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# Preliminary Palynological Study of the Ordovician-Silurian Transition in the San Juan Precordillera, Argentina

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**Resumen:** *ESTUDIO PALINOLÓGICO PRELIMINAR DE LA TRANSICIÓN ORDOVÍCICO-SILÚRICO EN LA PRECORDILLERA DE SAN JUAN, ARGENTINA.* En la Precordillera de San Juan, Argentina, la Transición Ordovícico-Silúrico, (Hirnantiano-Rhuddaniano), está representada por una sucesión estratigráfica que registra evidencias sedimentológicas, bioestratigráficas y de cambios climáticos, resultantes de los eventos glacial y postglacial, incluyendo procesos transgresivos significativos. Esta sucesión está representada en los estratos basales de la Formación La Chilca (Hirnantiano-Wenlockiano Temprano) en la Precordillera Central, y en la parte superior de la Formación Don Braulio (Hirnantiano-Llandoveriano), en la Precordillera Oriental. Con la finalidad de realizar un estudio palinológico, se colectaron muestras de los estratos basales de la Formación La Chilca en el área de Talacasto (secciones de Baños de Talacasto, Quebrada Ancha y Poblete Norte), y en el Miembro de Fangolitas Ocres de la Formación Don Braulio. Se registraron varias asociaciones de palinomorfos compuestas por especies de acritarcos, quitinozoos y criptoesporas, con diversidad variable y estado de preservación entre pobre a bueno. En la sección de Poblete Norte, en los estratos basales de la Formación La Chilca, se reporta una palinoasociación constituida por diez especies de quitinozoos, siete especies de acritarcos y seis especies de criptoesporas. Esta asociación representa el primer registro ilustrado de palinomorfos del Hirnantiano para la Precordillera de San Juan. Entre los taxones diagnósticos, la presencia de *Armoricochitina* sp. cf. *Armoricochitina nigerica* confirma una edad Hirnantiano, de acuerdo con el registro de la Zona de graptolites *M. persculptus*, en la sección de Poblete Norte, y en las secciones de Baños de Talacasto y Quebrada Ancha. Una asociación palinológica similar se menciona aquí por primera vez en la sección tipo del Miembro de Fangolitas Ocres de la Formación Don Braulio. Inferencias paleoambientales y paleobiogeográficas son presentadas sobre la base de los resultados preliminares obtenidos.

**Abstract:** In the San Juan Precordillera, the Ordovician-Silurian Transition (OST) is represented by sedimentological, biostratigraphic, and climatic change as evidence of glacial and postglacial events, including significant transgressive processes. This interval was identified in two stratigraphic units: in the La Chilca Formation (Middle Hirnantian-Early Wenlockian) Central Precordillera, and in the Don Braulio Formation (Hirnantian-Llandovery), Eastern Precordillera (Hirnantian-Llandovery). For a palynological study, samples were collected from the basal strata of the La Chilca Formation in the Talacasto area (Baños de Talacasto, Quebrada Ancha and Poblete Norte sections), and from the Ocher Mudstone Member of the Don Braulio Formation, Villicum Range. Several associations of palynomorphs composed of species of acritarchs, chitinozoans and cryptospores were recorded, with variable diversity and state of preservation between poor to good. In the Poblete Norte section, from the basal strata of La Chilca a palynoassemblage composed of ten species of chitinozoans, seven species of acritarchs and six species of cryptospores, represents the first record of Hirnantian palynomorphs illustrated in the Argentine Precordillera. Among the diagnostic taxa, the presence of *Armoricochitina* sp. cf.

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*Armoricochitina nigerica* confirms the Hirnantian age in agreement with the record of the *M. persculptus* graptolite Zone, documented in the Poblete Norte section, as well as in the Baños de Talacasto and Quebrada Ancha sections. Characteristic Hirnantian palynomorphs have been registered for the first time in the Ocher Mudstone Member of the Don Braulio Formation in its type section. Paleoenvironmental and paleobiogeographic inferences based on these preliminary data are also addressed.

**Palabras clave:** Palinomorfos. Ordovícico. Silúrico. Precordillera de San Juan. Argentina.

**Key words:** Palynomorphs. Ordovician. Silurian. San Juan Precordillera. Argentina.

## Introduction

In the San Juan Precordillera, the Ordovician-Silurian (Hirnantian-Rhuddanian) Transition (OST), is characterized by its brachiopods (Benedetto, 1986, 1990; Astini and Benedetto, 1992), trilobites (e.g. Baldis and Blasco, 1975), and graptolites (Peralta, 1985; Cuerda *et al.*, 1988; Peralta and Baldis, 1990; Rickards *et al.*, 1996; Lenz *et al.*, 2003; López *et al.*, 2020), sponge spicules (Jiménez-Sánchez *et al.*, 2014; Beresi and Gómez, 2023), among others.

Mostly Silurian associations of palynomorphs referred to *Atavograptus atavus* (Rhuddanian) graptolite Zone (Peralta, 1985; Cuerda *et al.*, 1988; López *et al.*, 2020) were identified in the La Chilca and Tambolar formations (Central Precordillera) (Melendi and Volkheimer, 1982; Pöthe de Baldis, 1997a, b, 2003; Peralta *et al.*, 1997; García-Muro and Rubinstein, 2015; García-Muro *et al.*, 2016), and in the Don Braulio Formation (Eastern Precordillera) (Volkheimer et al., 1980). Pöthe de Baldis and Peralta (1999) also provided an extensive list of Silurian chitinozoans, acritarchs, and prasinophyceans species as well as some taxa documented in the *Metabolograptus persculptus* (Hirnantian) graptolite Zone (Peralta and Baldis, 1990).

Palynologic studies related to the Late Ordovician Mass Extinction (LOME event), reveal that chitinozoans and phytoplankton survived the extinction events (Martin, 1993; Grahn and Paris, 2011; Servais *et al.*, 2016). In the Early Silurian, some taxa disappeared and several others appeared revealing assemblages with high diversity (García-Muro *et al.*, 2016, and references therein). According to these authors, the Silurian events evidence a succession of changes in the biosphere that began in the Late Ordovician and continued up to the Early Devonian.

The La Chilca Formation is a very rich-palynomorph siltstone and fine-grained sandstone developed in a shoreface environment, as well also yields abundant amorphous organic matter (AOM), indicating a low-energy environment on the inner platform (García-Muro *et al.*, 2016). The palynological associations comprise phytoplankton with a cosmopolitan distribution during the Llandovery and Wenlockian age. The cryptospore assemblage is represented, in a low frequency (3%), by *Gneudnaspora divellomedia* and a few specimens of the Wenlockian *Hispanaediscus* genus (García-Muro and Rubinstein, 2015). Both associations showed no evidence of paleolatitudinal control or geographic barriers. The observed changes in relative abundance would support that physicochemical changes in the water controlled their distribution (Gómez *et al.*, 2023).

At the Villicum range, Lower Silurian chitinozoans described from the Upper Ferriferous Member of the Don Braulio Formation, such as *Cyathochitina campanulaeformis* and *Conochitina chydaea*, indicate a Llandovery age for the palynomorph assemblage (Volkheimer *et al.*, 1980). A temperate to warm climate and a high-energy shallow marine environment is suggested by Pöthe de Baldis (1997b).

This paper describes species of palynomorphs collected in the basal strata of the La Chilca Formation and in the Ocher Mudstone

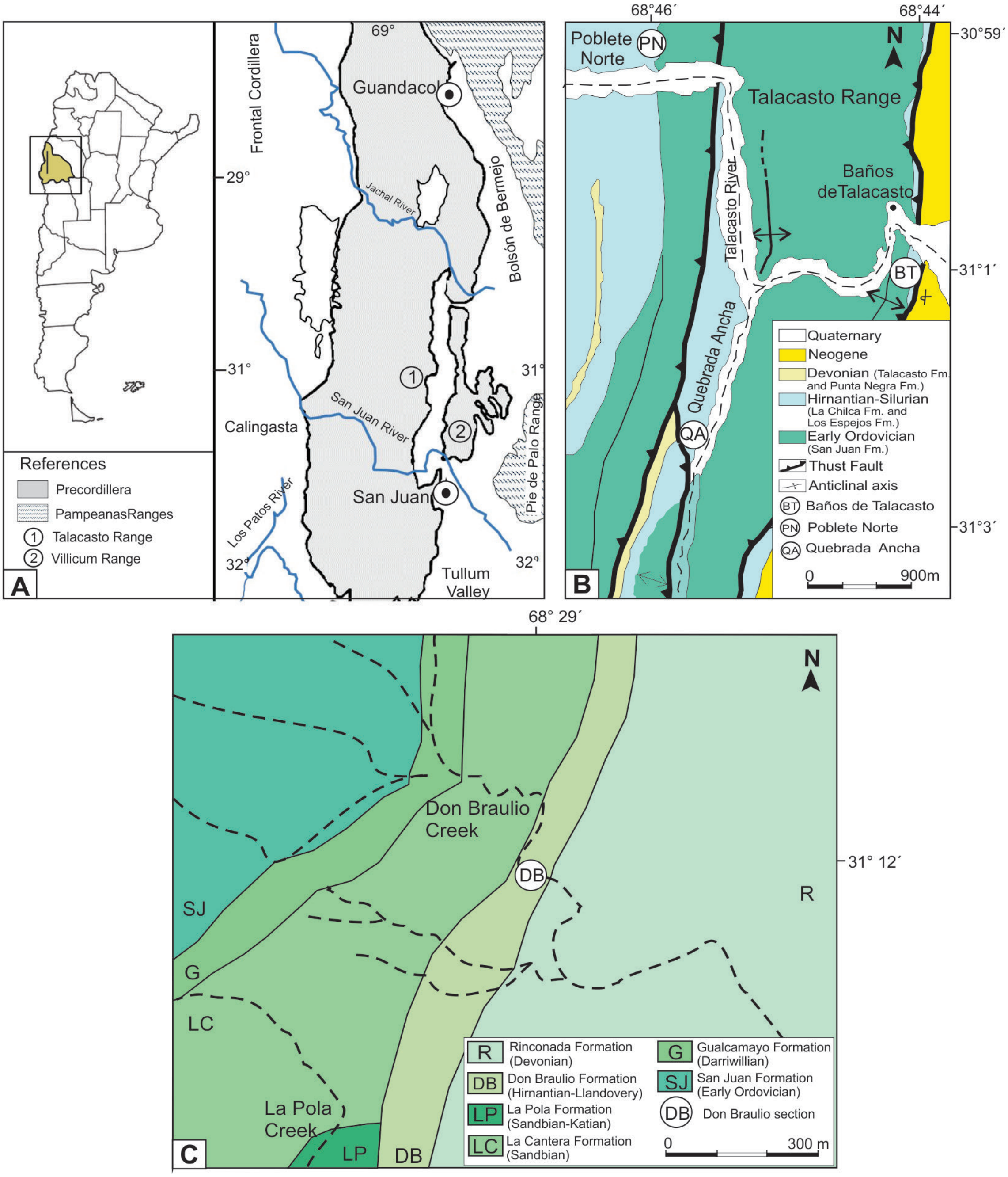


**Figure 1. A)** Map of the San Juan Precordillera showing the sections analyzed in this work (modified from Baldis *et al.*, 1982). **B)** Geological map of the Talacasto area, with the Quebrada Ancha, Baños de Talacasto, and Poblete Norte sections (modified from Baldis *et al.*, 1984a). **C)** Geological map of the Villicum Range showing the location of the Don Braulio creek (modified from Gómez, 2022). / **Figura 1. A)** *Mapa de la Precordillera de San Juan mostrando las secciones analizadas en este trabajo (modificado de Baldis* et al.*, 1982).* **B)** *Mapa geológico del área de Talacasto con la ubicación de las secciones de Quebrada Ancha, Baños de Talacasto y Poblete Norte (modificado de Baldis* et al.*, 1984a).* **C)** *Mapa geológico del área de Villicum mostrando la ubicación de las quebradas Don Braulio y La Pola (modificado de Gómez, 2022).*

Member of the Don Braulio Formation (Figure 1), which suggest a Hirnantian age, as well as their biostratigraphic, paleobiogeographic and paleoenvironmental importance.

## Geologic Setting

The Geological Province of Precordillera, Western Argentina (Furque and Cuerda, 1979) is divided into three morpho-structural units. The Eastern Precordillera, characterized as a West-directed thick-skinned fold belt (Ortiz and Zambrano, 1981); the Central Precordillera characterized as an East-directed thin-skinned fold belt (Baldis and Chebli, 1969; Baldis *et al.*, 1984a), and the Western Precordillera, which is an East-directed thin-skinned fold belt (Baldis *et al.*, 1984a; Ramos, 1999). An important difference between these morpho-structural units is the wide distribution of the Hirnantian-Silurian succession in the Central Precordillera. This succession is represented by shallow water siliciclastic deposits of the Tucunuco Group (Cuerda, 1969), and its correlative Tambolar Formation (Peralta *et al.*, 1997). In the Eastern Precordillera these deposits are scarce, only represented by the Don Braulio Formation (Baldis *et al.*, 1982; Peralta, 1993).

In the Central Precordillera, the Hirnantian-Silurian siliciclastic succession is represented by the La Chilca and Los Espejos formations, conforming both the Tucunuco Group (Cuerda, 1969). These units are composed of parallel strata bounded by flooding surfaces that are considered herein as disconformities or erosive surfaces in the sense of Blackwelder (1909), Miall (2016) and Kabanov (2017). The regressive arrangement of strata revealed by thickening-coarsening upward successions (Peralta *et al.*, 1985; Peralta, 2006), considered as parasequences in the sense of Van Wagoner *et al.* (1990). These formations were developed in a platform environment (Astini and Piovano, 1992; Peralta, 2006, 2007), with significant fossil content (Castellaro, 1966; Cuerda, 1969; Benedetto, 1987; Cuerda *et al.*, 1988; Sánchez *et al.*, 1991; Astini and Benedetto, 1992; Benedetto *et al.*, 1992a, b; Lenz *et al.*, 2003).

The La Chilca Formation is characterized by variations in thickness, with maximum values in the Jáchal area (Astini and Maretto, 1996), gradually decreasing towards the south and west (Cuerda, 1969; Baldis *et al.*, 1984b). At the base, this unit is characterized by ortho-conglomerates with tabular geometry bearing chert clasts and a thickness of c. 30 to 50 cm (Marchese, 1972). It is paraconformably covered by a succession composed of shales, siltstones and fine-grained sandstones with scattered ooids, and a ferro-phosphatic oolites level (Gómez, 2022; Gómez *et al.*, 2022). The basal conglomerate represents a transgressive stage (Astini and Piovano, 1992; Peralta, 2006), followed by inner platform deposits (Salto Macho Member), with dark gray to yellowish rich-graptolite siltstone, bearing graptolites of the *M. persculptus*, *P. acuminatus*, and *A. atavus* zones (Baldis *et al.*, 1984b; Cuerda *et al.*, 1988). These deposits are gradually replaced by a fine-grained, yellowish-green quartz sandstones succession, with hummocky cross-stratification (HCS) structures (Baldis *et al.*, 1984b). At the top, a ferriferous-phosphate level occurs related to the drowning surfaces as a result of a transgressive event (Peralta *et al.*, 1985). In the Talacasto area, the La Chilca Formation overlies paraconformably (erosive surface) limestone beds of the San Juan Formation (Early Ordovician), and in turn is conformably overlain (flooding surface) by transgressive deposits of the Los Espejos Formation (Baldis *et al.*, 1984b), middle Wenlockian-Pridolian in age.

In the eastern Precordillera, the Don Braulio Formation (Baldis *et al.*, 1982) is divided into four members (Peralta, 1993). A basal Lower Diamictite Member composed of greenish-gray pebbly mudstone including channel–fill conglomerate structures, in which gravel–size clasts predominate, composed of sandstone, plutonic and carbonate rocks, as well as bioclastic debris to a lesser extent. In some parts, channel-fill deposits exhibit normal grading (Peralta, 1993; Peralta and Carter, 1999; Astini, 2001), and they are intercalated with thin to medium-layered sandstones and pebbly mudstones. Occasionally, the filling contains bioclastic debris of brachiopods, bryozoans, and crinoids related to the *Hirnantian Fauna* (Peralta, 1993). This member presents sedimentologic and paleontologic evidence that confirms its relationship with the Late Ordovician Glacial Event (Peralta and Carter, 1990, 1999; Astini, 1991, 1993, 2001; Astini

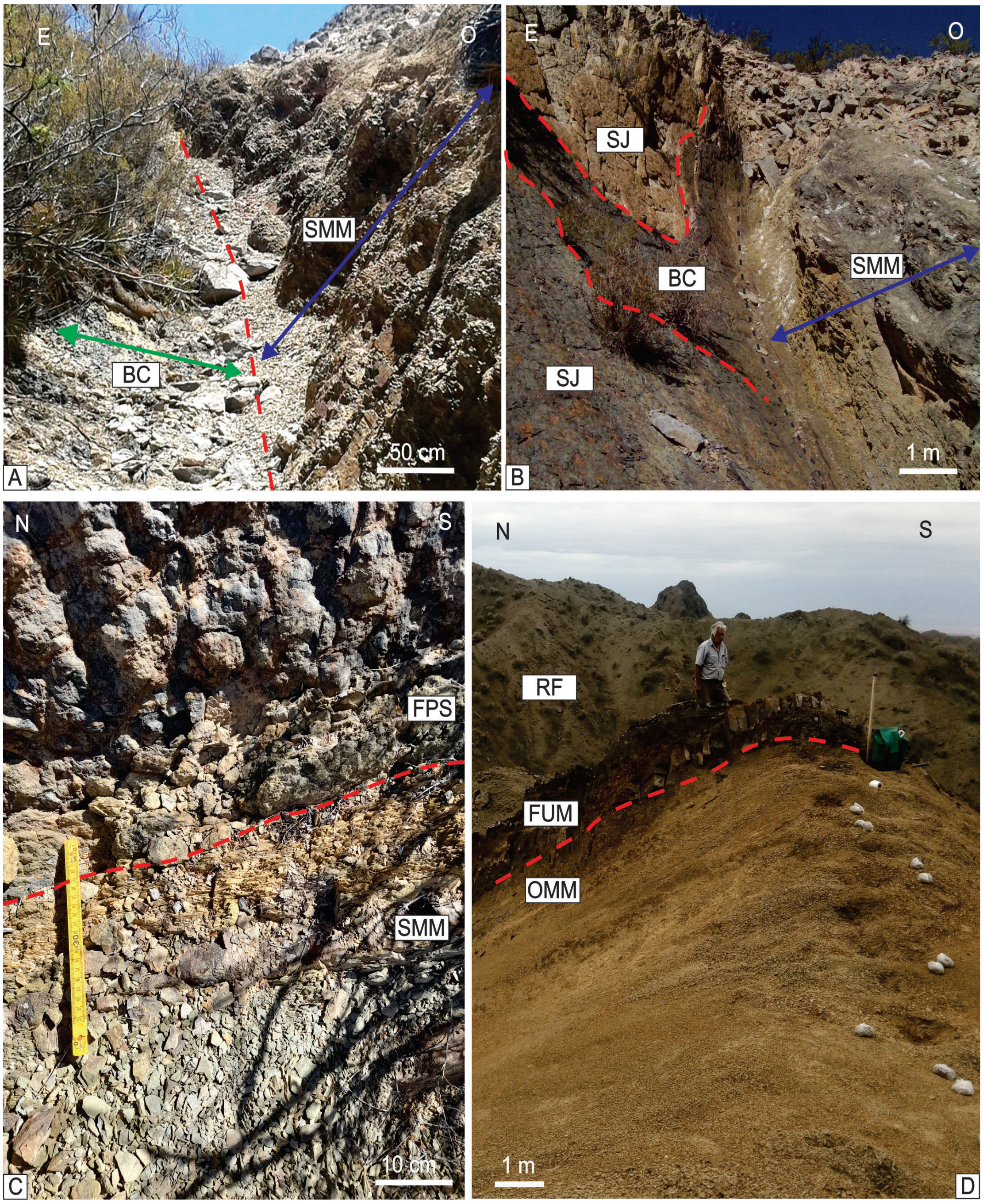


**Figure 2. A)** Baños de Talacasto section, the red stroke line represents the sharp contact between the basal conglomerate (BC) and the fossiliferous siltstone of the Salto Macho Member (SMM) of the La Chilca Formation. **B)** Quebrada Ancha section, the red stroke line shows the erosive contact between the San Juan Formation (SJ, Early Ordovician) and the basal conglomerates (BC) of the La Chilca Formation. The black line is the sharp contact between the psefitic level and the Salto Macho Member (SMM). **C)** Poblete Norte Section, the red stroke line shows the contact between ferro-phosphatic sandstones (FPS) at the base of the La Chilca Formation, and the succession of siltstone and sandstones with dispersed ooids at the base of the Salto Macho Member (SMM). **D)** Don Braulio section (Don Braulio Formation), yellowish bioturbated mudstone succession of the Ocher Mudstone Member (OMM), the red line represents the contact with the Upper Ferriferous Member (FUM). / **Figura 2. A)** *Sección Baños de Talacasto, la línea roja representa el contacto neto entre el conglomerado basal (BC) y la pelita fosilífera del Miembro Salto Macho (SMM) de la Formación La Chilca.* **B)** *Sección Quebrada Ancha, la línea de trazo roja muestra el contacto erosivo entre la Formación San Juan (SJ, Ordovícico Temprano) y el conglomerado basal (BC) de la Formación La Chilca. La línea negra de trazo representa el contacto neto entre el nivel psefítico y la sucesión del Miembro Salto Macho (SMM).* **C)** *Sección de Poblete Norte, la línea de trazo roja muestra el contacto entre las areniscas ferro-fosfáticas (FPS) en la base de la Formación La Chilca y la sucesión de pelitas y areniscas con ooides dispersos en la base del Miembro Salto Macho (SMM). D) Sección de la Quebrada Don Braulio (Formación Don Braulio), se observa la sucesión de fangolitas bioturbadas del Miembro Fangolitas Ocres (OMM) en contacto (línea de trazo roja) con el Miembro Ferrífero Superior (FUM).*

and Buggish, 1993; Buggish and Astini, 1993).

The Lower Diamictite Member is paraconformably- covered by a thin layered polymictic basal conglomerate overlain by greyish-green shales and fine-medium grained sandstones, including fossiliferous calcareous lenses of the Fossiliferous Mudstone and Sandstone Member (Peralta, 1993; Peralta and Carter, 1999). In this member, the trilobites *Dalmanitina sudamericana* and *Eohomalonothus villicunensis* (Baldis and Blasco, 1975), brachiopods of the typical *Hirnantian Fauna* (Levy and Nullo, 1974; Benedetto, 1986, 1990), a monospecific association of *Metabolograptus* (ex *Normallograptus*) *persculptus* (Peralta and Baldis, 1990), and the bivalves *Modilopsis cuyana* and *Palaeoneila* sp. (Sánchez, 1985, 1990) have been recorded. This member is overlain in sharp contact, by yellowish bioturbated mudstone, with abundant trace fossils, mainly borings and dwellings, and poorly preserved biserial graptolite structures (Ocher Mudstone Member) (Peralta and Carter, 1999). This member is paraconformably overlain by the Upper Ferriferous Member, composed by a succession of reddish-brown ferriferous sandstone and oolite beds, interbedded with black to dark gray shales and siltstones (Astini, 1992). Graptolites from the *A. atavus* Zone (Peralta, 1985) and Llandoverian palynomorphs (Volkheimer *et al.*, 1980) have been recorded in these deposits. At its type locality, the Don Braulio Formation lies paraconformably (erosive surface) over the La Cantera Formation and in turn is erosively (paraconcordance) covered by the olistostrome of the Devonian Rinconada Formation (Peralta, 1993).

## Material and methods

In the basal strata of the La Chilca Formation, forty-three samples were collected for palynology in four sections: six samples in Baños de Talacasto (BT) (31° 1´ 33” S; 68° 44´ 58” O), ten samples in Quebrada Ancha (QA) (31° 2’ 54” S; 68° 46´ 22” O), and three samples in Poblete Norte (PN) (30° 59´ 60” S; 68° 46´ 27” O) (Figures 2-3). The sampling was carried out in the Salto Macho Member, immediately above the basal conglomerate up to the *P. acuminatus* / *A. atavus* zones (Cuerda *et al.*, 1988; Lenz *et al.*, 2003; López *et al.*, 2020). Due to the extensive record of known palynomorphs in the Upper Ferriferous Member of the Don Braulio Formation (Volkheimer *et al.*, 1980; Pöthe de Baldis, 1997b), our sampling focused on the underlying Ocher Mudstone Member (DB) (31° 12’ 49.81” S; 68° 29’ 6.45” O). Twenty-four samples were collected every 50 cm (intervals) up to the contact with the overlying Upper Member. The samples were coded according to the name of the section and level (e.g. Baños de Talacasto level 5, BT5) (Figures 3-4).

Palynological samples were processed according to standard techniques (Traverse, 2007) at the Palynostratigraphy and Paleobotany Laboratory (LPP) of the CICYTTP (CONICET-ENTRE RÍOS-UADER) Research Center (Diamante, Entre Ríos province). Samples (15 to 20 grams) fragmented in pieces of around c. 5 mm and macerated with HCl (20%, 24 hours) and HF (45%, 48-72 hs) successively, and several washes with distilled water applied up to reach neutralization after each acid. The presence of organic matter in the residues was inspected under a stereomicroscope, and fertile residues were treated with hot HCl (10%) to disaggregate lumps of organic matter, washed and sieved through a mesh of 25 μm and 10 μm, and Trabasil used as the mounting medium for preparing slides. Identification of palynomorphs carried on using an optical microscope Leica DM500 and photomicrographs obtained with a digital video camera AmScope 14 Mpixels. Palynomorphs manually-picked from residues under a stereomicroscope mounted in stubs to be illustrated with scanning electron microscope (SEM) Phenom ProX (Jenck) at the CICYTTP (CONICET-ENTRE RÍOS-UADER). Rocks, residues and slides housed at the Palynologic Collection of the LPP (Table 1) under the acronym CICYTTP-Pl (di Pasquo and Silvestri, 2014).

| Sample | Collection number (CICYTTP-Pl) | *Cheleutochroa diaphorosa* | *Ancyrochitina* sp. cf. *Ancyrochitina merga* | *Armoricochitina* sp. cf. *Armoricochitina nigerica* | *Calpichitina lenticulari* | *Conochitina minnesotensis* | *Euconochitina lepta* | *Lagenochitina deunffi* | *Spinachitina bulmani* | *Crassiangulina tesselita?* | *Quadraditum fantasticum?* | *Leiosphaeiridia* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PN4 | 2472 | X | X | X | X | X | X | X | X | X | X | - |
| BT | 2477 | - | - | - | - | - | - | - | - | X | - | - |
| | 2478 | - | - | - | - | - | - | - | - | X | - | - |
| QA | 2489 | - | - | - | - | - | - | - | - | - | X | - |
| | 2545 | - | - | - | - | - | - | - | - | - | - | X |
| DB | 2567 | X | X | X | X | X | X | X | X | - | - | - |
| | 2568 | X | X | X | X | X | X | X | X | - | - | - |

**Table 1.** Distribution of palynomorphs (chitinozoans, acritarchs, cryptospores) in the sections BT (Baños de Talacasto), QA (Quebrada Ancha), PN (Poblete Norte), and DB (Don Braulio). Codes used for field samples in the study sections and equivalence of collection numbers of the repository at the LPP (CICYTTP). / **Tabla 1.** *Distribución de palinomorfos (quitinozoarios, acritarcas, criptoesporas) en las secciones BT (Baños de Talacasto), QA (Quebrada Ancha), PN (Poblete Norte), y DB (Don Braulio).Códigos utilizados para las muestras en las secciones de estudio, y números de colección del repositorio LPP (CICYTTP).*

## Results

The preliminary qualitative and semi-quantitative results presented herein are the first attempt to document palynomorphs with biostratigraphic significance to constrain the OST in the stratigraphic successions studied in the framework of the doctoral research carried out by Gómez (2022). Vertical distribution of the main palynologic groups (acritarchs, chitinozoans, cryptospores, others) and main features of the palynofacies components of the kerogen (amorphous organic matter, black remains, others), identified in each section are addressed herein (Figures 3-4-5-6, Table 1).

### Baños de Talacasto Section

In the Baños de Talacasto section, most of the levels presented dark brown and black palynomorphs (chitinozoans and acritarchs). A high content of amorphous organic matter (AOM) is observed towards the base, which decreases in the upper levels. The diversity of possible identifiable species is low at the lower levels, however the species *Crassiangulina tesselita?* has been registered at levels BT2 and BT3, and at the BT5 level, cryptospores and a few indetermined organic remains.

### Quebrada Ancha Section

All the samples along this section yielded remains of chitinozoans and acritarchs of dark brown and black color and amorphous organic matter (AOM). In the oolitic sandstone lithofacies (Level QA-B3), fragments of phytoclasts and scolecodonts are recorded, associated with fragments of chitinozoans and cryptospores. *Quadraditum fantasticum?* is identified at level QA-T3 (Table 1). Towards the top of this lithofacies (QA-T2 level), abundant black organic matter (BOM) is reported, along with fragments of indeterminate chitinozoans and cryptospores. A detailed ongoing palynologic analysis, found that a few spores could be observed in level QA6, and at level QA8, the first appearance of tracheids was recorded (Figure 3). At the top, level QA10, frequent cryptospore-like spheroidal forms and *Leiosphaeridia* are recognized.

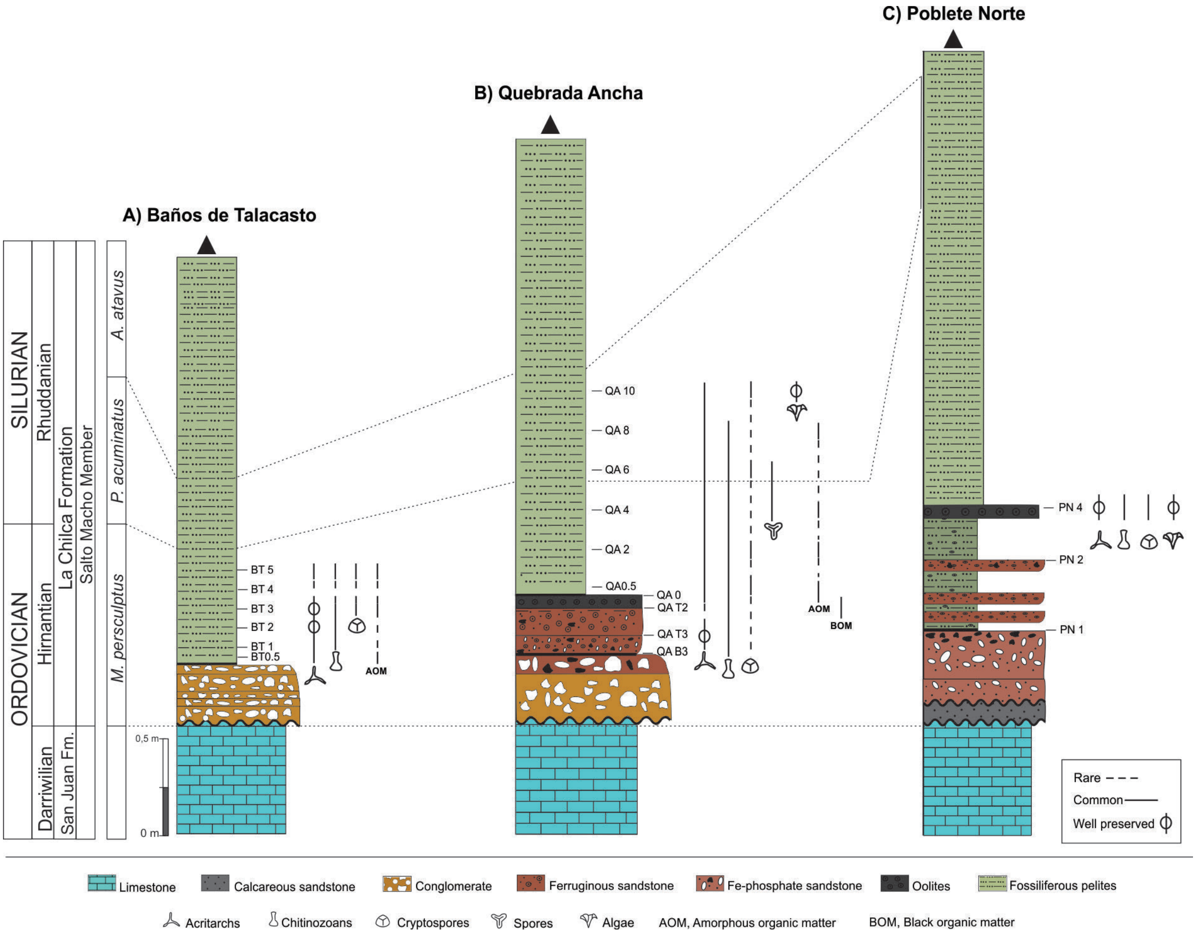


**Figure 3.** Schematic stratigraphic section of La Chilca Formation in the Talacasto area, showing the location of the samples and the relative abundance of acritarchs, chlorophytes and cryptospores. **A)** Baños de Talacasto, **B)** Quebrada Ancha; **C)** Poblete Norte. / **Figura 3.** *Sección estratigráfica de la Formación La Chilca en el área de Talacasto que muestra la ubicación de las muestras, así como la abundancia relativa de acritarcos, clorofitas y criptosporas.* **A)** *Baños de Talacasto,* **B)** *Quebrada Ancha,* **C)** *Poblete Norte.*

## Poblete Norte Section

A well-preserved palynomorph association was recognized in the Poblete Norte section (PN4 level). This association is composed of ten species of chitinozoans, seven acritarchs and six cryptospores (Figures 5-6). Several age-diagnostics of the late Ordovician recorded are the acritarch *Cheleutochroa diaphorosa*, and *Chitinozoans Ancyrochitina* sp. cf. *Ancyrochitina merga*, *Armoricochitina* sp. cf. *Armoricochitina nigerica*, *Calpichitina lenticularis*, *Conochitina minnesotensis*, *Euconochitina lepta*, *Lagenochitina deunffi*, *Spinachitina bulmani* (Gómez *et al.*, 2021b). The sampled levels below and above of the PN4 level have not provided palynological information up to now, but new samplings will be carried on to improve the present result.

## Quebrada Don Braulio section

Preliminary palynologic results have been obtained from nine of the twenty-five samples of the Ocher Mudstone Member (Figure 4). These assemblages are composed of fragmented black organic matter (BOM) and some entire chitinozoans have been documented at DB 2, DB 2.5, DB 7, and DB 8 levels. The presence of marine palynomorphs at the DB 2 and DB 2.5 levels (Table 1) stands out, similar to those recorded in the Poblete Norte section (Figure 3). At the top of the Ocher Mudstone Member,

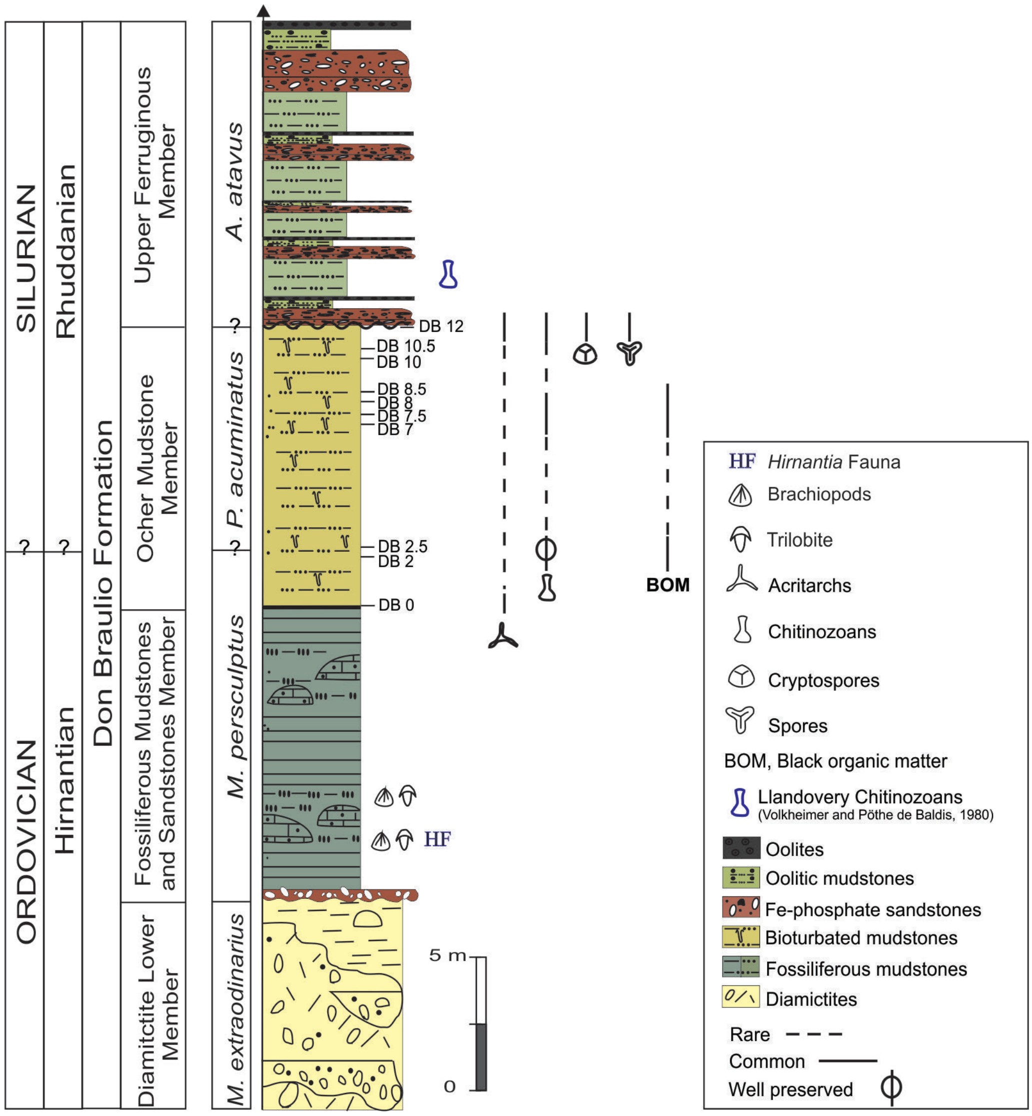


**Figure 4.** Schematic stratigraphic section of Don Braulio Formation at the Villicum Range showing the location of the samples (DB 0 to DB 12), distances in meters from the base, and the relative abundance of acritarchs, chitinozoans and cryptospores. / **Figura 4.** *Sección estratigráfica esquemática de la Formación Don Braulio en la Sierra de Villicum, mostrando la ubicación de las muestras (DB 0 a DB 12), distancia en metros desde la base y la abundancia relativa de acritarcos, quitinozoos y criptosporas.*

below the contact with the Upper Ferriferous Member, the DB 12 sample records a diverse association of chitinozoans, cryptospores, acritarchs, and possible few spores and tracheids (Figure 4).

## Discussions

### Age and biostratigraphic correlation

The palynological study in the successions of the OST contributes to improve the understanding the paleoecological evolution of the biofacies present in the Precordillera. Previous studies of palynomorphs in the basal levels of the La Chilca Formation, recorded mainly a Llandovery age (Pöthe de Baldis, 1997a, b, 2003; García-Muro and Rubinstein, 2015; García-Muro *et al.*, 2016), and Gómez *et al.* (2021b) presented a summary of the Poblete Norte association, which is described and illustrated in this contribution for the first time along with associations from other localities. However, in the Quebrada Ancha section, the presence of cosmopolitan species characteristic of the Upper Ordovician has been mentioned in the levels

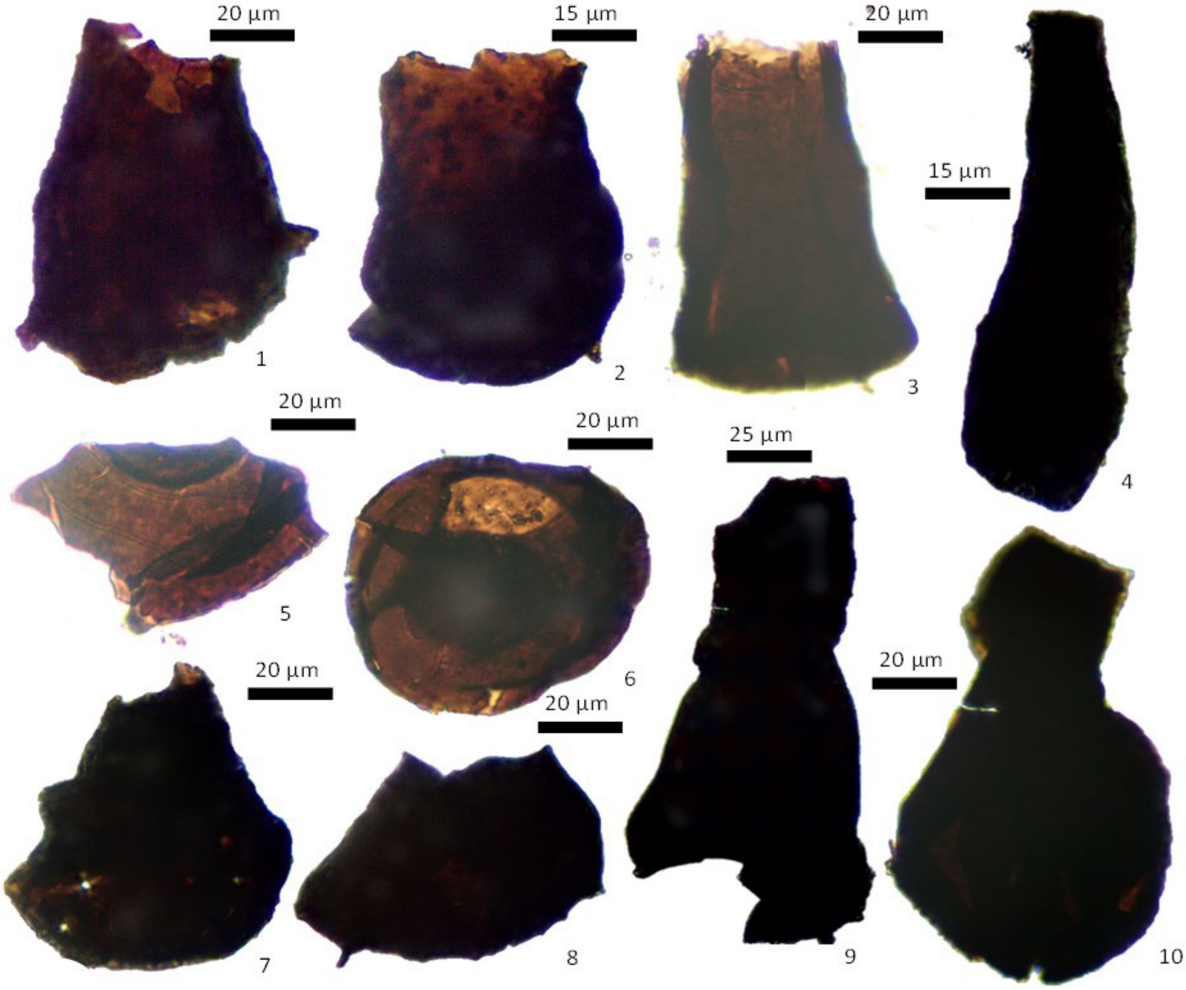


**Figure 5.** Selected chitinozoans from the Poblete Norte section (see figure 3, and for references consult the appendix herein and Palynodata webpage). **1.** *Ancyrochitina* sp. cf. *Ancyrochitina merga*, CICYTTP-Pl 2472-1+10-hf1 England Finder coordinates (EF) K36/0. **2.** *Armoricochitina* sp. cf. *Armoricochitina nigerica*, CICYTTP-Pl 2472-2new-+10-hf1 EF D26/3. **3.** *Cyathochitina calix*, CICYTTP-Pl 2472-1new-+10-hf1 EF H22/0. **4.** *Conochitina minnesotensis*, CICYTTP-Pl 2472-3-11-2019-HF EF R38/4. **5-6.** *Calpichitina lenticularis.* **5.** CICYTTP-Pl 2472-3-11-2019-HF EFS29/2. **6.** CICYTTP-Pl 24722-1-10-2019-HF EF M29/0. **7.** *Euconochitina lepta*, CICYTTP-Pl 2472-2-11-2019-HF EF Z57/4. **8.** *Ancyrochitina* sp., CICYTTP-Pl 2472-1-10-2019-HF EF Q58. **9.** *Spinachitina bulmani*, CICYTTP-Pl 2472-1-10-2019-HF EF L52/0. **10.** *Lagenochitina deunffi*, CICYTTP-Pl 2472-1-10-2019-HF EF U28/0. / **Figura 5.** *Lista de quitinozoos registrados en la sección de Poblete Norte (véase figure 3, y consultar referencias en el Apéndice de este trabajo y en la página Palynodata).* **1.** Ancyrochitina sp. cf Ancyrochitina merga*, CICYTTP-Pl 2472-1+10-hf1 sistema de coordenadas England Finder (EF) K36/0.* **2.** Armoricochitina sp. cf Armoricochitina nigerica*, CICYTTP-Pl 2472-2new-+10-hf1 EF D26/3.* **3.** Cyathochitina calix, *CICYTTP-Pl 2472-1new-+10-hf1 EF H22/0.* **4.** Conochitina minnesotensis, *CICYTTP-Pl 2472-3-11-2019-HF EF R38/4.* **5-6.** Calpichitina lenticularis. **5.** *CICYTTP-Pl 2472-3-11-2019-HF EFS29/2.* **6.** *CICYTTP-Pl 24722-1-10-2019-HF EF M29/0.* **7.** Euconochitina lepta, *CICYTTP-Pl 2472-2-11-2019-HF EF Z57/4.* **8.** Ancyrochitina sp., *CICYTTP-Pl 2472-1-10-2019-HF EF Q58.* **9.** Spinachitina bulmani, *CICYTTP-Pl 2472-1-10-2019-HF EF L52/0.* **10.** Lagenochitina deunffi, *CICYTTP-Pl 2472-1-10-2019-HF EF U28/0.*

2 m above the basal conglomerate (García-Muro and Rubinstein, 2015 and citations therein).

The results obtained herein at Poblete Norte, Quebrada Ancha and Baños de Talacasto sections, indicate a variety of variably fragmented palynomorphs with moderate preservation. Nevertheless, some important species with biostratigraphic significance are distingui-

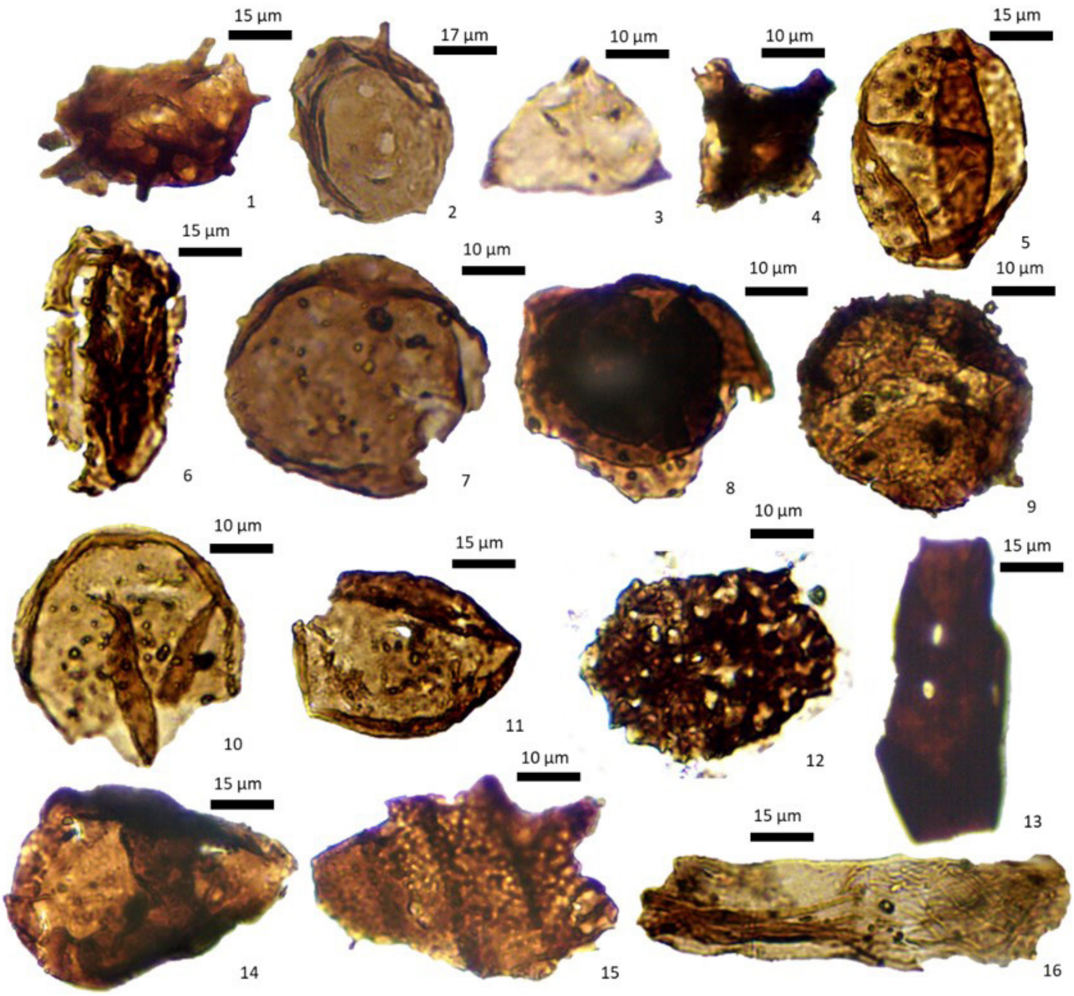


**Figure 6.** Selected palynomorphs (acritarchs, cryptospores, others) from the Poblete Norte section. **1.** *Cheleutochroa diaphorosa, CICYTTP-Pl 2472-2new-+10-hf1 EF Z26/0.* **2.** *Orthosphaeridium sp. (fragment), CICYTTP-Pl 2472-2new-+10-hf1 EF M43/2.* **3.** *Crassiangulina tesselita, CICYTTP-Pl 2472-1+10-hf1 EF G50/0.* **4.** *Quadraditum deunffii, CICYTTP-Pl 2472-2-11-2019-HF EFD44/3.* **5.** *Leiosphaeridia sp., CICYTTP-Pl 2472-3-11-2019-HF EF D52/2.* **6.** *Dactylofusa sp. cf. D. maranhensis, CICYTTP-Pl 2472-3-11-2019-HF EF U58/1.* **7.** *Lophosphaeridium sp., CICYTTP-Pl 2472-2new-+10-hf1 EF N23/0.* **8.** *Sphaerasaccus glabellus, CICYTTP-Pl 2472-1-11-2019-HF EFE45/0.* **9.** *Hispanaediscus sp., CICYTTP-Pl 2472-3-11-2019-HF EF Y30/0.* **10.** *Laevolancis chibrikovae, CICYTTP-Pl 2472-2-11-2019-HF L62/1.* **11.** *Gneudnaspora divellomedia, CICYTTP-Pl 2472-1-11-2019-HF EF L36/0.* **12.** *Chelinohilates maculatus, CICYTTP-Pl 2472-1-10-2019-HF EF E38/1.* **13.** *Possible fragment of chitinozoa. CICYTTP-Pl 2472-1+10-hf1 EF J26/3.* **14.** *Dyadaspora murusdensa /murusattenuata, CICYTTP-Pl 2472-1-11-2019-HF EF Y48/0.* **15.** *Graptolite cuticle (*see in Mizusaki *et al.,* 2002). *CICYTTP-Pl 2472-3-11-2019-HF EF E60/0.* **16.** Moyeria cabottii? in Miller and Eames (1982) and Strophomorpha ovata? in Steemans *et al., (1996) CICYTTP-Pl 2472-1-10-2019-HF EF G50/3.* **/ Figura 6.** *Lista de palinomorfos (acritarcas, criptoesporas, otros) provenientes de la sección de Poblete Norte.* **1.** Cheleutochroa diaphorosa, *CICYTTP-Pl 2472-2new-+10-hf1 EF Z26/0.* **2.** Orthosphaeridium sp. (fragmento), *CICYTTP-Pl 2472-2new-+10-hf1 EF M43/2.* **3.** Crassiangulina tesselita, *CICYTTP-Pl 2472-1+10-hf1 EF G50/0.* **4.** Quadraditum deunffii, *CICYTTP-Pl 2472-2-11-2019-HF EFD44/3.* **5.** Leiosphaeridia sp., *CICYTTP-Pl 2472-3-11-2019-HF EF D52/2.* **6.** Dactylofusa sp. cf. D. maranhensis, *CICYTTP-Pl 2472-3-11-2019-HF EF U58/1.* **7.** Lophosphaeridium sp., *CICYTTP-Pl 2472-2new-+10-hf1 EF N23/0.* **8.** Sphaerasaccus glabellus, *CICYTTP-Pl 2472-1-11-2019-HF EFE45/0.* **9.** Hispanaediscus sp., *CICYTTP-Pl 2472-3-11-2019-HF EF Y30/0.* **10.** Laevolancis chibrikovae, *CICYTTP-Pl 2472-2-11-2019-HF L62/1.* **11.** Gneudnaspora divellomedia, *CICYTTP-Pl 2472-1-11-2019-HF EF L36/0.* **12.** Chelinohilates maculatus, *CICYTTP-Pl 2472-1-10-2019-HF EF E38/1.* **13.** Posible fragmento de quitinozoo, *CICYTTP-Pl 2472-1+10-hf1 EF J26/3.* **14.** Dyadaspora murusdensa /murusattenuata, *CICYTTP-Pl 2472-1-11-2019-HF EF Y48/0.* **15.** Espícula de graptolito (ver Mizusaki et al., 2002), *CICYTTP-Pl 2472-3-11-2019-HF EF E60/0.* **16.** Moyeria cabottii? en Miller y Eames (1982), y Strophomorpha ovata? en Steemans et al., (1996) *CICYTTP-Pl 2472-1-10-2019-HF EF G50/3.*

shed in the PN4 level (Table 1) of the Poblete Norte section having a wider range between the Katian and the Silurian (Gómez *et al.*, 2021b). Among the chitinozoans, *Ancyrochitina* sp. cf.

*Ancyrochitina merga* (range: Katian-Hirnantian, Wang *et al.*, 2021), *Armoricochitina* sp. cf *Armoricochitina nigerica* (Hirnantian, Steemans *et al.*, 1996; Paris *et al.*, 2000), *Conochitina minnesotensis* (Middle-Upper Ordovician, Paris *et al.*, 2000), *Calpichitina lenticularis* (Late Ordovician-Early Silurian, Paris *et al.*, 2015), *Euconochitina lepta* (Katian-Hirnantian?-Ashgillian, Paris *et al.*, 1999 in Ghavidel- Syooki, 2017; Wang *et al.*, 2021), *Spinachitina bulmani* (Late Ordovician, Vanderbroecke, 2008), *Lagenochitina deunffi* (Middle Ordovician, Paris, 1981) were identified (figure 5). However, the presence of the chitinozoan *Armoricochitina* sp. cf. *Armoricochitina nigerica* and the acritarch Cheleutochroa diaphorosa (see Steemans *et al.*, 1996) (Figure 6, Table 1), which probably corresponds to *Multiplicisphaeridium* sp. cf. *arbusculiferum* known from the late Ordovician at Talacasto area (Melendi and Volkheimer, 1982), confirm a Hirnantian age for this section having a main Gondwanan affinity (Gómez *et al.*, 2021b). The age of this assemblage correlates with the graptolite assemblage akin to the *M. persculptus* Zone (López *et al.*, 2020), found immediately above the oolitic level (Figure 3).

Some typical forms of the Llandovery-Wenlockian were recorded in the PN4 association. The presence of *Crassiangulina tesselita* stands out because, in previous works it is documented in the upper part of the La Chilca Formation (García-Muro and Rubinstein, 2015), as well as *Quadraditum deunffii* that was found in the lower member of the Los Espejos Formation (Pöthe de Baldis, 1981; Pöthe de Baldis and Peralta, 1999). The temporal distribution of these species has been reviewed (Le Hérissé *et al.*, 2001; Ghavidel-Syooki *et al.*, 2011), therefore the redeposition in youngest sediments cannot be ruled out (Gómez *et al.*, 2021a).

## Paleoenvironment and paleoclimate interpretation

The occurrences of various assemblages of palynomorphs such as acritarchs, chitinozoans and cryptospores registered in the Central and Eastern Precordillera provide new data to a better understanding of the notorious environmental changes that occurred at the end of the Ordovician.

In the Central Precordillera, an inner platform with low oxygen bottom- conditions is suggested, due to the preservation of the chitinozoan assemblages present in the La Chilca Formation at the Poblete Norte and Quebrada Ancha sections (Figure 3). Cryptospores, typically linked to primitive plants such as vascular bryophytes or primitive rhyniophytoid that lived in terrestrial environments close to marine environments (Steemans et al., 1996, 2012; Rubinstein and Vaccari, 2004), are documented in the BT0.5 and QA B3 levels of the Talacasto sections (Figure 3-6). In the upper Hirnantian, the presence of chitinozoans suggests mainly marine facies (BT1, BT2, QA T2, QA0) during the *M. persculptus* Zone (Figure 3), whereas in the *P. acuminatus* Zone, a reactivation of the terrestrial contribution can be observed (BT3, BT5, QA4, QA6), which continues into the *A. atavus* Zone (QA10). Hence, we interpret that during a shoreface receding (3rd transgressive pulse, Gómez, 2022), and the beginning of the sea-level rise (4th transgressive pulse, Gómez, 2022), the basin received input from marginal terrestrial environments (Gómez *et al.*, 2023).

In the Don Braulio section, Villicum Range (Figure 4), the lower and middle part of the Ocher Mudstones Member (DB), indicate deposition in marine environments consistent with the presence of glauconite (Sánchez *et al.*, 1991; Peralta, 1993; Peralta and Carter, 1999), and marine palynomorphs in the DB2 and DB2.5 levels. It is worth noting the similarity of this litho-biofacies with that of the Hirnantian PN4 palynoassemblage at Talacasto. At the DB12 level, the Rhuddanian litho- and biofacies would indicate a shallowing of the basin and reactivation of terrestrial input from freshwater environments into the marginal – marine depocenters.

From the paleoecological and paleoclimatic point of view, despite the scarcity of productive levels recovered, the Ocher Mudstones

Member is promising. The intense bioturbation documented is indicative of a higher level of oxygenation in the bottom that would have prevented the preservation of organic matter in those deposits (Peralta, 1993; Peralta and Carter, 1999). In the overlying Ferriferous Upper Member, Pöthe de Baldis (1997a) suggested that the acritarch assemblages were deposited in open sea shallow waters under temperate to warm conditions.

A crisis in biodiversity and abundance of phytoplankton through the OST is corroborated, likely related to physical-chemical changes in upwelling currents (Gómez *et al.*, 2021a). These paleoenvironmental controls are evidenced by the low diversity of phytoplankton in the Don Braulio and at the base of the La Chilca formations. A relationship with the Gondwana-Perigondwana regions can be established based on sharing chitinozoans (e.g. *Ancyrochitina* sp. cf. *Ancyrochitina merga*, *Armoricochitina* sp. cf. *Armoricochitina nigerica*, *Conochitina minnesotensis*, *Calpichitina lenticularis*, *Euconochitina lepta*, *Spinachitina bulmani*, *Lagenochitina deunffi*) and other taxa (e.g. *Cheleutochroa diaphorosa*, *Hyspaneidiscus* sp., *Sphaerasaccus glabellus*). After that, a clear recovery observed in overlying levels together with graptolite associations (Pöthe de Baldis, 2003; Gómez, 2022, and references herein; Gómez *et al.*, 2023).

## Conclusions

Based on comparisons with described microfloras from Precordillera and other parts of the world, the palynoassociation from the basal strata of the La Chilca Formation, just over 1 m above contact with the San Juan Formation, is here assigned to the Late Ordovician (Hirnantian), in agreement with the record of the *M. persculptus* Zone. A Gondwana-Perigondwana affinity can be established based on sharing chitinozoans such as *Ancyrochitina* sp. cf. *Ancyrochitina merga*, *Armoricochitina* sp. cf. *Armoricochitina nigerica*, *Conochitina minnesotensis*, *Calpichitina lenticularis*, *Euconochitina lepta*, *Spinachitina bulmani*, *Lagenochitina deunffi*) and some other taxa (e.g. *Cheleutochroa diaphorosa*, *Hyspaneidiscus* sp., *Sphaerasaccus glabellus*), which are also documented in the basal part of the Ocher Mudstone Member of the Don Braulio Formation confirming a Hirnantian age.

Despite the palynologic analyses presented in this study are still limited due to a low number of productive samples, they indicate the high potential for new studies with a more significant number of samples.

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## APPENDIX

COMMENTED LIST OF TAXA CITED IN THE TEXT

### INVERTEBRATES

*Graptolites*
*Metabolograptus persculptus (Glyptograptus persculptus* Salter; = *Metabolograptus persculptus* Elles and Wood)
*Atavograptus atavus* (Rickards)
*Parkidograptus acuminatus* (Nicholson)
*Trilobites*
*Dalmanitina sudamericana* (Baldis and Blasco)
*Eohomalonothus villicunensis* (Baldis and Blasco)
*Bivalves*
*Modilopsis cuyana* (Sánchez)
*Palaeoneila* sp. (see Sánchez, 1990)

**PALYNOMORPHS** (for a complete authority of taxa see Palynodata)

*Acritarchs*
*Cheleutochroa diaphorosa* Turner
*Crassiangulina tesselita Jardiné et al.* emend. Wauthoz et al.
*Dactylofusa* sp. cf. *D. maranhensis* Brito and Santos (see Le Hérissé *et al.*, 2001)
*Lophosphaeridium* sp. (Remarks: It is similar to specimens illustrated by García-Muro *et al.* (2016, Pl. 3, fig. 21), and *Buedingiisphaeridium balticum* (Uutela and Tynni in Delabroye *et al.* 2011, Katian-Hirnantian of Laurentia and Baltica)
*Moyeria cabottii?* in Miller and Eames (1982)
*Multiplicisphaeridium* sp. cf. *arbusculiferum* (Downie) Lister
*Quadraditum fantasticum* Cramer
*Quadraditum deunffii* Pöthe de Baldis
*Strophomorpha ovata?* in Steemans *et al.* (1996)
*Chitinozoans*
*Ancyrochitina* sp. cf. *Ancyrochitina merga* (Jenkins)
*Ancyrochitina* sp. (similar to *Ancyrochitina* sp. in Volkhei-

mer *et al.*, 1980)
*Armoricochitina* sp. cf *Armoricochitina nigerica* Bouché
*Calpichitina lenticularis* Bouché
*Conochitina chydaea* Jenkins
*Conochitina minnesotensis* Stauffer
*Cyathochitina calix* (Eisenack) (late Ordovician-Silurian, Wang *et al.*, 2021)
*Cyathochitina campanulaeformis* (Eisenack)
*Euconochitina lepta* Jenkins
*Lagenochitina deunffi* Henry *et al.* (= *Lagenochitina* cf. *pirum* in Paris *et al.*, 2000, Middle Ordovician)
*Spinachitina bulmani* Jansonius
*Cryptospores*
*Chelinohilates maculatus* Steemans et al. (Rhuddanian, Steemans *et al.*, 2000)
*Dyadaspora murusdensa /murusattenuata* Ströther and Traverse (Ashgillian-Devonian, Steemans *et al.*, 1996, 2000).
*Hyspanaediscus* sp. (Rhuddanian, Steemans *et al.*, 2000; Wellman *et al.*, 2000)
*Laevolancis chibrikovae* Steemans *et al.* (Rhuddanian, Steemans *et al.*, 2000)
*Gneudnaspora (Laevolancis) divellomedia* (Chibrikova) Balme (see in Rubinstein and Brussa, 1999)
*Sphaerasaccus glabellus* Steemans *et al.* (Rhuddanian, Steemans *et al.*, 2000)

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