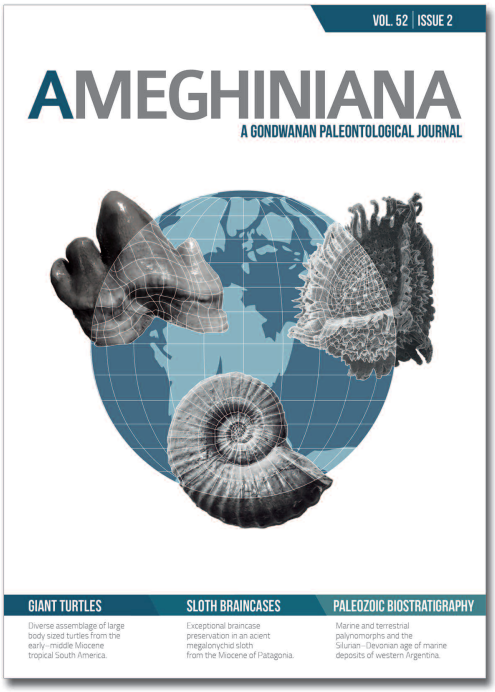
AMEGHINIANA
A GONDWANAN PALEONTOLOGICAL JOURNAL



NEW BIOSTRATIGRAPHIC PROPOSAL FOR THE LOWER PALAEOZOIC TUCUNUCO GROUP (SAN JUAN PRECORDILLERA, ARGENTINA) BASED ON MARINE AND TERRESTRIAL PALYNOMORPHS

VICTORIA J. GARCÍA-MURO[1]
CLAUDIA V. RUBINSTEIN[1]

[1]Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), CCT CONICET Mendoza, A. Ruiz Leal s/n, Parque General San Martín, M5502IRA Mendoza, Argentina.

Submitted: August 27th, 2014 - **Accepted:** December 14th, 2014

To cite this article: Victoria J. García-Muro and Claudia V. Rubinstein (2015). New biostratigraphic proposal for the Lower Palaeozoic Tucunuco Group (San Juan Precordillera, Argentina) based on marine and terrestrial palynomorphss. *Ameghiniana* 52: 265–285.

To link to this article: http://dx.doi.org/10.5710/AMGH.14.12.2014.2813

ISSN 0002-7014

AMEGHINIANA - 2015 - Volume 52 (2): 265 – 285 ARTICLES

NEW BIOSTRATIGRAPHIC PROPOSAL FOR THE LOWER PALAEOZOIC TUCUNUCO GROUP (SAN JUAN PRECORDILLERA, ARGENTINA) BASED ON MARINE AND TERRESTRIAL PALYNOMORPHS

VICTORIA J. GARCÍA-MURO[1] AND CLAUDIA V. RUBINSTEIN[1]

[1]Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), CCT CONICET Mendoza, A. Ruiz Leal s/n, Parque General San Martín, M5502IRA Mendoza, Argentina. *vgarcia@mendoza-conicet.gob.ar*, *crubinstein@mendoza-conicet.gob.ar*

Abstract. This is an exhaustive analysis of the palynomorph assemblages, organic-walled marine phytoplankton and miospores from the Tucunuco Group. This group includes the La Chilca and Los Espejos formations and is exposed in the Central Precordillera of San Juan. Four localities were included in this study, *i.e.*, Río Jáchal, Río de las Chacritas, Cerro La Chilca and Quebrada Ancha. Previous data concerning several fossil groups, such as graptolites, conodonts and brachiopods, suggest a mainly Llandovery–Wenlock? age for the La Chilca Formation and a Wenlock to locally Lochkovian age for the Los Espejos Formation. Marine palynomorphs are predominant in the two formations in all the studied sections. Although terrestrial palynomorphs are the minor component, trilete spores are abundant, diverse and biostatigraphically relevant in the Los Espejos Formation. Correlations using marine palynomorph assemblages and miospore biozones recognized worldwide allow constraining the age of the two stratigraphic units. Based on marine phytoplankton, the middle–upper part of the La Chilca Formation is assigned to the Wenlock. In the Los Espejos Formation, palynomorph assemblages allow the recognition, from the base to the top, of the Wenlock with doubts, the Ludlow, and the Pridolí. The Lochkovian has been documented exclusively in the northern part of the basin. This confirms the presence of the Silurian/Devonian boundary in the upper part of the Los Espejos Formation. A north-south correlation panel of the studied sections is presented.

Key words. Biostratigraphy. Organic-walled phytoplankton. Miospores. Tucunuco Group. Silurian. Devonian. Argentinian Precordillera.

Resumen. NUEVA PROPUESTA BIOESTRATIGRÁFICA PARA EL GRUPO TUCUNUCO (PALEOZOICO INFERIOR), PRECORDILLERA DE SAN JUAN, ARGENTINA, BASADA EN PALINOMORFOS MARINOS Y TERRESTRES. Se realizó un análisis exhaustivo de las asociaciones palinológicas (fitoplancton marino de pared orgánica y mioesporas) del Grupo Tucunuco, Precordillera Central de San Juan, registradas en las localidades de Río Jáchal, Río de las Chacritas, Cerro La Chilca y Quebrada Ancha. Las dataciones previas, provenientes de diversos grupos fósiles como graptolitos, conodontes y braquiópodos, sugieren una edad principalmente llandoveriana–wenlockiana? para la Formación La Chilca y wenlockiana, hasta localmente lochkoviana, para la Formación Los Espejos. Se destaca la predominancia de los palinomorfos marinos en ambas unidades y en todos los perfiles analizados. Si bien los palinomorfos terrestres constituyen el componente minoritario, en la Formación Los Espejos las esporas trilete son abundantes, diversas y estratigráficamente relevantes. A partir de la correlación con asociaciones de palinomorfos marinos y con biozonas de esporas reconocidas en distintas regiones del mundo, se ajustan las edades de ambas formaciones, presentándose un nuevo esquema estratigráfico. Se confirma la edad wenlockiana para la parte media–superior de la Formación La Chilca, en base a su contenido fitoplanctónico. En la Formación Los Espejos los palinomorfos permiten distinguir, de base a techo, depósitos posiblemente wenlockianos, ludlovianos, pridolianos y lochkovianos exclusivamente en el perfil más septentrional estudiado. Se confirma por lo tanto la presencia del límite Silúrico/Devónico en la parte superior de esta formación. Se propone un esquema de correlación norte-sur de los perfiles estratigráficos estudiados.

Palabras clave. Bioestratigrafía. Fitoplancton de pared orgánica. Mioesporas. Grupo Tucunuco. Silúrico. Devónico. Precordillera argentina.

During the Middle–Late Ordovician, the Cuyania Terrane collided with the Cambro–Ordovician western margin of Gondwana causing its partial destruction (Benedetto, 1993). This collision produced a drastic change in the basin sedimentary configuration, determining the arrangement of the Silurian–Devonian deposits (Benedetto, 2010). Astini (1992) and Astini *et al.* (1995) recognized the development of a flexural bending which formed the Talacasto-Tambolar arch in the Central Precordillera. This arch underwent recurring relaxation and contraction events, causing wedging of the stratigraphic units and important interruptions in the sedimentation process (Astini *et al.*, 1995).

The Silurian–Devonian deposits of the Precordillera infilled a typical foreland basin and reach a maximum thickness of 1100 m in the northern outcrops, decreasing southwards (Astini *et al.*, 1995). The Silurian of the Central Precordillera of San Juan Province is represented by the Tucunuco Group (Cuerda, 1969a), which includes the La Chilca (Cuerda, 1965) and the Los Espejos (Cuerda, 1965) formations. Its maximum thickness is 500–600 m in the Jáchal area, decreasing southwards down to 200 m in the Sierra de la Dehenza (Baldis and Peralta, 1999).

Cuerda (1965) studied graptolite assemblages indicating an Early Llandovery to Early Wenlock age for the La Chilca Formation at its type locality (Cerro La Chilca). Melendi and Volkheimer (1982, 1983) found an acritarch assemblage with no biostratigraphic value in beds near the base of the unit, at 5.5 m above the basal conglomerate bed in the Quebrada de Talacasto section. These levels also contain Llandovery graptolites, such as *Climacograptus* aff. *hughesi* and *Monograptus* spp.. The basal part of the formation was assigned to the Hirnantian (Late Ordovician) followed by the Rhuddanian (Early Silurian), based on the *Normalograptus persculptus* and, probably, the *Parakidograptus acuminatus* and *Atavograptus atavus* graptolite zones (Brussa, 1987; Cuerda *et al.*, 1988; Rickards *et al.*, 1996). On the basis of the presence of *Monograptus priodon,* Kerlleñevich and Cuerda (1986) assigned a Llandovery–Wenlock? age to the lower–middle part (19.4 m below the top of the section) of the La Chilca Formation exposed near the locality known as Talacasto. These authors pointed out that *M. priodon* had been recorded worldwide in levels "just below" the Wenlock. At a later date, Pöthe de Baldis (1987) studied the palynomorphs from the upper part of the La Chilca Formation in the Aguada de Los Azulejitos area. The presence of the acritarch genera *Deunffia* and *Domasia* suggested a Late Llandovery to Early Wenlock age for this part of the section. Based on the brachiopod fauna Benedetto (1995) confirmed an Early Llandovery age (Rhuddanian) for the lower to middle part of the La Chilca Formation at the Cerro del Fuerte and Cerro La Chilca sections. Later, Pöthe de Baldis (1997) recognized an acritarch assemblage in a bed near the middle part of the La Chilca Formation at Quebrada de Talacasto. Because of the presence of *Tylotopalla robustispinosa* and *Oppilatala eoplanktonica*, the author referred this level as early to middle Llandovery. Lehnert *et al.* (1999) recorded conodonts of the *Distomodus kentuckyensis* Zone from the lower part of the section at the Cerro del Fuerte locality, indicating a middle Rhuddanian to Aeronian age. Upon review of previous palynological papers, Pöthe de Baldis and Peralta (1999) suggested a Late Ordovician–Early Wenlock age for the La Chilca Formation, but their work needs to be reassessed since several palynomorphs have been re-dated. Finally, Rubinstein and Brussa (1999) integrated studies on phytoplankton, miospores and graptolites from several sections of the La Chilca Formation and recognized two palynological assemblages. Assemblage 1 occurs near the base of the stratigraphic unit, in levels assigned to the *Normalograptus persculptus* graptolite Zone, which indicates a Hirnantian age. Phytoplankton in this assemblage was scarce, badly preserved and whithout stratigraphic value. Assemblage 2 occurs in the lower part of the formation, in levels assigned to the upper part of the *Stimulograptus sedgwickii* Zone and the lower part of the *Spirograptus turriculatus* Zone, pointing to a Late Aeronian–Early Telychian age. *Tylotopalla caelamenicutis* and *Tylotopalla digitifera* were identified among the acritarchs of the Assemblage 2, thus supporting the age indicated by the graptolites. It is important to note that the paleontological records come mainly from the lower to middle part of the La Chilca Formation while they are scarce in the upper part, which was tentatively assigned to the Wenlock.

The first paleontological dating of the Los Espejos Formation was from the middle part of the unit at the Cerro La Chilca section, where Cuerda (1969b) recorded *Monograptus uncinatus notouncinatus* Cuerda, *Monograptus leintwardinensis* var. *incipiens* Elles and Wood, and *Monograptus argentinus* Cuerda; the author proposed an early Ludlow age for these beds and a probable Wenlock age for the basal part. Later, Hünicken and Sarmiento (1988) recorded conodonts in the middle–upper part of the unit in the Quebrada Ancha area. The recognition of the *Polygnathoides siluricus* Zone and the *Pedavis latialata* Zone suggested an age no older than Ludfordian. However, Albanesi *et al.* (2006) found conodonts of the *Kockelella variabilis variabilis* Zone in the middle–upper part of the Sierra de Talacasto section; these pointed to an Early Ludlow age (Gorstian). They remarked that the species recorded by Hünicken and Sarmiento (1988) do not confirm the proposed age.

Sánchez *et al.* (1991) and Benedetto *et al.* (1992) inter-

preted the age of the Los Espejos Formation on the basis of the brachiopod fauna from the northern outcrop at Cerro del Fuerte, near Jáchal. These authors recognized four faunas and assigned them to the Wenlock?, Ludlow, Pridoli and Early Lochkovian. The youngest age is present only in the northern outcrops of the Los Espejos Formation. According to these authors, the lower to middle part of the section does not contain any biostratigraphically relevant brachiopods. Meanwhile, in the upper part of the unit, the presence of *Coelospira extensa* Benedetto and Toro would indicate a Pridoli age. Additionally, the presence of the genera *Molongella* and *Australocoelia* in the uppermost levels suggests a Lochkovian age. Rickards *et al.* (1996) recognized the *Neodiversograptus nilssoni-Lobograptus scanicus* graptolite zones. This finding in the upper third of the Los Espejos Formation, in the Cerro del Fuerte area, would suggest a maximum Early Ludlow age for these beds. Near the top of the section there are not graptolites neither palynomorphs (Rubinstein and Brussa, 1999). Heredia *et al.* (2007) and Rodríguez *et al.* (2010) analyzed the conodonts in Loma de los Piojos and Cerro del Fuerte sections. They confirmed that the upper part of the Los Espejos Formation is Gorstian because of the occurrence there of *Kockelella variabilis variabilis*, hence excluding the possibility of younger ages for the unit even though these authors did not record conodonts in the upper beds of the section. Pöthe de Baldis and Peralta (1999), in a reassessment of previous palynologycal studies, proposed a Ludlow–Lochkovian? age for the Los Espejos Formation. However, the probable Lochkovian age was misinterpreted by the latter authors because it was based on palynological results of Rubinstein (1992), from the Loma de Los Piojos section, which indicated a probable Pridoli age for the upper levels of the Los Espejos Formation at this locality.

Summarizing, the available paleontological information does not allow constraining the age of the lower part of the Los Espejos Formation. Contrarily, the middle and upper parts yielded fossils such as brachiopod faunas that helped to constrain a more precise age for the unit. This age is younger in the northern sections and changes throughout the basin. To date, the Early Devonian age of the uppermost part of the Los Espejos Formation could not be confirmed by means of other fossil groups.

The difference in the thickness of both formations (La Chilca and Los Espejos) throughout the basin, the discontinuity of the strata, the marked diachronism, and the magnitude and extent of the outcrops as well as the lack of stratigraphically valuable fossils, hinder precise dating (Rubinstein, 1995). The aim of this contribution is to propose a new biostratigraphic scheme for the Tucunuco Group following an analysis of several palynological assemblages from various stratigraphic sections, thus contributing to constrain the age of the stratigraphic units.

GEOLOGY

Cuerda (1965) described the La Chilca Formation as formed by alternation of grey-light-yellow sandstone and grey-dark green pelites at the type locality in Cerro La Chilca. Although the author assigned an Early Llandovery to Early Wenlock age to the formation based on the graptolite fauna, later works suggested a Hirnantian–Wenlock? age for this unit, as mentioned above. The La Chilca Formation reaches a maximum thickness of 128 m in the Jáchal area, in the central-northern part of the Central Precordillera of San Juan. This thickness decreases to the south-west reaching 25 m in the Talacasto area (Sánchez *et al.*, 1991; Astini and Maretto, 1996). The La Chilca Formation overlies different Ordovician units, which are generally younger from north to south. Its upper contact with the Los Espejos Formation is an erosive hiatus observed throughout the basin (Astini and Maretto, 1996). Such unconformity was already noted by Cuerda (1965).

The La Chilca Formation recorded a transgressive to highstand sea-level history. Above a basal conglomerate level, a few maximum-flooding events would be indicated by the occasional presence of dark shaly intervals (Brussa and Astini, 1995). The maximum shallowing is observed towards the top of the unit. Its upper contact is represented by an erosive unconformity, diachronic from north to south, related to the flexural bending of the foreland basin (Astini and Maretto, 1996).

Astini and Piovano (1992) recognized two facies associations and later Astini and Maretto (1996) identified four facies associations in the La Chilca Formation, *i.e.*, (a) basal conglomerates, (b) laminate pelites, (c) rhythmically intercalated sandstones and pelites, (d) amalgamated quartz-sandstones. According to Astini and Maretto (1996), the Silurian stratigraphic units of the Precordillera (La Chilca

and Los Espejos formations) start with thin-tabular basal conglomerates with abundant chert and ferruginous oolites, which indicate erosive periods and mechanic contraction capable of eliminating the underlying sedimentary record. Therefore –according to these authors– there would be an erosive hiatus between both formations.

The Los Espejos Formation was also described by Cuerda (1965), although its type locality was designated later at northwestern Cerro La Chilca, in the Río Los Espejos creek, San Juan Province (Cuerda, 1985). The author described the formation as mainly composed by olive-green shales with parallel stratification alternating with green-grey muddy-sandstone to the top. The outcrops of this unit, as those of the La Chilca Formation, become thicker to the north, near the Río Jáchal, reaching about 500–600 m in the Cerro del Fuerte and the Loma de Los Piojos sections. Thickness decreases southwards, reaching 50 m at the Río San Juan (Sánchez *et al.*, 1991; Astini and Maretto, 1996; Benedetto *et al.*, 1996).

The base of the Los Espejos Formation is a thin conglomerate, rich in iron veneer and phosphate, followed by muddy shelf deposits with no influence of wave action. It changes upwards into a storm-wave-dominated shelf and shoreface facies, culminating the regressive cycle (Sánchez *et al.*, 1991; Astini and Piovano, 1992). The lower third of the unit is dominated by shales, the middle third is characterized by shales and sandstones, and an increase of the number and thickness of sandstone beds are observed towards the top (Sánchez, 1991). The Los Espejos Formation has been interpreted as a highstand sequence with an upward thickening and coarsening trend (Sánchez *et al.*, 1993; Astini and Maretto, 1996).

Astini and Piovano (1992) recognized three facies associations in the Los Espejos Formation and later Astini and Maretto (1996) identified seven facies associations, *i.e.*, (a) ferruginous conglomerates, (b) green-purple pelites, (c) thin tabular rhythmites, (d) thin heterolithic, (e) thick heterolithic, (f) amalgamated sandstones and (g) deformed heterolothic complex. In the middle and northern parts of the basin, where the formation reaches its youngest age, the facies association of deformed heterolothic complex is interpret as a result of liquefaction and fluence triggered by seismic activity. According to Astini and Maretto (1996), the seismic activity is related to the Precordillerana diastrophic phase, which could have caused the remarkable hiatus between this unit and the overlying Talacasto Formation (Astini and Maretto, 1996).

MATERIALS AND METHODS

This study includes palynomorph assemblages from 63 productive levels of the La Chilca and Los Espejos formations. The marine palynomorphs comprise acritarchs and clorophyte algae and the terrestrial palynomorphs include cryptospores and trilete spores. The studied sections are Río Jáchal, Río de las Chacritas, Cerro La Chilca and Quebrada Ancha (Tab. 1, Fig. 1.1 and 1.2). These stratigraphic sections were selected after considering major changes in the basin, in a north to south transect, with special emphasis on the lower and upper stratigraphic limits of both units.

The samples were prepared in the Palynology Laboratory of Liège University, Belgium, and in the Paleopalynology Laboratory of the Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales, Centro Científico Tecnológico CONICET Mendoza. The studied slides were those processed in Liège University except for the ones from the Río de las Chacritas section, which were wholly processed

Table 1 - Localities and samples studied per formation.

Formation	*Locality*	*Samples collected*	*Palyniferous samples*
La Chilca	*Cerro La Chilca*	*7*	*1*
	Quebrada Ancha	*24*	*23*
Los Espejos	*Río Jáchal*	*9*	*9*
	Cerro La Chilca	*7*	*7*
	Río de las Chacritas	*19*	*9*
	Quebrada Ancha	*18*	*14*

in the laboratory of IANIGLA. The methods applied in both laboratories were similar, using standard palynological HCl-HF-HCl acid maceration techniques. The oxidation in IANIGLA was carried out with NOH_3 for 2 minutes and, in Liège University, with "low-grade" Schulze solution (with 65% NOH_3) for 2 hours. The organic residues were then screened on a 12 µm sieve. The preparation technique used for the Río de las Chacritas samples is further detailed in Rubinstein and García Muro (2011).

The palynological slides are housed in the palynological collection of the IANIGLA, CCT CONICET Mendoza, Argentina. Specimen locations are referred using England Finder coordinates. The complete list of recorded palynomorphs has been provided by Rubinstein and García Muro (2011), García Muro *et al.* (2014a,b) and García (2014).

The proposed ages for the studied sections are based on coeval trilete spore biozones established for different regions in different palaeocontinents (García Muro *et al.*, 2014a) and on the worldwide stratigraphic distribution of the organic-walled phytoplankton, particularly those taxa with recognized biostratigraphic value.

RESULTS

The marine phytoplankton is the most diverse in the

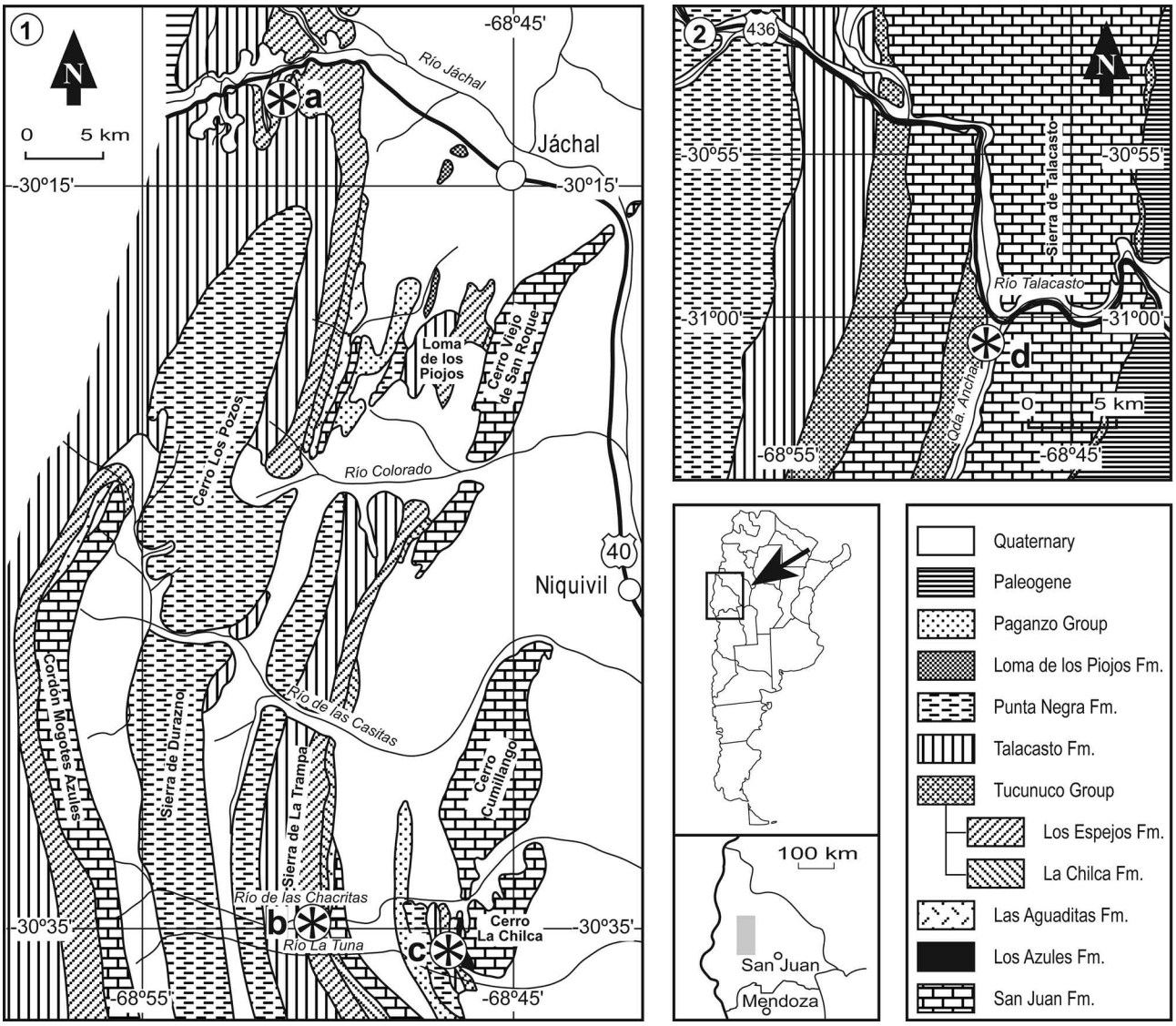


Figure 1.1, Geologic map of the localities studied, norther area. **a=** Río Jáchal; **b=** Río de Las Chacritas; **c=** Cerro La Chilca; **2,** Geologic map of the localities studied, southern area. **d=** Quebrada Ancha. Modified from Baldis (1975), Ferrero (2006) and Rustán (2011).

studied sections in both formations, representing 35–66% of the total palynomorph taxa, in coincidence with the marine environment previously described. Even though terrestrial palynomorphs –particularly the trilete spores– are less diversified than the marine palynomorphs, they show a clear increase in diversity and abundance toward the younger beds. The total number of species of all palynomorph groups recorded per stratigraphic unit, section and level, are detailed in García (2014). In this contribution, the species of recognized biostratigraphic significance are specially taken into account.

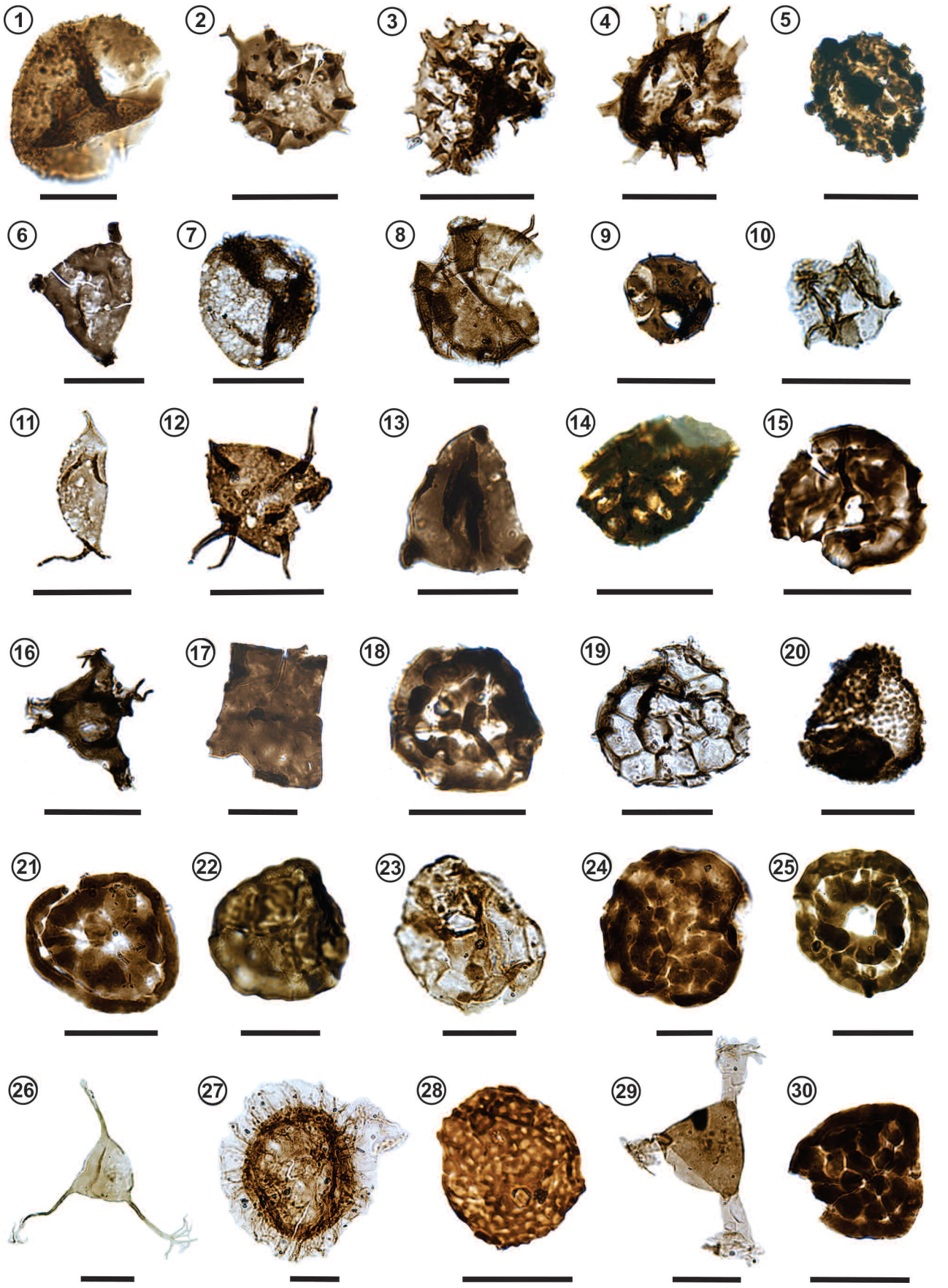
A single productive level (6-61052) at the type locality of the La Chilca Formation yielded badly preserved and poorly diversified palynomorphs. Fragmented palynomorphs constituted 80% of the assemblage, thus rendering very difficult any positive taxonomic indentification. In the same formation but in the Quebrada Ancha section, 23 productive levels yielded 100 palynomorph species. Marine phytoplankton is predominant in all of them, whereas the terrestrial palynomorphs are less than 3% of the palynomorph assemblage. Terrestrial palynomorphs only include cryptospores such as *Gneudnaspora divellomedia* and few specimens of the genus *Hispanaediscus*. Among the phytoplankton, the presence of species such as of *Multiplicisphaeridium bifurcatum*, *Tylotopalla caelamenicutis*, *T. digitifera*, *Schismatosphaeridium guttulaferum*, *Crassiangulina variacornuta*, *Stellinium rabians*, *Percultisphaera incompta* and *P.* cf. *stiphrospinata* may be highlighted (Fig. 2).

The palynomorph assemblage in the Los Espejos Formation is characterized by the abundance and diversity of the marine organic-walled phytoplankton, with some exceptions in certain levels (*i.e.*, 2-61161, 9-61063 in Río Jáchal, 14-60982 in Quebrada Ancha). Many species of stratigraphic value were recorded and their implications are discussed below.

In the northern locality, Río Jáchal, the abundance of trilete spores increases towards the upper levels, reaching up to 50% of the palynological assemblage. Nevertheless, miospore diversity is lower than phytoplankton diversity, with 36 miospore species and 47 phytoplankton species. Biostratigraphically relevant species were identified among the trilete spores, such as *Chelinospora* cf. *cantabrica*, cf. *Streelispora newportensis* and *Cymbosporites paulus*? in Wellman 1993a. The most useful species of phytoplankton were cf. *Thysanoprobolus polykion*, *Polyedrixium*? *asperum* and *Polyedryxium condensum* (Fig. 2). A comprehensive analysis of this section was provided by García Muro *et al.* (2014b).

In the Río de Las Chacritas section, *Chelinospora verru-*

Figure 2. 1, *Helosphaeridium* sp. A in Mullins, 2001, 6-61052 (L43), La Chilca Formation, Cerro La Chilca; **2, *Multiplicisphaeridium*** cf. ***bifurcatum*** Staplin, Jansonius and Pocock, 1965, 1-60975 (T40), La Chilca Formation, Quebrada Ancha; **3, *Tylotopalla caelamenicutis*** Loeblich, 1970, 2-60973 (M36 /1), La Chilca Formation, Quebrada Ancha; **4, *Tylotopalla digitifera*** Loeblich, 1970, 2-60973 (V36), La Chilca Formation, Quebrada Ancha; **5, *Schismatosphaeridium guttulaferum*** Le Herissé 1989, 3-60972 (X48 /1), La Chilca Formation, Quebrada Ancha; **6, *Crassiangulina variacornuta*** Wauthoz, Dorning and Le Hérissé,2003, 4-60971 (L50 /1), La Chilca Formation, Quebrada Ancha; **7, *Melikeriopalla polygonia*** (Staplin, 1961) Mullins, 2001, 8-60805 (R34), La Chilca Formation, Quebrada Ancha; **8, *Percultisphaera incompta*** Richards and Mullins, 2003, 9-60803 (P46 /4), La Chilca Formation, Quebrada Ancha; **9, *Nanocyclopia*** sp., 14-60737 (G46 /1), La Chilca Formation, Quebrada Ancha; **10, *Stellinium rabians*** (Cramer, 1964) Eisenack, Cramer and Díez, 1976, 10-60801 (J43 /2), La Chilca Formation, Quebrada Ancha; **11, *Domasia trispinosa*** Downie, 1960, 10-60801 (G44 /1), La Chilca Formation, Quebrada Ancha; **12, *Percultisphaera*** cf. ***stiphrospinata*** Lister, 1970, 14-60737 (G34 /2), La Chilca Formation, Quebrada Ancha; **13,** cf. ***Crassiangulina tesselita*** Jardiné, Combaz, Magloire, Peniguel and Vachey, 1972, 23-60701 (W38); **14, *Chelinospora*** cf. ***cantabrica*** Richardson, Rodríguez and Sutherland, 2001, 1-61161 (M26 /1), Los Espejos Formation, Río Jáchal; **15,** cf. ***Streelispora newportensis*** (Chaloner and Streel, 1968) Richardson and Lister, 1969, 6-61118 (F42 /4), Los Espejos Formation, Río Jáchal; **16,** cf. ***Thysanoprobolus polykion*** Loeblich and Tappan, 1970,4-61120, Los Espejos Formation, Río Jáchal; **17, *Schizocystia pilosa*** Jardiné, Combaz, Magloire, Peniguel and Vachey, 1972, 6-61118 (L43) , Los Espejos Formation, Río Jáchal; **18, *Amicosporites streelii*** Steemans, 1989, 10-61063 (L39 /3); **19,** cf. ***Dictyotriletes emsiensis*** **Morphon** Rubinstein, Melo and Steemans, 2005, 8-61116 (F21), Los Espejos Formation, Río Jáchal; **20, *Cymbosporites paulus*?** in Wellman, 1993a, 6-61118 (T41 /2), Los Espejos Formation, Río Jáchal; **21, *Amicosporites streelii*** Steemans, 1989, 13-60984 (S29 /1), Los Espejos Formation, Quebrada Ancha; **22, *Chelinospora*** cf. ***hemiespherica*** in Richardson, Rodríguez and Sutherland, 2001, MPLP 10-4733B (K35 /1), Los Espejos Formation, Río de las Chacritas; **23, *Schismatosphaeridium algerense*** Cramer and Díez, 1976, 1-61065 (G27 /4), Los Espejos Formation, Cerro La Chilca; **24, *Hispanaediscus lamontii*** Wellman, 1993b, 4-61059 (L44 /1), Los Espejos Formation, Cerro La Chilca; **25, *Coronaspora cromatica*** (Rodríguez, 1978) Richardson, Rodríguez and Sutherland, 2001, 4-61059 (Q28), Los Espejos Formation, Cerro La Chilca; **26, *Opilatalla insolita*** (Cramer and Díez, 1972) Dorning, 1981, 4-61059 (O49 /2), Los Espejos Formation, Cerro La Chilca; **27, *Fimbriaglomerella divisa*** Loeblich and Drugg, 1968, 4-61059 (G49 /2), Los Espejos Formation, Cerro La Chilca; **28, *Chelinohilates lornensis*** Wellman and Richardson, 1996, 1-60667 (N50 /1), Los Espejos Formation, Quebrada Ancha; **29, *Ozotobrachion palidodigitatus*** (Cramer, 1966 emend. Cramer, 1970) Playford, 1977, 7-60736 (P48 /4), Los Espejos Formation, Quebrada Ancha; **30, *Chelinospora verrucata*** var. ***verrucata*** **Morphon** García Muro, Rubinstein and Steemans, 2014a, 2-60704 (V37 /2), Los Espejos Formation, Quebrada Ancha. The bars represent 20 µm.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

cata var. *verrucata* Morphon and *Chelinospora* cf. *hemiesferica* were recorded among the trilete spores. *Polyedryxium helenaster*, *Fimbiraglomerella divisa*, *Stellinium rabians* and the genus *Ozotobrachion* are the most interesting marine taxa from a biostratigraphic point of view. A detailed analysis of this section was published by Rubinstein and García Muro (2011).

The Cerro La Chilca section yielded phytoplankton species such as *Schismatosphaeridium algerense*, *Fimbriaglomerella divisa* and *Ozotobrachion palidodigitatus*. Terrestrial palynomorphs include *Hispanaediscus lamontii*, *Chelinospora* cf. *cantabrica* (Fig. 2) and *C. sanpetrensis*.

The southernmost studied section, Quebrada Ancha, yielded the highest diversity of trilete spores, including 43 species. The most relevant taxa from the lower part of the section are *Coronaspora cromatica* (Fig. 2), *Emphanisporites* sp. D in Richardson *et al.,* 1981, *Stellatispora inframurinata* var. *inframurinata*, *Chelinospora* cf. *hemisferica*, *Brochotriletes foveolatus*, *Leonispora argovejae* (Fig. 3) and *Cymbosporites* cf. *catillus* in Richardson and Lister 1969. The presence of *Synorisporites verrucatus*, *Amicosporites* cf. *streelii* and *Emphanisporites* cf. *splendens* (Fig. 3) can be highlighted in the upper part of the section. Moreover, marine phytoplankton is represented by 120 species, with the noteworthy presence of *Melikeriopalla polygonia*, *Fimbriaglomerella divisa*, *Schismatosphaeridium perforatum* and *Leiofusa bernesga*. The exhaustive analysis of the trilete spores from the Quebrada Ancha section and its correlation with coeval worldwide miospore zones was published in García Muro *et al.* (2014a).

DISCUSSION

The La Chilca Formation has been considered Hirnantian–Wenlock based on several fossil groups, such as graptolites, phytoplankton, conodonts and brachiopods (*e.g.*, Kerleñevich and Cuerda, 1986; Pöthe de Baldis, 1987; Benedetto, 1995; Rubinstein and Brussa, 1999; Albanesi *et al.*, 2006).

At the type locality of the La Chilca Formation, Cerro La Chilca, the palynomorphs are badly preserved. However, some genera such as *Leprotolypa* and *Micrhystridium*, besides a few specimens of *Veryhachium* and *Helosphaeridium*

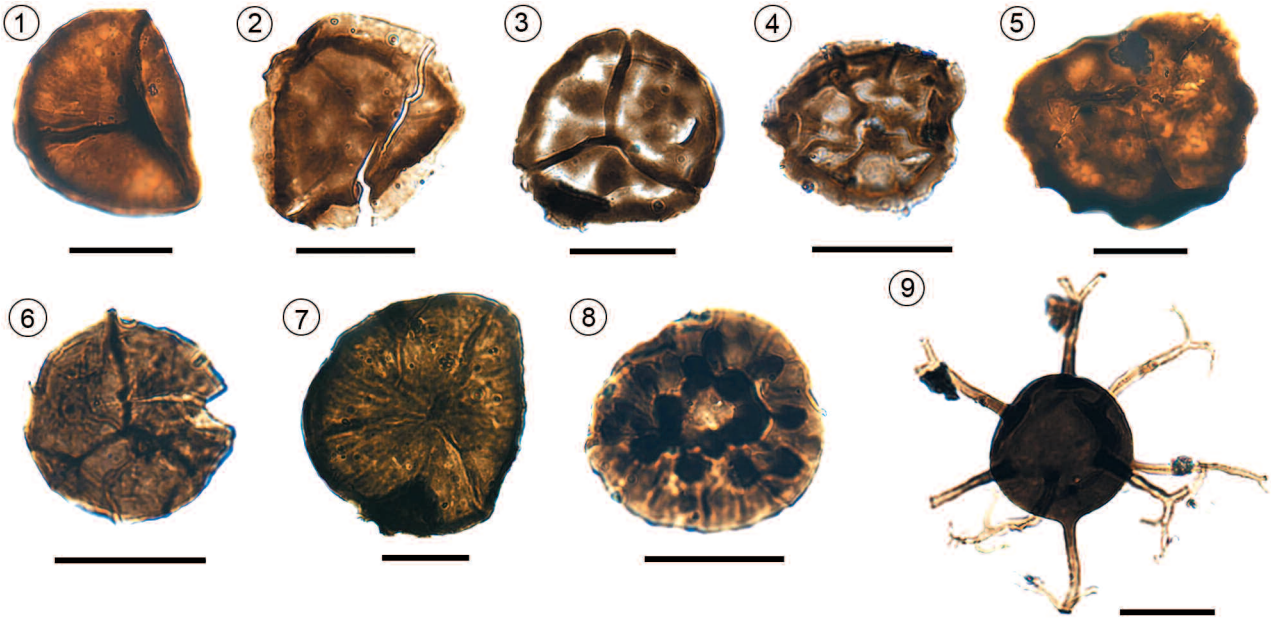


Figure 3. 1, *Stellatispora inframurinata* var. ***inframurinata*** (Richardson and Lister) Burgess and Richardson ,1995, 3-60659 (S28 /0), Los Espejos Formation, Quebrada Ancha; **2, *Breconisporites* sp. B** in Richardson, Rodríguez and Sutherland, 2001, 3-60659 (T28 /1), Los Espejos Formation, Quebrada Ancha; **3, *Synorisporites tripapillatus*** Richardson and Lister, 1969, 7-60736 (O32), Los Espejos Formation, Quebrada Ancha; **4, *Chelinospora*** cf. ***hemiesferica*** in Richardson, Rodríguez and Sutherland, 2001, 8-60677 (K33 /3), Los Espejos Formation, Quebrada Ancha; **5, *Brochotriletes foveolatus*** Naumova, 1953, 9-60664 (H27 /1), Los Espejos Formation, Quebrada Ancha; **6, *Leonispora argovejae*** Cramer and Diez, 1975, 9-60664 (E26 /4), Los Espejos Formation, Quebrada Ancha; **7, *Emphanisporites* sp. D** in Richardson, Rasul and Al-Ameri, 1981, 7-60736 (M31 /1), Los Espejos Formation, Quebrada Ancha; **8, *Emphanisporites*** cf. ***splendens*** Richardson and Ioannides, 1979, 13-60984 (J47 /1), Los Espejos Formation, Quebrada Ancha; **9, *Oppilatala ramusculosa*** (Deflandre, 1945) Dorning, 1981, 7-60736 (N37 /4), Los Espejos Formation, Quebrada Ancha. The bars represent 20 µm.

(Fig. 4.1), could be recognized. Noteworthy is the presence of *Helosphaeridium* sp. A in Mullins (2001), of which the only previous record was in the Wenlock of the United Kingdom.

Phytoplankton is better preserved and more diversified in the same formation in the Quebrada Ancha area. A single specimen doubtfully assigned to *Multiplicisphaeridium bi-*

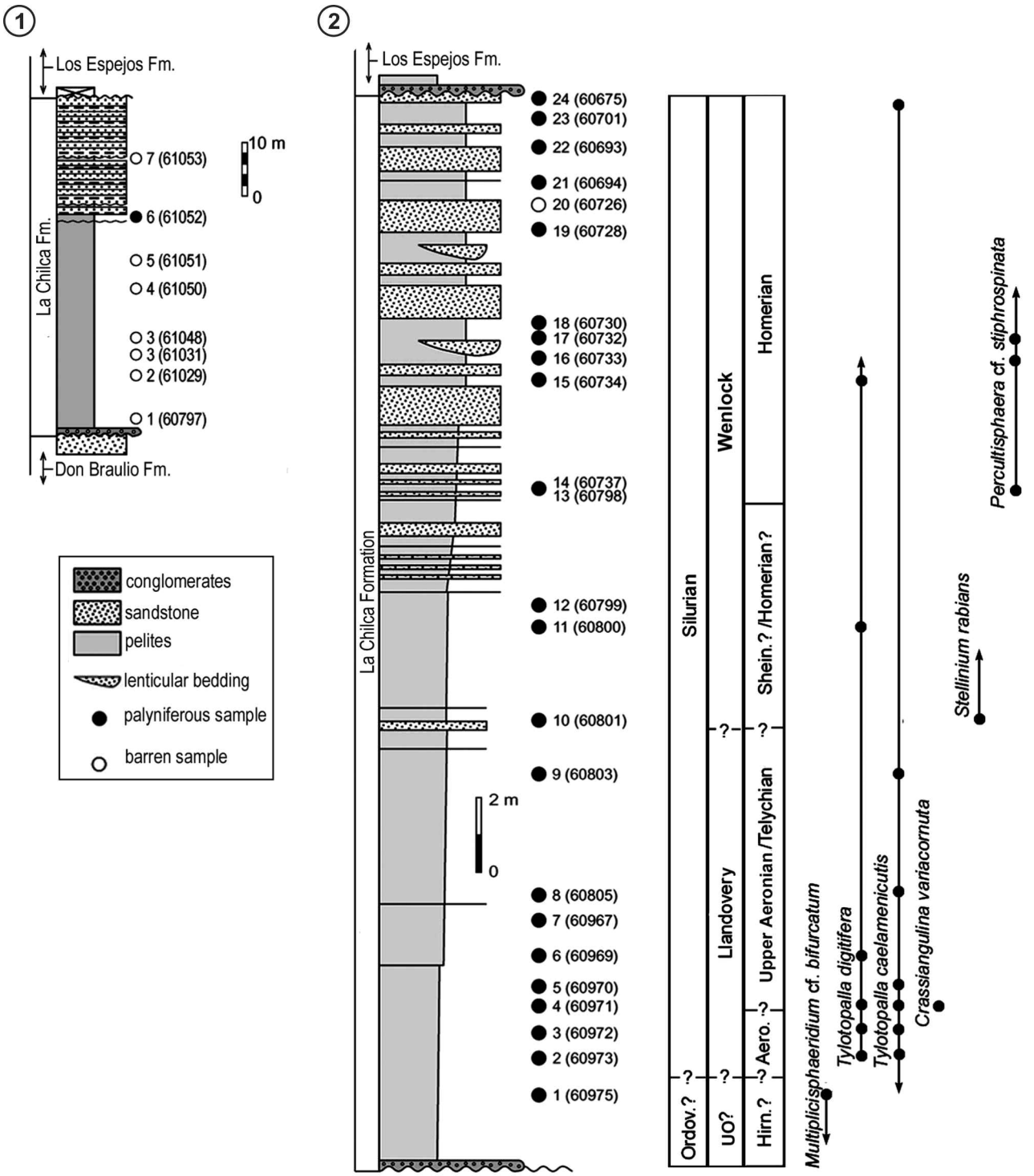


Figure 4. Stratigraphic distribution of the most relevant species of the La Chilca Formation; **1,** Cerro La Chilca section; **2,** Quebrada Ancha section. Lines and arrows point out the known biocron for the species, black circle on them indicate the presence of the species in the level. **Ordov.= Ordovician; UO= Upper Ordovician; Hirn.= Hirnantian; Aero.= Aeronian; Telych.= Telychian; Shein.= Sheinwoodian**.

furcatum occurs in the first level (1-60975). This is a cosmopolitan Upper Ordovician species (*e.g.*, Staplin *et al.*, 1965; Rubinstein and Vaccari, 2004; Ghavidel-Syooki, 2000). Its occurrence would support a Late Ordovician age for the basal part of the section, thus agreeing with the age based on the graptolite fauna (Brussa, 1987; Cuerda *et al.*, 1988; Rickards *et al.*, 1996).

Several specimens of *Tylotopalla caelamenicutis* and *T. digitifera* first occur in level 2-60973. Even if *T. caelamenicutis* first appears in the Late Hirnantian (Masiak *et al.*, 2003), *T. digitifera* has its first worldwide appearance in the Aeronian (Loeblich, 1970). Therefore, an Early Llandovery age can be inferred for this level. The same level also yielded *Dictyotidium faviforme*, *D. biscutulatum* and *D. stellatum*, which first appear in the Llandovery (Schultz, 1967; Kiryanov, 1978; Le Hérissé, 1989; Wauthoz, 2005).

Schismatosphaeridium guttulaferum (Fig. 4.2) was identified in level 3-60972. This species was described for the first time in the Visby Formation (Llandovery–Wenlock boundary) and the Mulde Formation (Wenlock), both in Gotland, Sweden (Le Hérissé, 1989).

Crassiangulina variacornuta occurs in the level 4-60971. This species is considered a Late Aeronian–Telychian biostratigraphic marker in Gondwana and Baltica, but has never been recorded in Laurentia (Wauthoz *et al.*, 2003; Rubinstein and Toro, 2006). Also still present are *Tylotopalla caelamenicutis* and *T. digitifera*, both frequent until level 5-60970. The presence and abundance of these two species in the lower part of the La Chilca Formation were already noted by Rubinstein and Brussa (1999). These authors assigned a Late Aeronian–Early Telychian age to these levels. Such an age is also supported by the graptolites of the *Stimulograptus sedgwickii* (upper part) - *Spirograptus turriculatus* (lower part) zones.

Upwards in the section, levels 5-60970 to 7-60967 yielded species having a long stratigraphic range such as *Diexallophasis remota* Group, *Veryhachium trispinosum* Group, *Ammonidium microcladum*, *Lophosphaeridium parverarum*, *Dorsennidium europaeum* and *Tylotopalla robustispinosa*. Results obtained herein, up to the level 7-60967, corroborate those of Benedetto (1995) and Lehnert *et al.* (1999), who proposed an Early–Middle Llandovery age for the lower part of the La Chilca Formation based on brachiopods, conodonts and graptolites.

The prasinophyte *Melikeriopalla polygonia* occurs in level 8-60805; its first worldwide appearance is in the Wenlock (Tappan and Loeblich, 1971). Other species found in this level do not wholly confirm the age. Therefore, this record alone is not enough to date the level with certainty.

The following level, 9-60803, yielded *Cymatiosphaera* aff. *ledburica*, described by Mullins (2001) for the Wenlock–Ludlow of the United Kingdom. Also recorded was *Percultisphaera incompta*, described by Richards and Mullins (2003) for the Ludlow of the United Kingdom. The age of this level as suggested by the phytoplankton disagrees with the age based on graptolites corresponding to the *Stimulograptus sedgwickii-Spirograptus turriculatus* Zone (Rubinstein and Brussa, 1999). Besides, this level yielded *Monograptus* cf. *Priodon* (Rubinstein *et al.*, unpublished data). The graptolite fauna points to an Early Aeronian–Late Telychian age, older than the age suggested by the palynomorphs. Therefore, a Telychian age is proposed up to level 9-60803, at 18.5 m below the top of the La Chilca Formation. This age agrees with the one previously proposed by Kerlleñevich and Cuerda (1986) for the Talacasto area.

Stellinium rabians first appears in the section at level 10-60801. Its oldest worldwide record is from the Ludlow (Cramer, 1964; Jardiné *et al.*, 1972; Rubinstein *et al.*, 2008). Rubinstein and Brussa (1999) recorded *S. rabians* in the Assemblage A3 of the Los Espejos Formation, indicating that it could not be older than Homerian even though this age has not been confirmed by graptolites. Significantly, *Domasia trispinosa,* that ranges from the Llandovery to the Lower Ludlow (*e.g.* Thusu, 1973; Le Hérissé, 1989; Cardoso, 2005; Rubinstein and Brussa, 1999), is also present in this level.

Percultisphaera incompta, previously unknown in beds older than Ludlow, occurs in the La Chilca Formation in levels dated as Llandovery (Late Aeronian–Early Telychian) based on graprolites. Likewise, the range of *Stellinium rabians* – whose previous older records were Gorstian (Rubinstein and Brussa, 1999; Tappan and Loeblich, 1971)– seems to locally reach down to the Sheinwoodian, because of its presence in the middle part of the La Chilca Formation in the studied section.

No biotratigraphically relevant species was found in levels 11-60800 to 13-60798. *Percultisphaera* cf. *stiphrospinata* was identified from level 14-60737 at 11 m below the

top of the section; its first worldwide appearance is in the Homerian (Molyneux *et al.*, 1996; Higgs and Williams, 2011). *P.* cf. *stiphrospinata* and *P. imcompta* are still present in levels 16-60733 and 17-60732. Thus, a Homerian age is assigned to the uppermost 11 m of the La Chilca Formation in the Quebrada Ancha section.

Although the following levels (18-60730 to 22-60694) do not present biotratigraphically useful species, the assemblage includes *Cymatiosphaera* aff. *multisepta*, *V. trispinosum* Group, *Lophosphaeridium* sp., *Percultisphaera imcompta* and *Nanocyclopia* sp.

Tylotopalla caelamenicutis and *Domasia trispinosa*, the youngest records of which are in the Wenlock and Early Ludlow respectively, were also recognized in the uppermost levels (23-60701 and 24-60675). A single specimen of *Crassiangulina* cf. *tesselita* is present in level 23-60701. This species is frequent in the Devonian, but it has been recorded recently in the Upper Ordovician (Jardiné *et al.*, 1972; Le Hérissé *et al.*, 2001; Ghavidel-Syooki *et al.*, 2011).

Concerning terrestrial palynomorphs, cryptospores such as *Gneudnaspora divellomedia* are recorded in low percentages. Given the fact that the oldest record of trilete spores corresponds to the Katian of Saudi Arabia (Steemans *et al.*, 2009), their absence in the La Chilca Formation is remarkable. Moreover, trilete spores are known to occur in South America since the Hirnantian in the Cordillera Oriental, northwestern Argentina (Rubinstein, unpublished data) and since the Llandovery in Brazil (*e.g.*, Gray *et al.*, 1992; Steemans and Pereira, 2002).

Based on the analysis of the palynological assemblages of the La Chilca Formation, a local biostratigraphic scheme is proposed mainly based on the first records of the most relevant phytoplankton species (Fig. 4.2).

The most significant occurrences in the Los Espejos Formation are detailed below, from the northernmost localities near Jáchal to the southernmost Quebrada Ancha section.

In the Río Jáchal section, the lower levels yielded trilete spores such as cf. *Chelinospora cantabrica* and *Chelinospora verrucata* var. *verrucata* Morphon. These spores are found in the *reticulata-sanpetrensis* (RS) Biozone (Richardson *et al.*, 2001), consequently suggesting a Ludlow–Early Pridoli? age. Species that first appear in younger strata were recorded further up the section. Among them, cf. *Streelispora newportensis*, *Chelinospora retorrida*, *Cymbosporites paulus*?

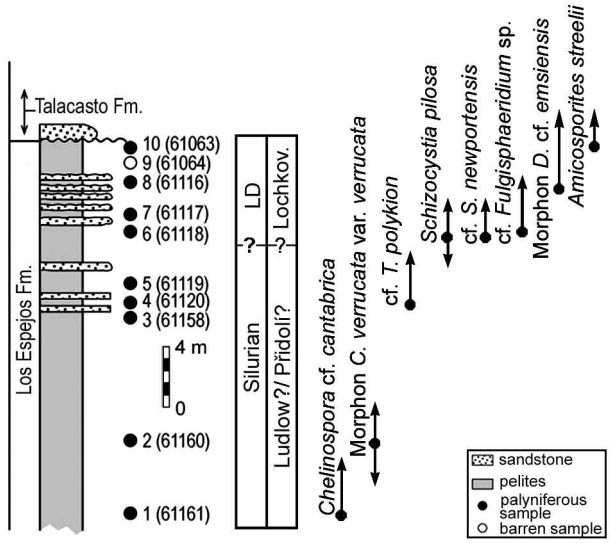


Figure 5. Stratigraphic distribution of the most relevant species of the Los Espejos Formation, Río Jáchal section. Lines and arrows point out the known biocron for the species, black circle on them indicate the presence of the species in the level. **LD= Lower Devonian; Lochkov.= Lochkovian.**

and *Dictyotriletes* cf. *emsiensis* Morphon allow recognizing the *micrornatus-newportensis* (MN) Biozone (Richardson and McGregor, 1986). This would indicate a Lochkovian age for the uppermost beds of the Los Espejos Formation in the studied section. Besides, the presence of phytoplankton species such as cf. *Tysanoprobolus polykion*, *Schizocystia pilosa* and *Fulgisphaeridium*? sp. supports the age indicated by the spores (Fig. 5). Therefore, the palynological data from the upper part of the Los Espejos Formation allows the identification of the Lower Devonian (Lochkovian), previously recognized only by the brachiopod fauna (Sánchez *et al.*, 1991; Benedetto *et al.*, 1992). Consequently, the Silurian/Devonian boundary would lay at approximately 6 m below the top of the Los Espejos Formation in the Río Jáchal section (García Muro *et al.*, 2014b).

The Río de Las Chacritas section yielded typical Ludlow phytoplankton and miospores. A detailed and complete palynological study has been already published (Rubinstein and García Muro, 2011). *Amicosporites* cf. *streelii*, with its Silurian characteristic shape (Steemans, 1989; García Muro *et al.*, 2014a), and *C. verrucata* var. *verrucata* Morphon are the most significant miospores. Biostratigraphic markers such as *Fimbriaglomerella divisa* and *Ozotobrachion palidodigitatus* are among the phytoplankton species. The up-

permost productive sample, 10-4733, yielded *Chelinospora* cf. *hemiesferica*, which is typical of the *hemiesferica* (H) Biozone (Richardson *et al*., 2001), thus suggesting a probable Pridoli age for the bearing level (Fig. 6).

In the lowermost level, 1-61065, of the Cerro La Chilca section, the phytoplankton species *Schismatosphaeridium algerense* was recorded (Fig. 7). It ranges from the Llandovery to the Late Wenlock in USA and Sweden (Cramer and Díez, 1976; Le Hérissé, 1989). It co-occurs with the cryptospore *Hispanaediscus lamontii*, which first appears in the middle Homerian of the UK (Burgess and Richardson, 1991). These taxa would indicate a probable Wenlock age for the basal bed of the Los Espejos Formation in the Cerro La Chilca section. Because of the presence of Early Ludlow graptolites in the middle part of the section, at the same locality, Cuerda (1969b) already proposed a Wenlock age for the lower part of the formation.

The following level, 2-61057, yielded *Fimbiraglomerella divisa*, whose first global appearance is immediately above the Wenlock/Ludlow boundary (Rubinstein, 1993). The presence of miospores such as *Synorisporites verrucatus*, unknown in beds older than Late Ludlow (Rubinstein and Steemans, 2002), supports a Ludlow age.

Ammonidium ludloviense occurs for the first time in the overlying level, 3-61058, although its first appeareance is in the Wenlock (Lakova and Göncüoğlu, 2005 and references therein). *Ozotobrachion palidodigitatus*, which first appears in the Ludlow (Rubinstein, 1997), is also present. The palynological assemblage of this level is badly preserved and, consequently, other species of stratigraphic value have not been identified.

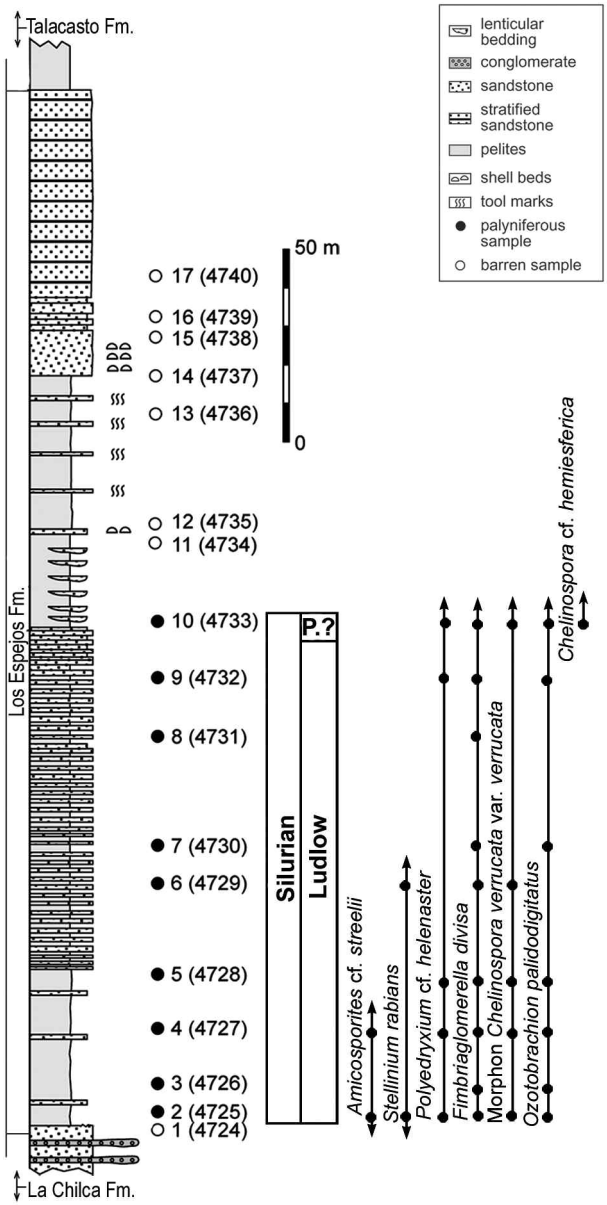


Figure 6. Stratigraphic distribution of the most relevant species of the Los Espejos Formation, Río de Las Chacritas section. Lines and arrows point out the known biocron for the species, black circle on them indicate the presence of the species in the level. **P.= Pridoli.**

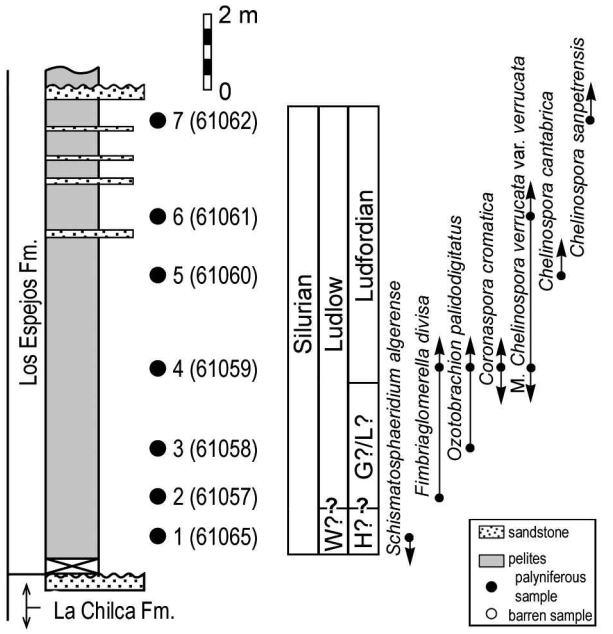


Figure 7. Stratigraphic distribution of the most relevant species of the Los Espejos Formation, Cerro La Chilca section. Lines and arrows point out the known biocron for the species, black circle on them indicate the presence of the species in the level. **W= Wenlockian; H= Homerian; G= Gorstian; L= Ludfordian.**

Level 4-61059 is characterized by the abundance of polygonomorphitic acritarchs (*e.g.*, *Veryhachium*, *Dorsennidium*) and netromorphitic acritarchs (*e.g.*, *Leiofusa*, *Eupoikilofusa*) with exceptionally preserved long processes. The most relevant terrestrial palynomorphs in this level are *Chelinospora verrucata* var. *verrucata* Morphon, *Emphanisporites rotatus* and *Coronaspora cromatica*. The latter species occurs in the RS Biozone in Spain, thus indicating a Ludfordian age (Richardson *et al.*, 2001). In addition, there are several species of the genus *Oppilatala* such as *O. insolita,* hence supporting the age inferred from the trilete spores.

Meaningfully, *Chelinospora cantabrica* occurs in level 5-61061. Its oldest record is Ludfordian and it occurs in the RS Biozone (Richardson *et al.*, 2001). Taxa recorded from level 6-61061 are not interesting from a stratigraphic point of view. In level 7-61062, the presence of *Chelinospora sanpetrensis*, which also belongs to the RS Biozone, indicates a Ludfordian age for this part of the section (Fig. 7).

The palynological assemblage recovered from the southernmost studied section of the Los Espejos Formation (Quedrada Ancha), proved to be the best preserved and most abundant from all the studied sections. The miospore assemblages were exhaustively studied and published (García Muro *et al.*, 2014a). The sampling was focused on the lower and upper parts of the stratigraphic unit in order to constrain its age and its relationships with the underlying and overlying formations (La Chilca and Talacasto respectively). The first level, 1-60667, yielded *Chelinospora verrucata* var. *verrucata* Morphon, whose first appearance belongs to the *libycus-poecilomorphus* (LP) Biozone (Richardson and McGregor, 1986), therefore hinting at an age not older than Gorstian (Fig. 8). It is interesting that the cryptospore *Chelinohilates lornensis* was recorded here, as it has only been mentioned from the Lochkovian of Scotland (Wellman and Richardson, 1996). However, the poorly known stratigraphic range of *Chelinohilates lornensis* hamper its value as an age constrainer.

In the next level, 2-60704, phytoplankton species such as *Fimbiraglomerella divisa* suggest a Ludlow age. Among the recognized terrestrial palynomorphs, are *Coronaspora cro-*

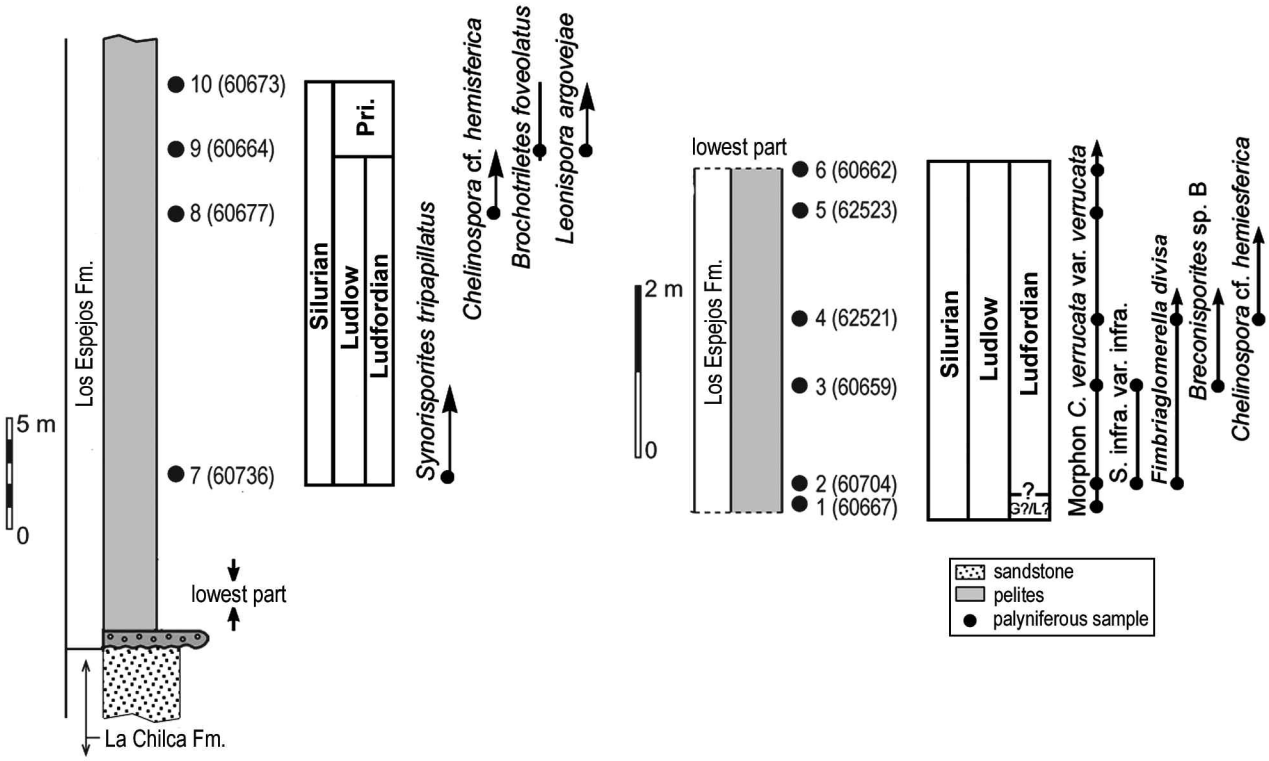


Figure 8. Stratigraphic distribution of the most relevant species of the Los Espejos Formation, lower part of the Quebrada Ancha section. Lines and arrows point out the known biocron for the species, black circle on them indicate the presence of the species in the level. **G.= Gorstian; L.= Ludfordian; Pri.= Pridoli**.

matica, *Emhanisporites* sp. D and *Stellatispora inframurinata* var. *inframurinata*. *Coronaspora cromatica* belongs to the RS Biozone from the Ludlow. *S. inframurinata* var. *inframurinata* is the eponym species of the sub-biozone proposed by Burgess and Richardson (1995), equivalent to the upper part of the RS Biozone, thus indicating a Ludfordian to Early Pridoli? age. Therefore, an age not older than Ludfordian is proposed for this level.

In the level 3-60659 there are no marine palynomorphs of any particular stratigraphic value. Regarding the trilete spores, the presence of *Breconisporites* sp. B in Richardson *et al.*, 2001 and *Breconisporites* sp. should be highlighted as this genus first appears in the Pridoli (Richardson *et al.*, 2001; Rubinstein and Steemans, 2002). This level also contains *Concentricosisporites agradabilis,* which first appears within the RS Biozone in Spain (Richardson *et al.*, 2001) and is an accessory species of the *tripapillatus-spicula* (TS) Biozone (Richardson and McGregor, 1986) dated as Ludlow–Pridoli.

Chelinospora cf. *hemiesferica* in Richardson *et al.* (2001) and *Chelinospora* cf. *cantabrica* were recorded in level 4-62521. As mentioned above, *C.* cf. *hemiesferica* first occurs in the H Biozone and *Chelinospora cantabrica* in the RS Biozone. Consequently, a maximum Ludfordian age is proposed for this level.

The next two levels, 5-62523 and 6-60662, yielded no biostratigraphically helpful species, as the marine and terrestrial palynomorph assemblages were poor in diversity and preservation.

Level 7-60736 displayed a highly diversified and abundant assemblage with exceptionally well preserved palynomorphs. It exhibited many new occurrences for the section, including *Cymatiosphaera octoplana*, *Pterospermella pertonense*, *Pterospermella bernardinae*, *Pterospermella martinii*, *Muraticavea wenlockia*, *Carminella maplewoodensis* and several species of *Oppilatala*. On the contrary, terrestrial palynomorphs did not display new records except for the presence of *Synorisporites tripapillatus*, an eponym species of the TS Biozone (Richardson and McGregor, 1986; Burgess and Richardson, 1995). Accordingly, a Ludfordian age is suggested up to this level.

Level 8-60677 yielded a less diversified but well preserved assemblage. *Cymatiosphaera lawsonii* and *Cymatiosphaera acuminata* occur for the first time. Their younger stratigraphic records, albeit scarce, are considered as Ludlow (Le Hérissé, 1989; Mullins, 2001; Cardoso, 2005). Among miospores, *Breconisporites* sp., *C. verrucata* var. *verrucata* Morphon and *C.* cf. *hemiesferica* are relevant to constrain the age. *Chelinohilates lornensis* is also present; nevertheless, it is not useful for biostratigraphy because it is only known from the Lochkovian of Scotland (Wellman and Richardson, 1996).

In the following level, 9-60664, the presence of *Leonispora argovejae* and *Cymbosporites* cf. *catillus* –unknown in beds older than Lochkovian– is significant. *L. argovejae* is the eponym species of the *newportensis-argovejae* sub-biozone (Richardson *et al.*, 2001), thus pointing to an early (not basal) Lochkovian age. The presence of *Brochotriletes foveolatus* in this level is also relevant. This species, previously unknown from beds older than Early Devonian, was found in strata assigned to the Early Pridoli of Brazil, independently dated by chitinozoans (Steemans *et al.*, 2008). Thus, it is possible that the oldest records of *C. catillus* and *L. argovejae*, as *B. foveolatus* in Brazil, are from Gondwana. This would allow assigning this level to the Pridoli (Fig. 8).

The palynological assemblage of level 10-60673 is poor and badly preserved. It does not contain relevant biostratigraphic species.

Fimbiraglomerella divisa and *Leiofusa bernesgae* occur in level 11-61020, at 11 m below the top of the section. Both species of phytoplankton are frequent in the Ludlow and Pridoli (Rubinstein and García Muro, 2011 and references therein). Terrestrial palynomorphs are a minor component and have no stratigraphic value. Level 12-60986 yielded more diversified and better preserved miospores. Especially relevant among them, are *Coronaspora cromatica*, *Chelinospora verrucata* var. *verrucata* Morphon, *Emphanisporites* sp. D and *Synorisporites verrucatus*. These taxa have prior Pridoli records in coincidence with the age proposed for the previous levels.

The following level, 13-60984, yielded a poor phytoplankton assemblage. Marine palynomorphs are mainly represented by *Dictyotidium* sp., *Micrhystridium* sp. and the *Veryhachium trispinosum* Group; all of them with no stratigraphic value. On the other hand, miospores include some interesting species such as *Emphanisporites* sp. D, *Amicosporites* cf. *streelii* and *Emphanisporites* cf. *splendens* (*e.g.*, Richardson *et al.*, 1981; Steemans, 1995; Steemans *et al.*, 2008).

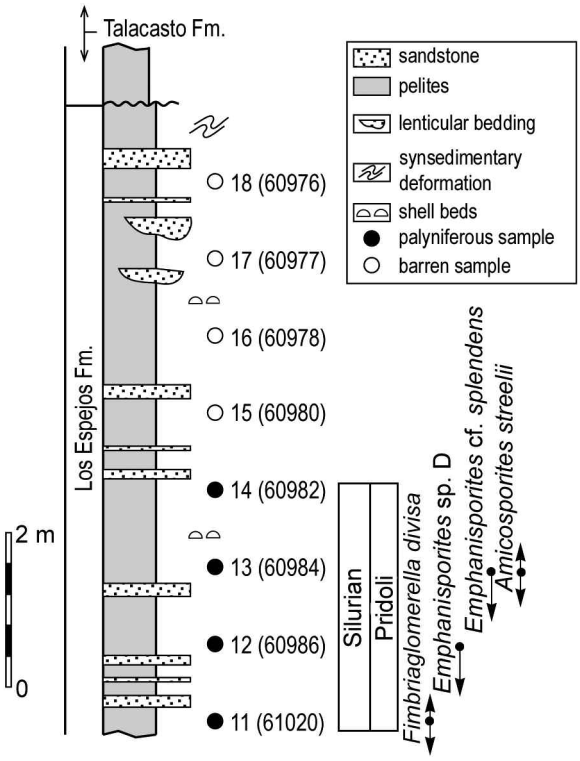


Figure 9. Stratigraphic distribution of the most relevant species of the Los Espejos Formation, upper part of the Quebrada Ancha section. Lines and arrows point out the known biocron for the species, black circle on them indicate the presence of the species in the level. **G.=** Gorstian; **L.=** Ludfordian; **Pri.=** Pridoli.

Palynomorphs from the uppermost productive level of the Quebrada Ancha section, 14-60982, located 5.5 m below the top of the section, show low diversity and poor preservation. Therefore, these were not useful to confirm the age. Without new elements, a similar age as the previous level is inferred (Fig. 9).

Consequently, a more accurate age and a new correlation scheme between the four sections of the Los Espejos Formation are proposed, based on the palynostratigraphic analysis (Fig. 10). The scarcity of palynological assemblages from the La Chilca Formation, particularly at the type locality, prevents the correlation between different stratigraphic sections.

CONCLUSIONS

The marine and terrestrial palynological assemblages of the La Chilca and Los Espejos formations, which constitute the Tucunuco Group in the Central Precordillera of San Juan, were analyzed. Even though the organic-walled phytoplankton was predominant in both formations in almost all the studied levels, the terrestrial palynomorphs, especially the trilete spores, prove very useful to determine ages. Based on the first record of certain palynomorph species of recognized stratigraphic value and on comparisons with miospore zones established for other regions, a new correlation scheme for the Tucunuco Group is proposed, with reviewed and adjusted ages for its two formational units.

The palynomorphs from the La Chilca Formation in the Quebrada Ancha section suggest a Hirnantian age for the base of the section. The Aeronian and afterwards the Late Aeronian–Telychian could be identified further up in the section, based mainly on the presence of *Crassiangulina variacornuta*. This age is supported by graptolites of the *Stimulo-graptus sedgwickii* (upper)-*Spirograptus turriculatus* (lower) zones (Rubinstein and Brussa, 1999). The age of the middle–upper part of the formation has been subject to several discussions based on its fauna. Herein, a Wenlock age would be assigned to the middle–upper part of the section because of the presence of *Percultisphaera* cf. *stiphrospinata* –which first appeared in the Homerian– together with *Stellinium rabians* and *Melikeriopalla polygonia*. Terrestrial palynomorphs are barely represented in this formation and do not help pinpointing the age.

The palynomorphs recorded from the Los Espejos Formation at four localities distributed from north to south indicate a mostly Ludlow age for the unit. A probable Wenlock age is proposed for the basal part of the Cerro La Chilca section mainly because of the presence of *Schismatosphaeridium algerense*. In the Ludlow, both stages could be distinguished, *i.e.*, the Ludfordian and doubtfully the Gorstian. The Pridoli is confirmed in Quebrada Ancha, the southernmost locality. In the northernmost studied section, Río Jáchal, the terrestrial palynomorph assemblage was the most diversified, thus allowing recognition of the Ludfordian–Pridoli? interval. The presence of cf. *Streelispora newportensis*, *Chelinospora retorrida*, *Cymbosporites paulus*? and *Dictyotriletes* cf. *emsiensis* Morphon confirms a Lochkovian age for the uppermost levels of the Los Espejos Formation. This finding suggests the occurrence of the Silurian/Devonian boundary in the upper part of the unit.

The presence of some Homerian sediments in the upper part of the La Chilca Formation in the Quebrada Ancha section and the lower part of the Los Espejos Formation in the

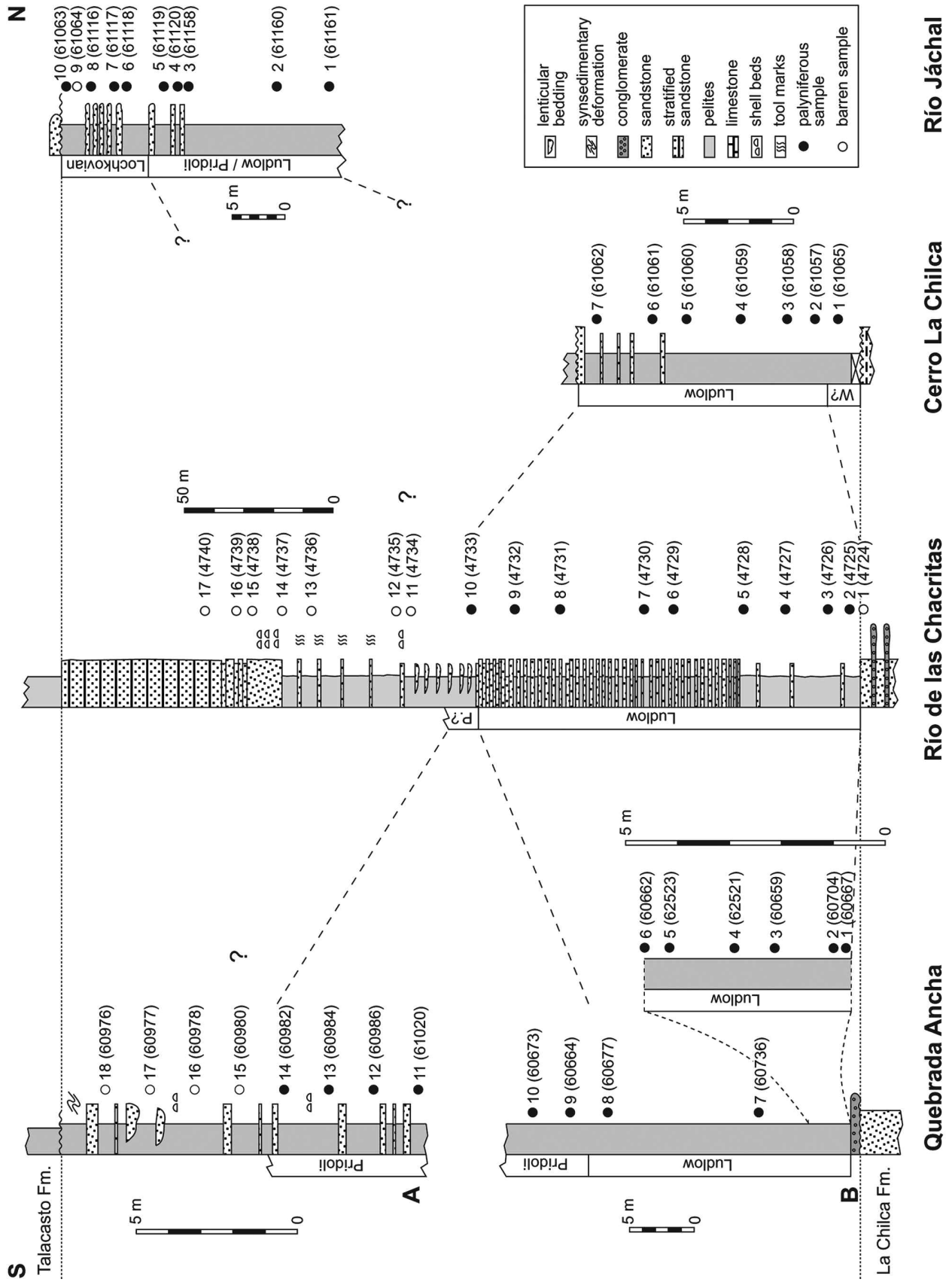


Figure 10. North-south correlation scheme of the studied sections in the Los Espejos Formation, based on the phytoplankton and miospores assemblages. **P=** Pridoli?; **W=** Wenlockian.

Cerro la Chilca section would suggest that the hiatus between both units could be less important than previously proposed, being limited to part of the Wenlock.

ACKNOWLEDGEMENTS

This work is part of the doctoral thesis funded by FONCYT (PICT 2006-1272 and 2013-2206), Bilateral Cooperation Program MINCYT (Argentina)-NFSR (Belgium) and CONICET (PIP 11220120100364). We are grateful to R. Bottero for the hand drawing; to R. Astini for helping in the field work and to F. Carotti for the meticulous language revision of the manuscript before submission. We also thank P. Breuer, G. Ottone and A. Le Hérissé for critically reviewing and improving the manuscript, and L. Benedetto for the final review.

REFERENCIAS

Albanesi, G.L., Ortega, G., and Hünicken, M.A. 2006. Bioestratigrafía de conodontes y graptolitos silúricos en la sierra de Talacasto, Precordillera de San Juan, Argentina. *Ameghiniana* 43: 93–112.

Astini, R.A. 1992. Tectonofacies ordovícicas y evolución de la cuenca Eopaleozoica de la Precordillera Argentina. *Estudios Geológicos* 48: 315–327.

Astini, R.A. and Piovano, E.L. 1992. Facies de plataforma terrígena del Silúrico de la Precordillera sanjuanina. *Revista de la Asociación Geológica Argentina* 47: 99–110.

Astini, R.A., Benedetto, J.L., and Vaccari, N.E. 1995. The Early Paleozoic evolution of the Argentine Precordillera as a Laurentian rifted, drifted and collided terrane= A geodynamic model. *Geological Society of America Bulletin* 107: 253–273.

Astini, R.A. and Maretto, H.M. 1996. Análisis estratigráfico del Silúrico de la Precordillera Central de San Juan y consideraciones sobre la evolución de la cuenca. *13º Congreso Geológico Argentino y 2º Congreso de Exploración de Hidrocarburos* (Buenos Aires), *Actas* 1: 351–368.

Baldis, B.A. 1975. El Devónico Inferior de la Precordillera Central. Parte I: Estratigrafía. Revista de la Asociación Geológica Argentina, 30 (1): 53–83.

Baldis, B.A. and Peralta, S.H. 1999. Silúrico y Devónico de la Precordillera de Cuyo y Bloque de San Rafael. *Geología Argentina, Instituto de Geología y Recursos NaturalesAnales* 29: 215–238.

Balme, B.E. 1988. Miospores from Late Devonian (early Frasnian) strata, Carnarvon Basin, Western Australia. *Palaeontographica, Abteilung B* 209: 109–166.

Benedetto, J.L. 1993. La hipótesis de alóctona de la Precordillera: un test estratigráfico y biogeográfico. *12º Congreso Geológico Argentino* (Mendoza) 3: 375–384.

Benedetto, J.L. 1995. Braquiópodos del Silúrico temprano (Llandoveriano) Malvinocáfrico, Formación La Chilca, Precordillera Argentina. *Geobios* 28: 425–457.

Benedetto, J.L. 2010. *El continente de Gondwana a través del tiempo. Una introducción a la Geología Histórica.* Academia Nacional de Ciencias, Córdoba, 384 p.

Benedetto, J.L., Racheboeuf, P.R., Herrera, Z.A., Brussa, E.D., and Toro, B.A. 1992. Brachiopodes et biostratigraphie de la Formation de Los Espejos, Siluro–Dévonien de la Précordillère (NW Argentine). *Geobios* 25: 599–637.

Benedetto, J.L., Peralta, P., and Sánchez, T.M. 1996. Morfología y biometría de las especies de *Clarkeia kozlowski* (Brachiopoda, Rhynchonellida) en el Silúrico de la Precordillera argentina. *Ameghiniana* 33: 279–299.

Breuer, P., Al-Ghazi, A., Al-Ruwaili, M., Higgs, K.T., Steemans, P., and Wellman, C.H. 2007. Early to Middle Devonian miospores from northern Saudi Arabia. *Revue de Micropaléontologie* 50: 27–57.

Brussa, E.D. 1987. [Estratigrafía y paleontología de la secuencia neo–ordovícica–silúrica del cerro del Fuerte, Precordillera de San Juan. Tesis de Licenciatura, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, 76 p. Unpublished.].

Brussa, E.D. and Astini, R.A. 1995. Relationships between graptolite-bearing strata (*Paraglossograptus tentaculatus* Zone) and sedimentary environments in eastern and western Argentina Precordillera= Preliminary study. *5º International Graptolite Conference* (Long Beach), p. 17–19.

Burgess, N.D. and Richardson, J.B. 1991. Silurian cryptospores and miospores from the Wenlock area, Shropsire, England. *Palaeontology* 34: 601–628.

Burgess, N.D. and Richardson, J.B. 1995. Late Wenlock to Early Pridoli cryptospores and miospores from south and south-west Wales-Great Britain. *Palaeontographica B.* 236: 1–44.

Cardoso, T.R.M. 2005. Acritarcos do Siluriano da Bacia do Amazonas= bioestratigrafia e geocronologia. *Arquivos do Museu Nacional, Rio de Janeiro* 63: 727–759.

Chaloner, W.G. and Streel, M. 1968. Lower Devonian spores from South Wales. *Argumenta Palaeobotanica* 1: 87–101.

Chibrikova, E.V. 1959. *Spores of the Devonian and older rocks of Bashkiria. Data on palaeontology and stratigraphy of Devonian and older deposits of Bashkiria.* Academy of Sciences of USSR, Bashkirian Branch, Ufá, 247 p.

Cramer, F.H. 1964. Microplankton from three Palaeozoic formations in the Province of León, NW Spain. *Leidse Geologische Mededelingen* 30: 253–361.

Cramer, F.H. 1966. Palynology of Silurian and Devonian rocks in northwest Spain. *Instituto Geológico y Minero de España, Boletin* 77: 225–286.

Cramer, F.H. 1968. Palynologic microfossils of the Middle Silurian Maplewood Shale in New York. *Revue de micropaléontologie* 5, 11: 61–70.

Cramer, F.H. 1970. Distribution of selected Silurian acritarchs. An account of the palynostratigraphy and paleogeography of selected Silurian acritarch taxa. *Revista española de micropaleontologia, número extraordinario*, 1–203.

Cramer, F.H. and Díez, M. del C.R. 1972. North American Silurian Palynofacies and their Spatial Arrangement=Acritarchs. *Palaeontographica B.* 158: 72–103.

Cramer, F.H. and Díez, M. del C.R. 1975. Earliest Devonian miospores from the Province of León, Spain. *Pollen et Spores* 17: 331–344.

Cramer, F.H. and Díez, M. del C.R. 1976. Acritarchs from the La Vid shales (Emsiano to lower Couvinian) at Colle, León, Spain. *Palaeontographica Abteilung B.* 158: 72–103.

Cuerda, A.J. 1965. *Monograptus leintwardensis* var. *incipiens* Wood en el Silúrico de la Precordillera. *Ameghiniana* 4: 171–178.

Cuerda, A.J. 1969a. El límite Silúrico/Devónico en el borde oriental de la Precordillera de San Juan. *Jornadas Geológicas Argentinas* (Buenos Aires), *Actas* 1: 229–237.

Cuerda, A.J. 1969b. Sobre las graptofaunas del Silúrico de San Juan, Argentina. *Ameghiniana* 6: 223–235.

Cuerda, A.J. 1985. Estratigrafía y bioestratigrafía del Silúrico de San Juan (Argentina) basada en sus faunas de graptolitos. *Ameghiniana* 22: 233–241.

Cuerda, A.J., Rickards, R.B., and Cingolani, C. 1988. A new Ordovician–Silurian boundary section in San Juan Province, Argentina, and its definite graptolite fauna. *Journal of the Geological Society, London* 145: 749–757.

Deflandre, G. 1945. Microfossiles des calcaires siluriens de la Mon-

tagne Noire. *Annales de Paléontologie* 31: 41–75.

Deunff, J. 1955. Un microplacton fossile Dévonien a Hystrichosphéres du Continent Nord-Américain. *Bulletin de Microscopie Appliquée* 2, 5 (11-12): 138–149.

Deunff, J. 1971. Le genre *Polyedryxium* Deunff. Révision et observations. In: S. Jardiné (Ed.),*Microfossiles Organiques du Paleozoique*, 3. Acritarches. Commission internationale de microflore du Paléozoique, Editions du Centre National de la Recherche Scientifique, Paris, p. 7–48.

Dorning, K.J. 1981. Silurian acritarchs from the type Wenlock and Ludlow of Shropshire, England. *Review of Palaeobotany and Palynology* 34: 175–203.

Downie, C. 1959. Hystrichospheres from the Silurian Wenlock shale of England. *Palaeontology* 2: 56–71.

Downie, C. 1960. *Deunffia* and *Domasia*, new genera of hystrichospheres. *Micropaleontology* 6 (2): 197–202.

Eisenack, A., Cramer, F.H., and Díez, M. del C. R. 1973. *Katalog der fossilen Dinoflagellaten, Hystrichosphären und verwandten Mikrofossilien. Band III Acritarcha 1*. Teil. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1104 p.

Eisenack, A., Cramer, F.H., and Díez, M. del C.R. 1976. *Katalog der fossilen Dinoflagellaten, Hystrichosphären und verwandten Mikrofossilien. Band IV Acritarcha 2.* Teil. E. Schweizertbart'sche Verlagsbuchhandlung, Stuttgart, 863 p.

Ferrero, J. 2006. [Cicloestratigrafía del Silúro-Devónico de la Precordillera Central (San Juan) a partir de la utilización de parámetros quimioestratigráficos. Tesis de grado. Dirigida por Dr. Astini, R.A. y Dr. Rodriguez, R. Universidad Nacional de Córdoba. Facultad de Ciencias Exactas, Físicas y Naturales. Departamento de Geología Aplicada. Córdoba, pp. 156. Unpublished.].

García, V.J. 2014. [*Palinología del Silúrico–Devónico Inferior de la Precordillera Central de San Juan= bioestratigrafía, paleobiogeografía y paleoambientes*. Tesis doctoral, PROBIOL, Universidad Nacional de Cuyo. Mendoza, pp 417. Unpublished.].

García Muro, V.J., Rubintein, C.V., and Steemans, P. 2014a. Upper Silurian miospores from the Precordillera Argentina= biostratigraphic, palaeonvironmental palaeogeographic implications. *Geological Magazine* 151: 472–490.

García Muro, V.J., Rubintein, C.V., and Steemans, P. 2014b. Palynological record of the Silurian/Devonian boundary in the Argentine Precordillera, western Gondwana. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* 274: 25–42.

Ghavidel-Syooki, M. 2000. Palynostratigraphy and palaeobiogeography of Lower Palaeozoic strata in the Ghelli area, northeastern Alborz range of Iran (Kopet-Dagh region). *Journal of Sciences Islamic Republic of Iran* 11: 305–318.

Ghavidel-Syooki, M., Álvaro, J.J., Popov, L., Ghobadi Pour, M., Ehsani, M.H., and Suyarkova, A. 2011. Stratigraphic evidence for the Hirnantian (latest Ordovician) glaciation in the Zagros Mountains, Iran. *Palaeogeography, Palaeoclimatology, Palaeoecology* 307: 1–16.

Gray, J., Boucot, A.J., Grahn, Y., and Himes, G. 1992. A new record of early Silurian land plant spores from the Paraná Basin, Paraguay (Malvinokaffric Realm). *Geological Magazine* 129: 741–752.

Heredia, S., Mestre, A., and Milana, J.P. 2007. Reappraisal of the Silurian stratigraphy at Cerro del Fuerte section (San Juan, Argentina). In: E. Díaz-Martínez and I. Rábano (Eds.). *4º Congreso de Paleontología y Bioestratigrafía de Latinoamérica. Publicaciones del Instituto Geominero de España, Serie Cuadernos del Museo Geominero* 8: 195–200.

Higgs, K.T. and Williams, B.P.J. 2011. Palynology and palaeoenvironments of the Silurian Coosglass Slate and Ferriter's Cove formations in the Dunquin Inlier (Dingle Peninsula, Ireland). *Geological Quarterly* 55: 95–108.

Hünicken, M.A. and Sarmiento, G.N. 1988. Conodontes Ludlovianos de la Formación Los Espejos, Talacasto, provincia de San Juan, R. Argentina. *4º Congreso Argentino de Paleontología y Bioestratigrafía* (Mendoza), Actas 3: 225–233.

Jardiné, S., Combaz, A., Magloire, L., Peniguel, G., and, Vachey, G. 1972. Acritarches du Silurien terminal et du Dévonien du Sahara Algérien. *Comptes rendus 7e Congrès international de stratigraphie et de géologie du Carbonifère* (Krefeld), 1: 295–311.

Kerlleñevich, S.C. and Cuerda, A.J. 1986. Monograptus priodon (Bronn) (Graptolithina) en la Formación La Chilca, Precordillera de San Juan, Argentina. *Ameghiniana* 23: 119–126.

Kiryanov, V.V. 1978. Akritarkhi silura Volyno-Podolii. Akademiya Nauk Ukrainskoi SSR. *Institut Geologicheskikh Nauk, Kiev, Naukova Dumka*, 1–116.

Lakova, I., and Göncüoğlu, M.C. 2005. Early Ludlovian (early Late Silurian) palynomorphs from the Palaeozoic of Çamdağ, NW Anatolia, Turkey. *Journal of the Earth Sciences Application and Research Centre of Hacettepe University* 26: 61–73.

Le Hérissé, A. 1989. Acritarches et kystes d'algues Prasinophycées du Silurien de Gotland, Suède. *Palaeontographia Italica* 76: 57–302.

Le Hérissé, A., Melo, J.H.G., Quadros, L.P., Grahn, Y., and Steemans, P. 2001. Palinological characterization and dating of the Tianguá Formation, Serra Grande Group, northern Brazil. *Correlaçâo de Seqüências Paleozóicas Sul-Americanas. Seção= Exploração de Petróleo* 20: 25–41.

Lehnert, O., Bergström, S.M., Benedetto, J.L., and Vaccari, N.E. 1999. First record of Lower Silurian conodonts from South America= biostratigraphic and palaeobiogeographic implications of Llandovery conodonts in the Precordillera of Argentina. *Geological Magazine* 136: 119–131.

Lister, T.R. 1970. The acritarchs and chitinozoa from the Wenlock and Ludlow Series of the Ludlow and Millchope areas, Shropshire. *Palaeontographical Society Monographs* 1: 1–100.

Loeblich, A.R.Jr. 1970. Morphology, ultrastructure and distribution of Paleozoic acritarchs. *Proceeding of the North American Paleontological Convention,* part G: 705–788.

Loeblich, A.R.Jr. and Drugg, W.S. 1968. New acritarchs from the Early Devonian (Late Gedinnian) Haragan Formation of Oklahoma, USA. *Tulane Studies in Geology* 6: 129–137.

Loeblich, A.R.Jr. and Tappan, H. 1970. *Thysanoprobolus,* a new acritarch genus from the Early Devonian (late Gedinnian) Haragan Formation of Oklahoma, USA. *Proceedings of the Biological Society of Washington* 83: 261–266.

Masiak, M., Podhalańska, T., and Stempień-Sałek, M. 2003. Ordovician–Silurian boundary in the Bardo Syncline, Holy Cross Mountains, Poland-new data on fossil assemblages and sedimentary succession. *Geological Quarterly* 47: 311–330.

McGregor, D.C. 1961. Spores with proximal radial pattern from the Devonian of Canada. *Geological Survey of Canada Bulletin* 76: 1–11.

McGregor, D.C. 1973. Lower and Middle Devonian spores of eastern Gaspé, Canadá. I. Systematics. *Plaentographica, Abteilung B* 142: 1–77.

Melendi, D. and Volkheimer, W. 1982. Datos palinológicos del límite Ordovícico–Silúrico de Talacasto, Provincia de san Juan. Parte I= Base del Silúrico. *Revista de la Asociación Geológica Argentina* 37: 221–236.

Melendi, D. and Volkheimer, W. 1983. Datos palinológicos del límite Ordovícico–Silúrico de Talacasto (Provincia de San Juan). Parte II= La microflora de los estratos con *Climacograptus putillus* (Hall). *Revista Técnica YPF* 9: 157–163.

Molyneux, A., Le Hérissé, A., and Wicander, R. 1996. Capítulo 6= Pa-

leozoic phytoplankton. In: J. Jansonius and D.C. McGregor (Eds.), *Palynology: priciples and applications.* Vol. 2. American Association of Stratigraphic Palynologists Foundation, Salt Lake City, UT, p. 493–529.

Mullins, G.L. 2001. Acritarchs and prasinophyte algae of the Elton Group, Ludlow Series, of the type area. *Monograph of the Palaeontographical Society* 155: 1–154.

Naumova, S.N. 1953. Spore-pollen assemblages of the Upper Devonian of the Russian Platform and their stratigraphic significance. *Transactions of Institute of Geological Sciences, Academy of Science of the USSR*, 143, *Geological Series* 60: 1-204.

Playford, G. 1977. Lower to Middle Devonian acritarchs of the Moose River Basin, Ontario. *Geological Survey of Canada, Bulletin* 279: 1–87.

Pöthe de Baldis, D. 1987. Microplancton del Llandoveriano Superior–Wenlockiano Inferior. Asociación de *Deunffia-Domasia*, de la Formación La Chilca, Aguada de Los Azulejitos, San Juan, Argentina. *10º Congreso Geológico Argentino* (Tucumán), *Actas* 3: 89–94.

Pöthe de Baldis, D. 1997. Acritarcas y prasinofíceas del Llandoveriano temprano–medio de la Formación La Chilca, Quebrada de Talacasto, provincia de San Juan, Argentina. *Ameghiniana* 34: 461–479.

Pöthe de Baldis, D. and Peralta, S.H. 1999. Asociaciones palinológicas y bioestratigrafía del Grupo Tucunuco (Ordovícico Superior–Silúrico Superior). *Ameghiniana* 36: 359–367.

Richardson, J.B. and Lister, T.R. 1969. Upper Silurian and Lower Devonian spore assemblages from the Welsh Borderland and South Wales. *Palaeontology* 12: 201–252.

Richardson, J.B. and Ioannides, N.S. 1979. *Emphanispoirites splendens*, a new name for *Emphanisporites pseudoerraticus* Richardson and Ioannides 1973 (preoccupied). *Micropaleontology* 25: 111.

Richardson, J.B. and McGregor, D.C. 1986. Silurian and Devonian spore zones of The Old Red Sandstone continent and adjacent regions. G*eological Survey of Canada Bulletin* 364: 1–79.

Richardson, J.B., Rasul, M., and Al-Ameri, T. 1981. Acritarchs, miospores and correlation of the Ludlowian–Downtonian and Silurian–Devonian boundaries. *Review of Palaeobotany and Palynology* 34: 209–224.

Richardson, J.B., Rodríguez, R.M., and Sutherland, S.J.E. 2001. Palynological zonation of Mid–Palaeozoic sequences from the Cantabrian Mountains, NW Spain: implications for inter-regional and interfacies correlation of the Ludford/Pridoli and Silurian/Devonian boundaries, and plant dispersal patterns. *Bulletin of the Natural History Museum, Geology* 57: 115–62.

Richards, R.E. and Mullins, G.L. 2003. Upper Silurian microplankton of the Leinwardine Group, Ludlow Series, in the type Ludlow area and adjacent regions. *Palaeontology* 46: 557–611.

Rickards, R.B., Brussa, E.D., Toro, B., and Ortega, G. 1996. Ordovician and Silurian graptolite assemblages from Cerro del Fuerte, San Juan Province, Argentina. *Geological Journal* 31: 101–122.

Rodríguez, R.M. 1978. Mioesporas de la Formación San Predo/Furada (Silúrico superior–Devónico Inferior), Cordillera Cantábrica, NO de España. *Palinología* 1: 407–433.

Rodríguez, R.M. 1983. Palinología de las Formaciones del Silúrico Superior–Devónico Inferior de la Cordillera Cantábrica. *Servicio de Publicaciones, Universidad de León.* p. 1–231.

Rodríguez, M.C., Mestre, A., Sánchez, M.L., and Heredia, S. 2010. Los Espejos Formation: sedimentology, biostratigraphy and biofacies analysis. *18º International Sedimentological Congress. Sedimentology at the Foot of the Andes ISC* (Mendoza), p. 754.

Rubinstein, C.V. 1992. Palinología del Silúrico Superior (Formación Los Espejos) de Loma de los Piojos, Precordillera de San Juan, Argentina. *Ameghiniana* 29: 287–303.

Rubinstein, C.V. 1993. Acritarchs from the Upper Silurian of San Juan, Argentina: Biostratigraphy and Paleobiogeography. In: S. Molyneux and K. Dorning (Eds.), *Contributions to acritarch and chitinozoan research. Special Paper in Paleontology* 48: 67–78.

Rubinstein, C.V. 1995. Acritarchs from the Upper Silurian of Argentina. Their relations with Gondwana. *Journal of South American Earth Sciences* 8: 103-115.

Rubinstein, C.V. 1997. Silurian acritarchs from South America: a review. *Acta Universitatis Carolinae Geologica* 40: 603–629.

Rubinstein, C.V. and Brussa, E.D. 1999. A palynomorph and graptolite biostratigraphy of the Central Precordillera Silurian basin, Argentina. In: M. Tongiorgi and G. Playford (Eds.), *Studies in Palaeozoic Palynology. Selected papers from the CIMP Symposium at Pisa, 1998. Bolletino della Società Paleontologica Italiana* 38: 257–266.

Rubinstein, C.V. and Steemans, P. 2002. Miospore assemblages from the Silurian-Devonian boundary, in borehole A1-61, Ghadamis Basin, Libya. *Review of Palaeobotany and Palynology* 118: 395–421.

Rubinstein, C.V. and Vaccari, N.E. 2004. Cryptospore assemblages from the Ordovician/Silurian boundary in the Puna region, north-west Argentina. *Paleontology* 47 (2): 1037–1061.

Rubinstein, C.V., Melo, J.H., and Steemans, P. 2005. Lochkovian (earliest Devonian) miospores from the Solimões Basin, northwestern Brazil. *Review of Palaeobotany and Palynology* 133: 91–113.

Rubinstein, C.V. and Toro, B.A. 2006. Aeronian (Llandovery, Lower Silurian) palynomorphs and graptolites from the Lipeón Formation, eastern Cordillera, north-west Argentina. *Geobios* 39: 103–111.

Rubinstein, C.V., Le Hérissé, A., and Steemans, P. 2008. Lochkovian (Early Devonian) acritarchs and prasinophytes from the Solimões Basin, northwestern Brazil. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* 249: 167–184.

Rubinstein, C.V. and García Muro, V.J. 2011. Fitoplancton marino de pared orgánica y mioesporas silúricos de la Formación Los Espejos, en el perfil del Río de Las Chacritas, Precordillera de San Juan, Argentina. *Ameghiniana* 48: 78–102.

Rustán, J.J. 2011. [Trilobites devónicos de la Precordillera Argentina: sistemática, filogenia, paleobiogeografía y bioestratigrafía. Tesis doctoral. Universidad Nacional de Córdoba. Córdoba, p. 233. Unpublished.].

Sánchez, T.M., Waisfeld, B.G., and Benedetto, J.L. 1991. Lithofacies, taphonomy, and brachiopod assemblages in the Silurian of western Argentina: a review of Malvinokaffric Realm communities. *Journal of South America Earth Sciences* 4: 307–329.

Sánchez, T.M., Benedetto, J.L., and Astini, R.A. 1993. Eventos de recambio faunístico en secuencias depositacionales del Ordovícico tardío–Devónico temprano de la Precordillera de San Juan, Argentina. *12º Congreso Geológico Argentino y 2º Congreso de Exploración de Hidrocarburos* (Mendoza), 2: 281–288.

Schultz, G. 1967. Mikrofossilien des oberen Llandovery von Dalarne (Schweden). *Kölner Geologische Hefte* 13: 175–187.

Servais, T., Vecoli, M., Li, J., Molyneux, S.G., Raevskaya, E.G., and Rubinstein, C.V. 2007. The acritarch genus *Veryhachium* Deunff 1954: taxonomic evaluation and first appearance. *Palynology* 31: 191–203.

Staplin, F.L. 1961. Reef-controlled distribution of Devonian microplankton in Alberta. *Palaeontology* 4: 392–424.

Staplin, F.L., Jansonius, J., and Pocock, S.A.J. 1965. Evaluation of some acritarchous hystrichosphere genera. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* 123: 167–201.

Steemans, P. 1989. Etude Palynostratigraphique du Devonien Inferieur dans l'ouest de l'Europe. *Mémoires Explicatifs pour les Cartes Géologiques et Minières de la Belgiqu*e, Bruxelles 27: 1–453.

Steemans, P. 1995. Silurian and lower Emsian spores in Saudi Arabia. *Review of Palaeobotany and Palynology* 89: 91–104.

Steemans, P. and Pereira, E. 2002. Llandovery miospore biostratigraphy and stratigraphic evolution of the Paraná Basin, Paraguay–Palaeogeographic implications. *Bulletin de la Société Géologique de France* 173: 407–414.

Steemans, P., Rubinstein, C., and de Melo, J.H.G. 2008. Siluro–Devonian miospore biostratigraphy of the Urubu River area, western Amazon Basin, northern Brazil. *Geobios* 41: 263–282.

Steemans, P., Le Hérissé, A., Melvin, J., Miller, M.A., Paris, F., Verniers, J., and Wellman, C.H. 2009. Origin and Radiation of the Earliest Vascular Land Plants. *Science* 324: 353.

Stockmans, F. and Willière, Y. 1963. Les Hystrichosphères ou mieux les Acritarches du Silurien Belge. Sondage de la Brasserie Lust à Courtrai (Kortrijk). *Bulletin de la Société Belge de Géologie, de Paléontologie et d'Hydrologie* 71: 450–481.

Tappan, H. and Loeblich, A.R.Jr. 1971. Surface sculpture of the wall in Lower Paleozoic acritarchs Turnau, E. 1986. Lower to Middle Devonian spores from the vicinity of Pionki (Central Poland). *Review of Palaeobotany and Palynology* 46: 311–354.

Thusu, B. 1973. Acritarchs of the middle Silurian Rochester Formation of Southern Ontario. *Palaeontology* 16: 799–826.

Turnau, E. 1986. Lower to Middle Devonian spores from the vicinity of Pionki (Central Poland). *Review of Palaeobotany and Palynology* 46: 311–354.

Wauthoz, B. 2005. Correlation of the 83W421 Kortrijk (Sint-Antonius) and 83W44 Kortrijk (Lust) boreholes with acritarchs (Late Aeronian–early Telychian, Silurian, Belgium). *Geologica Belgica* 8: 176–184.

Wauthoz, B., Dorning, K.J., and Le Hérissé, A. 2003. *Crassiangulina variacornuta* sp. nov. from the late Llandovery and its bearing on Silurian and Devonian acritarch taxonomy. *Bulletin de la Société Géologique de France* 174: 67–81.

Wellman, C.H. 1993a. A Lower Devonian sporomorphs assemblage from the midland Valley of Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences* 84: 117–136.

Wellman, C.H. 1993b. A land plant microfossil assemblage of Mid Silurian age from the Stonehaven Group, Scotland. *Journal of Micropalaeontology* 12: 47–66.

Wellman, C.H. and Richardson, J.B. 1996. Sporomorph assemblage from the "Lower Old Red Sandstone" of the Lorne, Scotland. *Palaeontology* 55: 41–101.

APPENDIX

List of species mentioned in the text

Miospores

Amicosporites streelii Steemans 1989 (Fig. 2.18)
Amicosporites cf. *streelii* Steemans 1989 (Fig. 2.21)
Breconisporites sp. B in Richardson, Rodríguez and Sutherland 2001 (Fig. 3.2)
Brochotriletes foveolatus Naumova 1953 (Fig. 3.5)
Chelinospora cf. *cantabrica* Richardson, Rodríguez and Sutherland 2001 (Fig. 2.14)
Chelinospora cf. *hemiesferica* (Cramer and Diez 1975) in Richardson, Rodríguez and Sutherland, 2001 (Fig. 2.22, Fig. 3.4)
Chelinohilates lornensis Wellman and Richardson 1996 (Fig. 2.28)
Chelinospora retorrida Turnau 1986
Chelinospora sanpetrensis (Rodríguez 1978) Richardson, Rodríguez and Sutherland 2001
Chelinospora verrucata var. *verrucata* Morphon García Muro, Rubinstein and Steemans, 2014 (Fig. 2.30)
Concentricosisporites agradabilis (Rodriguez 1978) Rodriguez 1983
Coronaspora cromatica (Rodríguez 1978) Richardson, Rodríguez and Sutherland 2001 (Fig. 2.25)
Cymbosporites cf. *catillus* in Richardson and Lister, 1969
Cymbosporites paulus? in Wellman, 1993a (Fig. 2.20)
Dictyotriletes cf. *emsiensis* Morphon Rubinstein, Melo and Steemans, 2005 (Fig. 2.19)
Emphanisporites cf. *splendens* Richardson and Ioannides 1979 (Fig. 3.8)
Emphanisporites rotatus (McGregor 1961) McGregor 1973
Emphanisporites sp. D in Richardson, Rasul and Al-Ameri, 1981 (Fig. 3.7)
Gneudnaspora divellomedia (*Gneudnaspora divellomedia* Chibrikova 1959) Balme 1988 var. *minor* Breuer, Al-Ghazi, Al-Ruwaili, Higgs, Steemans and Wellman 2007
Hispanaediscus lamontii Wellman 1993b (Fig. 2.24)
Hispanaediscus sp. B in Burgess and Richardson, 1995
Leonispora argovejae Cramer and Diez 1975 (Fig. 3.6)
Stellatispora inframurinata var. *inframurinata* (Richardson and Lister 1969) Burgess and Richardson 1995 (Fig. 3.1)
cf. *Streelispora newportensis* (Chaloner and Streel 1968) Richardson and Lister 1969 (Fig. 2.15)
Synorisporites tripapillatus Richardson and Lister 1969 (Fig. 3.3)
Synorisporites verrucatus Richardson and Lister 1969

Phytoplankton

Ammonidium ludloviense Lister 1970 ex Dorning 1981 emend. Mullins 2001
Ammonidium microcladum (Downie 1963) Lister 1970
Carminella maplewoodensis Cramer 1968
cf. *Crassiangulina tessellita* Jardiné, Combaz, Magloire, Peniguel and Vachey 1972 (Fig. 2.13)
Crassiangulina variacornuta Wauthoz, Dorning and Le Hérissé 2003 (Fig. 2.6)
Cymatiosphaera acuminata Mullins 2001
Cymatiosphaera aff. *ledburica* Mullins 2001
Cymatiosphaera lawsonii Mullins 2001
Cymatiosphaera aff. *multisepta* Deunff 1955 in Mullins, 2001
Cymatiosphaera octoplana Downie 1959 emend. Mullins 2001
Dictyotidium faviforme Schultz 1967
Dictyotidium stellatum Schultz 1967
Diexallophasis remota Group (Deunff 1955) Playford 1977
Domasia trispinosa Downie 1960 (Fig. 2.11)
Dorsennidium europaeum (Stockmans and Willière 1960) Sarjeant and Stancliffe 1994 emend. Mullins 2001
Fimbriaglomerella divisa Loeblich and Drugg 1968 (Fig. 2.27)
Fulgisphaeridium sp.
Veryhachium trispinosum Group Servais, Vecoli, Li, Molyneux, Raevskaya and Rubinstein, 2007
Helosphaeridium sp. A in Mullins, 2001 (Fig. 2.1)
Helosphaeridium sp.
Leiofusa bernesga Cramer 1964
Leprotolypa sp.
Lophosphaeridium parverarum Stockmans and Willière 1963
Melikeriopalla polygonia (Staplin 1961) Mullins 2001 (Fig. 2.7)
Micrhystridium sp.
Multiplicisphaeridium cf. *bifurcatum* Staplin, Jansonius and Pocock

1965 (Fig. 2.2)
Muraticavea wenlockia Dorning 1981
Nanocyclopia sp. (Fig. 2.9)
Oppilatala eoplanktonica (Eisenack 1955) Dorning 1981
Oppilatala insolita (Cramer and Díez 1972) Dorning 1981 (Fig. 2.26)
Oppilatala ramusculosa (Deflandre 1945) Dorning 1981 (Fig. 3.9)
Ozotobrachion palidodigitatus (Cramer 1966 emend. Cramer 1970) Playford 1977 (Fig. 2.29)
Percultisphaera cf. *stiphrospinata* Lister 1970 (Fig. 2.12)
Percultisphaera incompta Richards and Mullins 2003 (Fig. 2.8)
cf. *Polyedrixium asperum* Cramer 1964
Polyedryxium condensum Deunff 1971
Polyedryxium helenaster Cramer 1964
Pterospermella bernardinae (Cramer 1964) Eisenack, Cramer and Díez 1973
Pterospermella martinii (Cramer 1966) Eisenack, Cramer and Díez 1973
Pterospermella pertonense Dorning 1981
Schismatosphaeridium algerense Cramer and Díez 1976 (Fig. 2.23)
Schismatosphaeridium guttulaferum Le Herissé 1989 (Fig. 2.5)
Schismatosphaeridium perforatum Staplin, Jansonius and Pocock 1965
Schizocystia pilosa Jardiné, Combaz, Magloire, Peniguel and Vachey 1972 (Fig. 2.17)
Stellinium rabians (Cramer 1964) Eisenack, Cramer and Díez 1976 (Fig. 2.10)
Tylotopalla caelamenicutis Loeblich 1970 (Fig. 2.3)
Tylotopalla digitifera Loeblich 1970 (Fig. 2.4)
Tylotopalla robustispinosa (Downie 1959) Eisenack, Cramer and Díez, 1973 emend. Mullins 2001
cf. *Thysanoprobolus polykion* Loeblich and Tappan 1970 (Fig. 2.16)
Veryhachium sp.

doi: 10.5710/AMGH.14.12.2014.2813

Submitted: August 27th, 2014
Accepted: December 14th, 2014