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# Early Devonian organic-walled phytoplankton and miospores from the Precordillera Basin of San Juan, Argentina: biostratigraphic and paleobiogeographic implications

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## ABSTRACT

The palynological assemblages of the Talacasto and Punta Negra formations, from the Argentinean Precordillera, were analysed. Marine phytoplankton is dominant in both stratigraphic units. *?Cymatiosphaera florida*, *Evittia sommeri*, *Palacanthus ledanoisii*, *Riculasphaera fissa*, *Schizocystia pilosa*, *Tysanopobolus polykion* and *Winwaloesia distracta* are among the most age-significant phytoplankton species of the Talacasto Formation, while *Amicosporites* sp. cf. *A. streelii*, *Dictyotriletes emsiensis* Morphon, *Dictyotriletes favosus* and *?Knoxisporites riondae* prove the most biostratigraphically significant miospore species. A Lochkovian to probably late Pragian age is interpreted based on the marine and terrestrial palynomorphs. The lower part of the Punta Negra Formation contains phytoplankton species such as *Cordobesia orientalis*, *Cordobesia uruguayensis*, *Duvernaysphaera stellata*, *Navifusa bacilla*, *Polyedryxium fragosulum* and *Pterospermella* sp. cf. *P. pernambucensis* as well as the miospores *Acinosporites* sp. cf. *A. lindlarensis* and *Apiculatasporites microconus*, which suggests an early Emsian age. Taxa such as *Cordobesia*, *Schizocystia* and *Winwaloesia* support affinities of the Argentinean assemblages with Gondwana.

## KEYWORDS

Early Devonian; Argentinean Precordillera; organic-walled phytoplankton; miospores; biostratigraphy; palaeobiogeography

## 1. Introduction

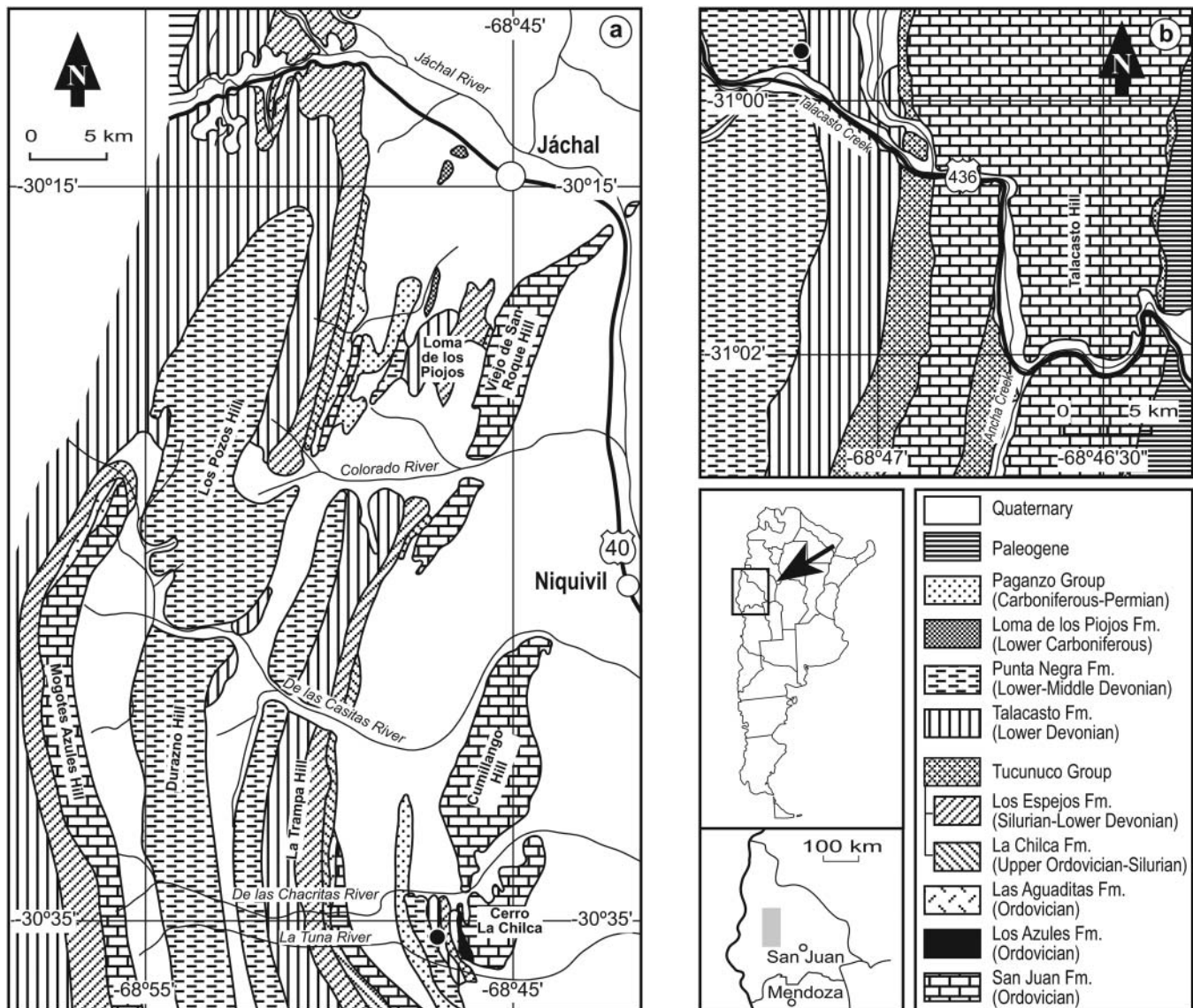
South-western Gondwanan Devonian marine basins are found in present-day South America (except for Venezuela and Colombia; Morzadec et al. 2015), Antarctica and sub-Saharan Africa. These basins are thought to have developed under cool/cold-water settings with distinct faunal associations that define the Malvinokaffric Realm (Richter & Richter 1942), a major circum-polar austral marine palaeobiogeographic region recognisable during the Early–Middle Devonian. In addition to the high endemism in taxa of suprageneric level and the unusual abundance of some taxonomic groups (such as hyoliths and conulariids), marine faunas from this extensive palaeobiogeographical region are conspicuously characterised by the virtual absence of critical Palaeozoic biostratigraphic guide fossil groups such as conodonts, graptolites and goniatites (Boucot & Racheboeuf 1993). This peculiarity has necessitated the utilisation of other fossil groups (mainly brachiopods and trilobites) for correlation, which has proved less effective and of only local to regional significance (e.g. Wolfart & Voges 1968; Herrera 1993; Salas et al. 2013; Noetinger et al. 2016).

In order to achieve a biostratigraphy suitable for establishing adequate international comparisons and correlations, considerable effort was directed to the understanding of the palynostratigraphy of Malvinokaffric successions. As a result, comprehensive stratigraphic revisions during the last few decades (especially for intracratonic basins from Brazil and the Andean region of Bolivia) have provided a good biostratigraphic

framework based on palynomorphs (e.g. Limachi et al. 1996; Grahn 2002, 2005; Loboziak & Melo 2002; Melo & Loboziak 2003; Rubinstein et al. 2005, 2008; Troth et al. 2011; Grahn et al. 2013; di Pasquo et al. 2015 and references therein). These reports focus mainly on chitinozoans and miospores, while acritarchs are comparatively less well studied.

In this scenario, and despite a long history of palaeontological investigations, the palynology of the Early Devonian successions of the Precordillera Basin in central-west Argentina (Figure 1) is still poorly known. In the central part of the basin, the main records are represented by the Early Devonian-age Talacasto Formation (Padula et al. 1967) and the Early–Middle Devonian-age Punta Negra Formation (Bracaccini 1949), which contains one of the richest fossiliferous records from the Andean region of the southernmost part of South America. Up to now, palynological data from these units have been preliminary reports (Le Hérissé et al. 1997; Rubinstein 1999, 2000), and one study mostly focused on the Silurian–Devonian transition (García Muro et al. 2014). Therefore, faunal biostratigraphic tools are of relative significance and the palynological data has so far prevented further interpretations. Because of this, some stratigraphic and biostratigraphic issues regarding the units from the Argentinean Precordillera remain unresolved.

Herein, we report on new palynomorph occurrence data including mainly marine phytoplankton and miospores from sections of the Talacasto and Punta Negra formations. Aside from recording the most abundant and diverse palynological



**Figure 1.** Locations and geological maps of the study areas. (a) Cerro La Chilca; (b) Talacasto Creek. Modified from García Muro & Rubinstein (2015). Black dots indicate locations of studied sections.

assemblages of the Lower Devonian of the Precordillera basin, this contribution seeks to address the controversial stratigraphy and age of both Devonian units. This will allow a comparison with the latest correlations based on megafaunas. Additionally, some palaeobiogeographic discussions on the palynomorph assemblages are provided.

### 1.1. Stratigraphy and biostratigraphy of the Gualilán Group

In the central part of the Precordillera Basin, western San Juan Province, the Talacasto and Punta Negra formations comprise the Gualilán Group (Baldis 1975), which geographically extends from the Jáchal River in the north to the San Juan River to the south. Some additional outcrops of the Talacasto Formation were subsequently identified in the La Rioja Province, towards the northernmost part of the basin (Rustán et al. 2011).

The Talacasto Formation is interpreted as a marine succession of intensely bioturbated greenish-grey mudstones with intercalated sandstone beds. A composite stratigraphic column typically displays dark muddy sediments (black to greenish mudstones and shales) at the base that pass stratigraphically upward into sandier levels. According to Astini (1991), this unit was formed on a muddy shelf depositional system during a high stand. It overlies the Wenlock to Lochkovian shelf deposits of the Los Espejos Formation (Cuerda 1965a). The boundary between the two units has been interpreted as a paraconformity (Astini & Maretto 1996) in which the hiatus probably encompasses a Ludlow to Lochkovian interval in the southern sections, while the basal part of the Lochkovian is present in the northern outcrops (Benedetto et al. 1992; Carrera et al. 2013; García Muro et al. 2014). The Talacasto Formation underlies the turbiditic system of the (mainly) Middle Devonian Punta Negra Formation (Bustos & Astini 1997).

The Talacasto Formation increases in thickness from the south, where it is 300 m thick at the type locality of Talacasto Creek (Figure 1b), to the north, where it reaches more than 1000 m at the Loma de los Piojos section, near the Jáchal River (Figure 1a). This unit is the source of the majority of the Devonian macrofossils recorded from Argentina. As in other Early–Middle Devonian Malvinokaffric basins, conodonts and graptolites are absent and biostratigraphic control is therefore based on alternative fossil groups. An early Lochkovian to late Emsian age was proposed for the Talacasto Formation based on brachiopod and palynological correlations (Benedetto et al. 1992; Herrera 1993, 1995a, 1995b; Le Hérisse et al. 1997; Herrera & Bustos 2001; García Muro et al. 2014).

Since the Silurian–Devonian boundary can only be recognised in the uppermost interval of the Los Espejos Formation at a few localities north of the Talacasto area, near Jáchal city (Benedetto et al. 1992; Carrera et al. 2013; García Muro et al. 2014), in almost all sections, the dark muddy lowest stratigraphic interval of the Talacasto Formation has been considered to be early (but not earliest) Lochkovian (Benedetto et al. 1992; Herrera 1993). This age, initially based on brachiopods, was further confirmed by palynological data and stratigraphic correlations from the Cerro del Fuerte and Jáchal River sections (Le Hérisse et al. 1997; García Muro et al. 2014).

The Lochkovian–Pragian transition proved very difficult to recognise in these successions (Herrera 1995a; Holloway & Rustán 2012; Carrera & Rustán 2015) and, based on the stratigraphic ranges of some brachiopods, was located near the top of the muddy lower stratigraphic interval (see Herrera 1993, 1995a; Rustán & Balseiro 2016). The overlying sandier stratigraphic interval of the Talacasto Formation has been considered to be mainly Pragian (Herrera 1993, 1995a) and this age date was reinforced by the presence of the Pragian cosmopolitan biostratigraphic marker trilobite *Reedops* sp. cf. *R. bronni* (Barrande 1846) (Holloway & Rustán 2012). Furthermore, the top of this sandy middle stratigraphic interval constitutes the uppermost levels of the Talacasto Formation at its Talacasto Creek type locality and was referred to the uppermost Pragian by Herrera & Bustos (2001, p. 369). Significantly, the very top of this sandy interval at the Talacasto Creek area corresponds to a distinctive ochre, nodule-bearing fossiliferous horizon nearly 10 m thick, which was interpreted as a marker bed by Keidel (1921) and Astini (1991). This bed is laterally continuous along more than 100 km (from the Talacasto Creek locality in the south to Loma de los Piojos in the north) and allows a reliable lithologically based correlation between the sections. Keidel's horizon has been interpreted as probably earliest Emsian or located around the Pragian/Emsian boundary, and the strata of the Talacasto Formation overlying it (mainly recorded in the thicker northernmost sections, approximately from Tucunuco to Jáchal) are consequently considered to be no older than Emsian (Rustán & Vaccari 2010; Salas et al. 2013; Sterren et al. 2015; Cichowolski & Rustán 2017). Although a late Emsian age was suggested for the upper part of the Talacasto Formation mainly based on the presence of the brachiopods *Australocoelia*, *Australospirifer* and *Pleurothyrella*, these were later recorded from older units in South America (Herrera 1993, 1995a; Benedetto et al. 1992; Noetinger et al. 2016).

The top of the Talacasto Formation was, thus, considered diachronous, with a lowermost Emsian age for the southern sections (Talacasto Creek area) and upper Emsian or younger for the northernmost Jáchal River area sections.

The Punta Negra Formation paraconformably overlies the Talacasto Formation. According to the age interpretations based on the Keidel horizon, the boundary between the two units is progressively younger to the north (Salas et al. 2013). It is noteworthy that the Punta Negra Formation lies directly above Keidel's bed in the Talacasto section and towards the south, exhibiting basal layers comprised of a 40–50 m interval of green and purple pelites. In contrast, in the sections to the north of the Talacasto area, the Talacasto Formation continues upwards with fossiliferous levels above Keidel's bed while the Punta Negra Formation overlies it with a clearly younger light green pelite interval. Therefore, the boundary between the two units proves sharply diachronous and occurs, in these northern sections, hundreds of metres above Keidel's horizon (Salas et al. 2013). The lighter green basal fine-grained interval of the Punta Negra Formation in the Loma de los Piojos section near Jáchal was reported as 'post Devonian strata' by Keidel (1921), and the sandy overlying strata were interpreted as Middle Devonian in age because of the presence of the trilobite *Acanthopyge* (*Lobopyge*) *balliviani* (Kozłowski), recognised nearly 250 m above Keidel's horizon in this locality (Rustán & Vaccari 2010). The Punta Negra Formation was also dated by a brachiopod fauna recorded from a single fossiliferous level 250 m above the base of the formation at the Las Chacritas River section (Herrera & Bustos 2001). According to the palaeontological data summarised by Herrera & Bustos (2001) and Salas et al. (2013), the oldest age of the Punta Negra Formation would correspond to the latest? Pragian–early Emsian in the south of the basin and would range from the Emsian to the Eifelian to the north.

Even though Rubinstein (1999) assigned an Eifelian to Givetian–Frasnian age to the Punta Negra Formation based on a preliminary palynological study carried out in the Talacasto Creek, these palynological assemblages were later reinterpreted and considered to be no younger than Middle Devonian (Rubinstein 2000). Given that Salas et al. (2013) interpreted an early Emsian age for the base of the Punta Negra Formation in the Talacasto Creek, as previously stated (Rubinstein 2000), a Middle Devonian age for the upper levels of the unit in the Talacasto section would suit such an interpretation.

In general, the Punta Negra Formation presents a coarsening and thickening upward succession of intercalated green to blackish/dark green sandstones and siltstones arranged in tabular heterolithic layers exhibiting conspicuous rhythmicity in the type locality at San Juan River (González Bonorino 1975; Bustos & Astini 1997). However, significant lateral changes of facies were observed towards the north-east and the west by Baldis (1973), where more greenish colours and a less obvious rhythmicity are present. The depositional environments have been broadly discussed by various authors. González Bonorino (1975) interpreted this unit as a submarine fan. A thickness of nearly 1000 m was considered for most of the basin by Bustos (1996) and Bustos & Astini (1997), who inferred that the Punta Negra Formation is composed of slope deltaic deposits with storm activity. Edwards et al. (2009) suggested that the stratigraphic sequence would represent a shallow, low-energy marine



deposit in an inner shelf setting and succeeded by turbiditic sandstone beds. Recently, Basilici et al. (2012) concluded, after a facies and palaeocurrent analysis, that the sedimentary succession is a marine shelf deposited above the storm wave base and with oscillatory flows as the depositional mechanism.

The sandy-mudstone succession of Punta Negra Formation is unconformably covered by the glacial diamictitic deposits of the base of the Late Carboniferous Guandacol Formation (Cuerda 1965b).

The samples of the Talacasto Formation were collected from the Cerro La Chilca section (Figures 1a, 2) (30°35'29"S, 68°48'16.7"W), in which approximately 850 m of the unit are very well exposed. Remarkably, the surveyed stratigraphic column includes the very top levels of the underlying Los Espejos Formation, in this locality represented by the same reddish mudstone interval as that of the Lochkovian uppermost interval from the Cerro del Fuerte section, which were previously considered equivalent in age (Carrera et al. 2013).

The Punta Negra section (30°59'51"S, 68°47'5"W) is located along the north bank of the Talacasto Creek (Figures 1b, 3). Its lower part is composed of the typical interval of alternating green and purple pelites that immediately overlies Keidel's horizon in southern sections of the Punta Negra Formation (Salas et al. 2013).

The palynological studies here focus on the lower 40 m pelite layers of the Punta Negra Formation in order to calibrate their age with that of the laterally equivalent upper levels of the Talacasto Formation at the Cerro La Chilca section to the north, both of which immediately overlie Keidel's guide horizon (Figures 2, 3).

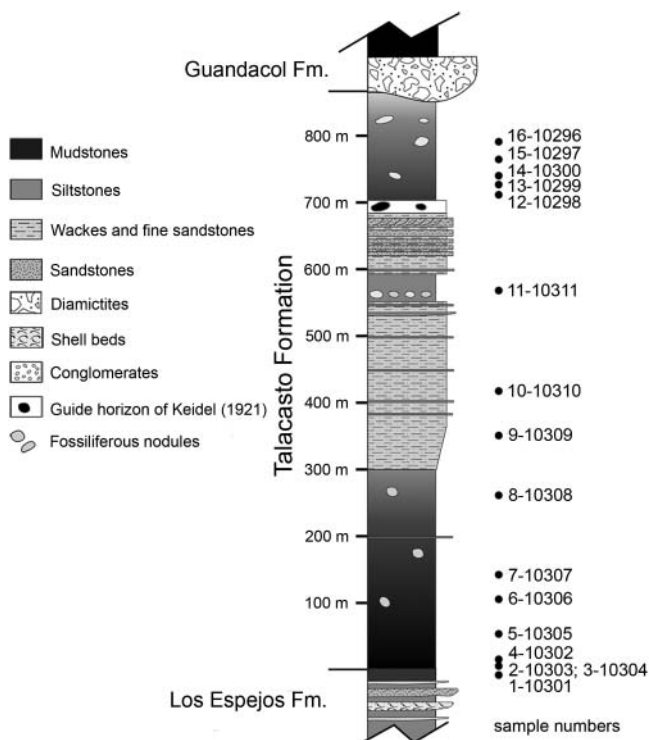


Figure 2. Stratigraphic section of the Talacasto Formation at Cerro La Chilca with the locations of studied samples.

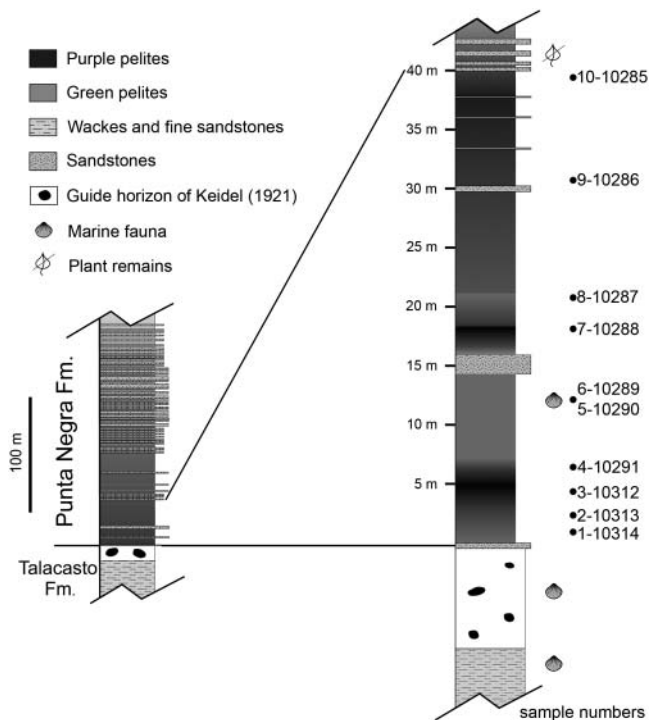


Figure 3. Stratigraphic section of the Punta Negra Formation at Talacasto Creek with the locations of studied samples.

## 2. Materials and methods

Sixteen samples were collected from the Talacasto Formation, at the Cerro La Chilca section (Figure 1a), and 10 samples from the Punta Negra Formation, at the Talacasto Creek section (Figure 1b). Three samples from the Punta Negra Formation proved to be barren (1-10314, 3-10312 and 5-10290).

Samples were processed in the Paleopalynology Laboratory of IANIGLA, CCT CONICET Mendoza, Argentina, using standard palynological hydrochloric acid (HCl)–hydrofluoric acid (HF)–HCl acid maceration techniques. The organic residues were sieved through a 10 µm sieve and oxidised for one or two minutes with nitric acid when necessary. Phytoplankton and spores were mounted in glycerin jelly as permanent palynological slides and examined using optical microscopy. These slides are housed in the palynological collection of IANIGLA, CCT CONICET Mendoza, Argentina. Specimens are located by Eng-land Finder™ coordinates.

## 3. Results

The recovered marine and terrestrial palynomorphs were poorly preserved – highly compressed, corroded or deformed by pyrite, with processes often truncated or completely broken off. Such preservation hindered, in many cases, positive identification at the species level. Nonetheless, biostratigraphically significant palynomorphs, mainly acritarchs, chlorophytes and a few trilete spores, were recognised. Diverse marine phytoplankton clearly dominates the assemblages, with 86 identified species. The subordinate terrestrial component is represented by a total of 19 species.

The complete list of species is given below and the corresponding illustrations are depicted in Plates 1–4. Remarks are

provided when differences with the original diagnoses of the species were observed. The stratigraphic distribution of marine organic-walled phytoplankton, non-marine palynomorphs and miospores for the studied sections are presented in Figures 4–7.

### 3.1. Marine phytoplankton

cf. *Buedingiisphaeridium* sp. (Plate 2, figure 1)  
*Cordobesia orientalis* Pöthe de Baldis 1977 (Plate 3, figure 5)  
*Cordobesia* sp. cf. *C. orientalis* Pöthe de Baldis 1977 (Plate 1, figure 11)  
*Cordobesia* sp. cf. *C. uruguayensis* (Martinez-Macchiavello) Pöthe de Baldis 1977 in Amenábar (2006) (Plate 1, figure 12)  
*Cordobesia uruguayensis* (Martinez-Macchiavello) Pöthe de Baldis 1977 (Plate 3, figure 6)  
*Cymatiosphaera daioariochora* Wicander 1974 (Plate 1, figure 6)  
*Cymatiosphaera fallax* Deunff 1966 (Plate 3, figure 7)  
? *Cymatiosphaera florida* Le Hérisse 2002 (Plate 1, figure 4)  
*Cymatiosphaera franjada* Cramer 1964 (Plate 1, figure 5)  
*Cymatiosphaera mirabilis* Deunff 1959 (Plate 3, figures 8, 9)  
*Cymatiosphaera multisepta* Deunff 1955  
*Cymatiosphaera* sp. aff. *C. multisepta* Deunff 1955 in Mullins (2001) (Plate 3, figure 10)  
*Cymatiosphaera* sp. cf. *C. multicristata* Mullins 2001  
*Cymatiosphaera octoplana* Downie 1959 emend. Mullins 2001 (Plate 1, figure 8)  
*Cymatiosphaera paucimembranae* Mullins 2001  
*Cymatiosphaera prismatica* Deunff ex Deunff 1961 (Plate 1, figure 9; Plate 3, figure 11)  
*Cymatiosphaera salopensis* Mullins 2001  
*Cymatiosphaera* sp. B in Wicander (1986) (Plate 1, figure 10)  
*Cymatiosphaera* spp. (Plate 1, figure 7)  
*Cymbosphaeridium* spp.  
*Dateriocradus lindus* (Cramer & Díez) Sarjeant & Vavrdová 1997 (Plate 1, figure 13)  
*Dictyotidium dictyotum* (Eisenack) Eisenack 1955 (Plate 3, figure 13)  
*Dictyotidium variatum* Playford 1977 (Plate 3, figure 14)  
*Dictyotidium* spp.  
*Diexallophasis remota* Group Mullins 2001 (Plate 2, figure 2)  
*Dorsennidium europaeum* (Stockmans & Williére) Sarjeant & Stancliffe 1994 emend. Mullins 2001 (Plate 3, figure 15)  
*Dorsennidium* spp.  
*Duvernaysphaera stellata* Deunff 1964 (Plate 3, figure 17)  
*Estiastra* sp. cf. *E. rhytidia* Wicander & Wood 1981 (Plate 3, figure 18)  
*Estiastra rugosa* Wicander 1974 (Plate 3, figure 19)  
*Estiastra* sp. cf. *E. stellata* Loeblich 1970 (Plate 1, figure 17)

Remarks: Specimens recovered from sample 4-10302A were provisionally attributed to Loeblich's species (1970), which has five processes extending from the central body in the same plane, whereas the specimen from the Talacasto Formation has two processes arising from another plane. Erkmen & Bozdogan (1979) recorded *E. stellata* from the Dadas Formation, upper Silurian of Turkey, with five processes in one plane and, apparently, three other processes perpendicularly oriented. However, the specimen was not described (p. 449, pl. 1, fig. 13). *Estiastra* sp., described by Ottone (1996) and recorded from the Early Devonian of Bolivia, has four processes in one plane plus two perpendicular ones. If the diagnosis of *Estiastra stellata* is

revised to incorporate those species that have perpendicular processes, Ottone's specimens could be included in this species.

cf. *Estiastra uruguaiensis* Pöthe de Baldis 1977 (Plate 1, figure 18)

Remarks: The specimen recorded from the Talacasto Formation has five processes instead of four, as originally described.

*Estiastra* sp. in Ottone (1996) (Plate 1, figure 19)

*Estiastra* spp.

*Evittia sanpetrensis* (Cramer) Lister 1970 (Plate 1, figure 20)

*Evittia sommeri* Brito 1967 (Plate 1, figures 21, 22)

Remarks: This species is morphologically highly variable, and two end-member morphologies seem to emerge. The first is represented by the specimens recorded as *Baltisphaeridium sommeri* from the Early and Middle Devonian of Spain and Libya by Cramer (1970) as well as from Bolivia by Vavrdová et al. (1996). These specimens have an inflated central body with a square outline. Short processes, located at each corner, are divided into a low number of digitate branches originating from near the base of the processes. Occasionally, one or two processes arise from the face of the central body. The second form is represented by the specimens recorded from the Emsian to Famennian of Brazil by Brito (1967) and Quadros (1982, 1988, 1999) as well as from the Middle Devonian of Bolivia by Troth et al. (2011). These specimens have longer bifurcate or rarely digitate processes and a more polygonal to rounded central body. The Talacasto Formation specimens are similar to those illustrated by Cramer (1970) and Vavrdová et al. (1996).

*Exochoderma triangulata* Wicander & Wood 1981 (Plate 1, figure 23)

*Exochoderma* spp.

cf. *Filisphaeridium* sp.

*Fimbriaglomerella divisa* Loeblich & Drugg 1968 (Plate 1, figure 24)

*Gorgonisphaeridium* spp. (Plate 1, figure 25; Plate 3, figure 20)

*Hapsidopalla* sp. cf. *H. exornata* (Deunff) emend. Playford 1977 (Plate 2, figure 3)

cf. *Hapsidopalla* spp.

*Helios aranaides* Cramer 1964 (Plate 3, figure 16)

*Hemiruptia legaultii* Ottone 1996 (Plate 2, figure 4)

*Hemiruptia* spp. (Plate 4, figure 1)

Remarks: According to The Phytopal Taxonomic Database (Mullins et al. 2007), the genus belongs to a group of uncertain prasinophytes (*Hemiruptia* spp.). The specimens have a simple median split. Ottone (1996) described this genus as marked by a psilate wall. Although some of the specimens studied herein have scabrate ornamentation, they are included within *Hemiruptia* because of their gross morphology, the thickness of their wall and the characteristic excystment structure.

*Leiofusa berneseae* Cramer 1964 (Plate 2, figure 5)

*Leiofusa* sp.

*Leiosphaeridia* spp.

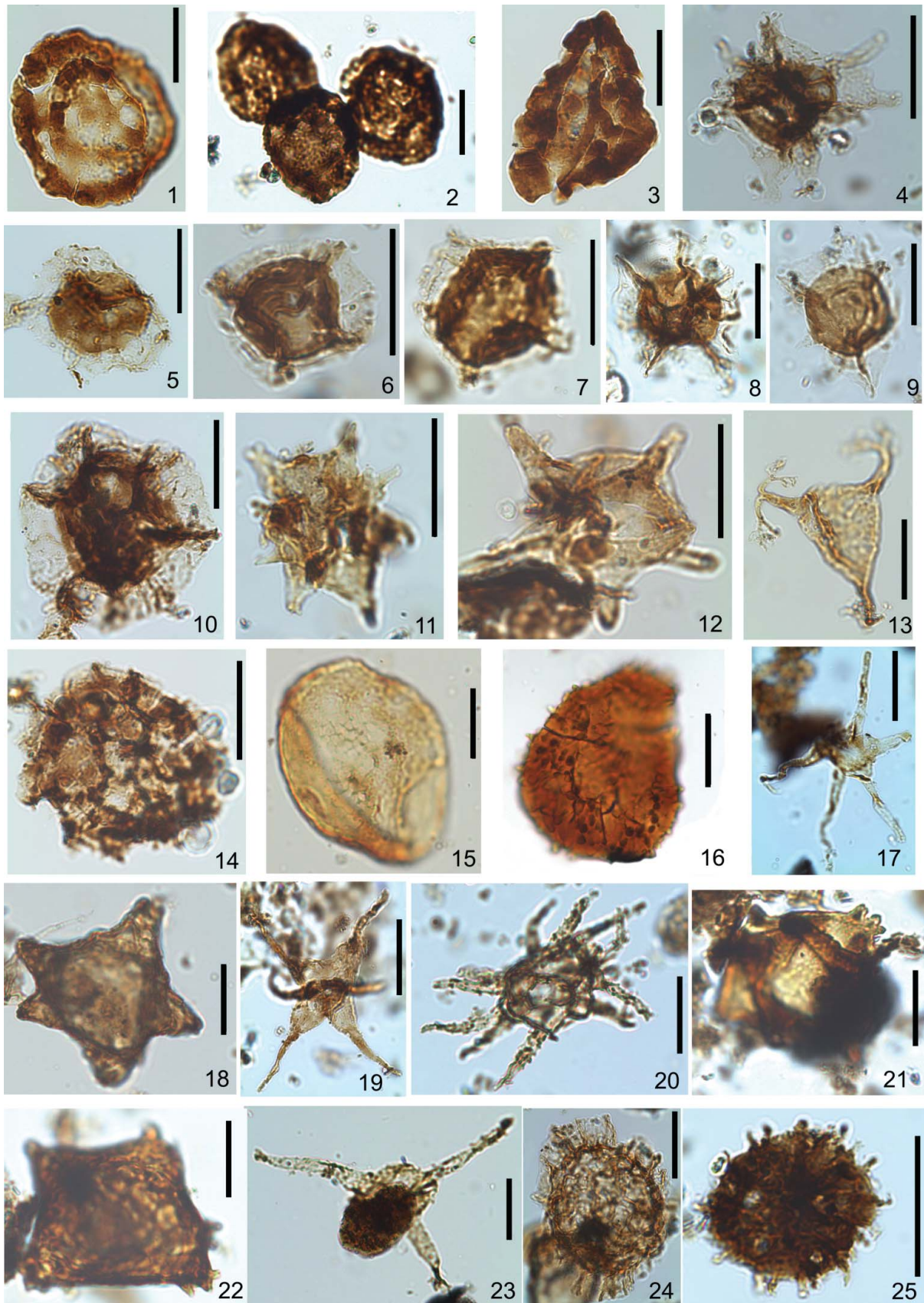
*Lophosphaeridium* sp. (Plate 3, figure 21)

*Melikeriopalla polygonia* (Staplin) Mullins 2001 (Plate 3, figure 22)

*Micrhystridium* spp. (Plate 2, figure 6)

*Multiplicisphaeridium ampliatus* Playford 1977 (Plate 2, figure 7)





*Multiplicisphaeridium arbusculiferum* var. *arbusculiferum* Lister 1970  
*Multiplicisphaeridium arbusculum* Dorning 1981 (Plate 3, figure 23)  
*Multiplicisphaeridium micropilare* Cramer ex Eisenack et al. 1973 (Plate 4, figure 2)  
*Multiplicisphaeridium neahgae* Cramer ex Eisenack et al. 1973 (Plate 2, figure 8)  
*Multiplicisphaeridium rochesterensis* (Cramer & Díez) Eisenack et al. 1973 (Plate 3, figure 25)  
*Multiplicisphaeridium* spp. (Plate 3, figure 24)  
*Navifusa bacilla* (Deunff) Playford 1977 (Plate 3, figure 26)  
*Oppilatalla insolita* (Cramer & Díez) Dorning 1981  
*Oppilatalla ramusculosa* (Deflandre) Dorning 1981 (Plate 2, figure 9)  
*Ozotobranchion palidodigitatus* (Cramer emend. Cramer) Playford 1977 (Plate 2, figure 10)  
*Palacanthus ledanoisii* (Deunff) emend. Playford 1977 (Plate 2, figure 11; Plate 4, figure 3)  
*Petalosphaeridium* sp. (Plate 4, figure 4)  
*Polyedryxium* sp. cf. *P. condensum* Deunff 1971 (Plate 4, figure 5)  
*Polyedryxium* sp. cf. *P. decorum* Deunff 1955 (Plate 2, figure 12)  
*Polyedryxium decorum* Deunff 1955 (Plate 4, figure 6)  
*Polyedryxium embudum* Cramer 1964 (Plate 4, figure 7)  
*Polyedryxium evolutum* Deunff 1955 (Plate 2, figure 13)  
*Polyedryxium fragosulum* Playford 1977 (Plate 4, figure 8)  
*Polyedryxium helenaster* Cramer 1964 (Plate 2, figure 14)  
*Polyedryxium leptum* Turnet 1991 (Plate 2, figure 15)  
*Polyedryxium* sp. cf. *P. multifrons* Deunff 1971 (Plate 4, figure 9)  
*Polyedryxium* sp. cf. *P. robustum* Deunff 1971 (Plate 4, figure 10)  
*Polyedryxium* sp. cf. *P. wenlockium* (Dorning) Le Hérisse 1989 (Plate 4, figure 11)  
*Polyedryxium* spp.  
 cf. *Pterospermella bernardinae* (Cramer) Eisenack et al. 1973 (Plate 2, figure 16)  
*Pterospermella circumstriata* (Jardiné et al.) Eisenack et al. 1973 (Plate 4, figure 12)  
*Pterospermella elliptica* Pöthe de Baldis 1981  
*Pterospermella* sp. cf. *P. pernambucensis* (Brito) Eisenack et al. 1973 (Plate 4, figure 13)  
*Pterospermella rajada* (Cramer) Eisenack et al. 1973 (Plate 2, figure 17)  
*Quadratum fantasticum* Cramer 1964 (Plate 2, figure 18)  
*Riculusphaera fissa* Loeblich & Drugg 1968 (Plate 2, figures 20, 21; Plate 4, figure 16)  
*Schizocystia pilosa* Jardiné et al. 1972 (Plate 2, figure 22; Plate 4, figure 17)

*Stellinium micropolygonale* (Stockmans & Williere) Playford 1977 (Plate 2, figure 23; Plate 4, figure 18)  
 cf. *Stellinium rabians* (Cramer) Eisenack et al. 1976  
 cf. *Tyligmasoma alargada* (Cramer) Playford 1977 (Plate 4, figure 20)  
*Tysanoprobolus polykion* Loeblich & Tappan 1970 (Plate 2, figure 24)  
*Veryhachium lairdii* Group sensu Servais et al. 2007  
*Veryhachium trispinosum* Group sensu Servais et al. 2007  
*Winwaloesia distracta* (Deunff) Deunff 1977 (Plate 2, figure 25)

### 3.2. Non-marine palynomorphs

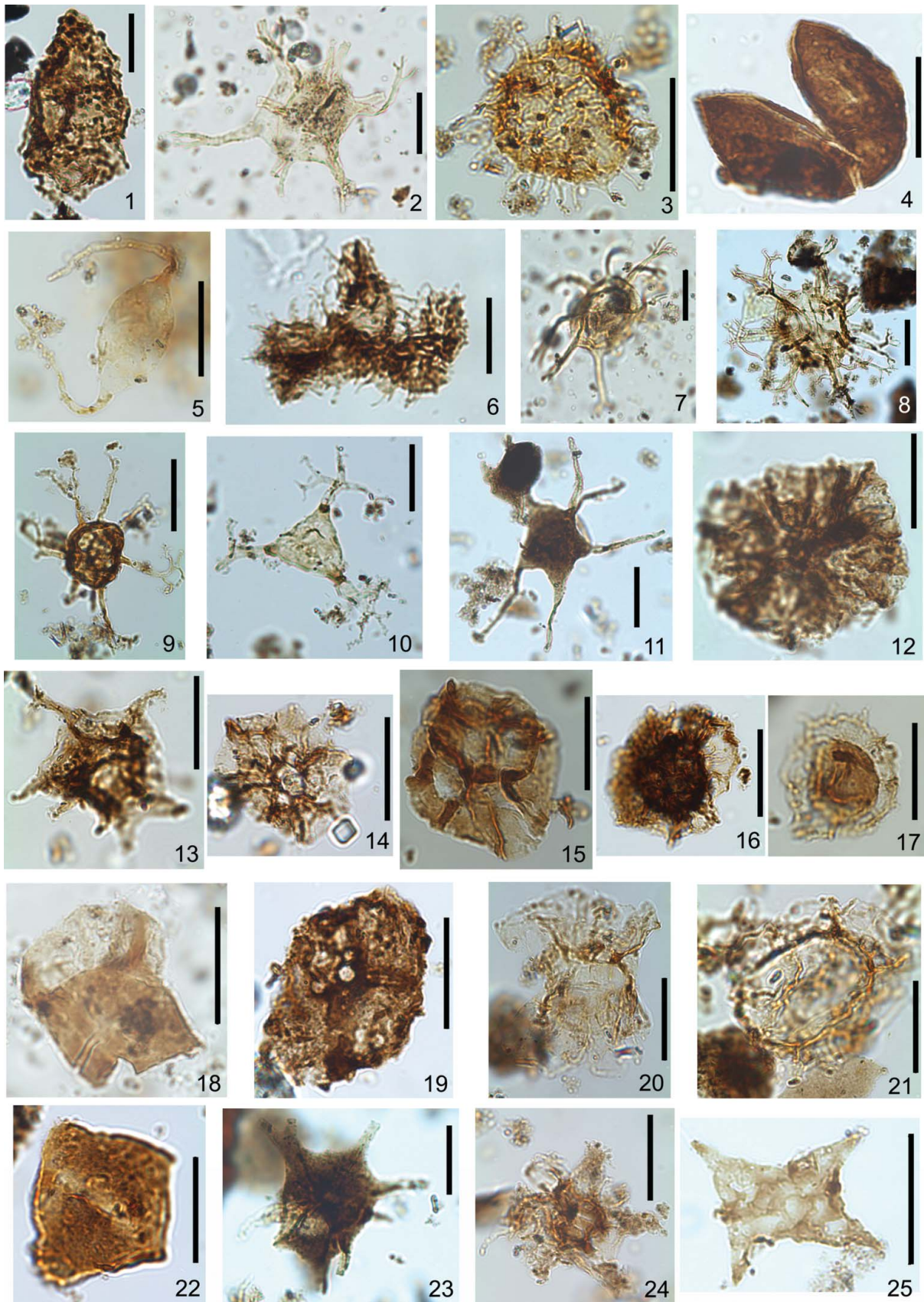
*Quadrifurcites variabilis* (Cramer) Ottone et al. 1996 (Plate 2, figure 19; Plate 4, figure 14)  
*Quadrifurcites* spp.

### 3.3. Miospores

*Acinosporites* sp. cf. *A. lindlarensis* Riegel 1968 (Plate 3, figure 1)  
*Acinosporites* sp.  
*Ambitisporites* sp.  
*Amicosporites* sp. cf. *A. streelii* Steemans 1989 (Plate 1, figure 1)  
 cf. *Amicosporites* sp.  
*Apiculatasporites microconus* (Richardson) McGregor & Camfield 1982 (Plate 3, figure 2)  
*Archaeozonotriletes chulus* (Cramer) Richardson & Lister 1969 (Plate 3, figure 3)  
*Chelinohilates* sp. A in Wellman et al. (2015) (Plate 1, figure 2)  
*Chelinospora* sp. 1 (Plate 3, figure 4)  
 Remarks: Even though this single specimen is well preserved, its morphological characteristics do not conform with those of described species of this genus. Breuer (pers. comm.) recorded similar specimens from the Lochkovian of Saudi Arabia.  
*Chelinospora* spp.  
*Cymbosporites* spp. (Plate 3, figure 12)  
*Dibolisporites* spp. (Plate 1, figure 16)  
*Dictyotriletes emsiensis* Morphon Rubinstein et al. (2005) (Plate 1, figure 14)  
*Dictyotriletes favosus* McGregor & Camfield 1976 (Plate 1, figure 15)  
*Dictyotriletes* spp.  
*Gneudnaspora divellomedia* (Chibrikova) Balme 1988 var. *minor* Breuer et al. 2007  
 ?*Knoxisporites riondae* Cramer & Díez 1975 (Plate 1, figure 3)  
*Retusotriletes* spp. (Plate 4, figure 15)  
*Tetraedraletes medinensis* (Strother & Traverse) Wellman & Richardson 1993 (Plate 4, figure 19)

**Plate 1.** Palynomorphs from the uppermost part of the Los Espejos Formation and Talacasto Formation. 1. *Amicosporites* sp. cf. *A. streelii* Steemans 1989, 10-10310E (W23/1); 2. cluster of *Chelinohilates* sp. A in Wellman et al. (2015), 5-10305B (H26/1); 3. ?*Knoxisporites riondae* Cramer & Díez 1975, 10-10310B (Y40); 4. ?*Cymatiosphaera florida* Le Hérisse 2002, 5-10305B (H25/2); 5. *Cymatiosphaera franjada* Cramer 1964, 10-10310E (V22); 6. *Cymatiosphaera daioariochora* Wicander 1974, 4-10302A (Q37); 7. *Cymatiosphaera* sp., 9-10309A (L33); 8. *Cymatiosphaera octoplana* Downie 1959 emend. Mullins 2001, 3-10304B (L23); 9. *Cymatiosphaera prismatica* Deunff ex Deunff 1961, 3-10304B (J38/2); 10. *Cymatiosphaera* sp. B in Wicander (1986), 8-10308B (D43/3); 11. *Cordobesia* sp. cf. *C. orientalis* Pöthe de Baldis 1977, 5-10305B (F36); 12. *Cordobesia* sp. cf. *C. uruguayensis* in Amenábar (2006), 4-10302A (J42/2); 13. *Dateriocradus lindus* (Cramer & Díez) Sarjeant & Vavrdová 1997, 8-10308B (O26); 14. *Dictyotriletes emsiensis* Morphon Rubinstein et al. (2005), 1-10301B (X37/1); 15. *Dictyotriletes favosus* McGregor & Camfield 1976, 9-10309A (M20/2); 16. *Dibolisporites* sp., 9-10309A (D26); 17. *Estiastra stellata* Loeblich 1970, 9-10309A (F38/4); 18. cf. *Estiastra uruguia* Pöthe de Baldis 1977, 4-10302A (P37/1); 19. *Estiastra* sp. in Ottone (1996), 4-10302A (Y41); 20. *Evittia sanpetrensis* (Cramer) Lister 1970, 4-10302A (V39/3); 21, 22. *Evittia sommeri* Brito 1967, 4-10302A (B20, Y33/1); 23. *Exochoderma triangulata* Wicander & Wood 1981, 8-10308B (R30/3); 24. *Fimbrigliomerella divisa* Loeblich & Drugg 1968, 4-10302A (U32); 25. *Gorgonisphaeridium* sp., 4-10302A (N42). Scale bars = 20 µm.





## 4. Discussion

### 4.1. Biostratigraphy

The uppermost sample of the Los Espejos Formation (sample 1-10301; Figures 4, 5) in the Cerro La Chilca section yielded a low-diversity assemblage of poorly preserved palynomorphs. However, the identification of specimens of *Dictyotriletes emsiensis* Morphon (Plate 1, figure 14) confirms the Early Devonian age previously interpreted by Rubinstein et al. (2005) for the upper part of this stratigraphic unit (Benedetto et al. 1992; García Muro et al. 2014). This species first appears in the Lochkovian N $\beta$  Zone, corresponding to the lower but not basal part of the Lochkovian, and ranges into the Emsian AB Zone (Stemans 1989).

The basal sample of the Talacasto Formation (Sample 2-10303; Figure 4) yielded only marine phytoplankton, scarce and poorly preserved, with species such as *Cymatiosphaera octoplana*, *Cymatiosphaera prismatica* and *Quadraditum fantasticum*, which fit well with a Lochkovian age (e.g. Deunff 1961; Cramer 1964; Pöthe de Baldis 1981; Mullins 2001; Rubinstein et al. 2008; Rubinstein & García Muro 2011).

*Evittia sommeri*, for which the oldest record is from the Lochkovian of the Tequeje Formation in Bolivia (Vavrdová et al. 1996), appears in sample 3-10304. Therefore, the palynomorphs identified from the basal 15 m of the Talacasto Formation at the Cerro La Chilca section suggest a Lochkovian age *sensu lato*.

Sample 4-10302 had the highest phytoplankton diversity (43 species) and yielded age-significant taxa such as *Palacanthus ledanoisii* and *Polyedryxium* sp. cf. *P. decorum*, both of which have a worldwide appearance in the Pragian (e.g. Molyneux et al. 1996; Wicander & Wood 1997; Mendlowicz Mauller et al. 2007; Grahn et al. 2013; Noetinger & di Pasquo 2013). Species such as *Tysanoprobolus polykion* and *Riculasphaera fissa*, for which the youngest worldwide records correspond to the Lochkovian, were recorded in sample 4-10302, while *?Cymatiosphaera florida* occurred in sample 5-10305 (e.g. Loeblich & Drugg 1968; Loeblich & Tappan 1970; Vavrdová et al. 1996; Le Hérisse 2002; Melo 2005; Rubinstein et al. 2008; Vavrdová et al. 2011; Molyneux et al. 2013; García Muro et al. 2014).

Sample 4-10302 has species that occur no younger than Lochkovian together with species that range no older than Pragian. These would suggest that either *Palacanthus ledanoisii* and *Polyedryxium* sp. cf. *P. decorum* extend into the Lochkovian and thus have their oldest record in the Argentinean Precordillera, or that *Tysanoprobolus polykion* and *Riculasphaera fissa* are stratigraphically younger here. Remarkably, *R. fissa* was also recorded from the early Emsian Punta Negra Formation section

(Figure 6), thus supporting the Pragian age interpreted for this sample. Even though *?Cymatiosphaera florida* is only known from the Lochkovian, its scarce records inhibit its biostratigraphic use.

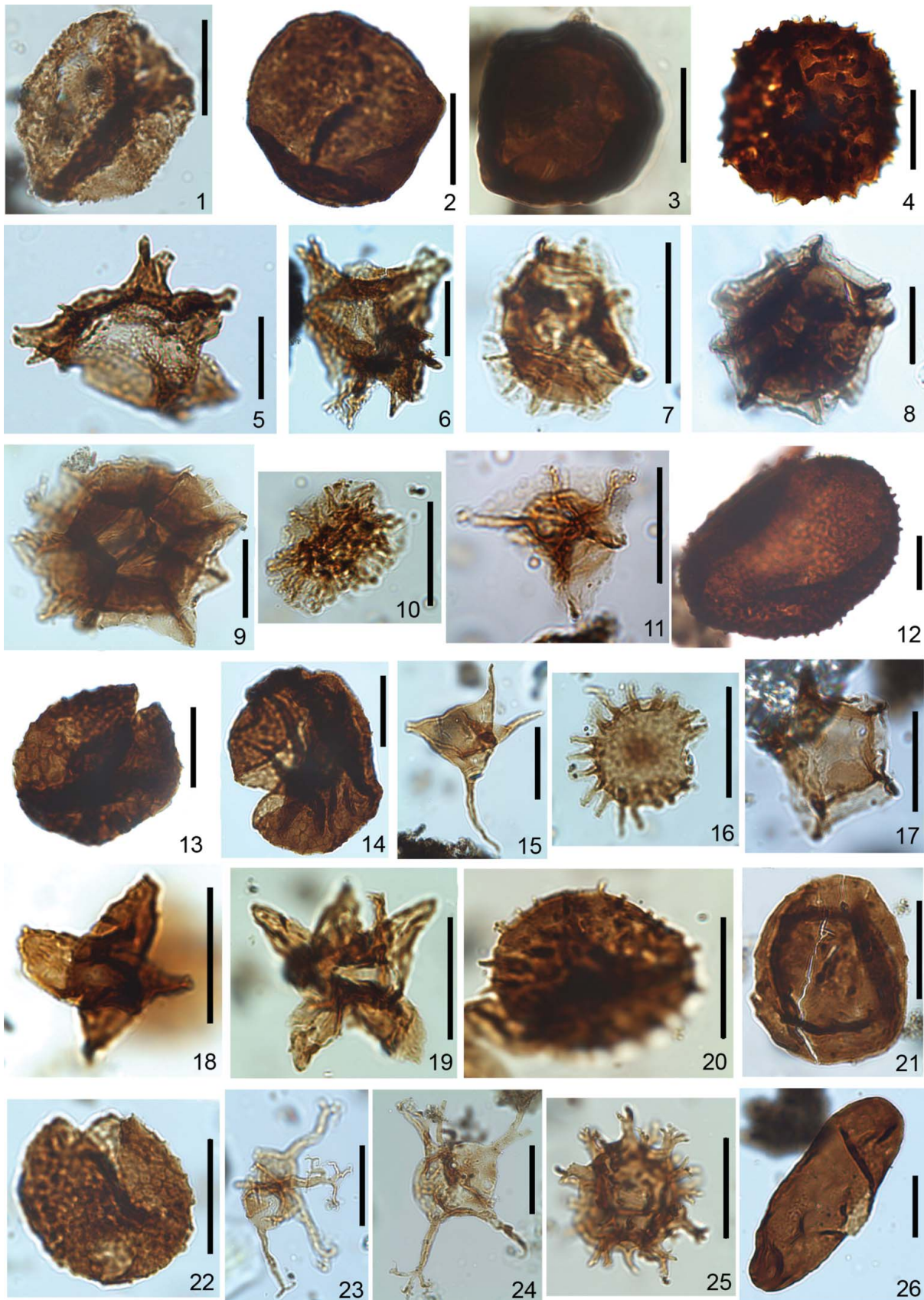
In sample 5-10305, *Cordobesia* sp. cf. *C. orientalis* appears. This species was first described from the Emsian of Uruguay (Pöthe de Baldis 1977) and later documented from older strata from Brazil dated as late Pragian–early Emsian (Bosetti et al. 2012). Recently, the age of the Uruguayan rocks bearing *Cordobesia* was reinterpreted as late Pragian–early Emsian (Daners et al. 2012; Rubinstein, unpublished data). Nevertheless, considering that this species constitutes the only evidence of a late Pragian age for sample 5-10305, a Pragian to probably late Pragian age is thus assigned to this sample.

These would be supported by the presence of marine palynomorphs such as *Exochoderma triangulata*, *Hemiruptia legaultii*, *Multiplicisphaeridium ampliatus*, *Multiplicisphaeridium ramusculosum*, *Polyedryxium embudum*, *Polyedryxium fragosulum* and *Pterospermella circumstriata*, and trilete spores *Amicosporites streelii*, *Dictyotriletes favosus* and *?Knoxisporites riondae* (e.g. Molyneux et al. 1996; Wicander & Wood 1997; Quadros 1999 and references therein; Filipiak 2011; Breuer & Stemans 2013). This means that the upper part of the Talacasto Formation above the Keidel horizon in the Cerro La Chilca section would be, based on the palynological results, no younger than late Pragian, and would accordingly dispute the early Emsian age previously proposed based on other fossil groups (Herrera 1993; Rustán & Vaccari 2010).

The lowest productive sample (2-10313) of the Punta Negra Formation at the Talacasto Creek (Figure 3), located 2.3 m above the top of the Keidel (1921) horizon, yielded *Navifusa bacilla* and *Cordobesia orientalis* (Figure 6). As previously mentioned, *Cordobesia orientalis* is characterised by a short biochron from the late Pragian to the early Emsian while *N. bacilla* first appears in the Emsian (Molyneux et al. 1996). Even though *Navifusa bacilla* has been reported to appear in the Ordovician, the species is not recorded during the Silurian and part of the Early Devonian, and it reappears in the late Early Devonian (Fatka & Brocke 2008; Bosetti et al. 2012; Grahn et al. 2013). *Cordobesia uruguayensis* was recognised in sample 6-10289, 12.7 m above the Keidel horizon, and was recorded from late Pragian–early Emsian to Givetian rocks of Uruguay and Brazil as well as from the Punta Negra Formation of Argentina (Pöthe de Baldis 1977; Oliveira 1997; Quadros 1999; Rubinstein 1999; Grahn et al. 2013). The presence of *Navifusa bacilla* and representatives of the genus *Cordobesia* suggest an age no older than early Emsian for the basal part of the Punta Negra Formation above the Keidel horizon in the Talacasto Creek section.

**Plate 2.** Palynomorphs from the Talacasto Formation. 1. cf. *Buedingiisphaeridium* sp., 10-10310E (F22); 2. *Diexallophasis remota* Group Mullins 2001, 3-10304B (N38); 3. *Hapsidopalla* sp. cf. *H. exornata* (Deunff 1967) emend. Playford 1977, 4-10302A (N39); 4. *Hemiruptia legaultii* Ottone 1996, 7-10307A (U21); 5. *Leiofusa berneseae* Cramer 1964, 4-10302A (B28/2); 6. cluster of *Michrystriidium* sp., 7-10307A (C23/4); 7. *Multiplicisphaeridium ampliatus* Playford 1977, 3-10304B (F30/1); 8. *Multiplicisphaeridium neahgae* Cramer 1970, 4-10302A (X22/1); 9. *Oppilatalla ramusculosa* (Deflandre) Dorning 1981, 4-10302A (H37); 10. *Ozotobrachion palidodigitatus* (Cramer) emend. Cramer) Playford 1977, 4-10302A (F35/2); 11. *Palacanthus ledanoisii* (Deunff) emend. Playford 1977, 4-10302A (R31/2); 12. *Polyedryxium* sp. cf. *P. decorum* Deunff 1955, 4-10302A (E32/3); 13. *Polyedryxium evolutum* Deunff 1955, 4-10302A (O35/2); 14. *Polyedryxium helenaster* Cramer 1964, 5-10305B (D28/3); 15. *Polyedryxium leptum* Turner 1991, 9-10309A (K31/1); 16. cf. *Pterospermella bernardinae* (Cramer) Eisenack et al. 1973, 4-10302A (C42); 17. *Pterospermella rajada* (Cramer) Eisenack et al. 1973, 9-10309A (K33/2); 18. *Quadraditum fantasticum* Cramer 1964, 2-10303B (U23/2); 19. *Quadrifurcites variabilis* (Cramer) Ottone et al. 1996, 5-10305B (J27/2); 20, 21. *Riculasphaera fissa* Loeblich & Drugg 1968, 4-10302A (U32/1, H42/3); 22. *Schizocystia pilosa* Jardine et al. 1972, 4-10302A (M39/4); 23. *Stellinium micropolygonale* (Stockmans & Willièrè) Playford 1977, 4-10302A (Y38); 24. *Thysanoprobolus polykion* Loeblich & Tappan 1970, 4-10302A (T32/4); 25. *Winwaloesia distracta* (Deunff) Deunff 1977, 4-10302A (H40/4). Scale bars = 20  $\mu$ m.







Sample 7-10288 yielded *Duvernaysphaera stellata*, which was first recorded from the Devonian of Tunisia (Deunff 1964) with no further age details, and later reported from the Late Devonian and Early Carboniferous of Portugal (Pereira et al. 2003, 2006) but not illustrated. Given that the *D. stellata* illustrated by Oliveira et al. (2009) would seem to be a specimen of *Duvernaysphaera kraeuselii* (Stockmans & Willièrè) Stockmans & Willièrè 1962, it is possible that their previous records do not correspond to *D. stellata* either. *Duvernaysphaera stellata* was also recorded from the early Frasnian of the Los Monos Formation, Bolivia, by Noetinger & di Pasquo (2011), who additionally indicated an Emsian–Famennian stratigraphic range for this species.

*Acinosporites* sp. cf. *A. lindlarensis* and *Apiculatasporites microconus* are present in sample 7-10288 (Figure 7). *Acinosporites lindlarensis* is a cosmopolitan species that ranges from the late Lochkovian, although it is most commonly recognised from the Emsian to early Frasnian (e.g. Steemans 1989; Amenabar et al. 2009; di Pasquo et al. 2009 and references therein; Rubinstein et al. 2010; Breuer & Steemans 2013 and references therein). *Apiculatasporites microconus* is a characteristic species of the early to early-late Emsian *Emphanisporites annulatus*–*Camarozonotriletes sextantii* Assemblage Zone (Richardson & McGregor 1986).

*Estiastra* sp. cf. *E. rhytidoa*, *E. rugosa*, *Pterospermella* sp. cf. *P. pernambucensis* and *Stellinium micropolygonale* appear in sample 9-10286. *Estiastra rhytidoa* was documented from the Middle to Late Devonian of USA, Brazil, Bolivia and Argentina (e.g. Wicander & Wood 1981; Wicander & Wright 1983; Vavrdová et al. 1991; Quadros 1999; Melo 2005; Amenábar 2006), while *E. rugosa* was recorded from the Famennian of the USA (Wicander 1974) and later only mentioned (not illustrated) from the Upper Devonian of Canada (Legault & Norris 1982). On the other hand, *Pterospermella pernambucensis* was recognised from the Middle Devonian of Brazil, Argentina and Bolivia (Brito 1967; Noetinger 2010; Noetinger & di Pasquo 2011). *Stellinium micropolygonale* first appears in the Pragian and ranges to the Late Devonian (Playford 1977; Molyneux et al. 1996; Higgs et al. 2002; Marynowski et al. 2010). Considering the aforementioned species a younger age, probably Middle Devonian, could be suggested, from sample 9-10286 to the upper part of the studied section of the Punta Negra Formation. Nonetheless, considering that the Precordillera specimens are very few and badly preserved, and were doubtfully assigned, the palynomorphs by themselves fail to unequivocally support the Middle Devonian age.

Of note, *Riculasphaera fissa* has a longer stratigraphic range, extending throughout the Early Devonian, indicated by its

presence in the Pragian of the Talacasto Formation (sample 9-10286).

#### 4.2. Palaeogeography

Although relevant palaeobiogeographic markers, typically restricted to Gondwana, such as *Cordobesia orientalis*, *C. uruguayensis*, *Schizocystia pilosa* and *Winwaloesia distracta*, occur, most of the phytoplankton taxa recorded from the Devonian formations studied have a more cosmopolitan distribution (Figure 8). *Cordobesia uruguayensis* and *C. orientalis* were recorded from Uruguay (Martínez-Macchiavello 1968; Pöthe de Baldis 1977) and, later, *C. uruguayensis* was also recognised in Brazil and Argentina (Oliveira 1997; Quadros 1999; Rubinstein 1999; Bosetti et al. 2012; Grahn et al. 2013).

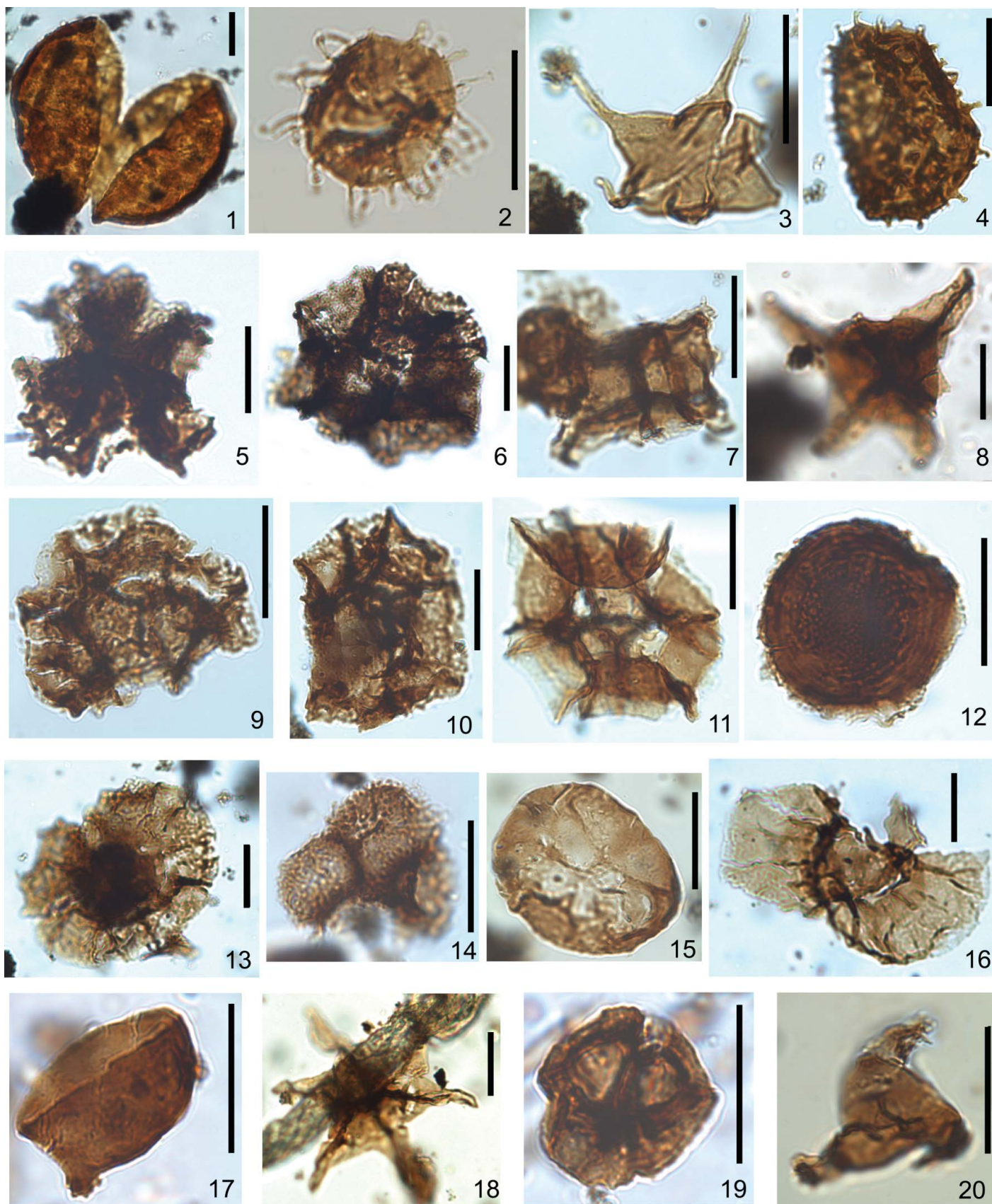
*Schizocystia pilosa* is a common species of the Early Devonian of Gondwana and is widely distributed and abundant, especially in the upper Lochkovian strata from Algeria, Brazil, Bolivia, Peru and Argentina (e.g. Vavrdová et al. 1996; Le Hérisse 2002; Rubinstein & Steemans 2007 and references therein; Rubinstein et al. 2008; Vavrdová et al. 2011). *Dictyotriletes emsiensis* Morphon was only recorded from Gondwana; that is, from Argentina, Brazil, Bolivia, Brittany and Saudi Arabia (e.g. Rubinstein et al. 2005 and references therein; Rubinstein & Steemans 2007; di Pasquo & Noetinger 2008; Steemans et al. 2008; García Muro et al. 2014). The stratigraphic and palaeogeographic relevance of *Schizocystia pilosa* and its relation with the *Dictyotriletes emsiensis* Morphon Assemblage Zone is discussed in Steemans et al. (2008) and Rubinstein et al. (2008).

*Winwaloesia distracta* first appears in the Lochkovian and is also restricted to Gondwana regions such as Tunisia, Morocco, Argentina, Brazil, Uruguay and France (e.g. Deunff 1966, 1980; Marhouni & Rauscher 1984; Rubinstein & Steemans 2007; Rubinstein et al. 2008; Amenábar 2009; Rubinstein, unpublished data).

The phytoplankton of the Talacasto Formation studied herein contains many species in common with the Tequeje Formation in the Madre de Dios Basin, northern Bolivia, such as *Fimbriaglomerella divisa*, *Ozotobracion* spp., *Diexallophasis remota* group, *Riculasphaera fissa*, *Evittia sommeri* and *Schizocystia pilosa* (Vavrdová et al. 1996).

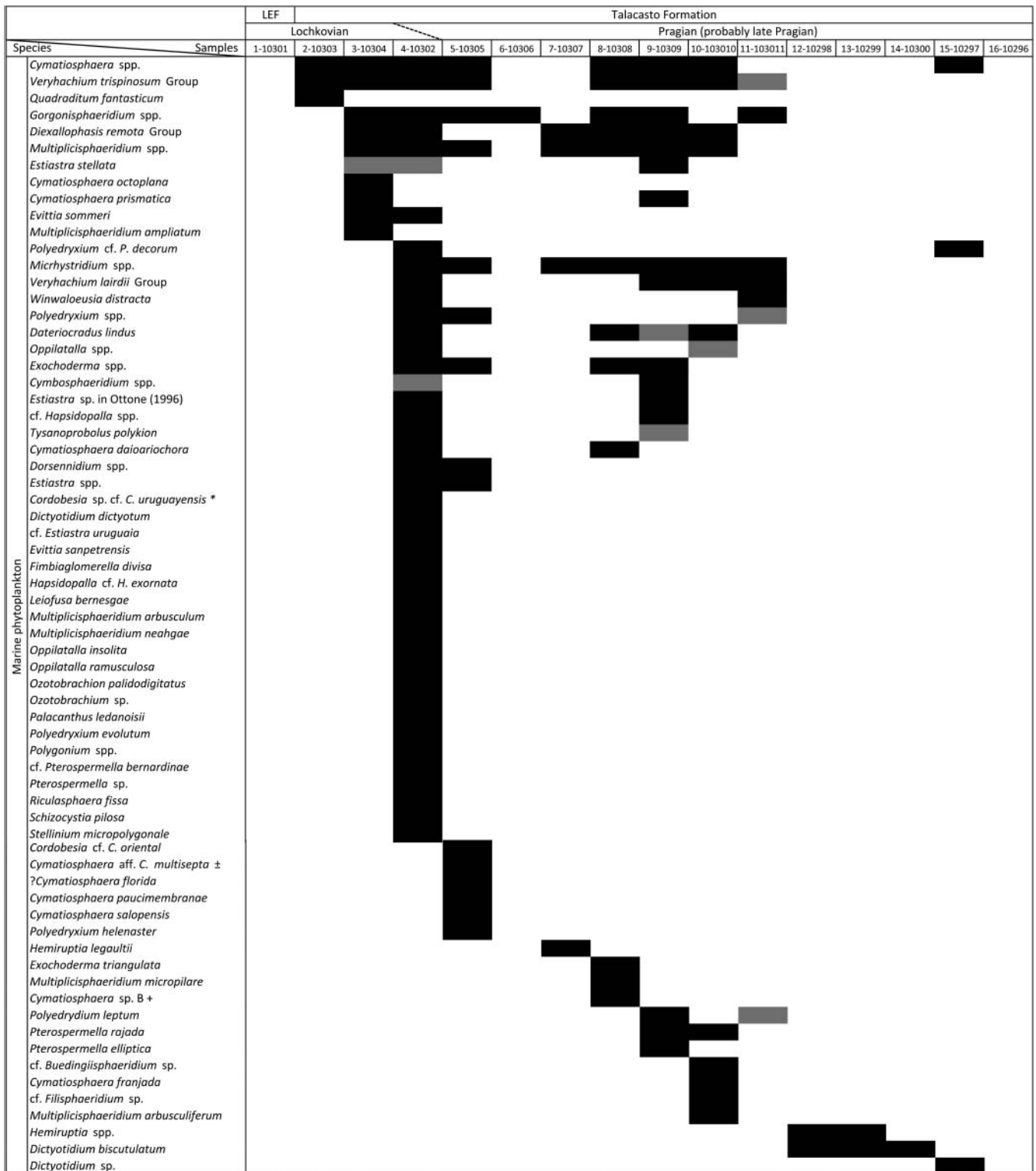
The Punta Negra Formation shares species such as *Cordobesia uruguayensis*, *Diexallophasis remota* group, *Navifusa bacilla*, *Palacanthus ledanoisii*, *Polyedryxium decorum* and *Veryhachium trispinosum* group (Grahn et al. 2013) with sequence B of the Ponta Grossa Formation and sequence C of the São Domingos Formation, Apucarana Sub-basin of the Paraná Basin, southern Brazil.

**Plate 3.** Palynomorphs from the Punta Negra Formation. 1. *Acinosporites* sp. cf. *A. lindlarensis* Riegel 1968, 7-10288A (G45); 2. *Apiculatasporites microconus* (Richardson) McGregor & Camfield 1982, 7-10288A (J35); 3. *Archaeozonotriletes chulus* (Cramer) Richardson & Lister 1969, 9-10286A (Z34/1); 4. *Chelinospora* sp. 1, 9-10286A (D39); 5. *Cordobesia orientalis* Pöthe de Baldis 1977, 2-10313A (Y22/1); 6. *Cordobesia uruguayensis* (Martínez-Macchiavello) Pöthe de Baldis 1977, 6-10289A (C23); 7. *Cymatiosphaera fallax* Deunff 1966, 7-10288A (S24/3); 8, 9. *Cymatiosphaera mirabilis* Deunff 1959, 6-10289A (Z38/1), 9-10286A (E30/4); 10. *Cymatiosphaera* sp. aff. *C. multisepta* Deunff 1955 in Mullins, 2001, 9-10286A (M43/2); 11. *Cymatiosphaera prismatica* Deunff ex Deunff 1961, 9-10286A (M43/2); 12. *Cymbosporites* sp., 9-10286A (E34/3); 13. *Dictyotidium dictyotum* (Eisenack) Eisenack 1955, 7-10288A (S36/2); 14. *Dictyotidium variatum* Playford 1977, 7-10288A (N24/3); 15. *Dorsennidium europeum* (Stockmans & Willièrè) Sarjeant & Stancliffe 1994 emend. Mullins 2001, 7-10288A (K39/4); 16. *Helios aranaides* Cramer 1964, 9-10286A (K28/2); 17. *Duvernaysphaera stellata* Deunff 1964, 7-10288A (T43/4); 18. *Estiastra* sp. cf. *E. rhytidoa* Wicander & Wood 1981, 9-10286A (X38/2); 19. *Estiastra rugosa* Wicander 1974, 9-10286A (G40/3); 20. *Gorgonisphaeridium* sp., 9-10286A (M39/3); 21. *Lophosphaeridium* sp., 7-10288A (V44/4); 22. *Melikeriopalla polygonia* (Staplin) Mullins 2001, 7-10288A (U23/3); 23. *Multiplicisphaeridium arbusculum* Dornig 1981, 6-10289A (W44/1); 24. *Multiplicisphaeridium* sp., 6-10289A (V23/1); 25. *Multiplicisphaeridium rochesterensis* (Cramer & Díez) Eisenack et al. 1973, 9-10286A (S35/1); 26. *Navifusa bacilla* (Deunff) Playford 1977, 6-10286A (J42/4). Scale bars = 20 µm.



**Plate 4.** Palynomorphs from the Talacasto Formation. 1. *Hemiruptia* sp., 12-10298 (C32); 2. *Multiplicisphaeridium micropilare* Cramer ex Eisenack et al. 1973, 8-10308B (H44/1). Palynomorphs from the Punta Negra Formation. 3. *Palacanthus ledanoisii* (Deunff) emend. Playford 1977, 9-10286A (J24/4); 4. *Petalosphaeridium* sp., 6-10289A (D31/1); 5. *Polyedryxium* sp. cf. *P. condensum* Deunff 1971, 2-10313A (P36/4); 6. *Polyedryxium decorum* Deunff 1955, 6-10289A (U24); 7. *Polyedryxium embudum* Cramer 1964, 9-10286A (V33/3); 8. *Polyedryxium fragosulum* Playford 1977, 9-10286A (W21/2); 9. *Polyedryxium* sp. cf. *P. multifrons* Deunff 1971, 2-10313A (N40/4); 10. *Polyedryxium* sp. cf. *P. robustum* Deunff 1971, 7-10288A (D35/2); 11. *Polyedryxium* sp. cf. *P. wenlockium* (Dorning) Le Hérisse 1989, 6-10289A (D36); 12. *Pterospermella circumstriata* (Jardiné et al.) Eisenack et al. 1973, 7-10288A (F29/1); 13. *Pterospermella* sp. cf. *P. pernambucensis* (Brito) Eisenack et al. 1973, 9-10286A (L24/4); 14. *Quadrsporites variabilis* (Cramer) Ottone et al. 1996, 9-10286A (W40/2); 15. *Retusotriletes* sp., 9-10286A (H33/1); 16. *Riculasphaera fissa* Loeblich & Drugg 1968, 9-10286A (L34/2); 17. *Schizocystia pilosa* Jardiné et al. 1972, 10-10285A (Z29/1); 18. *Stellinium micropolygonale* (Stockmans & Willière) Playford 1977, 9-10286A (E42/3); 19. *Tetraedraletes medinensis* (Strother & Traverse) Wellman & Richardson 1993, 10-10285A (D38); 20. cf. *Tyligmasoma alargada* (Cramer) Playford 1977, 9-10286A (M39/3). Scale bars = 20  $\mu$ m.





**Figure 4.** Stratigraphic distribution of marine phytoplankton in the uppermost part of the Los Espejos Formation (LEF) and the Talacasto Formation at Cerro La Chilca, and the proposed ages. Black rectangles indicate presence of the species; grey rectangles are questionable occurrences (+, in Wicander 1986; ±, in Mullins 2001; \*, in Amenábar 2006).

Meanwhile, the stratigraphically and palaeogeographically important acritarch genus *Bimerga* Wood 1995, which ranges from the late Pragian to the Frasnian exclusively in Gondwana (Wood 1995; Le Hérissé 2011), has also been identified in two sections of the Punta Negra Formation, at the Loma de los Piojos section (García Muro et al., unpublished data) and Talacasto Creek

(Rubinstein 2000). These findings would also reinforce the Gondwanan affinities for the Argentinean Precordillera phytoplankton.

Further palynological studies on the Punta Negra Formation are required in order to constrain the age of the entire stratigraphic unit as well as to establish more reliable correlations with other assemblages from Gondwana and other palaeocontinents.



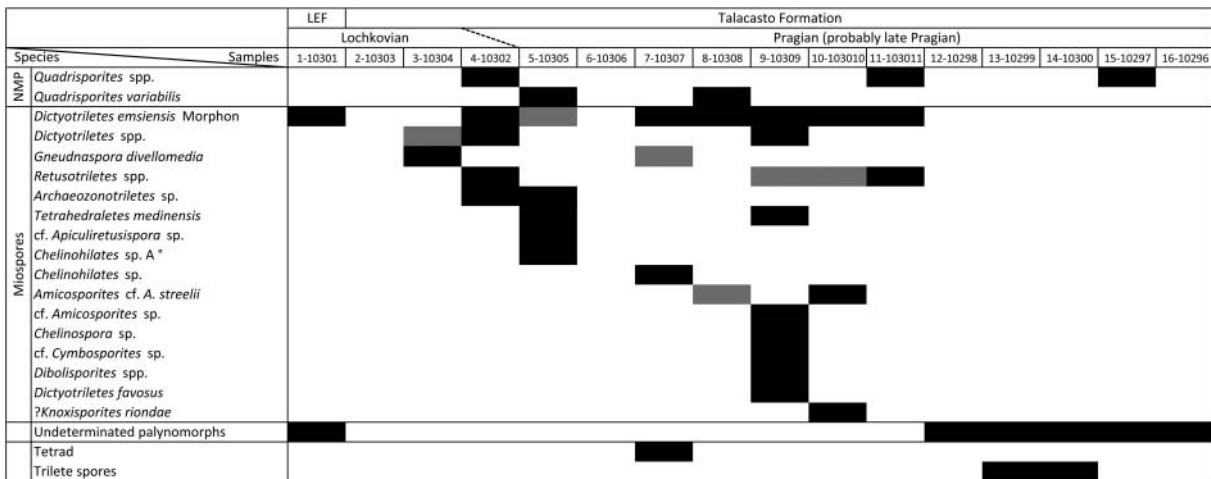


Figure 5. Stratigraphic distribution of non-marine palynomorphs (NMP) and miospores from the uppermost part of the Los Espejos Formation (LEF) and the Talacasto Formation at Cerro La Chilca, and the proposed ages. Black rectangles indicate presence of the species; grey rectangles are questionable occurrences (°, in Wellman et al. 2015).



Figure 6. Stratigraphic distribution of marine phytoplankton in the Punta Negra Formation at Talacasto Creek, and proposed ages. Black rectangles indicate presence of the species; grey rectangles are questionable occurrences (±, in Mullins 2001).

		Punta Negra Formation						
		early Emsian						
Species	Samples	2-10313	4-10291	6-10289	7-10288	8-10287	9-10286	10-10285
Marine phytoplankton	<i>Cymatiosphaera prismatica</i>						■	
	<i>Estiastra</i> cf. <i>E. rhytidoa</i>						■	
	<i>Estiastra rugosa</i>						■	
	<i>Helios aranaides</i>						■	
	<i>Multiplicisphaeridium rochesterensis</i>						■	
	<i>Palacanthus ledanoisii</i>						■	
	<i>Polyedryxium embudum</i>						■	
	<i>Polyedryxium fragosulum</i>						■	
	<i>Pterospermella</i> cf. <i>P. pernambucensis</i>						■	
	<i>Quadraditum</i> sp.						■	
	<i>Riculasphaera fissa</i>						■	
	<i>Stellinium micropolygonale</i>						■	
	cf. <i>Tyligmasoma alargadum</i>						■	
	<i>Schizocystia pilosa</i>							■
NMP	<i>Quadrisporites</i> spp.					■	■	■
	<i>Quadrisporites variabilis</i>					■	■	■
Miospores	<i>Retusotriletes</i> spp.	■					■	■
	<i>Ambitisporites</i> sp.			■				
	<i>Dibolisporites</i> spp.				■		■	
	cf. <i>Gneudnaspota divellomedia</i>				■	■		
	<i>Acinosporites</i> cf. <i>A. lindlarensis</i>				■	■		
	<i>Apiculatasporites microconus</i>				■	■		
	cf. <i>Dictyotriletes</i> sp.				■	■		
	<i>Acinosporites</i> sp.					■		
	cf. <i>Apiculiretusispora</i> sp.					■		
	<i>Archaeozonotriletes chulus</i>						■	
	<i>Chelinospora</i> sp. 1						■	
	<i>Cymbosporites</i> sp.						■	
<i>Tetrahedraletes medinensis</i>							■	
Indet.	ppr	■	■	■	■	■	■	■
	Trilete spore	■	■	■	■	■	■	■
	Tetrad	■	■	■	■	■	■	■
	Sphaerophytas				■		■	

Figure 7. Stratigraphic distribution of non-marine palynomorphs (NMP) and miospores in the Punta Negra Formation at Talacasto Creek, and the proposed ages. Black rectangles indicate presence of the species; the grey rectangle is a questionable occurrence. ppr = possible palynomorph remains; Sphaerophytas = sphaeromorphs.

Species	Age	late Silurian		Early Devonian			Middle Devonian		Late Devonian	
		Ludlow	Pridoli	Lochkovian	Pragian	Emsian	Eifelian	Givetian	Frasnian	Famennian
<i>Cymatiosphaera daioariochora</i>		Ar				?				Eu
<i>Melikeriopalla polygonia</i>		Ar	?				Eu			?
<i>Cymatiosphaera prismatica</i>		Ar	?				Eu			?
<i>Cymatiosphaera mirabilis</i>		Ar					Eu			
<i>Tylligmasoma alargada</i>				Ar - Bo - Bz - Ur - Eu - ME/Af - Sp/Fr						
<i>Cymatiosphaera multisepta</i>				Ar - Eu - ME/Af						
<i>Helios aranaides</i>				Ar - Bz - ME/Af - Sp/Fr			?			
<i>Ozotobracion palidodigitatus</i>				Ar - Bz - Eu						
<i>Polyedryxium helenaster</i>				Ar - Sp/Fr						
<i>Quadratum fantasticum</i>				Ar - Bz - Eu - ME/Af - Sp/Fr						
<i>Cymatiosphaera octoplana</i>				Ar - Eu						
<i>Oppilatala ramusculosa</i>				Ar - Eu - Sp/Fr						
<i>Stellinium rabians</i>				Ar - Bz - ME/Af - Sp/Fr						
<i>Cymatiosphaera multicristata</i>				Ar - Eu						
<i>Estiastra stellata</i>		Ar - Et		ME/Af						
<i>Pterospermella rajada</i>			Sp/Fr							
<i>Cymatiosphaera franjada</i>			Sp/Fr							
<i>Pterospermella circumstriata</i>				Ar - Bo - Bz - Ur - Eu - ME/Af						
<i>Schizocystia pilosa</i>				Ar - Bo - Bz - ME/Af						
<i>Polyedryxium embudum</i>							Ar - Eu			
<i>Polyedryxium multifrons</i>							Eu - ME/Af			
<i>Stellinium micropolygonale</i>							Ar - Bo - Ur - Eu - ME/Af - Sp/Fr			
<i>Winwaloesia distracta</i>				Ar - Bz - Ur - ME/Af - Sp/Fr						
<i>Riculasphaera fissa</i>				Bz - Bo - Eu - ME/Af						
<i>Tysanoprobolus polykion</i>				Ar - Bz - Eu						
<i>?Cymatiosphaera florida</i>				Ar - Bz - ME/Af						
<i>Evittia sommeri</i>							Ar - Bo - Bz - Ur - Sp/Fr			
<i>Palacanthus ledanoisii</i>							Ar - Bo - Bz - Ur - Eu - ME/Af			
<i>Polyedryxium decorum</i>							Ar - Ur - Eu - ME/Af - Sp/Fr			
<i>Polyedryxium fragosulum</i>							Ar - Bz - Ur - Eu - ME/Af			
<i>Exochoderma triangulata</i>							Ar - Bo - Ur - Eu - ME/Af			
<i>Cordobesia uruguayensis</i>							Ar - Bz - Ur			
<i>Cordobesia orientalis</i>							Ar - Bz - Ur			
<i>Navifusa bacilla</i>							Ar - Bo - Bz - Ur - Eu - ME/Af - Sp/Fr			
<i>Estiastra rhytdoa</i>							Ar - Bo - Bz - Eu			
<i>Hemiruptia legaultii</i>							Ar - Bo - Ur - Eu			
<i>Polyedryxium leptum</i>							Ar - Eu			
<i>Hapsidopalla exornata</i>							Ar - Bz - Eu			
<i>Pterospermella pernambucensis</i>							Ar - Bo - Bz			
<i>Dateriocradus lindus</i>						Sp/Fr				
<i>Duvernaysphaera stellata</i>							Ar - ME/Af			
<i>Polyedryxium evolutum</i>							Ar - Eu			
<i>Estiastra rugosa</i>										Eu
<i>?Knoxisporites riondae</i>			Sp/Fr		Ar - Bz - Ur - ME/Af - Sp/Fr					
<i>Amicosporites streelii</i>				Ar - Bz - Ur - Eu - ME/Af - Sp/Fr						
<i>Acinosporites lindlarensis</i>					Ar - Bo - Bz - Ur - Eu - ME/Af					
<i>Dictyotriletes emsiensis</i> Morphon					Ar - Bo - Bz - Ur - Sp /Fr					
<i>Dictyotriletes favosus</i>					Bz - Eu - ME/Af - Sp/Fr					
<i>Apiculatasporites microconus</i>							Ar - Bo - Eu			

**Figure 8.** Worldwide stratigraphic range and geographical distribution of selected species recognised in the Talacasto Formation and the lower part of the Punta Negra Formation, based on selected literature. Ar (Argentina): Amenabar (2006); di Pasquo & Noetinger (2008); Amenabar et al. (2009); Noetinger (2010); Rubinstein & García Muro (2011, 2013); Noetinger & di Pasquo (2011, 2013). Bo (Bolivia): Vavrdová et al. (1996); Troth et al. (2006); di Pasquo & Noetinger (2008); Wicander et al. (2011); di Pasquo et al. (2015). Bz (Brazil): Brito (1967); Quadros (1999); Cardoso & Rodrigues (2005); Rubinstein et al. (2005, 2008); Grahn et al. (2010, 2013). Ur (Uruguay): Pöthe de Baldis (1977); Daners et al. (2012); Rubinstein (unpublished data). Eu (Euramerica): Deunff (1961); Wicander (1974, 1986); Wicander & Wood (1981, 1997); Wicander & Wright (1983); Mullins (2001, 2004); Filipiak (2011); Turnau (2014). ME/Af (Middle East/Africa): Deunff (1966); Jardiné et al. (1974); Moreau-Benoit (1984); Ghavidel-syooki (2001); Breuer & Steemans (2013). Sp/Fr (Spain/France): Cramer (1964); Deunff (1980). References contained in the papers are also included.



## 5. Conclusions

The palynological assemblages reported from the Talacasto and the Punta Negra formations are dominated by marine phytoplankton and are the most diverse yet recovered from the Lower Devonian of the Argentinean Precordillera.

The phytoplankton and miospores from the Talacasto Formation analysed here suggest a Lochkovian to Pragian (probably late Pragian) age for the almost 850 m of section exposed at Cerro La Chilca. The Lochkovian is only represented in the basal part while the Pragian (probably late Pragian) age recognised for the lower part of the unit does not agree with the age based on megafauna, which indicates that at least the lower third of the formation is Lochkovian. Thus, the probable stratigraphic position of the Lochkovian/Pragian boundary, which is extremely difficult to recognise in the Precordillera, is proposed to be located around 11 m above the base of the Talacasto Formation, based on palynomorphs.

Furthermore, above the Keidel horizon, the faunas indicate an early Emsian age, whereas the palynomorphs from the Talacasto Formation at Cerro La Chilca indicate an age no younger than late Pragian. Palynological assemblages from the lower part of the Punta Negra Formation at Talacasto Creek, however, support the early Emsian age based on fauna.

This information is significant since it restricts the age of the Keidel horizon to late Pragian–early Emsian, as previously proposed, which reinforces it as an important lithostratigraphic marker. Further studies of additional sections throughout the basin could contribute to the resolution of age inconsistencies and a more accurate biostratigraphy for the units involved.

In spite of the cosmopolitan nature of most of the recorded taxa, the presence of palaeogeographically restricted palynomorphs supports Gondwanan affinities of the studied assemblages.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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