

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

Jessica C. GÓMEZ^{1,2}, Mercedes DI PASQUO⁴, Silvio H. PERALTA^{1,2,3} and Leonardo SILVESTRI⁴

Resumen: ESTUDIO PALINOLÓGICO PRELIMINAR DE LA TRANSICIÓN ORDOVÍCI-CO-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 Ocreas 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 Ocreas 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-Llandoverian), Eastern Precordillera (Hirnantian-Llandoverian). 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.

¹ Centro de Investigaciones de la Geósfera y la Biosfera (CIGEOBIO - CONICET). Universidad Nacional de San Juan. 5400, San Juan, Argentina. E-mail: jcgomez@conicet.gov.ar

² Instituto de Geología Dr. Emiliano Pedro Aparicio (INGEO). Universidad Nacional de San Juan. 5400, San Juan, Argentina. E-mail: speralta@unsj-cuim.edu.ar

³ Departamento de Geología, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de San Juan. 5400, San Juan, Argentina.

⁴ Laboratorio de Palinoestratigrafía y Paleobotánica, CICYTTP (CONICET- ENTRE RÍOS-UADER), Dr. Materi 149, E3105BRA Diamante, Entre Ríos, Argentina, E-mail: medipa@cicytpp.org.ar

* Autor a Cargo: Jessica Gómez, Perito Moreno 1490 Norte San Juan, Capital 5400. E-mail: Jessicagomez21@gmail.com

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 *Gneudnasporea 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 chydæa*, 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

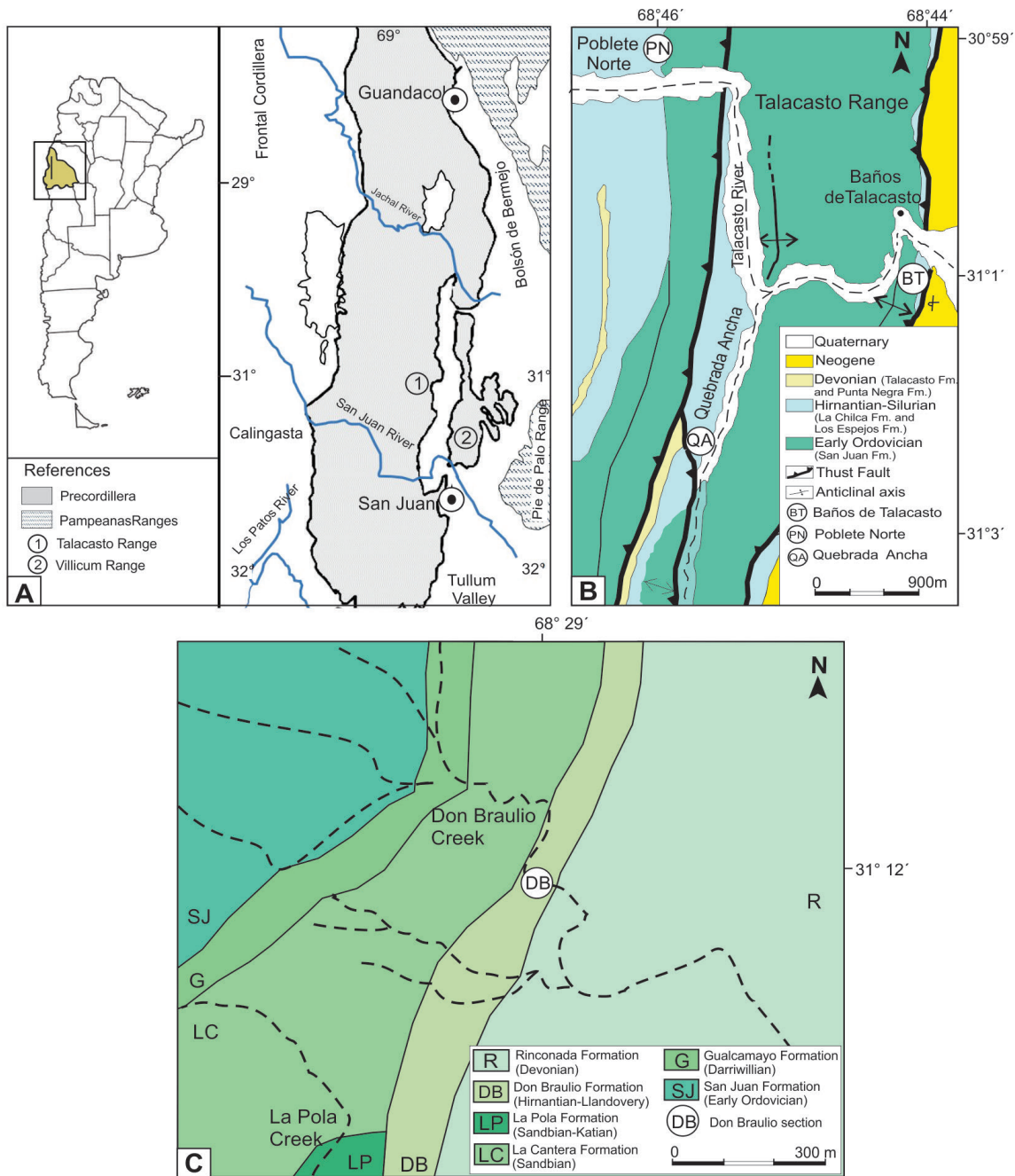


Figure 1. A) Map of the San Juan Precordillera showing the sections analyzed in this work (modified from Baldis *et al.*, 1982). **B)** Geological map of the Talacasto area, with the Quebrada Ancha, Baños de Talacasto, and Poblete Norte sections (modified from Baldis *et al.*, 1984a). **C)** Geological 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

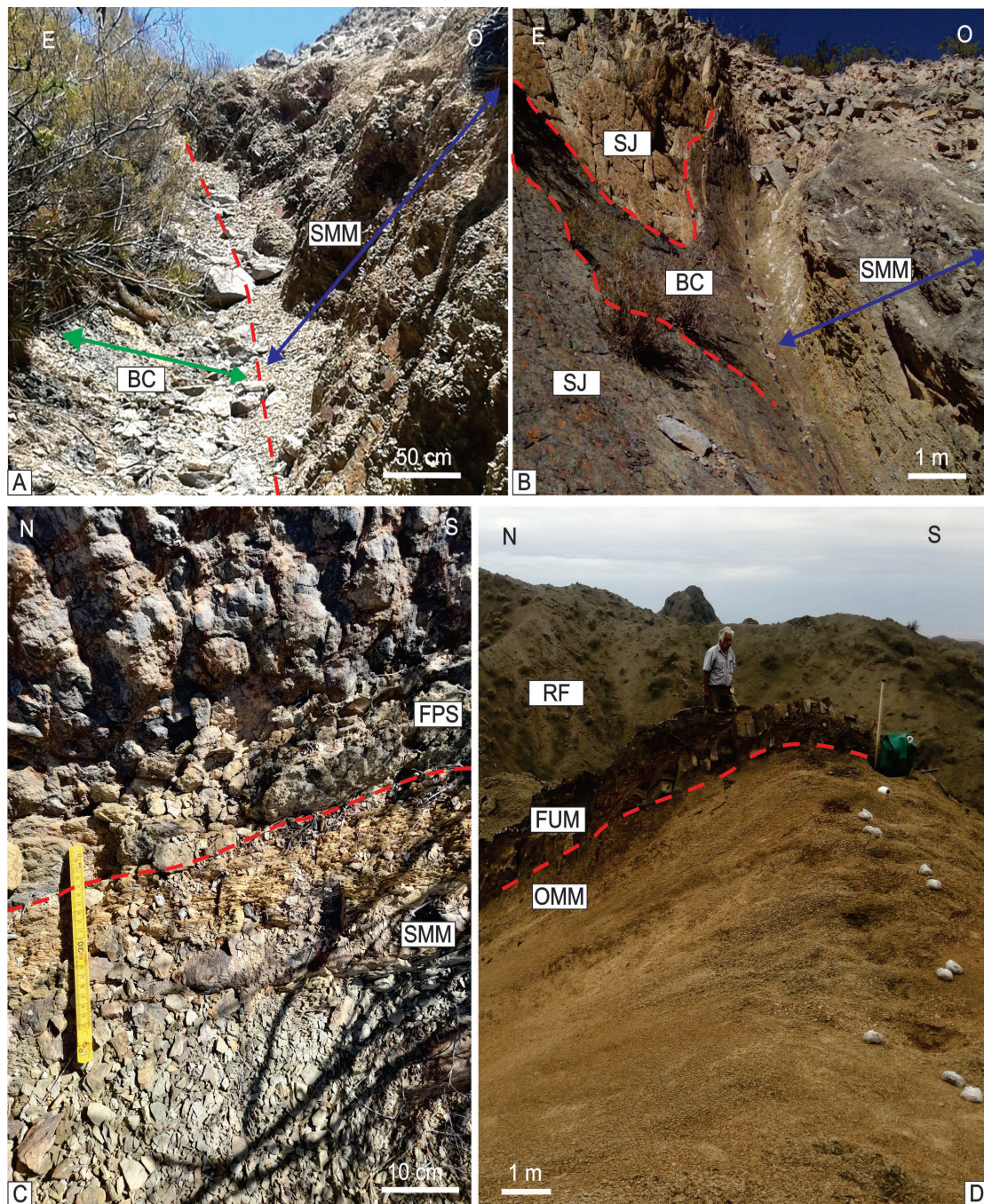


Figure 2. **A)** Baños de Talacasto section, the red stroke line represents the sharp contact between the basal conglomerate (BC) and the fossiliferous siltstone of the Salto Macho Member (SMM) of the La Chilca Formation. **B)** Quebrada Ancha section, the red stroke line shows the erosive contact between 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 psefitico 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 Braulío (Formación Don Braulío), se observa la sucesión de fangolitas bioturbadas del Miembro Fangolitas Ocher (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 *Eobomalonothus villicumensis* (Baldis and Blasco, 1975), brachiopods of the typical *Hirnantian Fauna* (Levy and Nulló, 1974; Benedetto, 1986, 1990), a monospecific association of *Metabolograptus* (ex *Normallograptus*) *persculptus* (Peralta and Baldis, 1990), and the bivalves *Modiolopsis 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 Llandoveryan 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 Trasil 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-PI (di Pasquo and Silvestri, 2014).

Sample	Collection number (CICYTTP-PI)	<i>Cheleutochroa diaphorosa</i>	<i>Ancyrochitina</i> sp. cf. <i>Ancyrochitina merga</i>	<i>Armoricochitina</i> sp. cf. <i>Armoricochitina nigerica</i>	<i>Calpichitina lenticulari</i>	<i>Conochitina minnesotensis</i>	<i>Euconochitina lepta</i>	<i>Lagenochitina deunffi</i>	<i>Spinachitina bulmani</i>	<i>Crassiangulina tessellata?</i>	<i>Quadradrutum fantasticum?</i>	<i>Leiosphaeridia</i>
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 tessellata?* 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. *Quadradrutum 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.

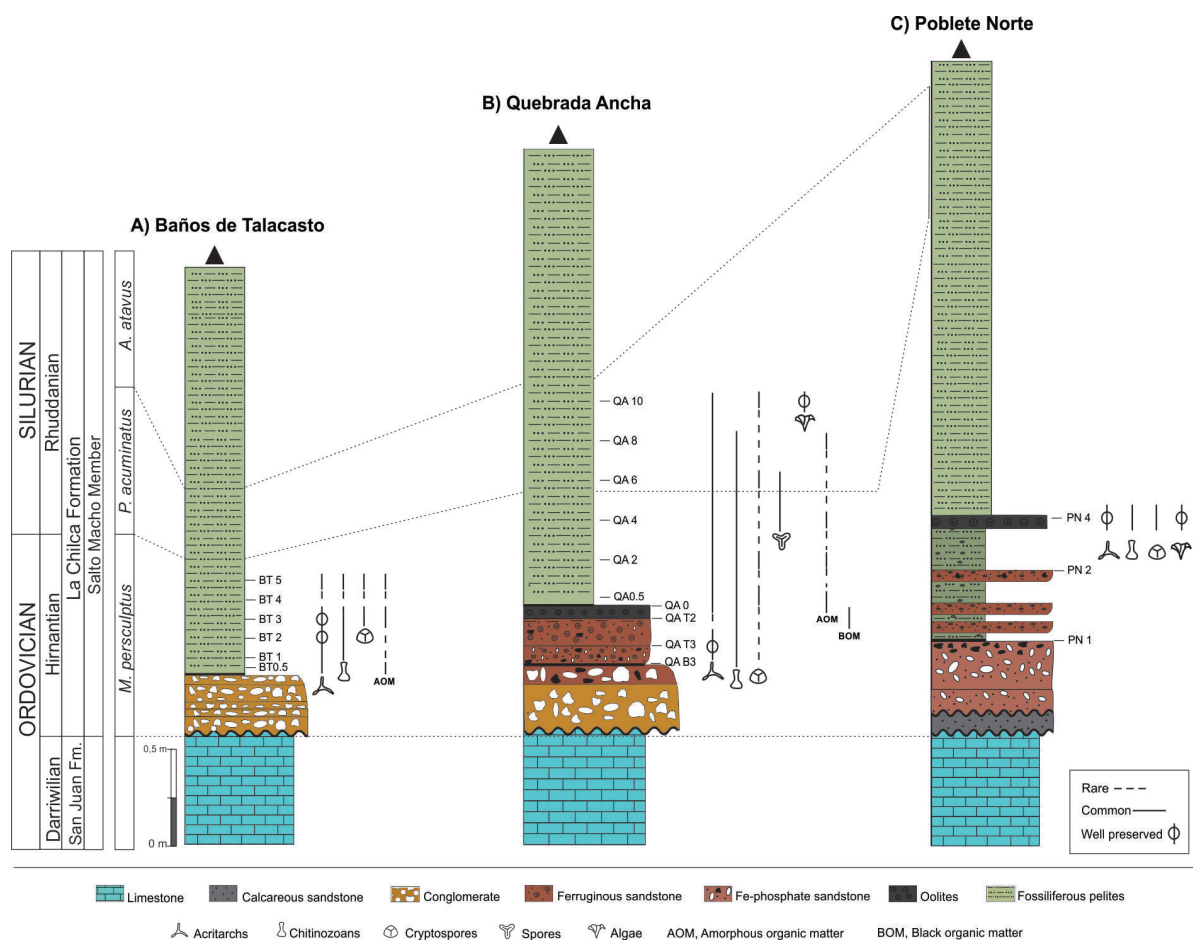


Figure 3. Schematic stratigraphic section of La Chilca Formation in the Talacasto area, showing the location of the samples and the relative abundance of acritarchs, chlorophytes and cryptospores. **A)** Baños de Talacasto, **B)** Quebrada Ancha; **C)** Poblete Norte. / **Figura 3.** Sección estratigráfica 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*, *Calpicbitina 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,

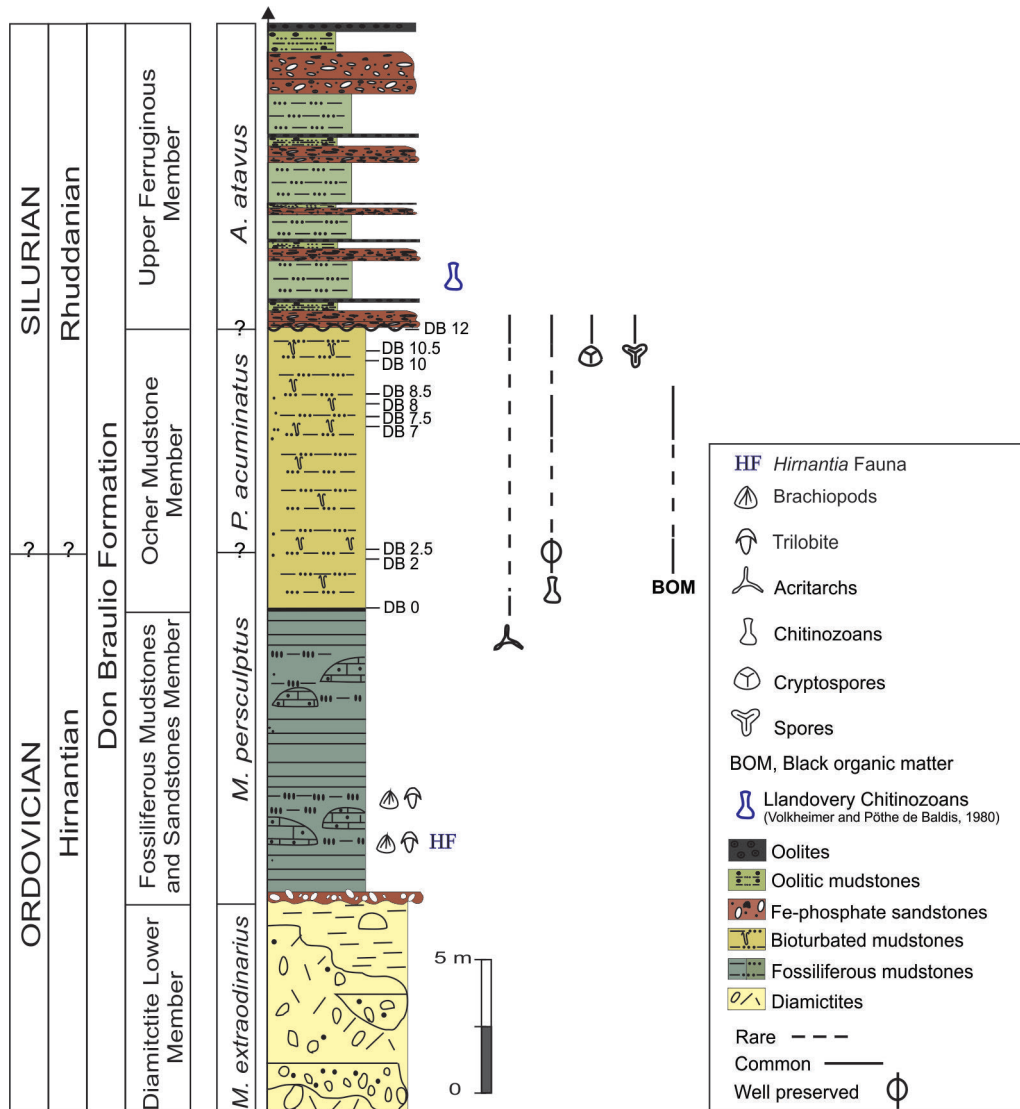


Figure 4. Schematic stratigraphic section of Don Braulio Formation at the Villicum Range showing the location of the samples (DB 0 to DB 12), distances in meters from the base, and the relative abundance of acritarchs, chitinozoans and cryptospores. / **Figura 4.** Sección estratigráfica esquemática 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

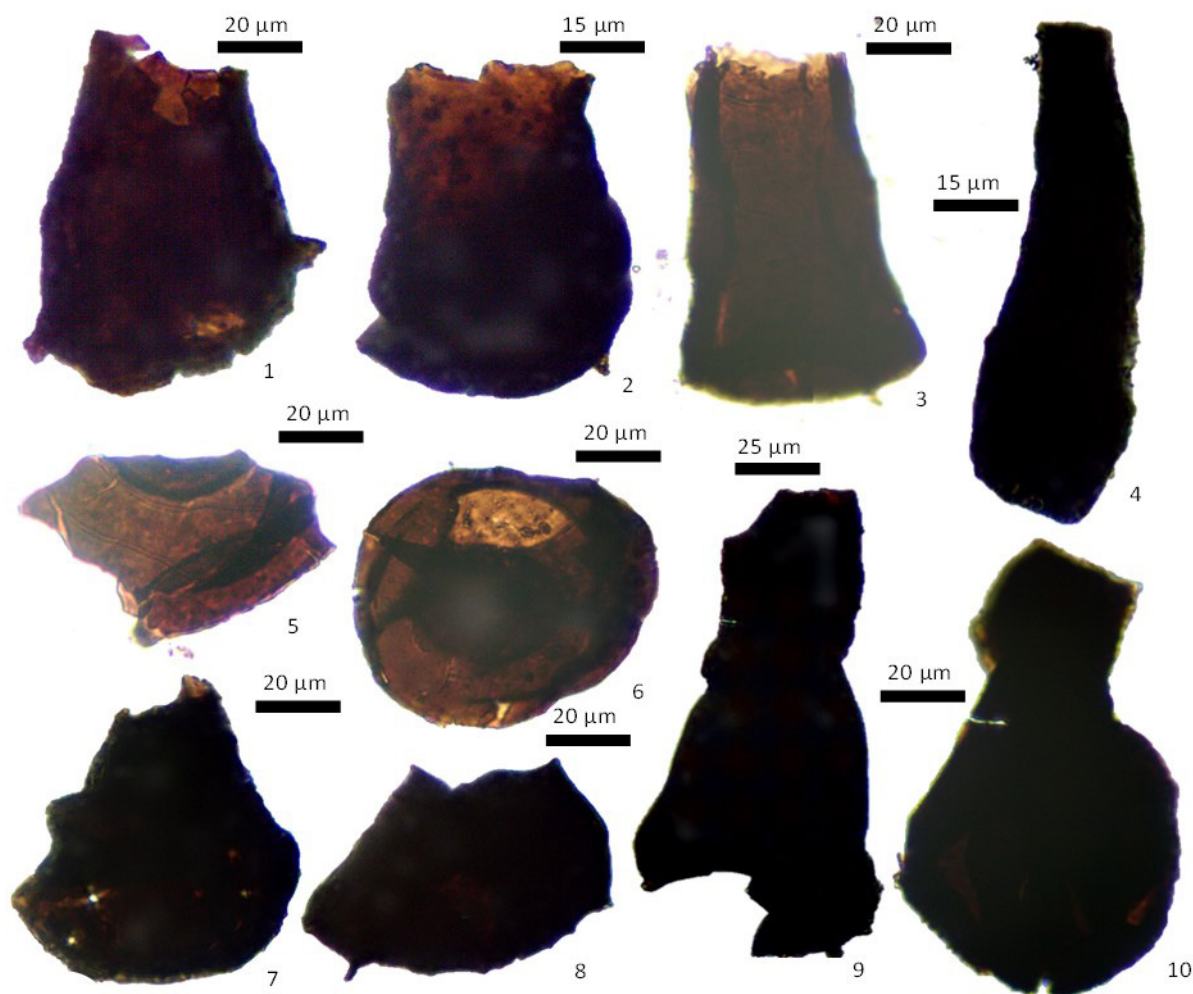


Figure 5. Selected chitinozoans from the Poblete Norte section (see figure 3, and for references consult the appendix herein and Palynodata webpage). **1.** *Ancyrochitina* sp. cf. *Ancyrochitina merga*, CICYTTP-PI 2472-1+10-hf1 England Finder coordinates (EF) K36/0. **2.** *Armoricochitina* sp. cf. *Armoricochitina nigerica*, CICYTTP-PI 2472-2new-+10-hf1 EF D26/3. **3.** *Cyathochitina calix*, CICYTTP-PI 2472-1new-+10-hf1 EF H22/0. **4.** *Conochitina minnesotensis*, CICYTTP-PI 2472-3-11-2019-HF EF R38/4. **5-6.** *Calpichitina lenticularis*. **5.** CICYTTP-PI 2472-3-11-2019-HF EFS29/2. **6.** CICYTTP-PI 24722-1-10-2019-HF EF M29/0. **7.** *Euconochitina lepta*, CICYTTP-PI 2472-2-11-2019-HF EF Z57/4. **8.** *Ancyrochitina* sp., CICYTTP-PI 2472-1-10-2019-HF EF Q58. **9.** *Spinachitina bulmani*, CICYTTP-PI 2472-1-10-2019-HF EF L52/0. **10.** *Lagenochitina deunffi*, CICYTTP-PI 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-PI 2472-1+10-hf1 sistema de coordenadas England Finder (EF) K36/0. **2.** *Armoricochitina* sp. cf. *Armoricochitina nigerica*, CICYTTP-PI 2472-2new-+10-hf1 EF D26/3. **3.** *Cyathochitina calix*, CICYTTP-PI 2472-1new-+10-hf1 EF H22/0. **4.** *Conochitina minnesotensis*, CICYTTP-PI 2472-3-11-2019-HF EF R38/4. **5-6.** *Calpichitina lenticularis*. **5.** CICYTTP-PI 2472-3-11-2019-HF EFS29/2. **6.** CICYTTP-PI 24722-1-10-2019-HF EF M29/0. **7.** *Euconochitina lepta*, CICYTTP-PI 2472-2-11-2019-HF EF Z57/4. **8.** *Ancyrochitina* sp., CICYTTP-PI 2472-1-10-2019-HF EF Q58. **9.** *Spinachitina bulmani*, CICYTTP-PI 2472-1-10-2019-HF EF L52/0. **10.** *Lagenochitina deunffi*, CICYTTP-PI 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 distinguished in the PN4 level (Table 1)

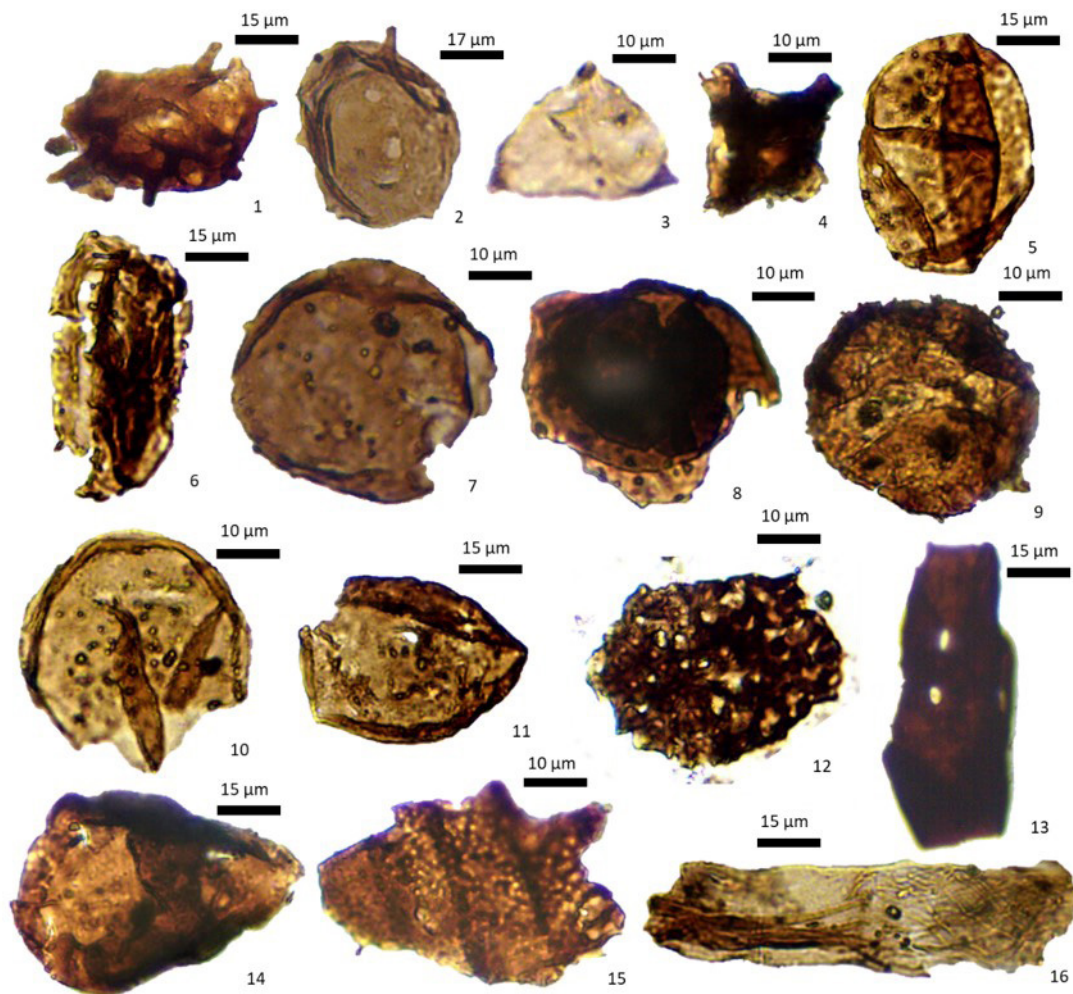


Figure 6. Selected palynomorphs (acritarchs, cryptospores, others) from the Poblete Norte section. **1.** *Cheleutochroa diaphorosa*, CICYTTP-Pl 2472-2 new -+10-*hf1* EF Z26/0. **2.** *Orthosphaeridium* sp. (fragment), CICYTTP-Pl 2472-2 new -+10-*hf1* EF M43/2. **3.** *Crassianguлина tessellata*, CICYTTP-Pl 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 2472-2 new -+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.** *Gneudnasporea divellomedea*, 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 EFE60/0. **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 2472-2 new -+10-*hf1* EF Z26/0. **2.** *Orthosphaeridium* sp. (fragmento), CICYTTP-Pl 2472-2 new -+10-*hf1* EF M43/2. **3.** *Crassianguлина tessellata*, 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 2472-2 new -+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.** *Gneudnasporea divellomedea*, 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.

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 leptota* (Katian-Hirnantian?-Ashgillian, Paris et al., 1999 in Ghavidel-Syooki, 2017; Wang et al., 2021), *Spinachitina bulmani* (Late Ordovician, Vanderbroecke, 2008), *Lagenochitina deumffi* (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 tessellata* 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 deumffi* 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 Hérisse 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 pla-

form 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 (Steeemans 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 paly-noassociation 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.

Acknowledgements

We are grateful to the institutions involved despite the restrictions imposed during the two years of the COVID's pandemic (2020 and 2021), which affected both fieldwork and laboratory procedures and microscopic analyses, among other aspects of the present research. To Jose Vilá for his assistance taking SEM pictures not included in this contribution, at the CICYTTP (CONICET-ER-UADER) in Diamante, Entre Ríos province, Argentina. This research was funded by the projects CONICET PIP 0812 (2015-2022) and CICITCA 2020-2022 (21/E1128).

References

- Astini, R. A. 1991. Paleoambientes sedimentarios y secuencias depositacionales del Ordovícico clástico de la Precordillera Argentina. Universidad Nacional de Córdoba, *Tesis Doctoral*, Córdoba, 851pp. Inédito.
- Astini, R. A. 1992. Descripción y Génesis de los Bancos de Oolitas Ferruginosas en la Base del Silúrico de la Precordillera Argentina. *Estudios Geológicos*, 48: 297-303.
- Astini, R. A. 1993. Facies glaciogénicas del Ordovícico tardío (Hirnantense) de la Precordillera argentina. *Boletín de la Real Sociedad Española de Historia Natural*, 88 (1-4): 137-149.
- Astini, R. A. 2001. Pavimentos estriados en la Forma-

- ción Don Braulio y naturaleza de la Glaciación Hirnantiana (Ordovícico tardío) en la región andina. *Revista de la Asociación Argentina de Sedimentología*, 8: 1-25.
- Astini, R. A. and Benedetto, J. L. 1992. The Late Ashgillian (Hirnantian) of the Cerro La Chilca in the Precordillera of San Juan, Argentina. *Ameghiniana*, 29 (3): 249-264.
- Astini, R. A. and Buggish, W. 1993. Aspectos sedimentológicos y paleoambientales de los depósitos glaciogénicos de la Formación Don Braulio, Ordovícico tardío de la Precordillera Argentina. *Revista de la Asociación Geológica Argentina*, 48(3-4): 217-232.
- 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 (1): 99-110.
- Astini, R. A. and Maretto, H. M. 1996. Análisis estratigráfico del Silúrico de la Precordillera Central de San Juan y consideraciones sobre la cuenca. *13° Congreso Geológico Argentino y 3° Congreso de Exploración de Hidrocarburos* (Buenos Aires), 1: 351-368.
- Baldis, B. A. and Blasco, 1975. Primeros trilobites ashgillianos del Ordovícico sudamericano. *1° Congreso de Paleontología y Bioestratigrafía* (San Miguel de Tucumán), 1: 33-48.
- Baldis, B. A. and Chebli, G. 1969. Estructura profunda del área Central de la Precordillera sanjuanina. *4° Jornadas Geológicas Argentinas* (Buenos Aires), 1: 47-66.
- Baldis, B. A., Beresi, M. S., Bordonaro, O. L. and Vaca, A. 1982. Primeros trilobites ashgillianos del Ordovícico sudamericano. *5° Congreso Latinoamericano de Geología* (Buenos Aires), 1: 399-445.
- Baldis, B. A., Beresi, M., Bordonaro, O. and Vaca, A. 1984a. The Argentine Precordillera a key to Andean structure. *Episodes*, 7(3): 14-26.
- Baldis, B. A., Peralta, S. H. and Uliarte, E. R. 1984b. Geología de la Quebrada Ancha y sus alrededores en el área de Talacasto, Precordillera Sanjuanina. *9° Congreso Geológico Argentino* (San Carlos de Bariloche), 4: 233-245.
- Benedetto, J. L. 1986. *The first typical Hirnantian Fauna from South America (San Juan Province, Argentine Precordillera)*. In: P.R., Racheboeuf, C.C., Eming (eds.), *Les Brachiopodes fossiles et actuels: Biostratigraphie du Paleozoic*, 4, pp. 439-447.
- Benedetto, J. L. 1987. Braquiópodos neo-Ordovícicos del flanco occidental del Cerro del Fuerte, Provincia de San Juan. *Ameghiniana*, 24: 169-174.
- Benedetto, J. L. 1990. Los géneros *Cliftonia* y *Paromalomena* (Brachiopoda) en el Ashgilliano tardío de la Sierra de Villicum, Precordillera de San Juan. *Ameghiniana*, 27: 151-159.
- Benedetto, J. L., Sánchez, T. M. and Brussa, E. D. 1992a. *Las cuencas Silúricas de América Latina*. In: J.C., Gutiérrez-Marco, J., Saavedra, I. Rábano (eds.), *Paleozoico inferior de Ibero-América*. Universidad de Extremadura, pp. 119-148.
- Benedetto, J. L., Racheboeuf, P., Herrera, Z., Brussa, E. and Toro, B. 1992b. Brachiopodes et biostratigraphie de la Formación Los Espejos, Siluro-Devonien de la Precordillera (NW Argentine). *Geobios*, 25: 599-637.
- Beresi, M.S. and Gómez, J. 2023. Hirnantian (Latest Ordovician) sponge spicules from the Precordillera at high latitudes of the Western Gondwana. *Serie de Correlación Geológica* 39 (1): 47 – 57.
- Blackwelder, E. 1909. The valuation of unconformities. *Journal of Geology*, 17: 289-299.
- Buggish, W. and Astini, R. 1993. *The Late Ashgillian Ice Age: New evidence from the Argentine Precordillera*. In: R.H., Unrug, R., Banks, J., Veevers (eds.), *Gondwana Eight*, Findlay, pp. 439-447.
- Castellaro, H. A. 1966. Guía Paleontológica Argentina. Parte I: Paleozoico, Sección III, Faunas Silúricas; Sección IV, Faunas Devónicas. *Publicación del Consejo Nacional de Investigaciones Científicas*: 1-164.
- Cuerda, A. J. 1965. *Monograptus leintwardinensis* var. *incipiens* Wood, en el Silúrico de la Precordillera. *Ameghiniana*, 6: 223-335.
- Cuerda, A. J. 1969. Sobre las graptofaunas del Silúrico de San Juan. *Ameghiniana*, 6: 223-225.
- Cuerda, A. J., Rickards, R. B. and Cingolani, C. 1988. A new Ordovician-Silurian boundary section in San Juan Province, Argentina, and its definitive graptolite fauna. *Journal of the Geological Society*, 145: 749-757.
- Delabroye, A., Munnecke, A., Vecoli, M., Copper, P., Tribouvillard, N., Joachimski, M., Desrochers, A. and Servais, T. 2011. Phytoplankton dynamics across the Ordovician/Silurian boundary at low palaeolatitudes: Correlations with carbon isotopic and glacial events. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 312: 79-97.
- di Pasquo, M. M. and Silvestri, L. 2014. Las colecciones de Palinología y Paleobotánica del Laboratorio de Palinoestratigrafía y Paleobotánica del Centro de Investigaciones Científicas y Transferencia de Tecnología a la Producción (CICYTTP), Entre Ríos, Argentina. *Boletín de la Asociación Latinoamericana de Paleobotánica y Palinología*, 14: 39 - 47.
- Furque, G. and Cuerda, A. J. 1979. Precordillera de La Rioja, San Juan y Mendoza. *2° Simposio de Geología Regional Argentina* (Córdoba), 1: 455-522.
- García-Muro, V. J. and Rubinstein, C. V. 2015. New biostratigraphic proposal for the Lower Palaeozoic Tucunuco Group (San Juan Precordillera,

- Argentina) based on marine and terrestrial palynomorphs. *Ameghiniana*, 52: 265-285.
- García-Muro, V. J., Rubinstein, C. V., and Martínez, M. 2016. Palynology and palynofacies analysis of a Silurian (Llandovery–Wenlock) marine succession from the Precordillera of western Argentina: Palaeobiogeographical and palaeoenvironmental significance. *Marine Micropaleontology*, 126: 50-64.
- Ghavidel-Syooki, M. 2017. Cryptospore and trilete spore assemblages from the Late Ordovician (Katian–Hirnantian) Ghelli Formation, Alborz Mountain Range, Northeastern Iran: Palaeophytogeographic and palaeoclimatic implications. *Review of Palaeobotany and Palynology*, 231: 48–71.
- 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.
- Gómez, J. 2022. Estratigrafía de alta resolución de la transición Ordovícico-Silúrico de la Precordillera de San Juan, Argentina. Facultad de Ciencias Exactas, Físicas y Naturales. Universidad Nacional de San Juan. *Tesis Doctoral*, San Juan, 313 pp. Inédito.
- Gómez, J., Peralta, S. and Beresi, M. 2021a. Depósitos de upwelling en la transición Ordovícico-Silúrico de la Precordillera de San Juan: significado estratigráfico y paleoambiental. *17° Reunión Argentina de Sedimentología y 8° Congreso Latinoamericano de Sedimentología* (Paraná, Argentina), 133.
- Gómez, J., di Pasquo, M. and Peralta, S. 2021b. Late Ordovician palynomorphs from the basal strata of the La Chilca Formation, Central Precordillera, Argentina. *Virtual Annual Meeting of IGCP 653; Virtual Annual Meeting of IGCP 735* (Lille, France), 36-37.
- Gómez, J., Peralta, S. and Beresi, M. 2022. Stratigraphic framework and facies changes in the Hirnantian-Rhuddanian transition San Juan, Precordillera Argentina: paleoenvironmental and tectosedimentary significance. *21° Congreso Geológico Argentino* (Puerto Madryn), 55-56.
- Gómez, J., Peralta, S., Sial, A.N. and di Pasquo M. 2023. Timeline of events in the Ordovician–Silurian Transition of the Precordillera (Argentina): Paleoenvironmental, paleoclimatic and paleobiologic implications. *Journal of South American Earth Sciences*, 131. <https://doi.org/10.1016/j.jsames.2023.104630>
- Grahn, Y. and Paris, F. 2011. Emergence, biodiversification and extinction of the chitinozoan group. *Geological Magazine*, 148 (2): 226–236.
- Jiménez-Sánchez, J., Beresi, M. S., Mestre, A. and Heredia, S. 2014. Upper Ordovician cryptostomatid bryozoans and microfossils from the Don Braulio Formation, Eastern Precordillera, Argentina. *Serie Correlación Geológica*, 30 (1): 25-33. Tucumán.
- Kabanov, P. 2017. *Stratigraphic unconformities: Review of the concept and Examples from the Middle-Upper Paleozoic*. In: G., Aiello (ed.), *Seismic and Sequence Stratigraphy and Integrated Stratigraphy*, IntechOpen, pp. 101-127.
- Le Hérisse, A., Melo, J. H. G., Quadros, L. P., Grahn, Y. and Steemans, P. 2001. *Palynological characterization and dating of the Tianguá Formation, Serra Grande Group, northern Brazil. Correlação de Sequências Paleozóicas Sul-Americanas*. In: J.H.G, Melo, G.J.S., Terra (eds), *Correlação de Sequências Paleozóicas Sul-Americanas. Ciência-Técnica-Petróleo, Seção Exploração de Petróleo*, 20, pp. 25–41.
- Lenz, A. C., Cuerda, A. and Peralta, S. 2003. Graptolites from the Upper Llandovery of the Talacasto area, Central Precordillera, San Juan, Argentina. *Journal of Paleontology*, 77: 1198-1202.
- Levy, R. and Nullo, F. 1974. La fauna del Ordovícico (Ashgilliano) de Villicum, San Juan, Argentina. *Ameghiniana*, 9(2): 173:194.
- López, F., León, L., Kaufmann, C., Contreras, V., Conde, O. and Campos, M. 2020. Graptofaunas del Miembro Salto Macho, Formación La Chilca (Ordovícico Superior-Silúrico Inferior), en la quebrada Pobleto Norte, Precordillera Central de San Juan, Argentina. *Serie de Correlación Geológica*, 36 (1-2): 5-26.
- Marchese, H. G. 1972. Sedimentología de la Formación San Juan (Ordovícico), y el conglomerado basal de la Formación Los Espejos (Silúrico) en la quebrada de Talacasto, Provincia de San Juan. *Revista de la Asociación Geológica Argentina*, 27(2): 215-222.
- Martin, F. 1993. Acritarchs: a review. *Biological Reviews*, 68: 475–538.
- Melendi, D. L. and Volkheimer, W. 1982. Datos palinológicos del límite Ordovícico-Silúrico de Talacasto, Provincia de San Juan. Parte I: Base del Silúrico. *Revista Asociación Geológica Argentina*, 37(2): 221-236.
- Miall, A. D. 2016. *Stratigraphy: A Modern Synthesis*. Berlin, Springer-Verlag, pp. 454.
- Miller, M. A. and Eames, L. E. 1982. Palynomorphs from the Silurian medina group (lower Llandovery) of the Niagara Gorge, Lewiston, New York, U.S.A. *Palynology*, 6: 221-254.
- Mizusaki, A. M. P., Melo, J. H. G., Vignol-Lelarge, M. L. and Steemans, P. 2002. Vila Maria Formation (Silurian, Paraná Basin, Brazil): integrated radiometric and palynological age determinations. *Geological Magazine*, 139 (04): 453-464.

- Ortiz, A. and Zambrano, J. J. 1981. La Provincia Geológica Precordillera Oriental. 8° Congreso Geológico Argentino, 3: 59-74.
- Paris, F. 1981. Les chitinozoaires dans le Paléozoïque du sudouest de l'Europe (cadre géologique, étude systématique, biostratigraphie). *Mémoire de la Société géologique et minéralogique de Bretagne*, Rennes, 26: 1-496.
- Paris, F., Bourahrouh, A. and Le Hérisse, A. 2000. The effects of the final stages of the Late Ordovician glaciation on marine palynomorphs (chitinozoans, acritarchs, leiospheres) in well NI-2 (NE Algerian Sahara). *Review of Palaeobotany and Palynology*, 113: 87-104.
- Paris, F., Verniers, J., Miller, M. A., Al-Hajri, S., Melvin, J. and Wellman, C. H. 2015. Late Ordovician-earliest Silurian chitinozoans from the Qusai-ba-1 core hole (North Central Saudi Arabia) and their relation to the Hirnantian glaciation. *Review of Palaeobotany and Palynology*, 212: 60-84. DOI 10.1016/j.revpalbo.2014.10.005
- Peralta, S. H. 1985. Graptolitos del Llandoveryano inferior en el Paleozoico inferior clástico en el pie oriental de la sierra de Villicum, Precordillera Oriental. 1° Jornadas Sobre Geología de Precordillera (San Juan), Relatorio: 134-138.
- Peralta, S. H. 1993. Estratigrafía y consideraciones paleoambientales de los depósitos marino clásticos eopaleozoicos de la Precordillera Oriental de San Juan. 12° Congreso Geológico Argentino y 2° Congreso de Exploración de Hidrocarburos, 1: 128-137.
- Peralta, S. H. 2006. Sea level fluctuations and forced regressions in the Silurian basin in the Precordillera of Western Argentina. GFF (Geologiska Föreningen), *The Geological Society of Sweden*, 128 (2): 181-184.
- Peralta, S. H. 2007. *The extensional history of the Devonian basin of Precordillera: Its tecto-sedimentary significance in the evolution of the Cuyania Terrane*. In: G.F., Aceñolaza, M., Vergel, S.H., Peralta, R., Herbst (eds.), Field Meeting Project IGCP 499 (IUGS-UNESCO) "Devonian land-sea interaction: evolution of ecosystems and climate" (DEVEC), (San Juan, Argentine), 102-105.
- Peralta, S. H. and Baldis, B. A. 1990. *Glyptograptus persculptus* en la Formación Don Braulio (Ashgilliano tardío-Llandoveryano temprano) en la Precordillera Oriental de San Juan. 5° Congreso Argentino de Paleontología y Bioestratigrafía, Serie Correlación Geológica (Tucumán), Relatorio, 7: 67-72.
- Peralta, S. H. and Carter, C. H. 1990. La glaciación Gondwánica del Ordovícico tardío: evidencias en fangolitas guijarrosas de la Precordillera de San Juan. 11° Congreso Geológico Argentino (San Juan), Relatorio 2: 181-185.
- Peralta, S. H. and Carter, C. H. 1999. Don Braulio Formation (late Ashgillian-early Llandoveryan, San Juan Precordillera, Argentina): stratigraphic remarks and paleoenvironmental significance. *Acta Universitatis Carolinae, Geologica*, 43 (1/2): 225-228.
- Peralta, S. H., Uliarte, E. R. and Lanzilotta, I. 1985. Estudio de los depósitos sedimentarios ferruginosos del Silúrico de la Precordillera de San Juan. 1° Jornadas sobre Geología de Precordillera (San Juan, Argentina), Relatorio: 301-306.
- Peralta, S. H., Pöthe de Baldis, D. y Aceñolaza, G. F. 1997. Elementos de correlación del Silúrico de la Precordillera Central de San Juan. 2° Jornadas sobre Geología de Precordillera (San Juan, Argentina), Relatorio: 48-53.
- Pöthe de Baldis, D. 1981. Paleomicroplanton y esporas del Ludloviano inferior de la Formación Los Espejos en el perfil Los Azulejitos, en la Provincia de San Juan, República de Argentina. *Revista Española de Micropaleontología*, 13 (2): 231-265.
- Pöthe de Baldis, D. 1997a. Acritarcas del Llandoveryano inferior-medio de la Formación Don Braulio, Precordillera Oriental, provincia de San Juan, Argentina. *Revista Española de Micropaleontología*, 29: 31-68.
- Pöthe de Baldis, D. 1997b. Acritarcas y prasinofíceas del Llandoveryano Temprano-Medio de la Formación La Chilca, Quebrada de Talacasto, Provincia de San Juan, Argentina. *Ameghiniana*, 34: 461-479.
- Pöthe de Baldis, D. 2003. Quitinozoos del Llandoveryano Temprano-Medio (*Zona de Atavograptus atavus*), de la Formación La Chilca, en la quebrada de Talacasto, Precordillera Central de San Juan, Argentina. Parte 1. *Ciencias*, 5-20.
- Pöthe de Baldis, E. and Peralta, S.H. 1999. Asociaciones Palinológicas y bioestratigráficas del Grupo Tucunuco (Ordovícico superior-Silúrico superior). *Ameghiniana*, 36: 359-367.
- Ramos, V. 1999. *Las provincias geológicas del territorio argentino*. In: Caminos, R. (ed.), Geología Argentina. Instituto de geología y recursos minerales, Anales, 29, pp. 41-96.
- Rickards, R. B., Brussa, E. D., Toro, B. A. and Ortega, G. 1996. Ordovician and Silurian graptolite assemblages from Cerro del Fuerte, San Juan Province, Argentina. *Geological Journal*, 31:101-122.
- Rubinstein, C. V. and Brussa, E. D. 1999. *A palynomorph and graptolite biostratigraphy of the Central Precordillera Silurian basin, Argentina*. In: M., Tongiorgi, 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 Vaccari, N. E. 2004. Cryptospore assemblages from the Ordovician–Silurian boundary in the Puna, north–west Argentina. *Palaeontology*, 47: 1037–1061.
- Sánchez, M. T. 1985. El género *Modiolopsis* (Bivalvia, Modiomorphoidea) en el Ashgilliano de la sierra de Villicum y la Comunidad de Hirnantia-*Momodiolopsis*. *Reunión de Comunicaciones Científicas, Asociación Paleontológica Argentina*, 58-59.
- Sánchez, M. T. 1990. Bivalvos del Ordovícico medio-tardío de la Precordillera de San Juan (Argentina). *Ameghiniana*, 27(3-4): 251-261.
- Sánchez, M. T., Benedetto, J. L. and Brussa, E. 1991. *Late Ordovician stratigraphy. Palaeoecology and sea level changes in the Argentine Precordillera*. In: C. R., Barnes, S. H., Williams, (eds.), *Advances in Ordovician Geology*. Geological Survey of Canada, 90-9, pp. 245-258.
- Servais, T., Martin, R.E. and Nützel, A. 2016. The impact of the ‘terrestrialisation process’ in the late Palaeozoic: pCO₂, pO₂, and the ‘phytoplankton blackout’. *Review of Palaeobotany and Palynology*, 224: 26–37
- Steenmans, P., Le Hérisse, A. and Bozdogan, N. 1996. Ordovician and Silurian cryptospores and miospores from Southeastern Turkey. *Review of Palaeobotany and Palynology*, 93: 35–76.
- Steenmans, P., Higgs, K. T. and Wellman, C. H. 2000. *Cryptospores and trilete spores from the Llandoverly, Nuayyim-2 Borehole, Saudi Arabia*. In: S., Al-Hajri, Owens, B. (eds.), *Stratigraphic palynology of the Palaeozoic of Saudi Arabia*. GeoArabia, Bahrain, pp. 92–115.
- Steenmans, P., Petus, E., Breuer, P., Mauller-Mendlowicz, P. and Gerienne, P. 2012. *Palaeozoic Innovations in the Micro- and Megafossil Plant Record: From the Earliest Plant Spores to the Earliest Seeds*. In: J.A., Talent (ed.), *Earth and Life, International Year of Planet Earth*. Springer Science Business Media B.V., pp. 437-477.
- Traverse, A. 2007. *Paleopalynology*. Second edition, Springer, pp. 813.
- Van Wagoner, J. C., Mitchum, R. M., Campion, K. M. and Rahmanian, V. D. 1990. Siliciclastic Sequence Stratigraphy in Well Logs, Cores, and Outcrops: Concepts for High-Resolution Correlation of Time and Facies. *AAPG Series, Methods in Exploration*, pp. 7-53.
- Vandenbroucke, T. R. A. 2008. Upper Ordovician chitinozoans from the type area in the U.K. *Monograph of the Palaeontological Society of London*, 161 (628): 1–113.
- Volkheimer, W., Pöthe de Baldis, D. and Baldis, B. A. 1980. Quitinozoos de la base del Silúrico de la Sierra de Villicum (Provincia de San Juan, República Argentina). *Revista Museo Argentino de Ciencias Naturales “Bernardino Rivadavia”*. *Paleontología*, 2 (6): 121-135.
- Wang, W., Gao, S., Servais, T., Singh, B. P. and Myrow, P. 2021. Preliminary palynological study on the Upper Ordovician Pin Formation in Northern Indian Himalaya. *Palynology*, 45 (2): 301-319.
- Wellman, C. H., Higgs, K. T. and Steemans, P. 2000. Spore assemblages from a Silurian sequence in Borehole Hawiyah-151 from Saudi Arabia. In: S., Al-Hajri, Owens, B. (eds.), *Stratigraphic Palynology of the Palaeozoic of Saudi Arabia*. GeoArabia, Bahrain, pp. 116–133.
- Online References:
 Palynodata. <https://paleobotany.ru/palynodata/taxa>.

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)
Eohomalonotbus villicunensis (Baldis and Blasco)
Bivalves
Modiolopsis cuyana (Sánchez)
Palaeoneila sp. (see Sánchez, 1990)

PALYNOMORPHS (for a complete authority of taxa see Palynodata)

- Acritarchs*
Cheleutocbroa diaphorosa Turner
Crassiangulina tessellata Jardíné et al. emend. Wauthoz et al.
Dactylofusa sp. cf. *D. maranbensis* Brito and Santos (see Le Hérisse et al., 2001)
Lophosphaeridium sp. (Remarks: It is similar to specimens illustrated by García-Muro et al. (2016, Pl. 3, fig. 21), and *Buedingisphaeridium 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
Quadratum fantasticum Cramer
Quadratum 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

Chelinobilates 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)

Gneudnaspota (*Laevolancis*) *divellomedia* (Chibrikova) Balme (see in Rubinstein and Brussa, 1999)

Sphaerasaccus glabellus Steemans *et al.* (Rhuddanian, Steemans *et al.*, 2000)

Received : August 23, 2023

Accepted : October 06, 2023