

# Palynofloras of the Chigua (Devonian) and Malimán (Mississippian) formations from the Precordillera Argentina: Age, correlation and discussion of the D/C boundary

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## Resumen

Se presenta el análisis cualitativo y cuantitativo de las asociaciones palinológicas obtenidas de las formaciones Chigua (Devónico) y Malimán (Mississippiano), aflorantes en la Cuenca Río Blanco, Precordillera Argentina. La relación estratigráfica entre ambas unidades es mediante una discordancia angular. Una detallada correlación de ambas palinofloras con otras coetáneas permite su datación precisa. La palinoflora de la Formación Chigua es correlacionable con la Zona *G. lemurata*-*C. magnificus* del Givetiano temprano de Euramerica. El alcance estratigráfico de las especies autóctonas halladas en la Formación Malimán sustentan una edad viséana temprana, aunque la presencia de algunas especies del Tournaisiano tardío sugieren que esta edad podría estar representada en la parte inferior de la formación. Esta palinoflora es correlacionada con 1) la Zona *Endoculeospora larga* del Viséano de Australia, 2) las zonas CM y Pu del Tournaisiano tardío – Viséano temprano de Euramerica y 3) la palinoflora de la Formación Itacua atribuida al Viséano temprano presente en el extremo sur de Bolivia. El hiato estratigráfico entre ambas formaciones está avalado por las distintas edades de las palinofloras encontradas y por el rango estratigráfico de los palinomorfos retrabajados registrados en la Formación Malimán. Así, se documentan dos períodos de acumulación de sedimentos durante el Frasniano y probablemente durante el Tournaisiano temprano. La ausencia de formas retrabajadas del Devónico más tardío (Famenniano tardío o “Struniano”) sugiere que no habría depositación durante este intervalo. Otros palinomorfos retrabajados del Silúrico Tardío y Devónico Temprano se encuentran en la Formación Malimán. La mezcla de palinomorfos del Silúrico al Tournaisiano temprano se vincula con la erosión penecontemporánea de áreas levantadas que habrían conformado la Protoprecordillera, por una combinación de procesos tectónicos y glacio-eustáticos durante el Frasniano tardío, Fameniense y Tournaisiano temprano.

**Palabras clave:** Palinoestratigrafía, Givetiano temprano, Viséano temprano, Retrabajo, Hiato, Argentina.

## Abstract

A qualitative and quantitative analysis is presented of palynological assemblages recovered from outcrops of the Chigua (Devonian) and Malimán (Mississippian) formations, in the Río Blanco Basin, Precordillera of Argentina. An angular unconformity separates these two formations. Both units are dated precisely in comparison with palynofloras elsewhere. The Chigua Formation is correlatable with the early Givetian *G. lemurata*-*C. magnificus* Zone of Euramerica. The stratigraphic ranges of the non-reworked taxa in the Malimán Formation support an early Viséan age. However, the presence of some late Tournaisian species suggests that the lower part of the formation correspond to this age. The palynoflora of the Malimán Formation suggests correlation with 1) the Viséan *Endoculeospora larga* Assemblage of Australia, 2) the late Tournaisian – early Viséan CM and Pu zones of Euramerica, and 3) the early Viséan assemblage of the Itacua Formation of southernmost Bolivia. A hiatus comprising Frasnian to early Tournaisian is confirmed on the basis of the different ages of the two assemblages and the stratigraphic ranges of reworked palynomorphs found in the Malimán Formation. These, attest to sedimentation and subsequent erosion of Frasnian and probably also Tournaisian strata. The absence of reworked forms of the latest Devonian (late Famennian or “Strunian”) suggests a corresponding period of non-deposition. The Malimán Formation also contains reworked palynomorphs of Late Silurian and Early Devonian ages. The reworking of palynomorphs documents the penecontemporaneous erosion of uplifted areas that would have conformed the Protoprecordillera, due to late Frasnian, Famennian and early Tournaisian tectonic and glacio-eustatic processes affecting the area involved.

**Key words:** Palynostratigraphy, Early Givetian, Early Viséan, Reworking, Hiatus, Argentina.

## 1. INTRODUCTION

Several contributions have improved the knowledge of the Mississippian palynofloras of South America. Earlier studies are related to the Retama Formation of the Madre de Dios Basin of Bolivia (Azcuy and Ottone, 1987) and the Zorritas Formation of Arizaro Basin of Chile (Rubinstein *et al.*, 1996).

In recent years the palynological investigations of Mississippian South American deposits have increased in number, dealing with the following: Parnaíba and Amazonas basins, Brazil (Melo and Loboziak, 2000, 2003); Ambo Formation, Peru (Azcuy and di Pasquo, 2005, 2006); Llanos Orientales Basin, Colombia (Dueñas and Césari, 2006); and the Kaka and Itacua formations of the Madre de Dios and Tarija basins respectively, Bolivia (Figure 1) (Fasolo *et al.*, 2006; di Pasquo, 2005, 2007a, b). Palynological work on the Mississippian deposits of Argentina is scarcer, Mississippian rocks with palynomorphs occur in the Precordillera of San Juan Province (Río Blanco and Calingasta-Uspallata basins), comprising the Malimán, Cortaderas and El Ratón formations (Figures 1, 2). Previous palynological studies consist only partly of publications with illustrations (Sessarego and Césari, 1989; Césari and Limarino, 1992, 1995; Césari and Gutiérrez, 2001); another papers does not include figures of palynomorphs, only lists (Limarino *et al.*, 1996). The most recent contributions are those by Rodríguez Amenábar *et al.* (2003), Pérez Loinaze and Césari (2003), Rodríguez Amenábar and di Pasquo (2004), Pérez Loinaze (2007), Pazos *et al.* (2005a, b), Amenábar (2006) and Amenábar *et al.* (2006, 2007). An exhaustive palynological investigation of the Chigua, Malimán and El Ratón formations was carried out by the first author for her Doctoral degree (Amenábar, 2007a).

With reference to the Devonian, rich palynological assemblages of different South American basins are known, e.g. the Amazonas, Paraná and Solimões basins, Brazil (Dino, 1999; Quadros, 1999; Melo and Loboziak, 2003; Rubinstein *et al.*, 2005; Grahn, 2005); Madre de Dios Basin, Bolivia (Vavrdová *et al.*, 1993, 1996; Ottone and Rossello, 1996; Vavrdová and Isaacson, 1997, 2000); and Tarija Basin of southern Bolivia and northern Argentina (Bliciek *et al.*, 1996; Ottone, 1996; Limachi *et al.*, 1996; Grahn

and Gutiérrez, 2001; Grahn, 2002; di Pasquo, 2005, 2007a, b, c; Noetinger and di Pasquo, 2007). In contrast, despite some palynological papers of these strata are known (Le Hérisse *et al.*, 1997; Rubinstein, 1999, 2000; Rubinstein and Steemans, 2007; Amenábar, 2007b, 2009), materials from the Precordillera of Argentina have retrieved poor palynofloras (Figure 1).

Studies on reworked palynomorphs are still required for a better knowledge of the Devonian and Mississippian palynofloras, as well as can be used to refine the D/C boundary definition in South America, and to improve the understanding of palaeogeographic and palaeoclimatic changes which influenced microfloral evolution in Western Gondwana (di Pasquo and Azcuy, 1997; Vavrdová and Isaacson, 2000; di Pasquo, 2007a, b, c). The present paper completes two previous contributions (Amenábar *et al.*, 2006, 2007) on the Chigua (Devonian) and Malimán (Mississippian) formations cropping out in the Precordillera of Argentina. Whilst the two first papers deal with the taxonomic description of the microplankton and spores in these units, the present contribution focuses on a comparison with palynofloras of similar ages in different parts of South America and elsewhere. This includes an assessment of the age and correlation of both assemblages. Additionally, a discussion is presented on the importance of the recognition of some Late Silurian and Early Devonian reworked palynomorphs in the Chigua Formation and also some Devonian and possibly Tournaisian reworked taxa recorded in the Malimán Formation (not previously mentioned by Amenábar, 2006). The palynological data also allow an estimation and characterisation of the stratigraphic gap between both formations (Figure 2B-C).

## 2. GEOLOGICAL SETTING

Palaeozoic deposits crop out in the northwestern part of the Precordillera Range in San Juan Province, at about 30° S and 69° W (Figure 2), represented by fossiliferous marine Devonian and marine/terrestrial Mississippian strata. The outcrops extend to east of the Río Blanco, on the western slope of the Punilla and Volcán ranges. The Devonian Pircas Negras and Chigua formations constitute the Chinguillos Group (Baldis and Sarudiansky, 1975). The succeeding

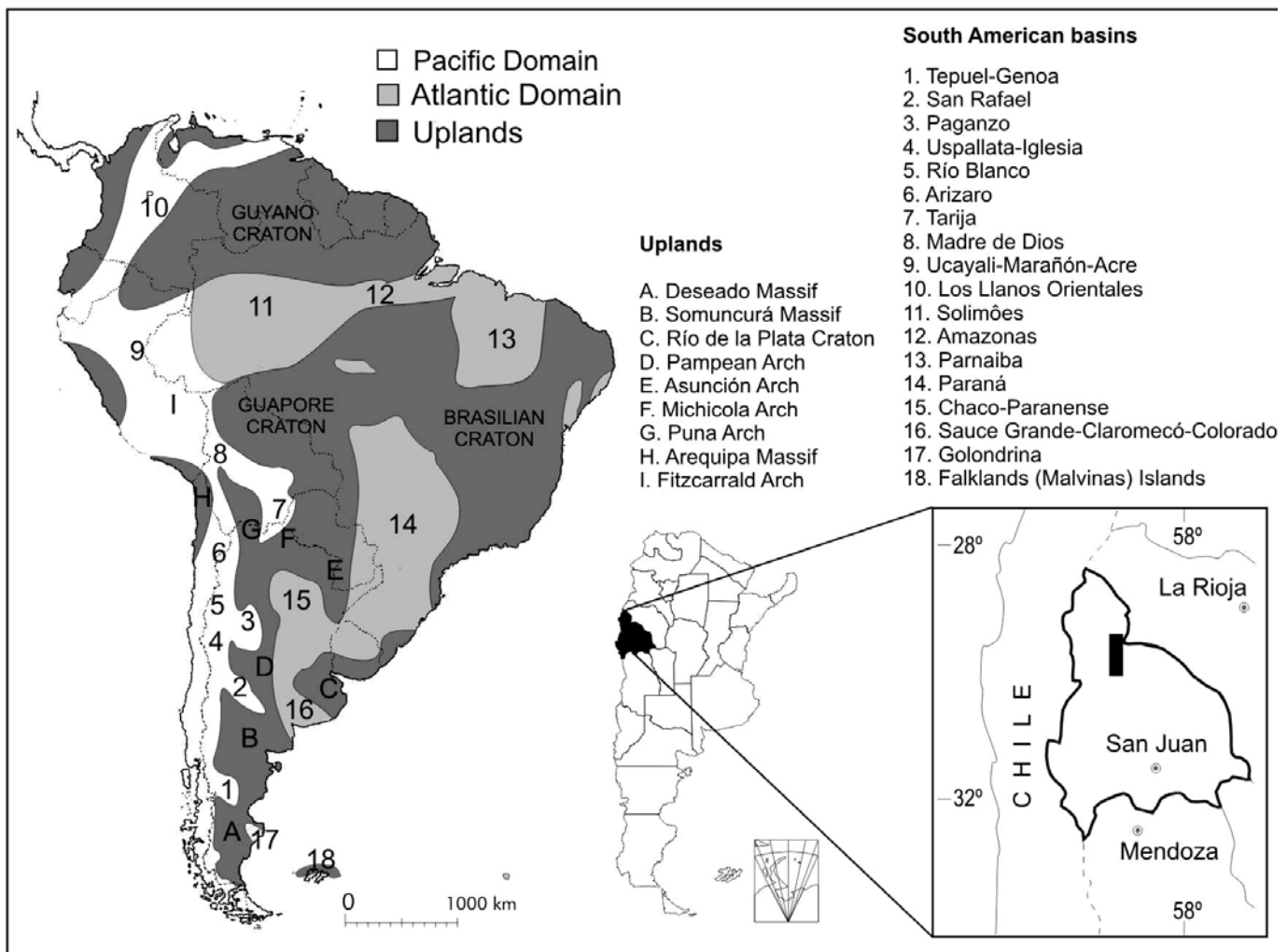


Figure 1. Main Carboniferous basins of South America (after Azcuy et al., 2007).

Mississippian Malimán and Cortaderas formations form part of the Angualasto Group (Limarino and Césari, 1993; Figure 2).

The Chigua Formation (700 m thick) is in tectonic contact with the Pircas Negras Formation; it underlies the Malimán Formation with angular unconformity (Figure 2). The Chigua Formation is subdivided into two members (Figure 2), viz. the lower Chavela (marine) and the upper Ramadita (marine/terrestrial). The Chigua lithology, with green-brown colours, consists mainly of shales with limestone nodules and lenses, and subordinate sandstone beds. Fossiliferous layers have yielded marine invertebrates including the trilobites *Punillaspis argentina* Baldis, *Phacops chavelai* Baldis and Longobucco and *Acanthopyge balliviani* Kozłowski, also the cephalopods

*Tornoceras baldisii* Leanza and *Orthoceras* sp., the cnidarian *Conularia* sp., as well as Gastropoda and Pelecypoda indet. (Baldis and Sarudiansky, 1975; Baldis and Longobucco, 1977). Herbaceous lycopsids "*Haplostigma*" *furquei* Frenguelli, "*H.*" *baldisii* Gutiérrez and ?*Cyclostigma* sp. are recorded (Baldis and Sarudiansky, 1975; Gutiérrez, 1996) from the Chavela Member, whilst the Ramadita Member contains mainly "*Haplostigma*" *furquei* and less frequent *Phacops* sp. and Gastropoda indet.

Homoclinal strata of the Malimán Formation (1300 m thick) are followed conformably by contact with the Cortaderas Formation at La Cortadera Valley (Figures 2A, 3). The Malimán Formation begins with thick-bedded paraconglomerates with a few intercalated fine-grained sandstones and shales with abundant herbaceous lycopsids

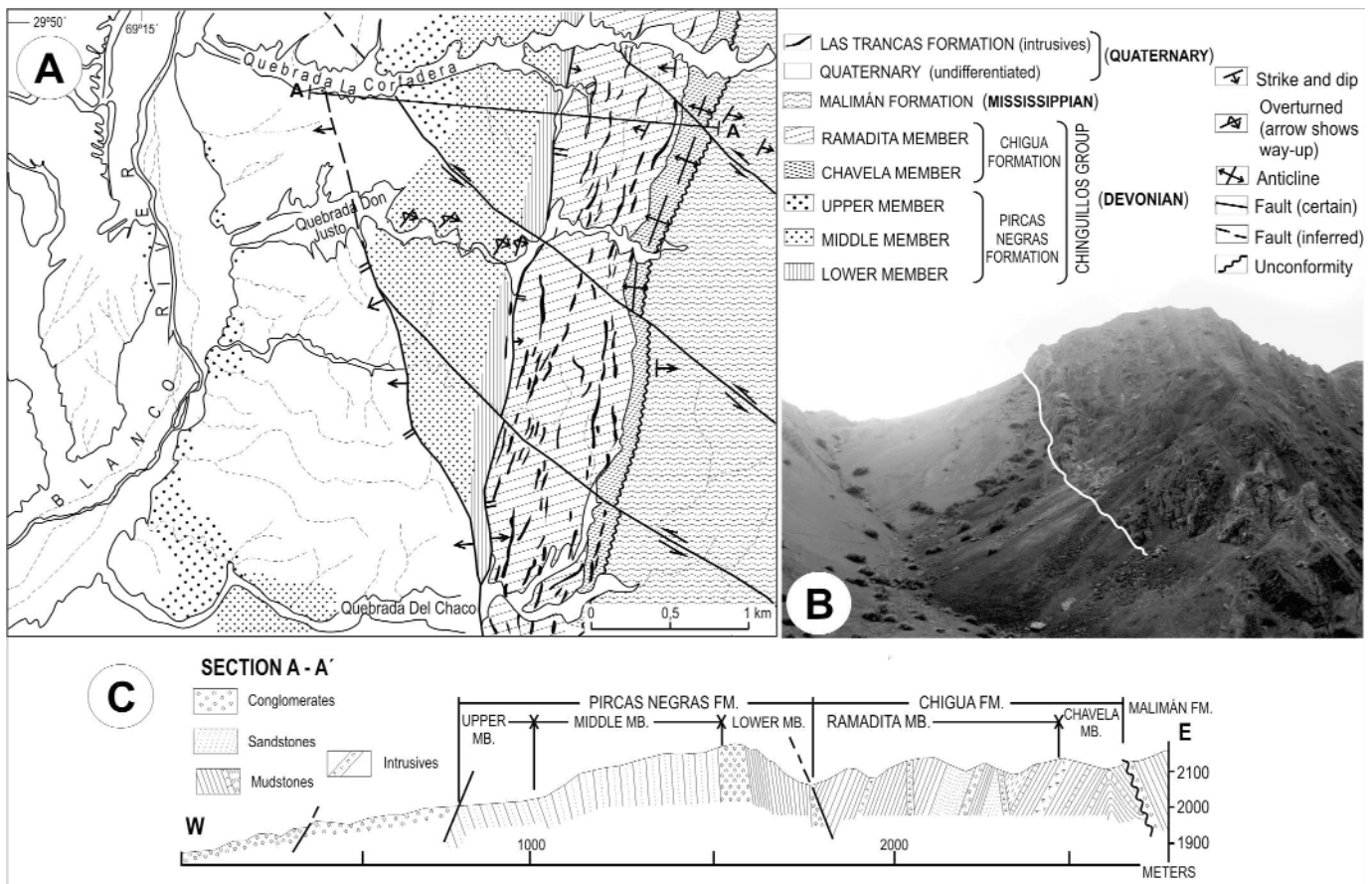


Figure 2. A, Geological map and geographic location of the Quebrada La Cortadera in San Juan Province, Argentina (modified from Baldis and Sarudiansky, 1975). B, Photograph illustrating the unconformity between the Chigua Formation (to the left of the white line) and the conglomerates of the basal Malimán Formation. C, Structural cross-section of the Chinguillos Group and Malimán Formation (modified from Baldis and Sarudiansky, 1975). Bar scale: 50 m.

and pteridosperms (Figure 3); species identified include *Frenguella eximia* (Frenguelli) Arrondo, Césari and Gutiérrez, "*Eusphenopteris*" *devonica* (Frenguelli) Sessarego and Césari and *Diplothemema bodenbenderi* (Kurtz) Césari (Azcuay *et al.*, 2000). Coarse to medium-grained sandstones overlie the conglomerates and contain similar megafloora remains. They are followed in turn by thick sandstone beds containing thin conglomerate lenses with massive organic-rich mudstone intercalations. The latter contain a marine fauna belonging to the *Protocanites scalabrini* - *Azurduya* (= *Paurorhyncha*) *chavelensis* Zone (Sabattini *et al.*, 2001) and comprising ammonoids, brachiopods, bivalves, gastropods, conulariids and crinoid stems (e.g., González, 1994; Sabattini *et al.*, 2001). The stratigraphic section continues upwards with alternating sandstones and siltstones, with subordinate fine-grained diamictites. This sandy and muddy section contains the same plant species present in the basal conglomerate unit,

together with some pteridosperms (e.g., "*Rhodea*" sp., "*Hyenya*" sp. and an *incertae sedis* form named *Paulophyton* sp.), which are characteristic of the *Frenguella*-*Paulophyton* Phytozone (Carrizo and Azcuay, 1997). The upper part of the stratigraphic succession is dominated by thick beds of sandstone and orthoconglomerate (Figure 3). The Malimán Formation represents mixed deposits with alternating transgressive-regressive cycles (Limarino and Césari, 1993). New studies carried out by Pazos *et al.* (2005b) in different localities, allowed the definition of various sections with different palaeontological and sedimentological features, thus improving the previous information. Pazos *et al.* (2005b) determined that the transgressive-regressive cycles in the Malimán Formation are due to glacio-eustatic/climatic influences. The unpublished (more detailed) stratigraphic section is presented in Figure 3.

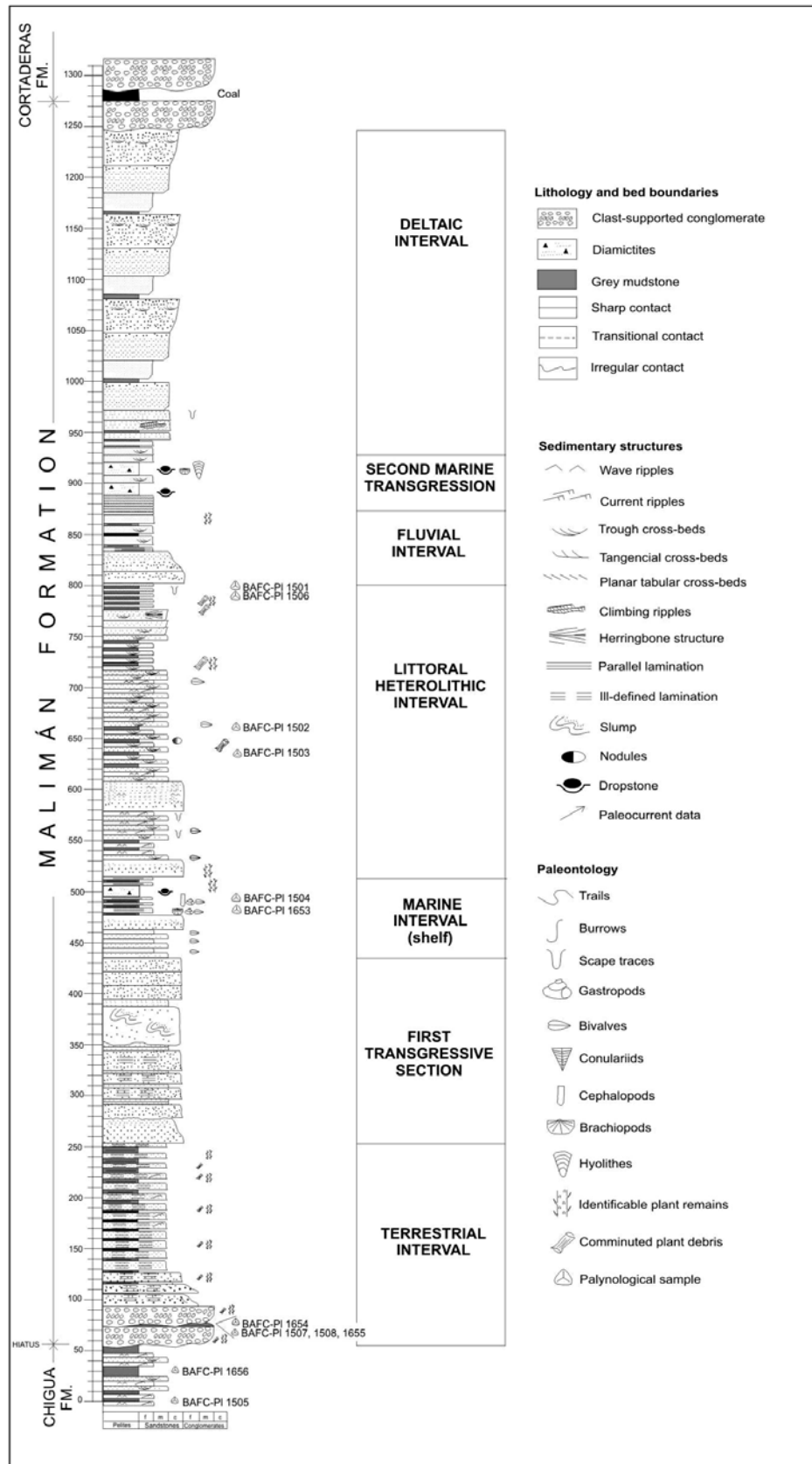


Figure 3. Stratigraphic section of the Chigua and Malimán formations at La Cortadera showing the location of palynological samples. Palaeoenvironmental interpretation after Pazos *et al.* (2005 a, b).

### 3. COMPOSITION, AGE AND CORRELATION OF THE PALYNOLOGICAL ASSEMBLAGES

#### 3.1. Chigua Formation

The palynoflora of the Chigua Formation (Chavela Member) was obtained from two shales located at 50 m (BAFC-PI 1505) and 30 m (BAFC-PI 1656) below the base of the Malimán Formation at Quebrada La Cortadera (type locality, Figure 3). Amenábar *et al.* (2006, 2007) presented the identification and the geographic and stratigraphic distribution of the species found in this unit. Additionally, a worldwide geographic and stratigraphic distribution of the species recorded through the Eifelian to the Frasnian in South America has been recently presented by di Pasquo *et al.* (2009). The palynomorphs are abundant and moderately diverse; some are fragmented and corroded but they are generally well preserved with diagnostic characters; their thermal maturity (TAI) varies between 2 and 3 according to the scale of Utting *et al.* (in Utting and Wielens, 1992). Both levels present quite similar proportions of major groups of palynomorphs, with the spores dominating slightly over the microplankton (Figure 4). The assemblage also includes some possibly reworked species (Amenábar *et al.*, 2006) that will be discussed subsequently in this paper. Spores belonging to the genus *Grandispora* in both levels are most abundant (e.g., *G. pseudoreticulata*) (Figure 4). The species recorded are listed in Figure 4 and some are illustrated on Plate 1.

An analysis of the stratigraphic ranges of the species recognised in the Chigua Formation allows the assignment of an early Givetian age (Figure 5). The species *Dictyotidium venulosum*, *Crucidia camirensis*, *Polygonium barredae*, *Cymatiosphaera perimembrana*, *Geminospora lemurata*, appear from basal Givetian upwards. Their occurrence together with species appearing slightly later,

Figure 4. Quantitative analysis of the assemblage of palynomorphs in the Chigua Formation. The species are organized by first appearance according to two major groups: spores and microplankton, and in alphabetical order within groups. Symbols refer to relative abundance (calculated from counts of ca. 200 specimens per sample): □ (empty square): <2.5%; ■ (black square): 2.5-6.4 %; ▲ (triangles): >6.4%. The species cited and/or illustrated for the first time in Middle Devonian sediments of South America are marked with a single asterisk (\*); whilst species cited for the first time in the Middle Devonian of Argentina with two asterisks (\*\*).

SPECIES RECORDED IN THE CHIGUA FORMATION		samples (BAFC-PI)	
		1505	1656
MICROPLANKTON	* <i>Botryococcus</i> sp.	□	
	* <i>Dictyotidium granulatum</i> Playford in Playford and Dring	□	
	* <i>Dictyotidium venulosum</i> (Playford in Playford and Dring) Colbath	□	
	<i>Estiastra rythidoides</i> Wicander and Wood	■	
	<i>Maranhites</i> sp.	□	
	* <i>Polyedryxium leptum</i> Turner	□	
	* <i>Pulvinosphaeridium trifidum</i> Kiryanov	□	
	<i>Quadrifurcatus granulatus</i> (Cramer) Ströther	■	
	<i>Stellinium micropolygonale</i> (Stockmans and Williére) Playford	□	
	<i>Anapiculatisporites</i> sp. A	□	
SPORES	** <i>Apiculatisporis grandis</i> Menéndez and Pöthe de Baldis	□	
	<i>Apiculatisporis</i> sp. A	□	
	* <i>Apiculiretusispora laxa</i> Amenábar, di Pasquo, Carrizo and Azcuy	□	
	<i>Apiculiretusispora plicata</i> (Allen) Streeel	□	
	<i>Cymbosporites catillus</i> Allen	□	
	* <i>Geminospora</i> sp. cf. <i>G. tuberculata</i> var. <i>tuberculata</i> McGregor	□	
	* <i>Leiotriletes trivialis</i> Naumova	□	
	<i>Leiotriletes</i> sp. B	□	
	* <i>Punctatisporites glaber</i> (Naumova) Playford	■	
	* <i>Punctatisporites planus</i> Hacquebard	□	
<i>Retusotriletes</i> spp.	□		
<i>Verrucosisporites tumulentus</i> Clayton and Graham	□		
<i>Verrucosisporites</i> sp.	□		
MICROPLANKTON	<i>Cymatiosphaera canadensis</i> Deunff	□	□
	* <i>Cymatiosphaera</i> sp. cf. <i>C. subtrita</i> Playford in Playford and Dring	□	□
	<i>Dictyotidium munificum</i> (Wicander and Wood) Amenábar, di Pasquo, Carrizo and Azcuy	■	□
	<i>Duvernaysphaera angelae</i> Deunff	□	□
	<i>Exochoderma arca</i> Wicander and Wood	□	□
	<i>Hemiruptia legaultii</i> Ottone	□	□
	<i>Leiosphaeridia</i> spp.	■	■
	<i>Navifusa bacilla</i> (Deunff) Playford	□	▲
	<i>Polyedryxium decorum</i> Deunff	□	□
	<i>Polygonium barredae</i> Ottone	□	□
<i>Pterospemella</i> sp. cf. <i>P. capitata</i> Wicander	□	□	
<i>Quadrifurcatus variabilis</i> (Cramer) Ottone and Rosello	■	□	
<i>Veryhachium</i> spp.	□	□	
SPORES	** <i>Acinosporites acanthomammillatus</i> Richardson	□	□
	** <i>Apiculatisporites microconus</i> (Richardson) McGregor and Camfield	■	□
	** <i>Archaeozonotriletes chulus</i> var. <i>chulus</i> (Cramer) Richardson and Lister	□	□
	** <i>Cymbosporites cyathus</i> Allen	□	□
	** <i>Dibolisporites</i> sp. cf. <i>D. eifeliensis</i> (Lanning) McGregor	□	▲
	** <i>Dibolisporites</i> sp. cf. <i>D. quebecensis</i> McGregor	□	□
	** <i>Dictyotriletes emsiensis</i> Morphon Rubinstein, Melo and Steemans	□	□
	<i>Emphanisporites rotatus</i> McGregor emend. McGregor	▲	■
	<i>Geminospora lemurata</i> Balme emend. Playford	□	□
	<i>Grandispora pseudoreticulata</i> (Menéndez and Pöthe de Baldis) Ottone	▲	■
<i>Grandispora</i> spp.	■	■	
** <i>Leiotriletes balapucensis</i> di Pasquo (= <i>Leiotriletes</i> sp. A in Amenábar, di Pasquo, Carrizo and Azcuy)	■	□	
<i>Punctatisporites</i> sp.	■	■	
<i>Verrucosisporites scurrus</i> (Naumova) McGregor and Camfield	□	□	
** <i>Verrucosisporites</i> sp. cf. <i>V. polygonalis</i> Lanning, 1968	□	□	
MICROPLANKTON	<i>Arkonites bilixus</i> Legault	□	□
	<i>Belonechitina</i> sp.	□	□
	<i>Crucidia camirensis</i> (Lobo Boneta) emend. Ottone	□	□
	<i>Cymatiosphaera perimembrana</i> Staplin	□	□
	* <i>Micrhystridium</i> sp. cf. <i>M. pentagonale</i> Stockmans and Williére	□	□
	<i>Micrhystridium</i> sp. A	□	□
	** <i>Onondagaella asymmetrica</i> (Deunff) Playford	■	□
	* <i>Orygmahapsis pachyderma</i> Colbath	□	□
	<i>Polyedryxium pharaonis</i> Deunff ex Deunff	□	□
	<i>Polyedryxium</i> sp.	□	□
<i>Stellinium octoaster</i> (Staplin) Jardiné, Combaz, Magloire, Peniguel and Vachey	□	□	
<i>Tunisphaeridium caudatum</i> Deunff and Evitt	□	□	
<i>Veryhachium polyaster</i> Staplin	□	□	
SPORES	<i>Acinosporites lindlarensis</i> Riegel	□	□
	* <i>Dibolisporites varius</i> Tiwari and Schaarschmidt	■	□
	<i>Emphanisporites annulatus</i> McGregor	□	□
	* <i>Granulatisporites muninensis</i> Allen	□	□
<i>Verruciretusispora</i> sp.	□	□	

e.g. *Orygmahapsis pachyderma*, *Pterospermella capitana* and *Geminospora tuberculata* var. *tuberculata* suggest a level within the lower Givetian. The presence of putative Frasnian elements such as *Micrhystridium pentagonale*, *Cymatiosphaera subtrita*, *Dictyotidium granulatum* and *Polyedryxium leptum* is not regarded as determinative, since the two former species are only identified with doubts, whilst the latter two corresponds to first records for Argentina (Figure 4; Amenábar *et al.*, 2006) and, therefore, not well constrained stratigraphically. A downward extension of their ranges to early Givetian is regarded as quite likely, but uncertain. On the other hand, the range of *O. asymmetrica*, which is currently known from the Silurian of Argentina (e.g., Rubinstein, 1997; Rubinstein and Brussa, 1999; Rubinstein and Toro, 2006) must be extended upwards to the early Givetian in the Precordillera (Figure 5). The large size of a majority of the spores (80 µm on average) in the Chigua Formation agrees with that found in other Middle Devonian palynofloras as determined by Loboziak (1999). Besides, younger Devonian species such as *Samarisporites triangulatus*, *Verrucosisporites bulliferus*, *Samarisporites* spp., *Pseudolunulidia imperatrizensis*, *Maranhites* spp., *Umbellasphaeridium deflandrei* present as reworked elements in the Malimán Formation due to the recycling of Frasnian deposits (Amenábar, 2006), are absent in the Chigua palynoflora, thus reinforcing its attribution to an age not later than Middle Devonian.

A comparison with selected Devonian palynofloras throughout the world but mainly from South America is presented in Figure 6. Ottone (1996) described a similar assemblage from the late Givetian – early Frasnian of the Tarija Basin in northern Argentina, whilst di Pasquo (2007a) documented two assemblages from the same basin in southern Bolivia; i.e. a late Eifelian and a middle to late Givetian one identified on the basis of key taxa and relative stratigraphic position. Despite several taxa in common (especially *Grandispora pseudoreticulata* along with other species of the same genus as well as many microplankton forms), there are compositional differences which support an early Givetian age for the assemblage from the Chigua Formation and prevent the exact correlation with either of the assemblages reported from the Tarija Basin. On the other hand, the Chigua assemblage may be correlated to the early Givetian *Verrucosisporites prem-*

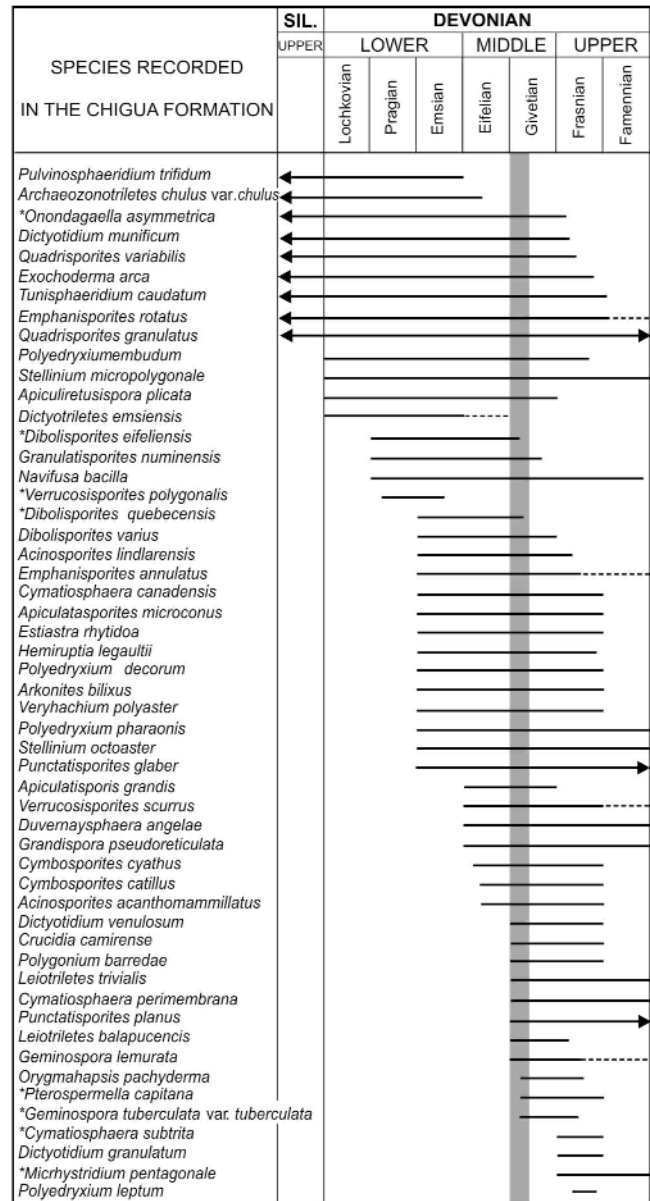


Figure 5. Stratigraphic ranges of species recorded in the Chigua Formation, after selected literature cited in Amenábar *et al.* (2006, 2007). The grey area corresponds to the time interval proposed for the assemblage. Dashed lines indicate doubtful records. Species marked with an asterisk are doubtfully identified (“cf.”).

*nus/V. scurrus* Zone from Bolivia (Limachi *et al.*, 1996) due to the common presence of *Verrucosisporites scurrus*, *Cymatiosphaera canadensis* and *Arkonites bilixus*, and the scarcity of *Maranhites*, which is more frequent in the subsequent *Samarisporites/Maranhites brasiliensis* Zone of late Givetian to Frasnian age (Figure 6).

The Punta Negra Formation, of the Precordillera in San Juan Province, Argentina, has yielded two assemblages,

i.e. A1 of the Middle Devonian (Eifelian-Givetian) and A2 straddling the Givetian/Frasnian boundary (Rubinstein, 1999, 2000). It is difficult to compare these assemblages with the palynoflora of the Chigua Formation because they only share non-age-diagnostic species.

The late Eifelian-early Givetian Association 5 from the Ponta Grossa Formation in the Paraná Basin (Dino, 1999) and the early Givetian *Geminospora lemurata*-*Chelinospora* ex gr. *ligurata* (LLi) Zone of Melo and Loboziak (2003) from the Amazonas Basin are also comparable. The first appearance of *Geminospora lemurata* accompanied by patinate spores with a prominent verrucate-baculate sculpture (*Cymbosporites catillus*, *C. cyathus*, *Chelinospora* ex gr. *ligurata* complex) and *Verrucosisporites scurrus* in all those assemblages support their correlation (Figure 6).

According to the miospore zonation established for the Old Red Sandstone Continent of Euramerica (McGregor, 1979; Richardson and McGregor, 1986; Streel et al., 1987; Braman and Hills, 1992) and that of Eastern Europe (Avchimovitch et al., 1993; Turnau, 1996), the Chigua Formation contains an assemblage correlatable with the early Givetian *G. lemurata*-*C. magnificus* and *Geminospora extensa* (EX) zones (Figure 6). Shared characters with the Euramerican palynofloras are the presence of *Geminospora lemurata* in conjunction with spores characterised by highly irregular warts or bacula (*Verrucosisporites* spp. and *Dibolisporites* spp.) as well as diverse patinate spores (*Archaeozonotriletes* spp., *Cymbosporites* spp.). The only species with a more restricted range in common with the Eastern Europe assemblages is *Geminospora tuberculata*; the other shared elements are long-ranging (Figure 5).

The Middle Devonian assemblages of the Rhadamés and Ghadamis basins in Libya (Moreau-Benoit, 1989; Loboziak and Streel, 1989) and the early Givetian palynoflora of Saudi Arabia (Breuer et al., 2007) share only cosmopolitan species with the Chigua Formation (e.g., *Acinosporites acanthomammillatus*, *Verrucosisporites scurrus*, *V. premnus*, *Geminospora lemurata*, *Cymbosporites catillus* and *C. cyathus*). Hashemi and Playford (2005) described three assemblages (I, II, III) from the Adavale Basin (Australia), of Emsian to early Frasnian ages, whilst Balme (1988) and Playford and Dring (1981) documented Frasnian palynofloras from the Gneudna Forma-

tion in the Carnarvon Basin (Australia). These papers showed that only a few cosmopolitan species of stratigraphic importance extend across the Gondwana area (Figures 5 and 6).

In summary, the Argentinian assemblage of Givetian age is composed of many cosmopolitan species (e.g., *Dibolisporites varius*, *Geminospora lemurata*, *Apiculiretusipora plicata*, *Cymbosporites catillus*, *Acinosporites acanthomammillatus*, *Verrucosisporites scurrus*) occurring together with endemic elements, such as *Grandispora pseudoreticulata*, *Leiotriletes balapucensis*, *Apiculatisporis grandis* and *Polygonium barredae*. Di Pasquo et al. (2007,

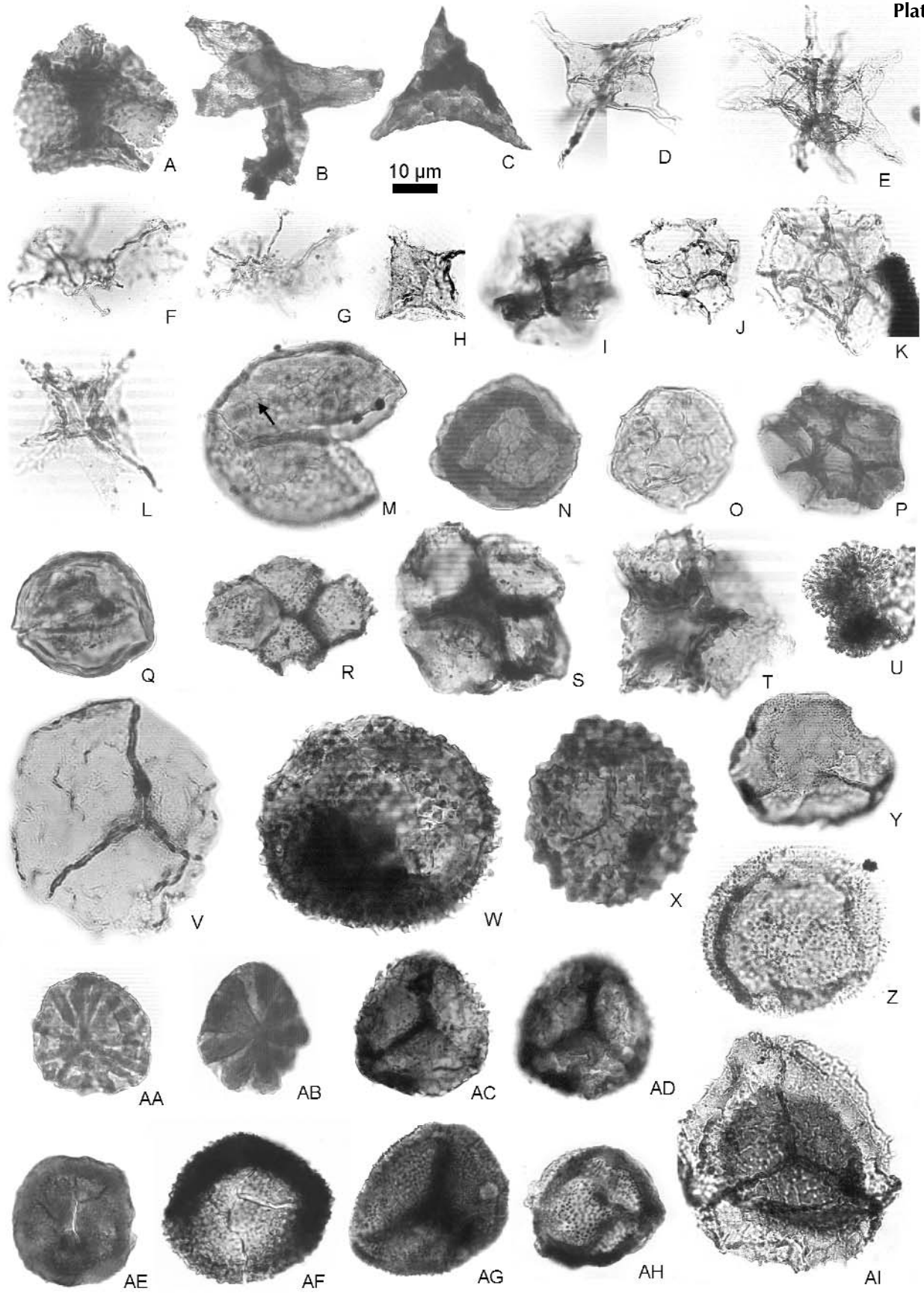
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Plate 1. Microplankton and spores from the Chigua Formation. Coordinates after EF (England Finder) graticule. Coordinates of the selected illustrated specimens are prefixed BAFC-PI referring to the repository of slides in the Palynostratigraphy and Paleobotany Laboratory, Department of Geology, University of Buenos Aires. Prefix is followed by the slide number and the reference. Scale bar: B, C, F, G, V, AF, AI = 20 µm (x 500), the remainder = 15 µm (x 750).

**A**, *Arkonites bilixus* Legault. BAFC-PI 1656 (1): N32/1. **B**, *Crucidia camirensis* (Lobo Boneta) emend. Ottone. BAFC-PI 1656 (2): B27. **C**, *Estiastra rhytidia* Wicander and Wood. BAFC-PI 1505 (2): O47/1. **D**, *Exochoderma arca* Wicander and Wood. BAFC-PI 1656 (1): S24/1-3. **E**, *Polyedryxium pharaonis* Deunff ex Deunff. BAFC-PI 1656 (2): K23/1. **F-G**, *Tunisphaeridium caudatum* Deunff and Evitt. BAFC-PI 1656 (2): U36. **H**, *Duvernaysphaera angelae* Deunff. BAFC-PI 1505 (2): W39/3. **I**, *Polyedryxium leptum* Turner. BAFC-PI 1505 (3): H48/4. **J**, *Cymatiosphaera perimembrana* Staplin. BAFC-PI 1656 (1): J26/3. **K**, *Cymatiosphaera canadensis* Deunff. BAFC-PI 1656 (1): Z32/4. **L**, *Stellinium octoaster* (Staplin) Jardiné, Combaz, Magloire, Peniguel and Vachey. BAFC-PI 1656(2): T42/2. **M**, *Orygmahapsis pachyderma* Colbath. BAFC-PI 1656 (1): M49/4. Arrow shows fields bearing an internal pore. **N**, *Dictyotidium venulosum* (Playford) Colbath. BAFC-PI 1505 (3): D22. **O**, *Dictyotidium granulatum* Playford in Playford and Dring. BAFC-PI 1505 (1): R38/1. **P**, *Dictyotidium munificum* (Wicander and Wood) Amenábar, di Pasquo, Carrizo and Azcuy. BAFC-PI 1505(5): Z24/2. **Q**, *Hemiruptia legaultii* Ottone. BAFC-PI 1656 (1): D35. **R**, *Quadrissporites variabilis* (Cramer) Ottone and Rosello. BAFC-PI 1656 (2): L45. **S**, *Quadrissporites granulatus* (Cramer) Strother. BAFC-PI 1505 (3): R43/2. **T**, *Polyedryxium decorum* Deunff. BAFC-PI 1656 (2): D31/3. **U**, *Botryococcus* sp. BAFC-PI 1505 (1): W50/1. **V**, *Leiotriletes balapucensis* di Pasquo BAFC-PI 1505 (2): B37. **W**, *Apiculatisporis grandis* Menéndez and Pöthe de Baldis. BAFC-PI 1505 (1): R52/1. **X**, *Verrucosisporites scurrus* (Naumova) McGregor and Camfield. BAFC-PI 1505 (5): 47/1. **Y**, *Apiculatasporites microconus* (Richardson) McGregor and Camfield. BAFC-PI 1505 (3): H29/3. **Z**, *Dibolisporites varius* Tiwari and Schaarschmidt. BAFC-PI 1656 (1): J29/3. **AA**, *Emphanisporites annulatus* McGregor. BAFC-PI 1656 (1): Z24. **AB**, *Emphanisporites rotatus* McGregor emend. McGregor. BAFC-PI 1656 (1): V27. **AC-AD**, *Acinosporites acanthomammillatus* Richardson. BAFC-PI 1656 (1): R35, **AC**, proximal face showing a labiate trilete mark; **AD**, distal face showing the rugulae pattern. **AE**, *Cymbosporites catillus* Allen. BAFC-PI 1505 (2): G38/2. **AF**, *Cymbosporites cyathus* Allen. BAFC-PI 1505 (3): C37/3. **AG** *Geminospora lemurata* Balme 1962 emend. Playford. BAFC-PI 1505 (5): D28/2. **AH**, *Geminospora* sp. cf. *G. tuberculata* var. *tuberculata* McGregor. BAFC-PI 1505 (2): P52/4. **AI**, *Grandispora pseudoreticulata* (Menéndez and Pöthe de Baldis) Ottone. BAFC-PI 1656 (1): F24/1.



Plate 1



2009) suggest that such endemisms among Middle Devonian palynofloras of South American and elsewhere justifies the definition of an Afro-South American Subrealm, due most likely, to palaeolatitude/paleoclimate as well as the palaeogeographical configuration (i.e. distribution of land and sea areas).

### 3.2. Malimán Formation

The palynoflora of the Malimán Formation was obtained from ten claystone and siltstone samples and one from fine-grained sandstone, collected from the lower and middle portions of the stratigraphic section in Quebrada La

GEOCHRONOLOGY			REGION							
			EURAMERICA	RUSSIA	AUSTRALIA	BRAZIL	BOLIVIA	BOL-ARG	ARG	
SYSTEM	SUB SYSTEM	STAGE	A	B	C	D	E	F	G	
LOWER CARBONIFEROUS	MISSISSIPPIAN	SERPUKHOVIAN	<i>S. triangulatus-R. knoxi</i>							
			<i>nitidus-carnosus</i>							
		VISEAN	<i>vetustus-fracta</i>							
			<i>nigra-marginatus</i>							
			<i>P. tessellatus-S. camptyloptera</i>							
			<i>K. Triradiatus-K. stephanophorus</i>	<i>D. variabilis</i> <i>D. intermedius</i> <i>K. literatus</i> <i>C. appendices</i> <i>L. pusilla-M. culta</i> <i>C. multiplicabilis</i>						
		TOURNAISIAN	<i>pusilla</i>							
			<i>claviger-macra</i>	<i>M. variomarginata-V. genuinus</i> <i>exiguus</i>						
			<i>pretiosus-clavata</i>	<i>uncatus</i>						
			<i>balteatus-polyptycha</i>	<i>P. monotuberculatus</i>						
	<i>hibernicus-distinctus</i>		<i>A. septalia</i> <i>G. upensis</i>							
	<i>vallatus-incohatus</i>		<i>T. malevkensis</i>							
	DEVONIAN	UPPER	FAMENNIAN	<i>lepidophyta-nitidus</i>	<i>V. pusillites-T. malevkensis</i> <i>V. pusillites-R. lepidophyta-I. explanatus</i> <i>lepidophyta-explanatus</i> <i>R. lepidophyta-T. mirabilis</i> <i>R. lepidophyta-K. literatus</i> <i>R. lepidophyta-A. verrucosa</i>	<i>R. lepidophyta</i>	<i>R. lepidophyta-V. vallatus</i> <i>R. lepidophyta</i>	<i>R. lepidophyta</i>		
				<i>pusillites-lepidophyta</i>						
				<i>flexuosa-comuta</i>	<i>D. versabilis-G. famenensis</i> <i>C. varicomata</i> <i>L. inmensus</i>					
			<i>torquata-gracilis</i>	<i>C. cristifer-D. zadonica</i> <i>C. vimineus-V. evianensis</i>	Microflora Brewer	<i>V. hystricosus</i> <i>R. radiata</i>	<i>T. torquata-A. pseudocrista</i>			
FRASNIAN			<i>ovalis-bulliferus</i>	<i>C. deliquescent-V. evlanensis</i> <i>A. ovalis-V. grumosus</i> <i>G. semilucensa-P. donensis</i> <i>C. optivus-S. krestovnikovii</i>		<i>R. bricei-D. mucronatus</i>	<i>Maranhites-Samarisporites</i>			
		<i>C. optivus-C. triangulatus</i>		Spinozonotriletes sp.	<i>V. bulliferus-G. pilliformis</i>					
MIDDLE		GIVETIAN	<i>lemurata-magnificus</i>	<i>G. extensa</i>	<i>G. lemurata</i> <i>Ancyrospora</i> sp.	<i>S. triangulatus</i>	<i>V. premnus-V. scururus</i>	Los Monos Palynoflora (A2)		
			<i>devonicus-naumovii</i>	<i>R. langii</i>	<i>Aratrisporites</i> sp. <i>Hystricosporites</i> sp. <i>Brochozonotriletes</i>	<i>G. lemurata-Ch. figurata</i>	<i>H. pseudoreticulatus</i>	No information	Chigua Palynoflora	
		EIFELIAN	<i>velatus-langii</i>	<i>P. tortus</i>		<i>G. permulta</i>		Los Monos Palynoflora (A1)		
LOWER		EMSIAN	<i>douglastownense-eurypterota</i>	<i>D. inassueta</i>		<i>Grandispora-Samarisporites</i>	<i>Evittia sommerii-Emph. annulatus</i>			
	<i>annulatus-sexanti</i>		<i>R. clandestinus</i>							
	PRAGIAN	<i>polygonalis-emsiensis</i>								
		<i>breconensis-zavallatus</i>				<i>D. emsiensis</i>				
	LOCHKOVIAN	<i>micronatus-newportensis</i>					<i>Schisocystia-Dictyotriletes</i>			

Figure 6. Correlation chart of the assemblages studied (G) and other biozones or assemblages of the Devonian and Mississippian. Literature references given after geography: (A) Western Europe and North America, (B) Eastern Europe, (C) Australia, (D) Brazil, (E) Bolivia, (F) Bolivia-Argentina. A: Richardson and McGregor (1986), Higgs *et al.* (1988); B: Avchimovitch *et al.* (1988, 1993), Byvsheva (1997); C: Playford (1985, 1991); Young (1996); D: Melo and Loboziak (2003); E: Suárez Soruco and Lobo Boneta (1983); Limachi *et al.* (1996); F: di Pasquo (2007a, b).

Cortadera. The upper part of the section is predominantly coarse-grained (sandstones and conglomerates), and therefore, is likely to be barren of palynomorphs (Figure 3). The taxonomic analysis and distribution of the species registered in the sampled unit were presented by Amenábar *et al.* (2006, 2007). Recovered palynomorphs are of moderate diversity and quality of preservation; their thermal maturity (TAI) varies between 2 and 4 on the scale of Utting *et al.* (in Utting and Wielens, 1992). Due to their dark colour, some specimens could not be identified specifically. Two different groups of palynomorphs may be distinguished on the basis of their quantitative distribution along the outcrop section, taphonomical characteristics, and their stratigraphic range. One comprises 79 spore species (acavate, cavate, pseudosaccate and cingulizone forms) and 10 microplankton taxa (Amenábar *et al.*, 2006, 2007), all considered to be autochthonous elements (Figure 7A-B). The other group consists of evidently reworked spores, acritarchs and prasinophytes (Amenábar, 2006; Amenábar *et al.*, 2007). A likely provenance for most of the reworked palynomorphs originating from Upper Silurian through Mid-Devonian units in the Precordillera was discussed by Amenábar (2006). The significance of certain species known to characterise late Famennian ("Strunian") to Tournaisian is considered in the present paper. Average percentages of spores and microplankton are shown in Figure 7A-B, and selected specimens are illustrated on Plate 2. Selected biozones or palynofloras of the Mississippian in South America and elsewhere are compared to the assemblage of the Malimán Formation, while the correlation age of the assemblage shown in Figure 6, are briefly discussed as follows.

Remarkable similarities exist between the Malimán assemblage and recently described palynofloras from the late Tournaisian-early Viséan in Colombia (Dueñas and Césari, 2006) and the Itacua Formation in southernmost Bolivia (di Pasquo, 2005, 2007b) (Figure 6). Moreover, the cosmopolitan index *Schopfites claviger* is shared also with the middle Tournaisian *Spelaeotriletes pretiosus-Colatisporites decorus* (PD) Interval Zone of Melo and Loboziak (2003) in the Amazonas Basin, Brazil (Figure 6). However, these authors have recognised a hiatus between the latter and the late Viséan *C. magnidictyus* (Mag) Zone that could explain the presence of certain Viséan taxa in the Malimán Formation not found in the Brazilian assemblages mentioned (Figure 8).

Several species are also shared with Western European assemblages (e.g., Clayton *et al.*, 1977; Higgs *et al.*, 1988). The age of the Mississippian miospore zonation in Ireland is calibrated with the aid of conodonts (see Higgs *et al.*, 1988). Turnau *et al.* (1997) and Utting and Giles (2004) discussed the correlation between the Tournaisian-Viséan biozones of Western Europe and Atlantic Canada, where the base of the Viséan is marked by the incoming of the genus *Lycospora* found throughout Europe. This is linked to the first occurrence of *Densosporites columbaris* and *Vallatisporites ciliaris* in Canada. None of these species regarded as determinative are present in the Malimán assemblage. On the other hand, although *Colatisporites decorus*, *Raistrickia clavata* and *Crassispora trychera* of the late Tournaisian PC Zone, and *Schopfites claviger* and *Anapiculatisporites hystricosus* of the CM Zone (Higgs *et al.*, 1988), are all present in the Malimán Formation, they persist into later assemblages of Viséan age (Pu Zone; Figures 4 and 6).

The palynoflora of the Malimán Formation shows a certain affinity with Mississippian assemblages from Australia, with which it has a number of common species (Figure 6). The latter do not contain reworked specimens (Dino and Playford, 2002). It is particularly close to the Viséan *Endoculeospora larga* Assemblage (*E. larga* (Playford) di Pasquo, 2007b) of Australia (Kemp *et al.*, 1977), showing the presence of *Schopfites claviger* together with earlier species such as *Apiculiretusispora semisenta*, *Grandispora spiculifera*, *Velamispores perinatus*, *Dibolisporites medaensis*, *Crassispora invicta* and *C. scrupulosa* (Playford, 1985, 1991). Jones and Truswell (1992) suggested later that the *E. larga* Assemblage would extend from the Tournaisian-Viséan boundary into the Serpukhovian in the Bonaparte, Canning and Drummond basins. They based their opinion on a comparison between Australian palynofloras and the British ones and a calibration provided by faunal remains in the Australian basins (Playford, 1971).

In view of the above considerations, some qualitative differences may be noted among these palynofloras and others elsewhere. In agreement with Dino and Playford (2002), such differences may be attributed to various factors, like the scarcity of palynological studies, the effects of floral distribution through migration patterns, local or regional palaeoenvironmental variations, and taxonomical imprecision and/or incorrect dating of palynomorph

assemblages. An accurate correlation between the early Viséan Euramerican and Argentinean assemblages is impeded due to the absence of *Lycospora* in Argentina and Australia (Playford, 1991) and throughout most of South America (abstraction made of some patchy occurrences could be found in the Amazonas Basin after Melo and Loboziak, 2003). *Schopfites claviger* is used as a marker for the base of the Viséan in the Australian palynozonation and for the late Tournaisian in Euramerican assemblages (Higgs *et al.*, 1988). Hence, even though a late Tournaisian age is possible for the lower part of the Malimán Formation, an early Viséan age is most likely for most of this unit due to the occurrence of many species known to appear in the early Viséan (Figures 4 and 6). The compositional differences (i.e., index species) between the assemblages of the late Viséan Cortaderas (Pérez Loinaze, 2007) and Malimán formations from the same basin (Figure 2A) support a late Tournaisian to early Viséan age for the Malimán Formation (Figures 1D and 4). Besides, the presence of *Cordylosporites magnidictyus* (Playford and Helby) Melo and Loboziak and *Schopfipollenites ellipsoides* (Ibrahim) Potonié and Kremp which characterises the Mag Zone of Melo and Loboziak (2003) in Brazil and Perú (Azcuay and di Pasquo, 2005), prevents the correlation with the Malimán Formation.

Finally, an abundance of specimens of *Cristatisporites*, some of which are identified at specific level (Figure 7A-B), is recorded in the Malimán Formation (Amenábar *et al.*, 2007). Several index taxa along with species of *Cristatisporites* are shared with the assemblage obtained from the Lower Member of the El Ratón Formation (cropping out next to Calingasta, Km 114-117), supporting the correlation of these two units (Amenábar, 2007a; Amenábar and di Pasquo, 2009). Also, *Cristatisporites matthewsii*, which was defined in the late Tournaisian of Ireland (CM Zone, Figure 6, Plate 2), is well-preserved and recorded frequently in the assemblage of the Malimán Formation (Figure 7A-B; Amenábar *et al.*, 2007). In the Tournaisian-early Viséan of Scotland a very similar spore was illustrated as *Acanthotriletes cf. macrogaleatus* Phillips and Clayton by Stephenson *et al.* (2004 in figure 9A-L). This is regarded as part of *C. matthewsii* since there is intergradation between these two taxa (Stephenson *et al.*, 2004). Therefore, an extension of its stratigraphic range into the early Viséan is proposed here.

## 4. ANALYSIS OF REWORKED SPECIES

Reworked palynomorphs were mainly interpreted on the recognition of species that are known to be recorded in older chronostratigraphic intervals than the age of the host unit. Other features such as frequency, preservation and taphonomy (e.g. thermal maturity, fragmentation, corrosion) and palaeoecology (e.g. marine or continental origin) of palynomorphs are also taken into consideration. The recognition of reworked palynomorphs may be applied to solve or improve chronological, diastrophic and palaeoenvironmental questions and to prevent an unwarranted extension of stratigraphic ranges. It is especially useful when the contact between stratigraphic units is a paraconformity, condensed section, or generally different to appreciate on field evidence (di Pasquo and Azcuay, 1997). The chronological meaning of such reworked species recorded in the Chigua and Malimán formations is discussed below.

### 4.1. Reworking in the Chigua Formation

The acritarch *Pulvinosphaeridium trifidum*, registered in the Chigua Formation, is well-known from the Late Silurian-Early Devonian deposits of Ukraine (Kiryanov, 1978). This species, which is rarely mentioned in the literature, was recorded in an early Serpukhovian palynoflora from northern Bolivia (Fasolo *et al.*, 2006), illustrated as *Pulvinosphaeridium* sp. in Azcuay and Ottone (1987, p. 249, plate III, fig. 6). It was regarded as derived from Devonian rocks together with some other species (e.g., *Retispora lepydophyta*). The spore *Verrucosiporites polygonalis* characterises the *V. polygonalis-D. emsiensis* Zone of the Pragian-Emsian in Europe (Richardson and McGregor, 1986). *Archaeozonotriletes chulus* var. *chulus* has been recorded from the Lochkovian to basal Eifelian in the Old Red Sandstone (e.g. Richardson and McGre-

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Figure 7. Quantitative analysis of the autochthonous palynomorphs found in the Malimán Formation. Spore species organised in order of first appearance. Symbols refer to relative abundance, based on counts of ca. 300 specimens per sample: □ (empty square): <1%; ■ (black square): 1-5.6 %; ▲ (triangles): >5.6%. Species cited and/or illustrated for the first time in Mississippian sediments of South America are marked with single asterisk (\*); species cited for the first time in the Mississippian of Argentina are marked with two asterisks (\*\*).

SPECIES REGISTERED IN THE MALIMAN FORMATION		samples (BAFC-PI)									
		1507	1508	1655	1654	1653	1504	1503	1502	1506	1501
SPORES	** <i>Cristatisporites indignabundus</i> (Loose) Potonié and Kremp emend. Staplin and Jansonius	■								■	
	* <i>Velamispores perinatus</i> (Hughes and Playford) Playford	■								■	□
	<i>Crassispora</i> sp.	■	□	□			■		■	■	□
	<i>Apiculiretusispora semisenta</i> (Playford) Massa, Coquel, Loboziak and Taugordeau-Lantz		■	□				□		□	□
	<i>Densosporites spinifer</i> Hoffmeister, Staplin and Malloy		□	□				□		□	
	** <i>Spelaotriletes arenaceous</i> Neves and Owens		□	□							
	** <i>Convolutispora insulosa</i> Playford		□	□							
	<i>Cyclogranisporites</i> sp.		□								
	<i>Retusotriletes</i> sp.		□								
	<i>Granasporites medius</i> (Dybová and Jachowicz) Ravn, Butterworth, Phillips and Peppers		□								
	* <i>Crassispora invicta</i> Playford		□								
	** <i>Crassispora trychera</i> Neves and Ioannides		□								
	<i>Grandispora debilis</i> Playford		■								
	** <i>Grandispora facilis</i> (Kedo) Avkhimovitch in Avkhimovitch, Byvscheva, Higgs, Strel and Umnova (= <i>Grandispora notensis</i> Playford)		□								
	<i>Grandispora spiculifera</i> Playford		■								
	** <i>Emphanisporites hibernicus</i> Clayton, Higgs and Keegan		□								
	<i>Bellisporites</i> sp.		□								
	* <i>Convolutispora</i> sp. cf. <i>C. usitata</i> Playford		□								
	* <i>Raistrickia gemmifera</i> Playford and Satterthwait		□								
	<i>Waltzisporea polita</i> (Hoffmeister, Staplin and Malloy) Smith and Butterworth		□								
	* <i>Lophozonotriletes dentatus</i> Hughes and Playford		□								
	* <i>Dibolisporites</i> sp. cf. <i>D. setigerus</i> Playford and Satterthwait		□								
	** <i>Auroraspora macra</i> Sullivan		□				□				
	** <i>Pustulatisporites dolbii</i> Higgs, Clayton and Keegan		□					□			
	<i>Crassispora scrupulosa</i> Playford emend. Playford and Satterthwait		□							□	
	* <i>Raistrickia intonsa</i> (Playford) Playford and Satterthwait		□								□
	** <i>Verrucosporites microtuberosus</i> (Loose) Smith and Butterworth		□								□
	<i>Dibolisporites microspicatus</i> Playford		□	▲	▲	■	■	▲	▲	■	▲
	* <i>Anapiculatisporites hystricosus</i> Playford			■	▲	■	■	■	▲	■	▲
	** <i>Convolutispora varicosa</i> Butterworth and Williams		□								
	* <i>Pustulatisporites papillosus</i> (Knox) Potonié and Kremp		□								
	* <i>Granulatisporites triconvexus</i> Staplin		□								
	* <i>Anapiculatisporites ampullaceus</i> (Hacquebard) Playford		□					□		□	
	* <i>Densosporites</i> sp. cf. <i>D. triangularis</i> Kosanke			■				□		■	□
	* <i>Densosporites asperus</i> Braman and Hills			▲				□	□		
	<i>Leiotriletes ornatus</i> Ishchenko			■					□	□	□
	** <i>Densosporites anulatus</i> (Loose) Schopf, Wilson and Bentall			■						□	□
	* <i>Densosporites gracilis</i> Smith and Butterworth			□						■	
	** <i>Auroraspora solisorta</i> Hoffmeister, Staplin and Malloy			□							□
	* <i>Pustulatisporites malimanensis</i> Amenábar, di Pasquo, Carrizo and Azcuy			■							□
	* <i>Densosporites secundus</i> Playford and Satterthwait			□			■			■	
	** <i>Vallatisporites pusillites</i> (Kedo) Dolby and Neves			■		■	□				
	<i>Anapiculatisporites amplus</i> Playford and Powis			■			□			□	■
	** <i>Densosporites regalis</i> (Bharadwaj and Venkatachala) Smith and Butterworth			■			□	□		□	
	<i>Schopfites claviger</i> (Sullivan) emend. Higgs, Clayton and Keegan					■					
* <i>Convolutispora tuberculata</i> (Waltz) Hoffmeister, Staplin and Malloy					■	□					

gor, 1986), whilst *Dictyotriletes emsiensis* Morphon (Rubinstein *et al.*, 2005) ranges from Lochkovian to early Emsian (N $\beta$  to AB zones of Steemans, 1989). These three spores are also known from the Early Devonian of Bolivia (McGregor, 1984; Limachi *et al.*, 1996) and Brazil (Dino, 1999; Melo and Loboziak, 2003; Rubinstein *et al.*, 2005; see also Figure 7A-B). A comparison between the assemblage of the Chigua Formation and Early Devonian palynofloras from the Precordillera of Argentina is fraught with difficulty because of the scarcity of productive assemblages in this region. The palynoflora of the Talacasto Formation, which is attributed to early Lochkovian-Emsian, has yielded only few palynomorphs (Le Hérissé *et al.*, 1997). Among these, the only common species is *Archaeozonotriletes chulus* (Figure 5). A recently documented palynoflora from the Villavicencio Formation in Mendoza Province is dated as late Pragian to early Emsian (Rubinstein and Steemans, 2007). It only has *Apiculiretusispora plicata* in common with the Chigua Formation (Figure 5). Therefore, the stratigraphic information on *Verrucosporites polygonalis*, *Dictyotriletes emsiensis*, *Archaeozonotriletes chulus* and *Pulvinosphaeridium trifidum* suggests that these are reworked elements from the eroded Lower Devonian, a conclusion which is supported by their low frequency (Figure 4). The presence of these Early Devonian reworked forms in the Chigua Formation suggests an input of fine sediment from a nearby source area composed of Upper Silurian and Lower Devonian strata. The evidence of uplift is in agreement with Astini's (1996) proposal regarding a compressional interval, called the Precordilleran Orogeny, occurring during Early to Mid Devonian times. However, it is also possible to assume that regressive-transgressive cycles within the Devonian might have contributed to a partial reworking of palynomorphs as suggested by Bustos and Astini (1997).

#### 4.2. Reworking in the Malimán Formation

Amenábar (2006) presented a preliminary list of reworked taxa in the Malimán Formation and discussed their provenance on the basis of their stratigraphic range and frequency of occurrence in the Carboniferous samples. She recognized two groups representing Early Devonian (Emsian) and Middle-Late Devonian (Givetian-early Famennian), respectively.

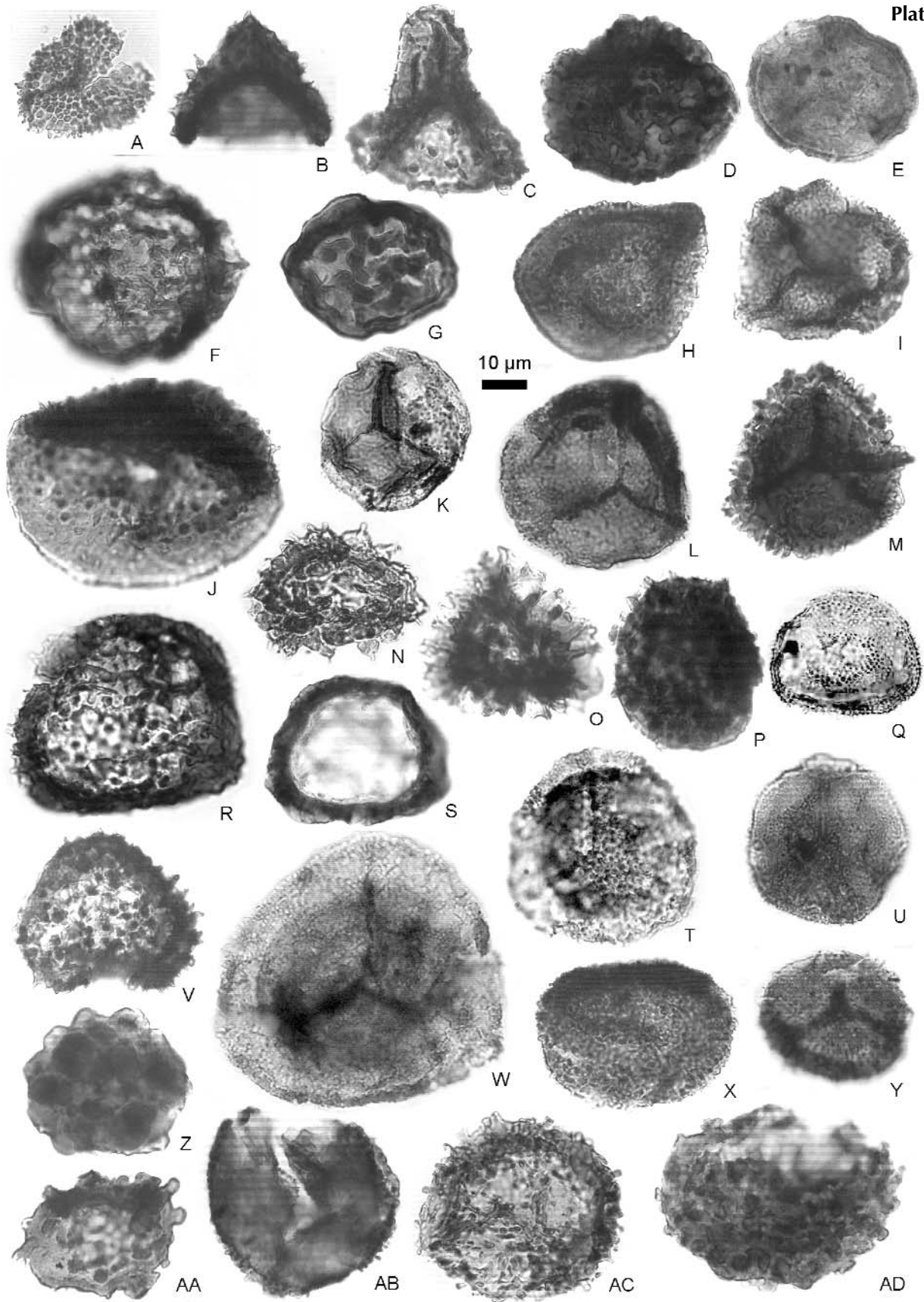
A third group comprised scarce forms of a probable Late Silurian age. Based on a comparison with Silurian and Devonian palynofloras of Argentina and taking into account the palaeogeographic reconstructions of the Mississippian in South America, the Precordillera was interpreted as the main source area. Additional reworked palynomorphs as identified by Amenábar *et al.* (2007) include the Givetian-Frasnian spore species *Hystricosporites* sp. cf. *H. gravis* Balme, *Hystricosporites* sp. cf. *H. porrectus* (Balme and Hassell) Allen and *Corytisorites* sp., as well as the Early Devonian acritarch *Estiastra improcera* Loeblich and the Givetian acritarch *Petalosphaeridium ancorum* (Wicander and Loeblich) Sargeant and Vavrdová.

Long-ranging spore species (Late Devonian to Viséan) recorded in the Malimán Formation (Figure 8) include *Auroraspora macra*, *A. solisorta*, *Bascaudaspora submar-*

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Plate 2. Autochthonous spores from the Malimán Formation. Scale bar: All 15  $\mu$ m (x 750). **A**, *Anapiculatisporites hystricosus* Playford. BAFC-PI 1654 (2): A28/3. **B**, *Anapiculatisporites ampullaceus* (Hacquebard) Playford. BAFC-PI 1655 (2): S32/2. **C**, *Anapiculatisporites amplus* Playford and Powis. BAFC-PI 1655 (2): Y50. **D**, *Bascaudaspora submarginata* (Playford) Higgs, Clayton and Keegan. BAFC-PI 1506 (4): A39/2. **E**, *Colatisporites decorus* (Bharadwaj and Venkatachala) Williams in Neves, Gueinn, Clayton, Ioannides, Neville and Kruszewska. BAFC-PI 1501 (1): R38/3. **F**, *Convolutispora varicosa* Butterworth and Williams. BAFC-PI 1655 (2): R31/2. **G**, *Convolutispora insulosa* Playford. BAFC-PI 1508 (1): V22. **H**, *Convolutispora tuberculata* (Waltz) Hoffmeister, Staplin and Malloy. BAFC-PI 1504 (2): Q39/2. **I**, *Convolutispora* sp. cf. *C. clavata* (Ischenko) Hughes and Playford. BAFC-PI 1506 (1): Q35. **J**, *Crassispora invicta* Playford. BAFC-PI 1508 (1): W36. **K**, *Crassispora trychera* Neves and Ioannides. BAFC-PI 1508(2): F49/4. **L**, *Crassispora scrupulosa* Playford emend. Playford and Satterthwait. BAFC-PI 1508(4): F23/2-4. **M**, *Cristatisporites indolatus* Playford and Satterthwait. BAFC-PI 1506(5): D50/1. **N**, *Cristatisporites matthewsii* Higgs, Clayton and Keegan. BAFC-PI 1655 (2): B40/1. **O**, *Cristatisporites indignabundus* (Loose) Potonié and Kremp emend. Staplin and Jansonius. BAFC-PI 1506 (2): K24/4. **P**, *Dibolisporites medaensis* (Playford) Playford. BAFC-PI 1506 (1): R25/2. **Q**, *Dibolisporites microspicatus* Playford. BAFC-PI 1655 (2): R31/2. **R**, *Cristatisporites peruvianus* Azcuy and di Pasquo. BAFC-PI 1506(4): Z50. **S**, *Densosporites anulatus* (Loose) Schopf, Wilson and Bentall. BAFC-PI 1506 (3): Y48. **T**, *Grandispora notensis* Playford. BAFC-PI 1508 (4): Z51/1. **U**, *Grandispora spiculifera* Playford. BAFC-PI 1508 (1): Z27/3. **V**, *Lophotriletes severus* Playford and Satterthwait. BAFC-PI 1504 (3): A53/1. **W**, *Grandispora debilis* Playford. BAFC-PI 1508 (3): K28/1. **X**, *Verrucosporites microtuberosus* (Loose) Smith and Butterworth, BAFC-PI 1508 (1): U30/1. **Y**, *Apiculatisporis castanea* (Butterworth and Williams) Amenábar, di Pasquo, Carrizo and Azcuy. BAFC-PI 1503 (2): J27/1. **Z**, *Pustulatisporites gibberosus* (Hacquebard) emend. Playford. BAFC-PI 1503 (1): V25/2. **AA**, *Raistickia clavata* Hacquebard emend. Playford. BAFC-PI 1501 (1): P27. **AB**, *Schopfites claviger* (Sullivan) emend. Higgs, Clayton and Keegan. BAFC-PI 1504 (2): D33/2. **AC**, *Raistickia gemmifera* Playford and Satterthwait. BAFC-PI 1508 (4): Y42/4. **AD**, *Verrucosporites morulatus* (Knox) Smith and Butterworth. BAFC-PI 1502 (2): P42.

Plate 2



*ginata*, *Pustulatisporites gibberosus*, *Crassispora scrupulosa*, *Cordylosporites marciae*, *C. spathulatus*, *Raistrickia clavata*, *Vallatisporites pusillites*, *Spelaeotriletes obtusus*, *Grandispora facilis* (= *G. notensis*) and *Grandispora spiculifera*. Although these taxa are widespread, being recognised in Brazil (Melo and Loboziak, 2003), Chile (Rubinstein *et al.*, 1996), northern Bolivia (Vavrdová *et al.*, 1996) and Australia (Playford, 1976), they are useless biostratigraphically. In the assemblage from the Malimán Formation, they may be indistinctly reworked or autochthonous. In this respect the present writers agree with di Pasquo (2007b, c) who proposed a re-evaluation of certain latest Devonian assemblages, mainly from Bolivia, so as to verify their ages, in this case because the Devonian/Carboniferous boundary strata in the Tarija Basin proved to contain quite important mixtures of autochthonous and reworked palynomorphs as result of tectonic and glacial processes which affected the western region of Gondwana (see also di Pasquo and Azcuy, 1997; Streel *et al.*, 2000).

Species recorded with a very low frequency in the Malimán Formation, i.e. *Cordylosporites marciae*, *Emphanisporites hibernicus*, *Raistrickia* sp. cf. *R. condylosa*, *C. spathulatus*, *Dictyotriletes trivialis*, *Spelaeotriletes obtusus*, *Vallatisporites pusillites*, *Pustulatisporites dolbii* and *Gorgonispora* sp. cf. *G. crassa* (Figures 7A-B and 8; Amenábar *et al.*, 2006, 2007), may have been derived from the reworking of upper Famennian and/or part of the Tournaisian strata although the physical evidence of strata of these ages seems absent from the Precordillera of Argentina. Hence, there is no incontrovertible proof as yet.

Practically all the microplankton species registered in the Malimán Formation are known to occur in Devonian strata. It is noted that they are found together with Devonian spores (e.g., *Archaeozonotriletes chulus*, *Emphanisporites rotatus*, *Grandispora pseudoreticulata*, *Verrucosisporites scurrus*) in the Chigua Formation (Figures 5 and 7A-B). Therefore, the proposal of Césari and Limarino (1992, 1995) of considering acritarchs, prasinophytes and chitinozoans as autochthonous in the Malimán and Cortaderas formations, is ruled out here. A remarkable fact supporting the idea that most of the microplankton registered in the Malimán Formation is recycled, is the

massive extinction noted in the marine realm near the Devonian/Carboniferous boundary, where a phytoplankton collapse occurred (e.g., Algeo *et al.*, 1995; Streel *et al.*, 2000; Filipiak, 2005). The expansion of a dense terrestrial vegetation coverage during the Late Devonian when the first leafy forests developed, may have caused the progressive retention of carbon, nitrogen and phosphorous in terrestrial environments. These elements constituting important nutrients in marine ecosystems were largely sequestered in the terrestrial environments, thus not being available for phytoplankton and producing a great planktonic crisis (Tappan, 1986). So, low planktonic diversity and scarce primary productivity, the so-called “phytoplanktonic blackout” (Riegel, 1996) characterised latest Famennian/Tournaisian times, during which only few opportunistic acritarchs and prasinophytes managed to survive. Thus, the autochthonous phytoplankton assemblages of Mississippian times throughout the world, were poor diversified, with species of the opportunistic genera *Veryhachium* and *Micrhystridium* being most dominant (e.g., Wicander, 1974; Streel, 1999). An example of this strong decrease in the diversity and abundance of microplankton was documented for Late Devonian and Mississippian assemblages of central Poland by Filipiak (2005). Only a few species from the long-ranging genera *Cymatiosphaera*, *Hemiruptia*, *Leiosphaeridia*, *Tasmanites*, *Dictyotidium*, *Micrhystridium* and *Veryhachium* are present in the upper Viséan. A careful analysis of the microplankton found in the Malimán Formation has shown the presence of well-preserved species identified as *Veryhachium* sp. cf. *V. trispinosum*, *Dictyotidium torosum*, and specifically unidentifiable forms of *Dictyotidium*, *Cymatiosphaera*, *Micrhystridium* and *Tasmanites* (Figure 7A-B). These were described and illustrated by Amenábar *et al.* (2007). They were obtained from marine and littoral strata (Figure 3) where they occurred together with several species of *Quadrisporites*, and could well represent autochthonous microplankton linked to a generalised Mississippian transgression. Instead, some other taxa (e.g., *Synsphaeridium* sp., scolecodonts indet.) are regarded of doubtful origin. It is clear that the use of acritarchs for palaeoenvironmental interpretations or biostratigraphy is valid only when their autochthonous nature is beyond doubt.

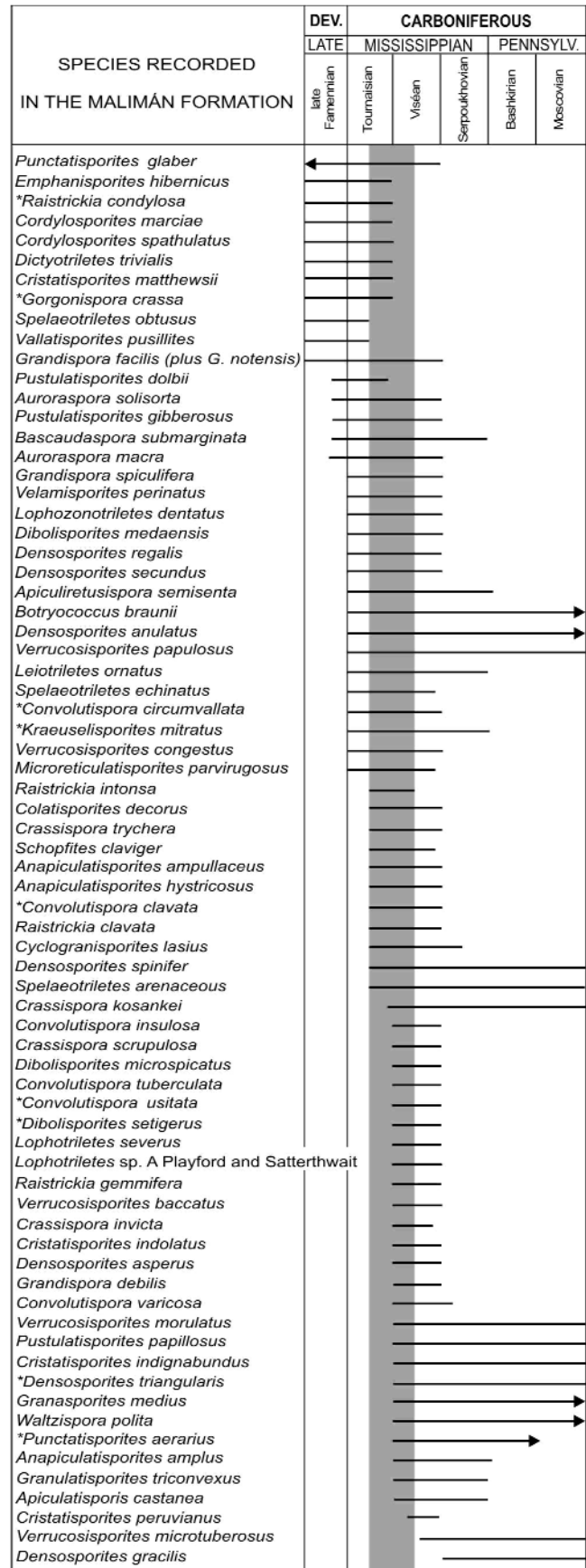


## 5. DISCONFORMITY AND HIATUS BETWEEN THE CHIGUA AND MALIMÁN FORMATIONS

The Devonian/Carboniferous boundary in the Late Palaeozoic basins of Argentina is characterised locally by an angular unconformity, which involved a different time-span depending on the location. The actual contact is often covered and paraconformable relationships exist in some areas (Azcuy *et al.*, 2007). An angular unconformity contact is recognised between the Devonian Chigua and the Mississippian Malimán formations in the area studied (Figure 2B-C). A stratigraphic gap between these two formations became apparent after the faunal and floral remains were studied from the Chigua Formation (see item 1), and also the sparse flora and scarce palynomorphs from the Malimán Formation (see items 1 and 4.2). An analysis of the stratigraphic ranges of the autochthonous palynomorphs (Figures 5 and 8) registered by Amenábar *et al.* (2006, 2007) in both formations, allowed changing the length of the time gap which proved to extend from the Frasnian to the early Tournaisian. The analysis of the reworked species recorded from the Malimán Formation, allowed further precision with regard to the geological history of the area during this time gap.

Different opinions about the nature of this unconformity still exist. Traditionally, the Devonian/Carboniferous unconformity was attributed to the Chanic Orogeny, which was described as a strongly compressional tectonic phase that caused the most important deformation of the Devonian deposits (see Azcuy *et al.*, 2000). Ramos (1988) related this tectonic phase to the collision of an allochthonous terrane (“Chilenia”) in the western part of the Gondwanaland that would have happened towards the end of the Devonian. The accretion of a “Chilenia” terrane would have been the main cause of uplift of a Protoprecordillera composed of Devonian and older rocks. This would have created a discontinuous mountainous chain, which separated different depocentres in the Carboniferous times (e.g., Azcuy *et al.*, 2000, 2007; Figure 1).

Figure 8. Stratigraphic ranges of species recovered from the Malimán Formation, after selected literature cited in Amenábar *et al.* (2006, 2007). Species marked with an asterisk are doubtful identifications (“cf.”). The grey area corresponds to the time interval proposed for the assemblage.



On the other hand, Astini (1996) suggested that this collision would have occurred earlier, i.e. in Middle Devonian times. He adduced structural, palaeontological as well as stratigraphic evidence. Astini's interpretation finds support in the presence of reworked Late Silurian-Early Devonian palynomorphs in the Chigua Formation discussed in the present paper. Astini (1996) stated that the uplift taking place in Late Devonian times would probably be linked to extension, an interpretation which is different from that of Ramos (1984, 2004), who suggested a strongly compressional phase near the end of the Devonian (Chanic Orogeny) as a result of the accretion of "Chilenia", as mentioned before. According to González Bonorino (1990) and Astini (1996), the unconformity has a strong erosional component related to glaciation affecting the western margin of Gondwanaland during the Late Devonian/Carboniferous. Scotese *et al.* (1999) referred to a Late Devonian (Famennian)-Early Permian Ice House divided into two Ice House intervals, separated by a warmer one. The first interval was assigned to the Tournaisian. However, the ice cap of Tournaisian times would be only of limited extent. Although they mentioned that this inference is based mainly on the occurrence of glendonite in shales from western Alberta, the hypothesis is in agreement with the record of glacial deposits in South America (Bolivia and Brazil) and Niger during the latest Famennian ("Strunian"); this are supposed to be related to palaeoequatorial cyclothems in North America and Europe (e.g., Isaacson *et al.*, 1999; Streel *et al.*, 2000; Isbell *et al.*, 2003). Hence, the contemporaneous shallow and marginal marine deposits in Gondwana such as the Precordillera of Argentina would have been affected.

The geological history of the Precordillera is obviously quite complex. Data presented in this paper strongly suggest that sediments accumulated during the Frasnian and probably also during the early Tournaisian. Indeed the stratigraphic ranges of some reworked species recorded in the Malimán Formation (Figures 6 and 8) point in this direction. The uppermost Devonian (late Famennian or "Strunian") may have been a time of non-deposition since cosmopolitan taxa restricted to this time are notably absent (e.g. *Retispora lepidophyta* and *Umbellasphaeridium saharicum*, see Vavrdová and Isaacson, 1999), whilst other reworked species corresponding to those times also occur in the Tournaisian assemblages elsewhere (Figure 8).

Hence, the presence of late Famennian species among the reworked taxa cannot be confirmed for the palynoflora of the Malimán Formation. The absence of Famennian deposits may be due to a combination of tectonics and glaciation, but this is conjectural. The tectonic effect might be due to the accretion of a "Chilenia" terrane in Late Devonian times, while glaciation refers to a lowering of sea level as the result of an ice cap covering an area located around 60° S lat. (after Scotese, 2003). However, a general lack of information of this time span in the Precordillera (Azcuay *et al.*, 2000, 2007) prevents an exact assessment.

In summary, the mixture of reworked palynomorphs with different stratigraphic ranges (Late Silurian to early Tournaisian), occurring together in the same assemblage with late Tournaisian-early Viséan autochthonous miospores, shows that older areas of uplift were being eroded (e.g., Protoprecordillera). This helps to complete part of the complex D/C geological history of erosion and sedimentation in the Rio Blanco Basin.

## 6. CONCLUSIONS

The palynological data analysed in this paper provide a more accurate dating and correlation of Devonian and Mississippian strata of the Precordillera in Western Argentina.

An early Givetian age is postulated here for the Chigua Formation (Chavela Member) at Quebrada La Cortadera, based on the stratigraphic ranges of several species. The Malimán Formation is assigned a late Tournaisian to early Viséan age on the basis of the stratigraphic ranges of 72 autochthonous spore species. A comparison with other assemblages in the world confirms that South American, Australian and Euramerican affinities exist. The absence of a few key taxa such as *Lycospora*, and the appearance of others (e.g., *Schopfites claviger*) suggest a late Tournaisian age for the lower part of the Malimán Formation. This palynoflora is here correlated to the *Endoculeospora larga* Assemblage defined in Australia, and recently found in the Itacua Formation of southernmost Bolivia, and also with the CM and Pu Zones of Euramerica.

The palynological analysis presented here confirms the conclusion published by Amenábar (2006) about the extension of the hiatus between the two formations analysed, and which ranges from Frasnian to early Tournaisian. The detailed analysis of stratigraphic ranges of taxa recognised as reworked elements has prevented an erroneous assumption of extended ranges for certain key-species and of unnecessary palaeoenvironmental interpretations. Some microplankton taxa with a restricted position in the Malimán Formation are recognised as autochthonous in the present paper, and this has allowed distinguishing a Mississippian microplankton assemblage which was still poorly known worldwide. The stratigraphic analysis of recycled palynomorphs in the Malimán Formation allowed the recognition of two intervals of sediment accumulation during the Frasnian and probably also during the early Tournaisian. No index species of uppermost Devonian (late Famennian or "Strunian") have been detected, thus suggesting a corresponding interval of non-deposition. The presence of reworked palynomorphs in both the Chigua and Malimán formations suggests that erosion of older uplifts areas took place (e.g., Protoprecordillera). Transgressive-regressive events during the Middle Devonian in this region may have been at least partially responsible for the reworking, but extensional tectonic processes may have been involved as well. Alternatively, reworking during late Tournaisian to early Viséan times might be due to a combination of both tectonics processes and glaciation.

## 7. ACKNOWLEDGEMENTS

The authors thank Drs. C.V. Rubinstein (IANIGLA-CRICYT, Mendoza, Argentina), R. Astini (UNC, Córdoba, Argentina), P. Alves de Souza (Universidade Federal do Rio Grande do Sul, Brazil) and Robert Wagner (Jardín Botánico de Córdoba, Spain) for their valuable comments that allowed the improvement of the manuscript. We are grateful to Dr. A. Amigo (U.S.A.) and Dr. G. Grader (Washington State University) for their suggestions and revising the English language of the manuscript. This research was supported with funds from the "Agencia Nacional de Promoción Científica y Tecnológica" PICTR 00313/03, the University of Buenos Aires UBACYT X 136 and X 428 and the "Consejo Nacional de Investigaciones Científicas y Técnicas" PIP 5518 CONICET. It is a contribution to the IGCP 499.

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MANUSCRITO RECIBIDO: 8 de septiembre, 2008

MANUSCRITO ACEPTADO: 12 de junio, 2009

