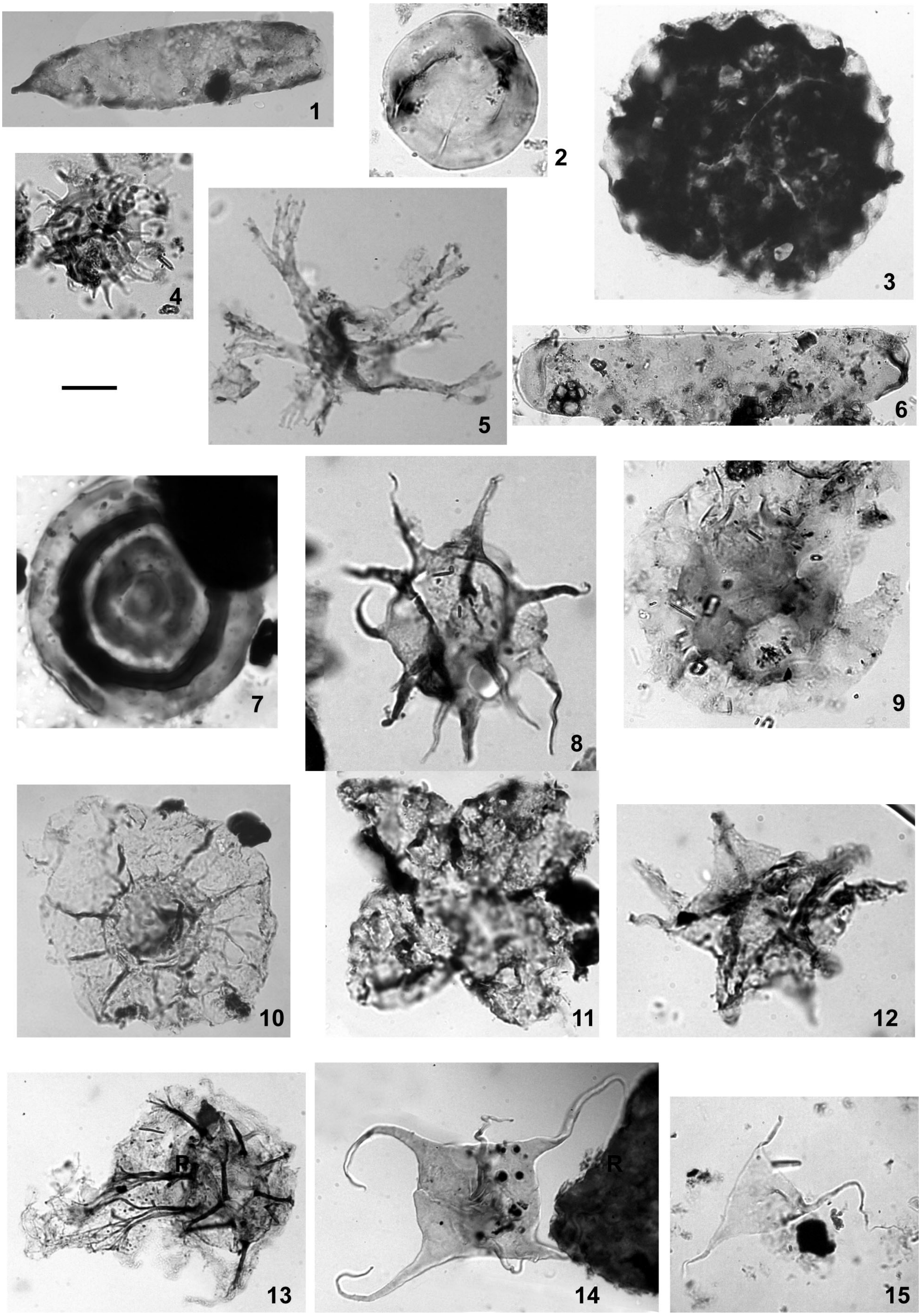
The palynofacies analysis and quantitative data displayed reflect paleoenvironmental changes during the deposition of the succession.

The palynoassemblage of BAFC-Pl 1258 and 1257 is very poorly preserved. There is a high proportion of structured and unstructured phytodebris and a very low diversity of palynomorphs. They have similar PMI values (chart 1) which fall within the lower values range. The high input of USP together with the low values of PMI could reflect a nearshore palaeoenvironment.

The lowest value of PMI is recorded in the palynoassemblage of BAFC-Pl 1256, in coincidence with the highest proportion of spores, structured phytodebris and black phytodebris (chart 1) supporting a very marginal deposition environment.

Both palynofloras of BAFC-Pl 1255 and 2080 yielded the highest PMI values and phytoplankton proportion although AOM is absent in the former and very abundant in the latter. This suggests a closer affinity with the BAFC-Pl 2081 where AOM proportion is high as well as the content of phytoplankton and chitinozoans (chart 1), features that would reinforce the idea of a marine origin for the amorphous organic matter (Batten, 1996). AOM is usually the dominant organic component of sediments accumulated under anoxic conditions, especially in areas removed from significant influence of terrestrial input (*e.g.*, Tyson, 1995). Therefore, a more distal environment is proposed for the levels BAFC-Pl 2080 and

Figure 7. 1, ***Leiofusa*** sp. BAFC-Pl 1255 (1) O41. **2,** ***Leiosphaeridia*** sp. BAFC-Pl 2080 (1) X37/2. **3,** ***Maranhites mosesii*** (Sommer) Brito *emend.* Burjack and Oliveira BAFC-Pl 1256 (1) U22/4. **4,** ***Micrhystridium? spinoglobosum*** (Staplin) Sarjeant and Stancliffe BAFC-Pl 2080 (1) L45. **5,** ***Multiplicisphaeridium ramispinosum*** (Staplin) Sarjeant and Vavrdová BAFC-Pl 1255 (1) M41/4. **6,** ***Navifusa bacilla*** (Deunff) Playford BAFC-Pl 2080 (1) P35. **7,** ***Papulogabata*** sp. ***A.*** BAFC-Pl 2081 (3) Y33/1. **8,** ***Polygonium barredae*** Ottone BAFC-Pl 1255 (2) R46/2. **9,** ***Pterospermella capitana*** Wicander BAFC-Pl 2080 (1) P37/2. **10,** ***Pterospermella pernambucencis*** (Brito) Eisenack, Cramer and Diez Rodriguez BAFC-Pl 1255 (1) U43/3. **11,** ***Quadrisporites granulatus*** (Cramer) Ströther BAFC-Pl 1255 (1) Y52. **12,** ***Stellinium micropolygonale*** (Stockmans and Willière) Playford BAFC-Pl 1255 (1) S47/4. **13,** ***Tunisphaeridium caudatum*** Deunff and Evitt BAFC-Pl 1255 (2) F20/3. **14,** ***Veryhachium*** **(*Tetraveryhachium*)** ***longispinosum*** (Jardiné *et al.*) Stancliffe and Sarjeant BAFC-Pl 1255 (2) U49. **15,** ***Veryhachium*** **(*Veryhachiurn*)** ***trispinosum*** (Deunff) Stancliffe and Sarjeant BAFC-Pl 2080 (1) T46/1. Scale bar / *escala gráfica*: 1, 6= 20 µm. 2, 3, 4, 5, 7, 9, 10, 11, 13, 14, 15= 15 µm. 8, 12= 10 µm.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2081. Even though level BAFC-Pl 1255 has a high PMI, meaning a high diversity of microplankton, this value accompanied by a similar proportion of spores and phytoplankton (see chart 1) suggests a more marginal setting -an intermediate deposition environment in between the level BAFC-Pl 1256, representing the nearest shore one- and the top levels (BAFC-Pl 2080, 2081).

Age assessment and correlation

Three assemblages are defined based on the stratigraphic distribution of taxa along the studied interval, presence/absence of key taxa (see figures 3, 9) as well as abundances of different groups of taxa (chart 1) and palynofacies analysis. Unfortunately, the only lithological information available for this study was the one provided by the interpretation of the electric log.

The assemblages are characterized by many species in common with palynofloras from South America and selected ones from other regions (figure 9).

Palynoassemblage To1 (3945-3640,5 m interval)

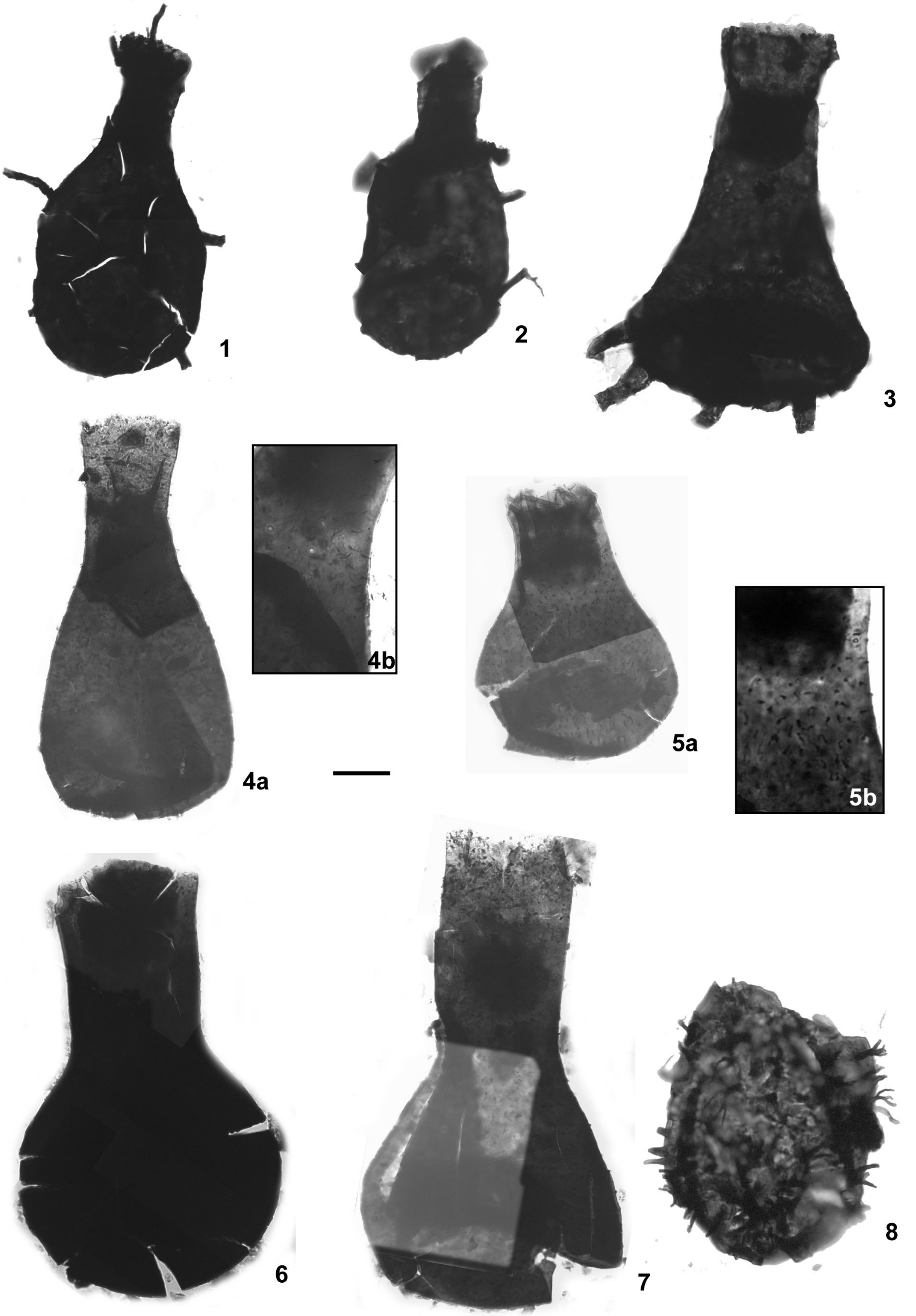
Although the general preservation of the organic matter is very poor, some stratigraphically important species are recognized. The inception and disapearance of some species with a restricted stratigraphic distribution support a late Eifelian to earliest Givetian age for this interval (see figure 9). The co-occurrence of *Acinosporites acanthomammillatus* and *Acinosporites* sp. cf. *A. macrospinosus* allow its correlation with the lower part of the late Eifelian AD (*Acinosporites acanthomammillatus–Densosporites devonicus*) Zone of the Ardenne-Rhenish region (Streel *et al*., 1987), and the *Calyptosporites velatus–Rhabdosporites langii* and *Densosporites devonicus–Grandispora naumovii* Assemblage Zones of the Old Red Sandstone Continent (Richardson and McGregor, 1986) and the *Grandispora pseudoreticulata* Zone (Limachi *et al*., 1996). Occurrence of *Grandispora permulta* supports the correlation with the *Grandispora permulta* Interval Zone (Per), of late early Eifelian through the Eifelian/Givetian transition, for the Amazon Basin (Melo and Loboziak, 2003). Several common species (*e.g.*, *Acinosporites acanthomammillatus*, *A. lindlarensis*, *A. macrospinosus*, *Dibolisporites eifeliensis*, *D. quebecensis*, *Grandispora douglastownense*) support its correlation with assemblage 1 of the Los Monos Formation at *Balapuca* (di Pasquo, 2007a,2007b) and the assemblage 2 of the Chigua Formation at Del Chaco Creek (Amenábar, 2007). Moreover, *Alpenachitina matogrossensis* and *Ancyrochitina simplex* are recorded in the *Alpenachitina eisenacki-Spinachitina biconstricta* Concurrent Range Zone of late Eifelian?–early Givetian age in the Paraná basin (Grahn *et al*., 2002), which is correlated to the *Alpenachitina eisenacki* Biozone for Western Gondwana (Grahn, 2005). Other taxa disappear around the early Givetian on a world–wide basis (*e.g*., *Dibolisporites eifeliensis*, *Verrucosisporites* sp. cf. *V. loboziakii*, *Alpenachitina* sp. cf. *A. eisenacki*, *Ramochitina* sp. cf. *R. ramosi*).

Palynoassemblage To2 (3365,5-3289,5 m Interval)

This assemblage is better preserved than the one below. The appearance of *Geminospora lemurata*, in agreement with the base of the *ensensis obliquimarginatus* Conodont Zone *sensu* Weddige (1984; see Loboziak and Streel, 1995) -together with *Biharisporites parviornatus* recognized as a ?late Eifelian – mid-late Givetian taxon in South America (see di Pasquo, 2007a)- suggests a Givetian age. The appearances within this interval of *Leiotriletes balapucensis*, *Aneurospora greggsii*, *Acinosporites ledundae*, *Raistrickia aratra*, *Arkonites bilixus*, *Ammonidium garrasinoi*, *Duvernaysphaera angelae*, *Exochoderma triangulata*, *Maranhites mosesii*, *Verrucosisporites tumulentus* among others reinforce this age (see figures 3 and 9).

This assemblage can be correlated with the mid-late Givetian assemblage 2 of Los Monos Formation at Balapuca (di Pasquo, 2007a, 2007b) from Bolivia, the assemblage 3 of Chigua Formation at La Cortadera Creek (Amenábar *et al*., 2006, 2007), partially with the palynoflora of the Los Monos Formation at Galarza Creek (Ottone, 1996) and probably with the microflora of the Punta Negra Formation (Rubinstein, 1999, 2000) from Argentina. In contrast, comparison with the Givetian *Verrucosisporites premnus*/*V. scurrus* Zone of Limachi *et al*. (1996) of Bolivia and with the *Geminospora lemurata–Chelinospora* ex gr. *ligurata* Interval Zone (LLi) for the Amazon Basin (Melo and Loboziak, 2003) is difficult because there are few species in common (*e.g.*,

Figure 8. 1, ***Alpenachitina matogrossensis*** Burjack and Paris BAFC-Pl 1257 (1) K32, BAFC-Pl 1257 (1) L52/1. **2,** ***Alpenachitina*** sp. cf. ***A. eisenacki*** Dunn and Miller BAFC-Pl 1258 (2) M36/3. **3,** ***Ancyrochitina simplex*** Grahn, Bergamaschi and Pereira BAFC-Pl 1257 (2) M54/2. **4a,** ***Angochitina katzeri*** Grahn and Melo BAFC-Pl 2081 (1) C38/3; **b,** Detail of ornamentation / *detalle de la ornamentación*. **5a,** ***Angochitina mourai*** Lange BAFC-Pl 2081 (1) V38/1; **b,** Detail of ornamentation / *detalle de la ornamentación*. **6,** ***Fungochitina*** sp. BAFC-Pl 2081 (1) O46/2. **7,** ***Fungochitina pilosa*** Collinson and Scott BAFC-Pl 2081 (1) E37/2. **8,** ***Ramochitina*** sp. cf. ***R. ramosi*** Sommer and Van Boekel BAFC-Pl 1257 (1) Q39/2. Scale bar / *escala gráfica*: 1, 2, 3, 4, 5, 6= 28 µm. 7= 26 µm. 8= 15 µm.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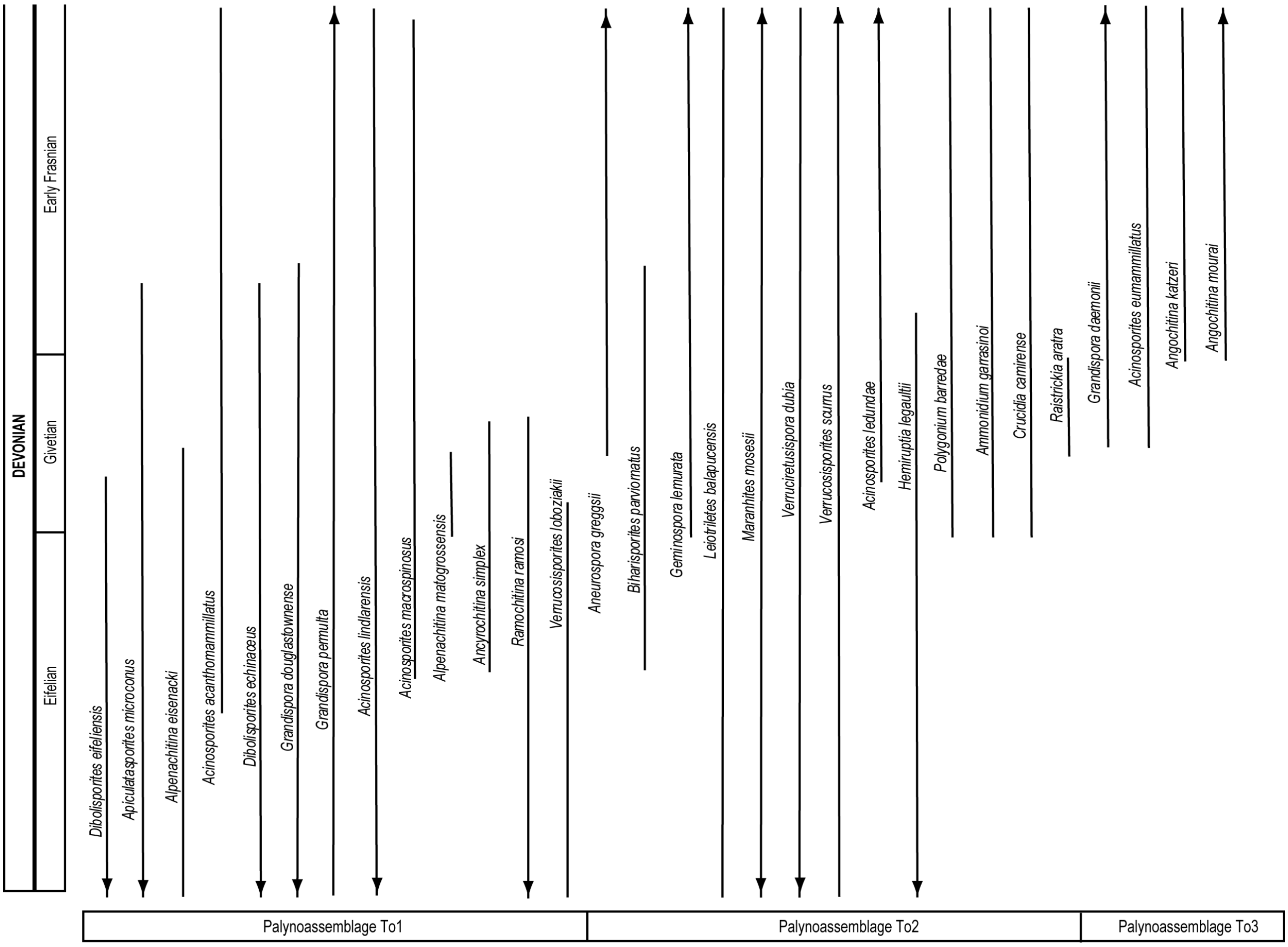

Figure 9. Stratigraphic ranges of selected taxa occuring in the Tonono x-1 Borehole based on the selected literature / *rangos estratigráficos de taxa seleccionados del Pozo* Tonono x-1: Marhoumi and Rausscher (1984), McGregor and Playford (1992), Turnau (1996), Quadros (1999), Vavrdová and Isaacson (1999), Marshall and Fletcher (2002), Grahn (2005 and references therein), Hashemi and Playford (2005), Grahn *et al.* (2006), di Pasquo (2007a, and references therein), Al-Ghazi (2007), Amenábar (2007), Amenábar *et al.* (2006, 2007, and references therein), di Pasquo and Noetinger (2008), di Pasquo *et al.* (2009, and references therein), González (2009).

Verrucosisporites scurrus, *Arkonites bilixus*, *Geminospora lemurata*).

Assemblage III of Hashemi and Playford (2005), attributed to the late Givetian-early Frasnian, and the Frasnian microfloras documented by Balme (1988) and Playford and Dring (1981) for the Gneudna Formation in the Carnarvon Basin (Australia) share with the studied Palynoassemblage To2 only the cosmopolitan age-diagnostic taxa such as *Geminospora lemurata*, *Verrucosisporites tumulentus*, *V. scurrus* and *Gorgonisphaeridium discissum*.

Palynoassemblage To3 (3133- 3077 m Interval)

Preservation of the palynomorphs is fairly good. Only a few key species are recognized at the top of the interval. These are *Acinosporites* sp. cf. *A. eumammillatus* together with some key chitinozoans such as *Angochitina katzeri*, *Fungochitina pilosa* and *Angochitina mourai*. The first occurence of *A. mourai* indicates the base of the Frasnian in all intracratonic basins of Brazil (Gaugris and Grahn, 2006) and its abundance associated to acritarchs and chitinozoans such as *Hoegisphaera glabra* and *Ancyrochitina* sp. render an upper Frasnian age in the Bolivian Devonian (Racheboeuf *et al.*, 1993). The occurrence of *Cymbosporites catillus* -that first appearsing in the highest levels of the LLi Zone (see Melo and Loboziak, 2003)- is recorded here within this interval. This assemblage shares several species with the wide ranging association documented by Ottone (1996) in the Los Monos Formation attributed to the late Givetian–early Frasnian. The association is correlated to the Concurrent Range Zone of *Hoegisphaera glabra* and *Ramochitina derbyi* -which defines the Frasnian beds of Brazil (Grahn *et al.*, 2002)- and the Frasnian *Hoegisphaera glabra* Biozone (Grahn, 2005) on the basis of the presence of the chitinozoans (see figure 3). Hence, a Frasnian age is supported for this assemblage by the significant increase of marine elements and AOM between To2 and To3, which would probably have occurred as a response to a maximum flooding event, possibly related to major global eustatic changes during this time (see Noetinger and di Pasquo, 2008b).

Concluding remarks

This study presents new palynological data on spores and microplankton for the Tonono x-1 borehole. The stratigraphic distribution of 73 species of trilete spores (35 species), microplankton including several prasinophycean and acritarch taxa together with chlorophycean algae such *Quadrisporites* (30 species) and chitinozoans (8 species) along the studied interval (between 3945-3077 m) of the Tonono x-1 allow the definition of three palynoassemblages. Diagnostic markers present in these assemblages support a late Eifelian to early Frasnian age to the whole interval. Palynoassemblage To1 ranges from the late Eifelian to earliest Givetian. A Givetian age is proposed for association To2 whilst an early Frasnian is suggested on the basis of few species for the assemblage To3.

The whole interval corresponds to the Tonono Formation. The upper part could be attributed to the Jollín Member and the basal part to the Michicola Formation according to lithology and age of the assemblages (see figure 2).

These assemblages contain many cosmpolitan index species (*e.g.*, *Geminospora lemurata*, *Dibolisporites eifeliensis*, *Verrucosisporites scurrus*, *Grandispora douglastownense* and *Acinosporites acanthomammillatus*) that support the correlation mainly with Brazilian and Euro-American zonations. Other age-diagnostic taxa are exclusively recorded from South America (*e.g.*, *Grandispora pseudoreticulata*, *Grandispora brevizonata*, *Leiotriletes balapucensis*, *Acinosporites ledundae*), belonging to the Mid-Devonian to Frasnian Afro-South American Subrealm (di Pasquo *et al.*, 2009). Assemblages To1 and To2 are interpreted as reflecting nearshore, shallow marine depositional conditions, characterized by a very high terrestrial input, and variable marine influence. This is in agreement with a trend towards a sea-level drop proposed by Albariño *et al*. (2002), and recorded in this region from the early Eifelian and apparently maintained through the Givetian. Assemblage To3 represents a transgressive period with high diversity and abundance of microplankton along with high AOM content. It seems that this change was gradual from continental conditions during the deposition of To2 (see chart 1) to shelf marine environments in To3, in agreement with the record of a new transgressive cycle in the latest Givetian-early Frasnian according to Albariño *et al.* (2002) and Noetinger and di Pasquo (2008b).

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