New palynological data from the Upper Ordovician of the Precordillera Basin, Argentina: A potential key for understanding the geological history of the Precordillera terrain

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ABSTRACT: Biostratigraphic data from the Precordillera Basin have traditionally been analyzed to contribute to the understanding of its biogeographic evolution as an allochthonous microcontinent accreted to the western Gondwanan margin in the Middle-Late Ordovician. The first palynological data from Late Ordovician units of the eastern Precordillera are incorporated in an attempt to better constrain the timing of the collision. The Las Vacas Formation has previously been assigned to the Sandbian (*gracilis–bicornis* zones). Chitinozoans from the Las Vacas Formation are poorly diversified. The basal part of this unit contains *Lagenochitina* sp. cf. *baltica*, previously recorded in the late Darriwilian of Precordillera and the late Darriwilian-early Sandbian of eastern Canada. The assemblages from its upper part contain primarily *Spinachitina bulmani*, *Cyathochitina* sp. cf. *kuckersiana*, *Cyathochitina* sp. aff. *macastyensis*, and *Desmochitina minor* form *typica*. The lower-upper part of this formation also yields *Kalochitina multispinata*. Acritarchs are poorly preserved and the few recognized genera are not biostratigraphically significant. Cryptospore findings contribute to the record of evidences for land plants in the Ordovician of Argentina and suggest that the upper part of the unit was deposited proximal to the shoreline. The lower part of the Trapiche Formation contains a few poorly preserved chitinozoans, acritarchs and algae (cf. *Gloeocapsomorpha* sp.), probably due to reworking of the material. The basal chitinozoan assemblage could indicate that the deposition of the Las Vacas Formation started during the Middle-Late Ordovician (late Darriwillian-basal Sandbian). Typical Katian chitinozoans from the uppermost part of the Las Vacas Formation indicate that these deposits would have reached the middle Late Ordovician. Palynological studies seem to be a useful tool to contribute to the biostratigraphic knowledge of controversial terrains, such as the Precordillera.

Keywords: Upper Ordovician; Chitinozoans; Palynomorphs; Northeastern Precordillera; Western Gondwana

INTRODUCTION

The Argentine Precordillera is considered to be part of Cuyania, a composite terrane that collided with the western Gondwanan margin during the early Paleozoic (Ramos et al. 1986; Ramos, Dallmeyer and Vujovich 1998; Ramos 2004; Cocks and Torsvik 2004). Different geodynamical models have been made to explain the origin of this microcontinent and its final placement. The models are based mainly on the hypothesis that the microcontinent had an allochthonous Laurentian origin (Ramos et al. 1986; Benedetto 1993; Astini, Benedetto and Vaccari 1995; Keller 1999; among others) and a para-authochtonous Gondwanan origin (Aceñolaza and Toselli 1989; Baldis, Peralta and Villegas 1989; Aceñolaza, Miller and Toselli 2002; Finney et al. 2003; 2004; Finney 2007).

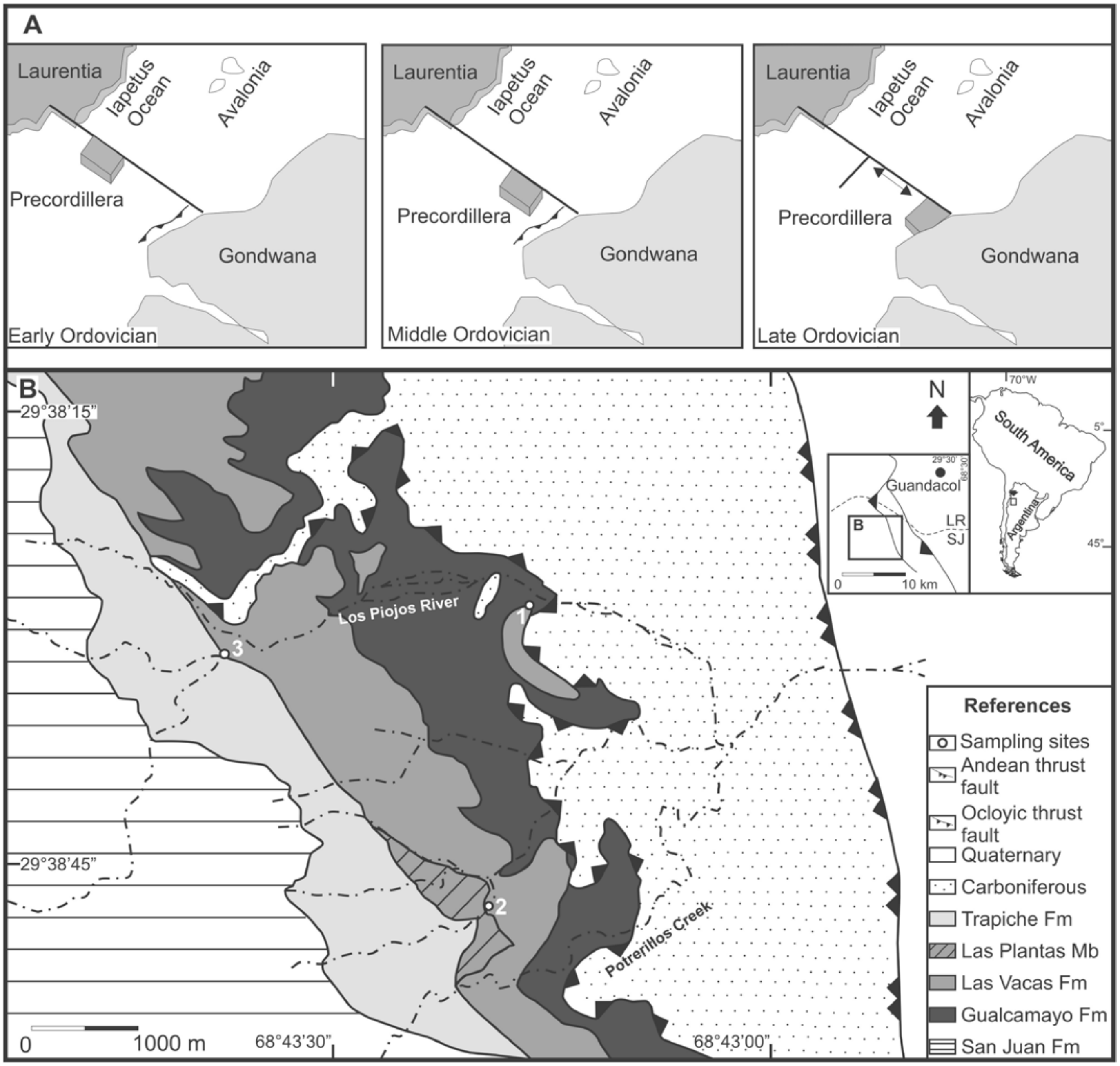
After two decades of intense research involving many different geological disciplines, there is a general consensus that the Cuyania microcontinent rifted from the southeast margin of Laurentia in the Cambrian, drifted across the southern Iapetus Ocean during the Early to Middle Ordovician and collided to the western margin of Gondwana in the upper Middle to Late Ordovician (Astini, Benedetto and Vaccari 1995; Thomas and Astini 1996; 1999; 2003; 2007; Ramos 2004; Rapalini 2012) (text-figure 1.A). Paleontological data from the Precordillera Basin have traditionally been analyzed to contribute to the understanding of its biogeographic evolution and the time between its detachment from Laurentia until its accretion onto Gondwana (Ramos 1988; Benedetto 1993; 1998; 2004; Benedetto et al. 1999; Albanesi and Ortega 2002).

The Middle to Late Ordovician Ocloyic orogeny reflects the collision of the Cuyania terrane with the pre-Andean margin of Gondwana (Ramos et al. 1986; Astini, Benedetto and Vaccari 1995; Ramos 2004). The collision event produced a major basinal reorganization which influenced the nature, distribution, and migration routes of the biota (Benedetto 2004). Study of the Late Ordovician units from the eastern Precordillera demonstrates that the west-directed Ocloyic thrusting was coeval with the deposition of the Las Vacas Conglomerate (Thomas and Astini 2007) (text-figure 1.B). In the work presented here, the first palynological data from the Las Vacas Formation, and associated clastic units, are presented in an attempt to better constrain the timing of the collision between the Precordillera (Cuyania) terrain and the western Gondwanan margin.

GEOLOGICAL SETTING

The Argentine Precordillera is a morpho-structural region characterized by the development of a fold and thrust belt in response to the Andean orogeny during the Late Neogene (Baldis and Chebli 1969; Allmendinger et al. 1983, 1990; Jordan et al. 1983, 1993; Gosen 1992). The Precordillera has been traditionally subdivided in western, central and eastern belts according to its morpho-tectonic characteristics (Ortiz and Zambrano 1981; Baldis et al. 1982; Ramos et al. 1986). Its complex geodynamic history, as part of one of the allochthonous terranes accreted to the active western Gondwanan margin during the Phanerozoic, has resulted in numerous studies.

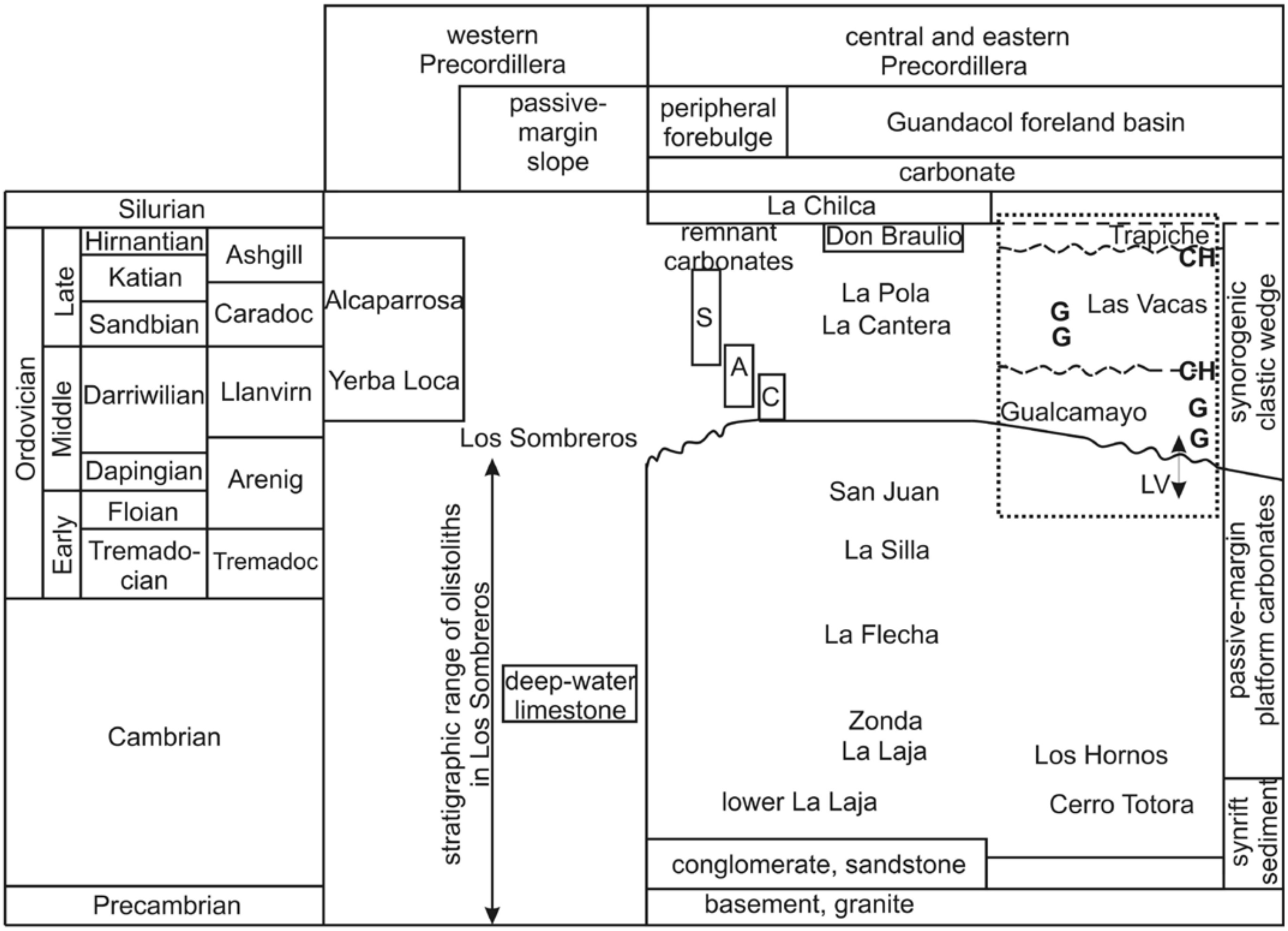
The Paleozoic Precordillera Basin includes deposits ranging from the Cambrian to the Carboniferous. A complex stratigraphic



TEXT-FIGURE 1
A. Geodynamical sketch of the Precordillera (Cuyania) during the Ordovician based on the allochthonous Laurentian hypothesis (redrawn from Rapalini 2012). B. Location and geologic map of the Los Piojos River area (modified from Thomas and Astini 2007); 1, 2 and 3. Sampling sites discussed in text. The Guandacol locality position and the San Juan (SJ) and La Rioja (LR) provincial limit (dashed line) are indicated on the right.

history is described for the early Paleozoic of the Precordillera, as many different vertically and laterally variable depositional environments were present (text-figure 2). The stratigraphic and structural studies have allowed the recognition of two different domains in the early Paleozoic Precordillera deposits: the western Precordillera is characterized by deep marine sediments and ocean-floor mafic and ultramafic rocks, corresponding to a passive margin slope environment; the eastern Precordillera is characterized by Cambrian-Ordovician passive margin carbonates, overlain by black shales and clastic facies, corresponding to synorogenic deposits in a foredeep environment. A forebulge is interpreted to have been in the centre of the basin (Astini 1992; Astini, Benedetto and Vaccari 1995; Thomas and Astini 2003).

The Los Piojos River area exposes Ordovician clastic units in the northernmost San Juan Province near the border with the La Rioja Province, southwest of the Guandacol locality (text-figure 1.B). These deposits, situated in the northern Precordillera Basin, belong to the eastern depositional facies (text-figure 2). They overlie the carbonate platform deposits (San Juan Formation) of the pre-orogenic passive margin (Astini 1998b). The clastic deposits are assigned to the Gualcamayo Formation and Trapiche Group. The Gualcamayo Formation represents



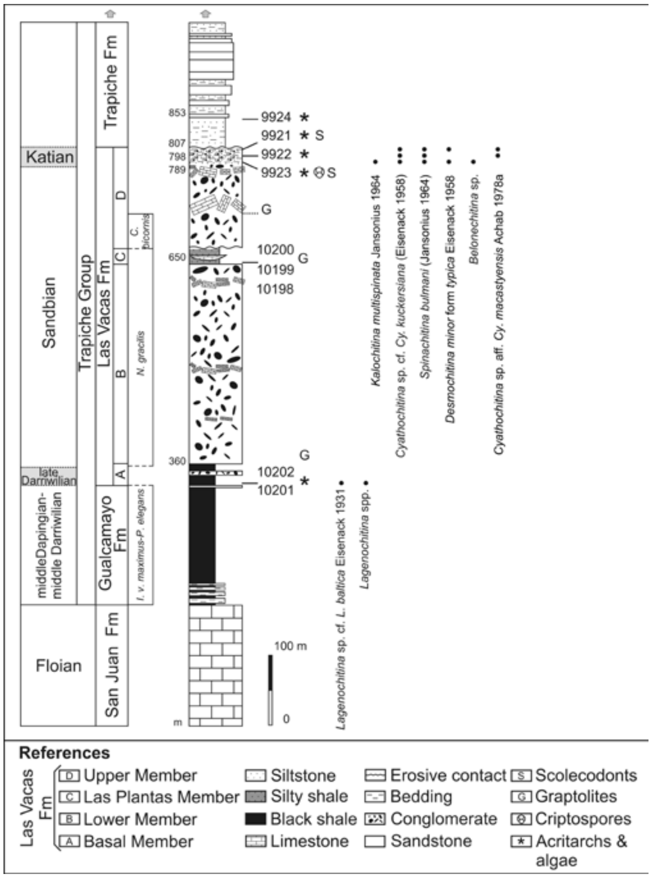
TEXT-FIGURE 2
Stratigraphy of the Cambrian and the Ordovician of the Precordillera (modified from Astini 1998a and Thomas and Astini 2003). C (Las Chacritas Formation), A (Las Aguaditas Formation), and S (Sassito Formation) represent remnant carbonates and related strata. The Los Piojos area location is marked with dotted lines; the relative position of chitinozoan (CH) and graptolite (G) data are indicated. Ordovician stages are from Bergström et al. (2009).

an important change in deposition from platform carbonates to deep-water black shales. The deposition of this unit started in the northeastern Precordillera and progressed diachronously across the basin from the Dapingian to the Darriwilian (middle Arenig-Llanvirn) (Astini 1994). It is interpreted to have been the result of oblique convergence during the closure of the basin (Benedetto et al. 1999). The Trapiche Group is composed of the Las Vacas and Trapiche formations, which are interpreted to have been the result of progradation of coarser detritus over the platform in a peripheral forebulge environment (Astini, Benedetto and Vaccari 1995; Thomas and Astini 2003). The equivalent units of the Trapiche Group to the west are considered to have been deposited in deeper slope settings in response to tectonic loading during the accretion to Gondwana in the upper Middle to Upper Ordovician (Thomas and Astini 1996, 2003; Thompson et al. 2012).

Stratigraphy and biostratigraphy

The Gualcamayo Formation (Furque 1963; 240 m) and the Trapiche Group (Furque 1963; *emend.* Astini 1998b), which contains the Las Vacas Formation (330 m) and the Trapiche Formation (>800 m), are Ordovician clastic units that are characteristic of the eastern deposits of Precordillera (text-figure 3). The classical sections for study of these units are exposed to the southwest of the Guandacol locality where graptolites have been extensively described (Cuerda, Caballé and Alfaro 2004, and references therein).

The Gualcamayo Formation is composed by graptolite-rich black shales deposited during the subsidence of a foreland basin by tectonic loading (Astini, Benedetto and Vaccari 1995; Thomas and Astini 2007). It records graptolite zones ranging from the *Isograptus victoriae maximus* to the *Pterograptus elegans* (middle Dapingian-middle Darriwilian) (Ortega, Toro and Brussa 1993; Ortega and Máspero Castro 2002). The first chitinozoan data from the Ordovician of South America comes from the basal Gualcamayo Formation, which crops out in the Potrerillos Creek, in the Los Piojos River area (Volkheimer, Cuerda and Melendi 1980) (text-figure 1.B). The association mainly yielded *Conochitina* sp. A and *Cyathochitina* sp. cf. *C. dispar* Benoit and Taugourdeau, 1961 (Volkheimer, Cuerda and Melendi 1980).



TEXT-FIGURE 3
Generalized stratigraphic column of the Las Vacas Formation from Los Piojos River area with palynological data (modified from Cuerda, Caballé and Alfaro 2004 and Thomas and Astini 2007). Ordovician stages are from Bergström et al. (2009); ages based on chitinozoan data are indicated in gray.

The Las Vacas Formation conglomeratic deposits overlie the Gualcamayo Formation or the San Juan Formation through an erosive contact. However, in the Los Piojos River area, a transitional contact between the Gualcamayo Formation and the Las Vacas Formation is exposed. The Las Vacas Formation, which has an upward-coarsening basal sandy succession containing conglomerate lenses, is characterized by the presence of large olistoliths from the intrabasinal deposits of the San Juan and Gualcamayo formations mixed with extrabasinal orogenic detritus (Astini 1998b; Thomas and Astini 2003). Several mechanisms have been proposed to explain its origin (see Thomas and Astini 2007). The stratigraphy and graptolite-based biostratigraphy of the Las Vacas Formation have been described in detail by Astini (1998b) and by Cuerda, Caballé and Alfaro (2004). The *Nemagraptus gracilis* Zone occurs in the lower part of this formation (Cuerda, Caballé and Alfaro 2004) and the middle levels of the Las Vacas Formation contain the *Climacograptus bicornis* Zone (Astini and Brussa 1997). In some outcrops, silty shales with limestone lenses containing a rich shallow marine fauna assigned to the Las Plantas Member transitionally overlie the conglomeratic facies (Astini, Benedetto and Carrera 1986). The *C. bicornis* Zone is recorded in this member (Ortega and Brussa 1990), although it has also been assigned to the *N. gracilis* Zone (Cuerda, Caballé and Alfaro 2004). The upper member of the Las Vacas Formation is composed of stratified conglomerate. It overlies the Las Plantas Member through an erosive contact with the lower member of the Las Vacas Formation. The upper member of the Las Vacas Formation contains the *C. bicornis* Zone (Cuerda, Caballé and Alfaro 2004) in its lower part. Therefore, a Sandbian age (*gracilis-bicornis* zones), is assigned to the Las Vacas Formation. The Las Vacas and Trapiche formations are separated by an angular unconformity.

TABLE 1
Values calculated on 119 individuals of *Spinachitina bulmani* from samples 9921, 9922 and 9923.

Values (µm)	L	Ln	Dp	dn	dcoll	L/D	L/Ln
Maximum	216	148	102	56	67	2.83	5.49
Mean	160	67	76	39	45	2.12	2.48
Minimum	103	28	57	26	27	1.54	1.00

The Trapiche Formation is composed of quartzose sandstone turbidites. Its age remains controversial. Unknown biostratigraphic relationships and the lack of diagnostic graptolite faunas from the Trapiche Formation have not allowed precise age determinations of this unit (Peralta and Finney 2003). Towards the south of the Guandacol area, this unit is assigned to the Katian (late Caradoc-earliest Ashgill) because of the presence of *Amorphognatus* aff. *superbus* (Albanesi, Hünicken and Ortega 1995) recovered from a 50-60 m-thick interval of debris flows, and it likely extends into the Hirnantian, based on the presence of *Trucizetina* sp. (Benedetto and Herrera 1987; Benedetto 1999). The Trapiche Group is overlain by Carboniferous deposits through an angular unconformity to the north and south of the Los Piojos River area.

MATERIAL AND METHODS

Nine samples were taken from the Las Vacas Formation (8) and Trapiche Formation (1). This palynological sampling was carried out as a preliminary study to test the usefulness of palynomorphs for constraining the age of the units representing the post-orogenic sedimentation in the Late Ordovician of the northeastern Precordillera Basin.

Samples were processed using HCl-HF-HCl acid maceration techniques. The organic residue was sieved using a 10µm sieve to remove fine organic particles. The phytoplankton and spores were mounted in Glycerin jelly as permanent palynological slides and examined using light microscopy with interference contrast. The chitinozoans were hand-picked and mounted on stubs for scanning electron microscope (SEM) examinations according to the technique described by Paris (1981).

The phytoplankton and spores photomicrographs were taken using a digital camera (Go-3) and the SEM photomicrographs were taken using a JEOL (JSM-6490LV) SEM at the MEByM (*Microscopía Electrónica de Barrido y Microanálisis con EDS*), CCT, Mendoza. Illustrated specimens are located with England Finder coordinates.

The palynological slides are housed in the collection of the Paleopalynology Unit, IANIGLA, CCT, Mendoza, labeled MPLP (*Mendoza- Paleopalinoteca-Laboratorio de Paleopalinología*).

PALYNOLOGICAL DATA

The palynological data are from the outcrops exposed along the Los Piojos River area in San Juan province, southwest of

TABLE 2
Values calculated on 7 individuals of *Lagenochitina* sp. cf. *baltica* from sample 10202.

Values (µm)	L	Ln	Dp	dn	da	L/D	L/Ln
Maximum	355	128	130	103	78	2.96	3.57
Mean	264	96	112	68	64	2.41	2.82
Minimum	200	61	95	48	55	1.99	2.46

TABLE 3
Values calculated on 7 individuals of *Cyathochitina* sp. cf. *Cy. kuckersiana* from samples 9921, 9922 and 9923.

Values (µm)	L	Ln	Dp	dn	da	lcar	L/D	L/Ln
Maximum	211	94	147	71	67	15	2.23	3.20
Mean	187	75	112	52	65	10	1.88	2.71
Minimum	146	53	90	34	62	7	1.71	2.20

Guandacol locality (text-figures 1B and 3). Two samples (10201 and 10202) are from the lowermost part of the Las Vacas Formation (transitional contact with the underlying Gualcamayo Formation) (text-figure 1.B, site 1); 3 samples (10198, 10199 and 10200) are from the middle part of the Las Vacas Formation (transitional contact with the Las Plantas Member) (text-figure 1.B, site 2); 3 samples (9923, 9922 and 9921) are from the upper member of the Las Vacas Formation (text-figure 1.B, site 3); and 1 sample (9924) is from the overlying Trapiche Formation (text-figure 1.B, site 3). One of the samples from the lowermost part of the Las Vacas Formation and two from its middle part (10198, 10199, 10200 and 10201) are barren of palynomorphs.

The material contains mostly chitinozoans, and is characterized by low diversity assemblages. Chitinozoans are described and analyzed in the following sections of this work. Scolecodonts are also present. The lower part of the Las Vacas Formation contains unidentifiable acritarchs and possible marine chlorophytes. Acritarchs from the upper part of the Las Vacas Formation are poorly preserved and the few recognized genera are not biostratigraphically significant. Cryptospores, represented by simple tetrads, suggest proximity to the coastline for the lower-upper part of the unit (Plate 6, figs. 1, 2). This cryptospore finding contributes to completing the record of spores in the Ordovician of Argentina, previously reported for the Dapingian, Darriwilian and Hirnantian (Ottone et al. 1999; Rubinstein and Vaccari 2004; Rubinstein et al. 2010; Rubinstein, Vecoli and Astini 2011). The sample (9924) from the Trapiche Formation contains a few poorly preserved acritarchs and algae such as cf. *Gloeocapsomorpha* sp. (Plate 6, fig. 7) and fragments of likely coenobial algae (Plate 6, fig. 8). This palynological association indicates a marine environment. However, it scarcity and the lack of reliable stratigraphic and paleoecological markers prevents going further with its interpretation.

Even though the single algal specimen identified from the Trapiche Formation could be assigned to the genus *Botryococcus*, taking into account the structure and layering of the cells of the figured colony, that are quite similar to *Gloecapsomorpha* Zalessky 1917, we prefer to classify the Precordillera specimen as cf. *Gloecapsomorpha* (see Tappan 1980; Colbath and Grenfell 1995; Wicander, Foster and Reed 1996; Derenne et al. 2000; Guy-Ohlson 1992; Lille 2003 and references therein). This is the first record of this colonial species (green or blue-green alga, according to different authors) for the Ordovician of Argentina with such preserved structure of cells.

Chitinozoans

Chitinozoans from the Las Vacas Formation show a low diversity (text-figure 3; Plates 1-5). The lowermost part of the Las Vacas Formation (member A) into its transitional contact with the underlying Gualcamayo Formation is characterized by *Lagenochitina* sp. cf. *L. baltica* Eisenack 1931 and *Lagenochitina* spp. The assemblages from the upper part of the Las Vacas Formation (member D) contain mainly *Spinachitina bulmani* (Jansonius 1964), *Cyathochitina* sp. cf. *kuckersiana* (Eisenack 1934), *Cyathochitina* sp. aff. *macastyensis* Achab 1978a, and *Desmochitina* minor form *typica* Eisenack 1958. The oldest sample from the upper part of the formation also yields *Kalochitina multispinata* Jansonius 1964 and *Belonechitina* sp. The sample from the basal Trapiche Formation contains a few damaged chitinozoans, which can be related to the Cyathochitininae, Conochitininae and possibly Spinachitininae sub-families, not included in the taxonomic study.

Chitinozoan biostratigraphy

Lagenochitina sp. cf. *L. baltica* from the transitional contact between Gualcamayo and Las Vacas formations is considered very similiar to the *L.* sp. cf. *L. baltica* described in the late Darriwilian (Middle Member of the Los Azules Formation) of the central Argentine Precordillera (Ottone et al. 2001). They are also comparable with *Lagenochitina* sp. A of Achab 1984, recorded in the late Darriwilian-early Sandbian of eastern Canada (Achab 1984; 1986).

Spinachitina species described from the Late Ordovician-lower Silurian are characterized by subtle differences. Their taxonomic assignments are frequently difficult to carry out and there is not a general consensus about their lineage or biostratigraphic potential. *S. bulmani* from the upper part of the Las Vacas Formation resembles the eastern Canada specimens recorded in the middle-late Katian (Achab 1977; 1987), characterized by a cylindrical neck and straight flanks. In Laurentian *Spinachitina*, the flexure becomes gradually less distinctive from the Katian to the Hirnantian (Vandenbroucke et al. 2003).

Cyathochitina sp. aff. *macastyensis* is recorded in the upper part of Las Vacas Formation and these specimens are also comparable with *Cy. kuckersiana patagiata*. *Cy. macastyensis* and *Cy. k. patagiata* are common components of the basal Katian of eastern and northern Canada (Martin 1975; 1983; Asselin, personal communication 2013).

Cy. kuckersiana is a long-range species but it is usually associated with *S. bulmani* and *K. multispinata* in the Katian of eastern Canada (Achab 1987) and, probably, northwestern Argentina (de la Puente and Rubinstein 2012).

D. minor form *typica*, a frequent component from the Middle to Upper Ordovician of the main paleocontinents, is observed from the Darriwilian to the Hirnantian in Argentina (Ottone et al. 2001; de la Puente and Rubinstein 2012).

Kalochitina multispinata, a common Laurentian species, has been recorded to be associated with *Cy. macastyensis* in the early Katian and *S. bulmani* in the middle-late Katian of eastern Canada (Achab 1978a). In central Precordillera of Argentina, *K. multispinata* is described in the Sandbian according to its record in the *C. bicornis* and *Amorphognathus tvaerensis* zones (Ottone et al. 2001).

TABLE 4
Values calculated on 11 individuals of *Cyathochitina* sp. aff. *Cy. macastyensis* from samples 9922 and 9923.

Values (µm)	L	Ln	Dp	dn	da	lcar	L/D	L/Ln
Maximum	254	102	171	77	84	16	1.71	3.79
Mean	208	69	133	61	64	10	1.49	3.11
Minimum	171	51	115	48	58	7	1.28	2.49

The Laurentian affinities observed in the chitinozoan assemblages for the Sandbian in the central Precordillera (Ottone et al. 2001) can also be suggested for the Katian in the northeastern Precordillera area. According to the chitinozoan biotopes established for the early Sandbian, *Lagenochitina* sp. A of Achab 1984 and *K. multispinata* indicate a Subtropic Biotope (25°–35° south), which is defined for Québec, Anticosti Island, Gaspé and Precordillera (Vandenbroucke et al. 2010).

SYSTEMATIC PALEONTOLOGY

Chitinozoa are described using the taxonomic and morphological terminology proposed by Paris et al. (1999). Measurements are given in micrometers and correspond to: L = length; Lp = chamber length; Ln = oral tube length; Dp = chamber diameter; da = oral tube diameter; dn = neck diameter; dcoll = collarette diameter; lcoll = collarette length; lcar = carina length; lsp = spine length. No correction factor has been applied to compensate for the flattening.

Group CHITINOZOA Eisenack 1931
Order PROSOMATIFERA Eisenack 1972
Family CONOCHITINIDAE Eisenack 1931 emend. Paris 1981
Subfamily SPINACHITININAE Paris 1981
Genus *Spinachitina* Schallreuter 1963 emend. Paris, Grahn, Nestor and Lakova 1999
Type Species: Conochitina cervicornis Eisenack 1931

Spinachitina bulmani (Jansonius 1964)
Plate 1, figures 1-6; Plate 2, figures 1-7

Conochitina bulmani JANSONIUS 1964, p. 907, pl. 1, figs. 3-4.
Spinachitina bulmani (Jansonius) – ELAOUAD-DEBBAJ 1984, p. 61-62; pl. 3, fig. 6, 7?, 8, 10, 12 (with complete synonymy). – ACHAB 1987, p. 1228, pl. 4, figs. 5-14. – VANDENBROUCKE, VERNIERS and CLARKSON 2003, p. 127; fig. 9, f-k.

Material: A hundred-twenty flattened specimens; necks are usually broken; spines frequently damaged. 61 individuals are from sample 9921, 21 from sample 9922 and 38 from sample 9923.

Description: Small *Spinachitina* specimens with conical chamber and cylindrical neck, usually flattened. The neck length is a one half to one fifth of the chamber length (a quarter mostly). The maximum diameter occurs on the basal margin or slightly above it. The base is convex (Plate 1, fig. 1) or folded inside the chamber by flattening (Plate 2, fig. 5). The flanks are straight to sligthly convex and the flexure is inconspicuous. The cylindrical neck slightly flares to the aperture (Plate 1, figs. 1, 6). In some cases, the collarette is finely denticulated (Plate 1, fig. 2). The chamber and neck surfaces are smooth and the rounded basal margin bear a crown of spines. The spines are highly variable according to their number (14-28) and shape. They are frequently broken or lost. Some spines are conical and sharp (Plate 1, fig. 1b) and some have irregular shape and length (Plate 1, fig. 2b),

TABLE 5
Values calculated on 6 complete individuals of *Desmochitina minor* form *typica* from samples 9921 and 9923.

Values (µm)	L	Dp	dn	dcoll	lcoll	L/D
Maximum	119	87	51	53	12	1.39
Mean	99	81	45	49	9	1.22
Minimum	77	70	38	46	6	0.93

but all are simple, short (maximum length 8µm), and directed away from the aperture (Plate 1, fig. 6b).

Dimensions: See Table 1.

Remarks: Specimens from Las Vacas Formation show a cylindrical neck and straighter flanks than those illustrated by Jansonius in the definition of the species (Jansonius 1964, Pl.1, figs. 3 and 4). They are very close to the specimens from eastern Canada described by Achab (1977; 1987), which also have a cylindrical neck, straight or slightly convex flanks and denticulated collarette, although they have longer spines. The general shape (especially the L/Ln ratio) and ornamentation observed in these specimens is similar to *S. bulmani* described in the early Hirnantian from the Moroccan Anti-Atlas (Elaouad-Debbaj 1984, pl. 3, figs. 6-8, 10, 12) and considered to be *S. oulebsiri* (Vandenbroucke et al. 2009b). Vandenbroucke et al. (2003) observed that the flexure between the neck and the chamber gradually disappears from the Katian to the Hirnantian in Laurentian sections. *S. oulebsiri* Paris, Bourahrouh and Le Hérissé 2000, defined in the Hirnantian of Gondwana, has an inconspicuous flexure and a short neck compared with Las Vacas Formation individuals. *S. fragilis* (Nestor 1980) from the Rhuddanian is slender and big, has a sharp basal margin, the neck is usually not distinct from the chamber, and the spines are simple, subcylindrical with blunt distal ends, while spines in *S. bulmani* from Precordillera are sharp, conical and more numerous. Some specimens illustrated as *S. fragilis* in the early Llandovery from Jordan (Butcher 2009) have a similar general shape, but are bigger and have more convex flanks, slightly higher L/D ratio and a more developed flexure than the specimens from the Las Vacas Formation. *S.* sp. aff. *bulmani* from northwestern Argentina has similar ornamentation than the Las Vacas Formation specimes but they are incomplete (de la Puente and Rubinstein 2012; de la Puente unpublished data).

Occurrence: *Spinachitina bulmani* is described in the Katian of Girvan area, Scotland (Jansonius 1964; Vandenbroucke et al. 2003) and Shropshire, England (Jenkins 1967; Vandenbroucke et al. 2009a). It is well documented in the middle-late Katian of eastern Canada (Martin 1975; Achab 1977; 1978a; 1987) and Northern Gondwana (Paris 1990), although in the latter it has also been recorded from the early to late Katian (upper *tanvillensis-nigerica zones*) (Paris et al. 2007) and the early Hirnantian (*Tanuchitina elongata* Zone) (Elaouad-Debbaj 1984). *S.* sp. aff. *bulmani* is observed in the Katian of the Central Andean Basin in northwestern Argentina (de la Puente and Rubinstein 2012).

Family LAGENOCHITINIDAE Eisenack 1931 emend. Paris 1981
Subfamily LAGENOCHITININAE Paris 1981
Genus *Lagenochitina* Eisenack 1931 emend. Paris, Grahn, Nestor and Lakova 1999
Type Species: *Lagenochitina baltica* Eisenack 1931

Lagenochitina* sp. cf. *baltica Eisenack 1931
Plate 3, figures 1-6

TABLE 6
Values calculated on 12 individuals of *Kalochitina multispinata* from sample 9923.

Values (µm)	L	Dp	dn	dcoll	lsp	lcoll	L/D
Maximum	130	85	61	38	10	12	2.02
Mean	117	74	38	36	6	9	1.63
Minimum	99	56	27	34	3	7	1.42

Material: Seven usually flattened specimens from sample 10202.

Description: Lagenochitinidae with an ovoid to cylindrical chamber. The cylindrical neck is around one third of the total length. The flexure is conspicuous and the basal margin is rounded. The base is flat (Plate 3, fig. 4) to convex (Plate 3, fig. 3), or folded inside the chamber (Plate 3, figs. 1, 2). The base is usually flattened, therefore no structure can be observed (Plate 3, fig. 6b). The maximum width is near the shoulders (Plate 3, fig. 4) or near the basal margin (Plate 3, fig. 5), and is sometimes affected by deformation. The specimen are poorly preserved, but a slight granulate ornamentation is observed (Plate 3, figs. 3b, 6b).

Dimensions: See Table 2.

Remarks: The total length of these Lagenochitinidae (200-355 µm) is a little longer than the original description of *Lagenochitina baltica* (200-250 µm) but similar to other descriptions, such as the Sweden specimens (Laufeld 1967), although they are less wide. The typical *Lagenochitina baltica* has also a conspicuous shoulders. These Lagenochitina are very similar to the specimens described as *Lagenochitina* sp. cf. *L. baltica* from Los Azules Formation in the Precordillera Argentina (Ottone et al. 2001). As Ottone et al. (2001) noted, these *Lagenochitina* are similar to some *Lagenochitina* sp. A illustrated by Achab (1986, pl. V, fig. 6). They are also comparable with some specimens of ? *Lagenochitina* sp. A of Achab 1984 (pl. VI, figs. 4-7), included later in *Lagenochitina* sp. A by Achab (1986).

Occurrence: *Lagenochitina baltica* is recorded in the Upper Ordovician (Katian) of Baltoscandia (Grahn 1982), Estonia (Eisenack 1962), Sweden (Laufeld 1967), the Welsh Borderland (Jenkins 1967), Portugal (Paris 1979), and Anticosti Island, Canada (Achab 1977). It is recorded in the Middle Ordovician (Darriwilian) of Newfoundland (Neville 1974; Martin 1978) and the subsurface of Alaska (Carter and Laufeld 1975). It occurs in the lower Middle Ordovician of the upper Lenoir Limestone at Pratt Ferry and Little Oak Limestone at Pelham, southern Appalachians, USA (Grahn and Bergström 1984). *Lagenochitina* sp. A of Achab 1984 is recorded in the late Darriwilian-early Sandbian (Llandeilian-early Caradoc) of the subsurface of Anticosti (NACP N° 1 well) and the Mictaw Group, Clemville, eastern Canada (Achab 1984; 1986). In the central Argentine Precordillera, *Lagenochitina* sp. cf. *L. baltica* is described in the late Darriwilian (late Llanvirnian) of the Middle Member of the Los Azules Formation (Ottone et al. 2001).

Subfamily CYATHOCHITININAE Paris 1981
Genus *Cyathochitina* Eisenack 1955 emend. Paris, Grahn, Nestor and Lakova 1999
Type Species: *Conochitina campanulaeformis* Eisenack 1931

Cyathochitina* sp. cf. *Cy. kuckersiana (Eisenack 1934)
Plate 4, figures 1-2

Material: Seven distorted specimens; necks and carina are usually broken. 2 individuals are from sample 9921, 4 from sample 9922 and 1 from sample 9923.

Description: the chamber, generally folded, is conical and the neck cylindrical to sligthly flaring toward the aperture. The flanks are straight and the base flat but usually folded inside the chamber. The carina is frequently broken. The surface wall is smooth.

Dimensions: See Table 3.

Remarks: Specimens from the Las Vacas Formation show a narrower aperture angle of the flanks than *Cyathochitina kuckersiana* and, therefore, the chamber is higher than it is wide.

Occurrence: *Cyathochitina kuckersiana* (Eisenack 1934) has a world-wide record ranging from the Middle Ordovician to the early Silurian. It is associated with *S. bulmani* and *K. multispinata* in the Katian of eastern Canada (Achab 1987). In the Central Andean Basin of northwestern Argentina it is observed in the lower part of the Upper Member of the Salar del Rincón Formation assigned to the Upper Ordovician (probably middle-late Katian) associated with S. sp. *aff. bulmani* (de la Puente and Rubinstein 2012).

Cyathochitina* sp. aff. *Cy. macastyensis Achab 1978a
Plate 4, figures 3-6

Material: Eleven flattened specimens; necks are usually broken. 5 individuals are from sample 9922 and 6 from sample 9923.

Description: *Cyathochitina* species of variable size, with a conical chamber and cylindrical neck. The neck length is arround 1/3 of the total length. The chamber is longer than wide. The flexure is conspicuous. The flanks are convex (Plate 4, figs. 3-6) due to flattening of the chamber, but become parallel toward the base. The aperture angle of the flank is ≤ 40°. The wall surface is smooth to slightly granulate (Plate 4, figs. 3, 6). The basal margin is rounded. The maximum diameter is above the basal margin. The base is flat but usually convex (Plate 4, fig. 5) or folded inside the chamber (Plate 4, figs. 4, 6) due to flattening. The carina is short (< 16 µm) and thick in some cases (Plate 4, fig. 6).

Dimensions: See Table 4.

Remarks: The variable shape, size and age of these chitinozoans and their transitional forms complicate the taxonomic and biostratigraphic studies. *Cyathochitina* sp. aff. *Cy. macastyensis* from the Las Vacas Formation are similar to the description of *Cyathochitina macastyensis*, although they are slightly shorter and bear a longer carina. Specimens illustrated in the basal Katian of Québec by Achab (1987, pl. 9, figs. 17, 18) as *Cyathochitina* cf. *Cy. macastyensis* are similar to the Las Vacas Formation small individuals. These *Cyathochitina* species differ from *Cyathochitina caputoi* da Costa (1971) by its higher size, the conical but cylindrical flanks toward the base, the rounded basal margin and thick carina (carina is not described in the definition of the species). It differs from *Cyathochitina kuckersiana* (Eisenack 1934) mainly by the aperture angle of the flanks although it can also be compared with the subspecies *Cyathochitina kuckersiana patagiata* Jenkins 1969, which has a short carina (4-12 µm).

Occurrence: *Cyathochitina macastyensis* is described in the Katian Macasty Formation (NACP N° 1 well) of Anticosti, Canada (Achab 1978a). *Cyathochitina* cf. *Cy. macastyensis* has been recorded in the earliest Katian of Québec, Canada (Bald Mountain Saint-Roch N° 1 well) (Achab 1987). *Cy. kuckersiana patagiata* has been described in the Katian of Shropshire (Jenkins 1967) and the Viola Formation of Oklahoma (Jenkins 1969). *Cy. macastyensis* and *Cy. k. patagiata* are present in the basal Katian (Chatfieldian-lower Edenian) of eastern and northern Canada (Martin 1975; 1983; Asselin, personal communication 2013).

Order OPERCULATIFERA Eisenack 1931
Family DESMOCHITINIDAE Eisenack 1931 emend. Paris 1981
Subfamily DESMOCHITININAE Paris 1981
Genus *Desmochitina* Eisenack 1931
Type Species: Desmochitina nodosa Eisenack 1931

Desmochitina minor* form *typica Eisenack 1958
Plate 4, figures 7-9

Desmochitina minor f. typica EISENACK 1958, p. 398, Pl. 2, fig. 29. – PARIS 1981, p. 123 (with complete synonymy). – MARTIN 1983, p. 16; pl. 5, figs. 22, 30 (with complete synonymy). – AL-HAJRI 1995, p. 39; pl. IV, fig. 5, pl. V, figs. 9-10. – OTTONE et al. 2001, pl. 1, figs. 7, 11. – PARIS et al. 2007, pl. 1, fig. 8, pl. 3, fig. 3. – GHAVIDEL-SYOOKI 2008, p. 130; pl. VI, fig. 4. – DE LA PUENTE and RUBINSTEIN 2012, p. 8, pl. 2, fig. 1.
Desmochitina? minor EISENACK 1931, p. 93; pl. 3, figs. 10-11. – ACHAB 1978b, pl. 2, fig. 6. – GRAHN 1982, p. 49, fig. 15, C-D (with complete synonymy). – ACHAB 1986, p. 280; pl. III, figs. 9-10. –ACHAB 1987, p. 1220; pl. 10, figs.1-5. – PARIS, VERNIERS and AL-HAJRI 2000, p. 39; pl. 1, fig. f. – MALO et al. 2001, pl. 1, fig. 11. – TAMMEK.ND, HINTS and N.LVAK 2010, fig. 3, E.
Desmochitina (Pseudodesmochitina) minor Eisenack - ELAOUAD-DEBBAJ 1984, p. 57; pl. 1, figs. 3, 16, 20, pl. 2, figs. 9, 14, 18. – ELAOUAD-DEBBAJ 1986, p. 42; pl. 3, figs. 3, 4. – ELAOUAD-DEBBAJ, DESTEUCQ and FOURNIER-VINAS 1987, pl. II, figs. 11, 16.

Material: Six flattened specimens. 1 individual is from sample 9921 (middle part of the Las Vacas Formation), and 5 from sample 9923 (upper part of the Las Vacas Formation).

Description: Desmochitinidae with spherical to ovoid chamber (L/D mean 1.1). The collarette flares from the smooth vesicle wall. The operculum is observed (Plate 4, fig. 8).

Dimensions: See Table 5.

Occurrence: *Desmochitina minor* form *typica* is widely recorded from the Middle to Upper Ordovician (Darriwilian to Hirnantian) of the main paleocontinents (e.g. Jenkins 1969; Grahn 1982; Achab 1986; Soufiane and Achab 2000; Paris et al. 2012). It has been reported in the Darriwilian (*Pterograptus elegans* and *Hustedograptus teretiusculus* zones and the upper part of *Eoplacognathus suecicus* and *Pygodus serra* zones) of the middle part of the Los Azules Formation of central Argentine Precordillera (Ottone et al. 2001). In the Central Andean Basin of northwestern Argentina, *D. minor* form *typica* is recorded in the Hirnantian glacial Zapla Formation of the Capillas River area in the Sierra de Zapla and equivalent levels from the Sierra de Zenta (de la Puente and Rubinstein 2012; de la Puente unpublished data).

Subfamily EISENACKITININAE Paris 1981
Genus *Kalochitina* Jansonius 1964
Type Species: Kalochitina multispinata Jansonius 1964

Kalochitina multispinata Jansonius 1964
Plate 5, figures 1-10

Kalochitina multispinata JANSONIUS 1964, p. 196-197; pl. 2, figs. 21-22. – ACHAB 1978a, p. 308, 310; pl. III, figs. 2-5 (with complete synonymy). – MARTIN 1983, p. 19; pl. 1, fig. 10; pl. 4, fig. 10; pl. 5, figs. 8-9, 31. – ACHAB 1986, p. 280-281; pl. I, figs. 7-9. – ACHAB and ASSELIN 1995, pl. III, fig. 8. – SOUFIANE and ACHAB 2000, pl. III, fig. 14. – MALO et al. 2001, p. 34; pl. 1, figs. 9-10. – OTTONE et al. 2001, p. 100; pl. 1, fig. 8.

Material: Eleven poorly preserved specimens; spines frequently damaged. 11 individuals are from sample 9923.

Description: Small chitinozoans poorly preserved with short and subcylindrical neck. The chamber is conical to hemispherical. The flanks are convex (Plate 5, figs. 1-6) to conical (Plate 5, fig. 7) and the flexure more or less marked. The base is slightly convex and the basal edge broadly rounded. The collarette length is 1/5 to 1/9 of the total length. It is usually broken. The vesicle is covered by bi (lambda-shaped), multirooted spines, < 10 µm in length. They seem to be arranged, forming some discontinuous crests of connected spines (Plate 5, fig. 9).

Dimensions: See Table 6.

Remarks: The Las Vacas Formation specimens are very similar to those illustrated by Achab (1978a, pl. IV, figs. 8-10), associated with *Cy. macastyensis* in the Macasty Formation and *S. bulmani* in the Vauréal Formation from eastern Canada. *K. multispinata* described in the Sandbian of the central Precordillera of Argentina (Ottone et al. 2001) are also close to Las Vacas Formation individuals.

Occurrence: The *Kalochitina* genus is restricted to the Upper Ordovician (Paris et al. 1999). *Kalochitina multispinata* is frequent from the upper Sandbian to the Katian (from Turinian to Richmondian) of eastern Canada (Jansonius 1964; Martin 1975; 1983; Achab 1978a; 1987; Malo et al. 2001) and Oklahoma (Jenkins 1969; 1970). It reaches the early Hirnantian in central Nevada and northern Canada (Soufiane and Achab 2000). It is also recorded from the Upper Member of the Los Azules Formation of the central Precordillera of Argentina, assigned to the Sandbian

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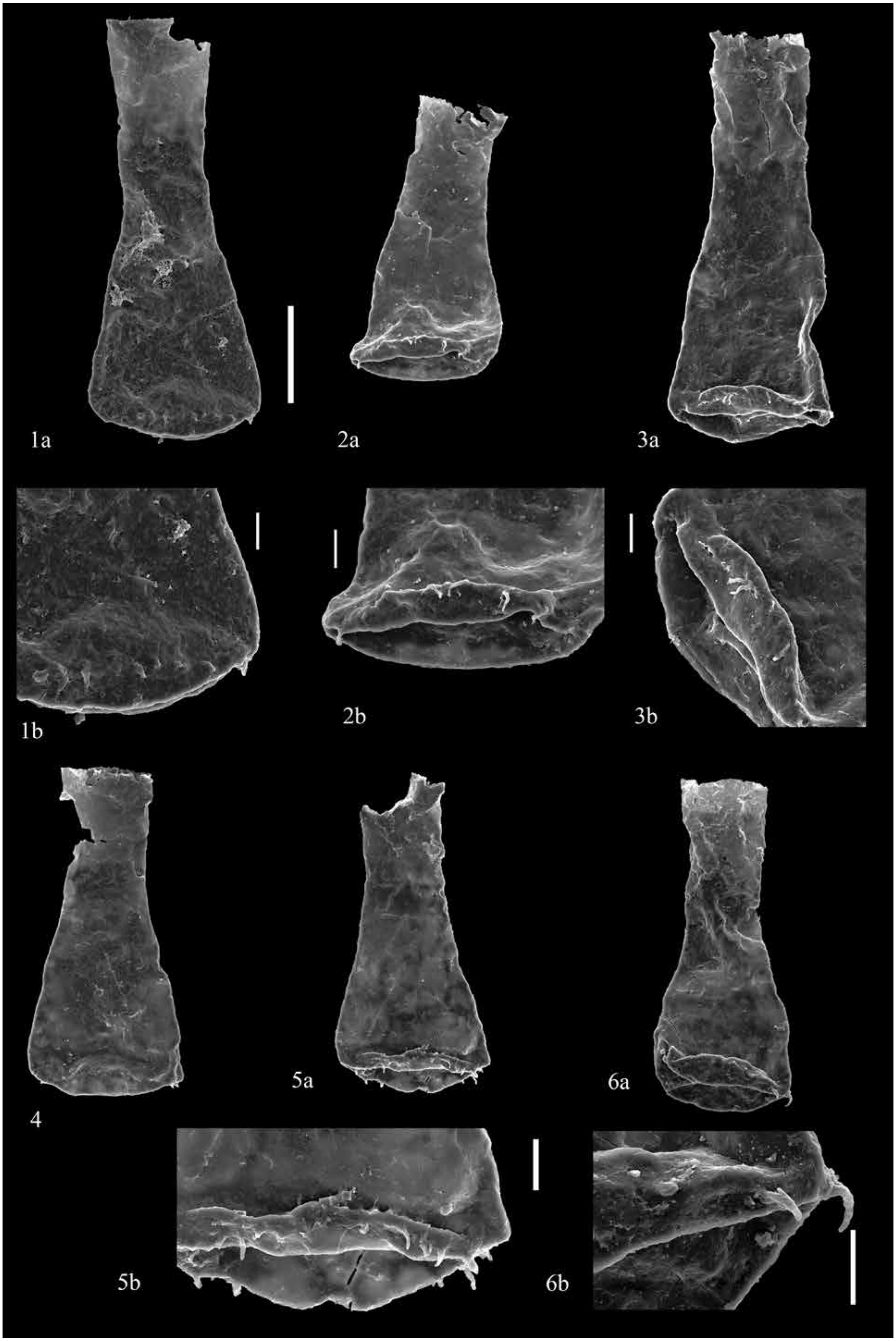
PLATE 1

Upper Ordovician chitinozoans from the eastern Argentine Precordillera.
Scale bar represents 50µm for 1a-3a, 4, 5a-6a. Details= 10µm except 6b = 5µm.

Spinachitina bulmani (Jansonius 1964)

1-6 Sample 9921; upper part of the Las Vacas Formation (Member D).


1a
2a
3a
1b
2b
3b
4
5a
6a
5b
6b

based on chitinozoan, graptolite and conodont zones (Ottone et al. 2001).

CONCLUSIONS

The first palynological data from Late Ordovician units of the eastern Precodillera (Los Piojos River area) are presented herein and the chitinozoans recovered from the Las Vacas Formation show a low diversity. They are from the lowermost and uppermost parts of the Las Vacas Formation, which have not been previously well-dated. The basal Las Vacas Formation, in its transitional contact with the underlying Gualcamayo Formation, contains *Lagenochitina* sp. cf. *L. baltica*, which has been recorded in the late Darriwilian (Middle Ordovician) of the central Argentine Precordillera and the late Darriwilian-early Sandbian (Middle-Upper Ordovician) of eastern Canada. The assemblages from its upper part contain mainly *Spinachitina bulmani, Cyathochitina* sp. cf. *kuckersiana*, *Cyathochitina* sp. aff. *macastyensis*, *Desmochitina minor* form *typica*, and *Kalochitina multispinata* exclusively in the lower-upper part. The Las Vacas Formation records the Sandbian (*gracilis-bicornis* zones), however its depositional timing in the northeastern Precordillera can be dated from the late Darriwilian-early Sandbian to the Katian, based on chitinozoan assemblages.

Acritarchs are poorly preserved and the few recognized genera are not biostratigraphically significant. Cryptospore findings constitute the first evidence of land plants for the Katian of Argentina. Land-derived palynomorphs suggest that the upper part of the unit was closed to the land. The lower part of the Trapiche Formation contains a poorly preserved and probably reworked marine assemblage of chitinozoans, acritarchs and algae, not allowing a precise age assignment. Although detailed studies are still required on the base of the Las Vacas Formation and the Trapiche Formation, palynological results prove to be a useful tool to contribute to the biostratigraphic knowledge of controversial terrains, such as the Precordillera.

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REFERENCES

ACEÑOLAZA, F. G. and TOSELLI, A. J., 1989. El Sistema de Famatina, Argentina. Su interpretación como orógeno de margen continental activo. In: Aceñolaza, E. G. and Lech, R. A., Eds., *Eventos del Paleozoico inferior en Latinoamerica*, 35–44. San Miguel de Tucumán: Universidad Nacional de Tucumán. Facultad de Ciencias Naturales e Instituto Miguel Lillo, Serie Correlación Geológica, 5.

ACEÑOLAZA, F. G., MILLER, H. and TOSELLI, A. J., 2002. Proterozoic–Early Paleozoic evolution in western South America: a discussion. *Tectonophysics*, 354: 121–137.

ACHAB, A., 1977. Les chitinozoaires de la zone à *Climacograptus prominens elongatus* de la Formation de Vauréal (Ordovicien supérieur), Ile d'Anticosti, Québec. *Canadian Journal of Earth Sciences*, 14: 2193–2212.

———, 1978a. Sur quelques chitinozoaires de la Formation Vauréal et de la Formation Macasty (Ordovicien Supérieur), Ile d'Anticosti, Québec, Canada. *Review of Palaeobotany and Palynology*, 25: 295–314.

———, 1978b. Les chitinozoaires de l'Ordovicien Supérieur–Formations de Vauréal et d'Ellis Bay de l'Ile d'Anticosti, Québec. *Palinologia*, núm. extraord., 1.

———, 1984. Chitinozoaires de l'Ordovicien Moyen de subsurface de l'Ile Anticosti. *Review of Palaeobotany and Palynology*, 43: 123–143.

———, 1986. Succession des assemblages de chitinozoaires dans l'Ordovicien Moyen du Québec et de l'est du Canada. *Review of Palaeobotany and Palynology*, 48: 269–294.

———, 1987. Chitinozoaires du Caradoc supérieur–Ashgill inférieur du Québec, Canada. *Canadian Journal of Earth Sciences*, 24: 1212–1234.

ALBANESI, G. L. and ORTEGA, G., 2002. Advances on conodont–graptolite biostratigraphy of the Ordovician System of Argentina. In: Aceñolaza, F. G., Ed., *Aspects of the Ordovician System in Argentina*, 143–166. San Miguel de Tucumán: Universidad Nacional de Tucumán. Facultad de Ciencias Naturales e Instituto Miguel Lillo, Serie Correlación Geológica, no. 16.

ALBANESI, G. L., HÜNICKEN, M. A. and ORTEGA, G., 1995. *Amorphognatus* aff. *superbus* (Conodonta) en la Formación Trapiche (Ordovícico Superior), Cerro Potrerillo, Precordillera Argentina. *Boletín de la Academia Nacional de Ciencias*, Córdoba, 60: 461–468.

PLATE 2

Upper Ordovician chitinozoans from the eastern Argentine Precordillera.
Scale bar represents 50µm for 1a-2a, 3, 4a-7a. Details= 10µm.

Spinachitina bulmani (Jansonius 1964)

1-2 Sample 9922; upper part of the Las Vacas Formation (Member D).

3-7 Sample 9923; upper part of the Las Vacas Formation (Member D).


1a
2a
3
1b
2b
4a
4b
5a
6a
7a
7b
5b
6b

ALLMENDINGER, R. W., FIGUEROA, D., SNYDER, D., BEER, J., MPODOZIS, C. and ISACKS, B. L., 1990. Foreland shortening and crustal balancing in the Andes at 30° S latitude. *Tectonics*, 9: 789–809.

ALLMENDINGER, R. W., RAMOS, V. A., JORDAN, T. E., PALMA, M. A. and ISACKS, B. I., 1983. Paleogeography and Andean structural geometry, northwest Argentina. *Tectonics*, 2: 1–16.

ASTINI, R. A., 1992. Tectofacies ordovícicas y evolución de la cuenca eopaleozoica de la Precordillera Argentina. *Estudios Geológicos*, 48: 315–327.

———, 1994. Análisis secuencial y paleoambientes de las pelitas negras (aloformación Gualcamayo) que suprayacen a las sucesiones carbonáticas eo–ordovícicas en la Precordillera argentina. *Revista de la Asociación Geológica Argentina*, 49: 71–84.

———, 1998a. Stratigraphical evidence supporting the rifting, drifting and collision of the Laurentian Precordillera terrane of western Argentina. In: Pankhurst, R. J. and Rapela, C. W., Eds., *The proto-Andean margin of Gondwana*, 11–33. London: The Geological Society. Special Publication 142.

———, 1998b. El Conglomerado de Las Vacas y el Grupo Trapiche: tectónica distensiva en el Ordovícico Tardío. *Revista de la Asociación Geológica Argentina*, 53: 489–503.

ASTINI, R. A. and BRUSSA, E. D., 1997. Dos nuevas localidades fosilíferas en el Conglomerado de Las Vacas (Caradociano) en la Precordillera Argentina: Importancia cronoestratigráfica. *Ameghiniana*, 34: 114. (Reunión de Comunicaciones Paleontológicas, Asociación Paleontológica Argentina).

ASTINI, R. A., BENEDETTO, J. L. and CARRERA, M., 1986. La fauna de trilobites de la Formación Las Plantas (Ordovícico), Precordillera de La Rioja, Argentina. In: Volkheimer, W., Ed., *IV Congreso Argentino de Paleontología y Bioestratigrafía, Actas 1*, 81–88. Mendoza.

ASTINI, R. A., BENEDETTO, J. L. and VACCARI, N. E., 1995. The Early Palaeozoic evolution of the Argentine Precordillera as a rifted, drifted and collided terrane: a geodynamic model. *Geological Society of America Bulletin*, 107: 253–273.

BALDIS, B. A. and CHEBLI, G. A., 1969. Estructura profunda del área central de la Precordillera Sanjuanina. In: Asociación Geológica Argentina, Eds., *IV Jornadas Geológicas Argentinas Mendoza, Actas 1*, 47–65. Buenos Aires (1970).

BALDIS, B. A., PERALTA, S. H. and VILLEGAS, R., 1989. Esquematizaciones de una posible transcurrencia del terrane de Precordillera como fragmento continental procedente de áreas pampeano–bonaerenses. In: Aceñolaza, E. G. and Lech, R. A., Eds., *Eventos del Paleozoico inferior en Latinoamérica*, 81–100. San Miguel de Tucumán: Universidad Nacional de Tucumán. Facultad de Ciencias Naturales e Instituto Miguel Lillo, Serie Correlación Geológica, no. 5.

BALDIS, B. A., BERESI, M. S., BORDONARO, L. O. and VACA, A., 1982. Síntesis evolutiva de la Precordillera Argentina. In: [EDITORS??], Eds., *5° Congreso Latinoamericano de Geología, Actas 4*, 399–445. Buenos Aires.

BENEDETTO, J. L., 1993. La hipótesis de la aloctonía de la Precordillera Argentina: un test estratigrágico y biogeográfico. In: Asociación Geológica Argentina, Eds., *12° Congreso Geológico Argentino, Actas 3*, 375–384. Mendoza.

———, 1998. Early Palaeozoic brachiopods and associated shelly faunas from western Gondwana: its bearing on the geodynamic history of the pre-Andean margin. In: Pankhurst, R. J. and Rapela, C. W., Eds., *The proto-Andean margin of Gondwana*, 57–83. London: The Geological Society. Special Publication 142.

———, 1999. Braquiópodos de la Formación Trapiche, Ordovícico tardío de la Precordillera de San Juan y La Rioja, Argentina. *Ameghiniana*, 36: 327–341.

———, 2004. The allochthony of the Argentine Precordillera ten years later (1993–2003): A new paleobiogeographic test of the microcontinental model. *Gondwana Research*, 7: 1027–1039.

BENEDETTO, J. L. and HERRERA, Z. A., 1987. Primer hallazgo de braquiópodos y trilobites en la Formación Trapiche (Ordovícico tardío), Precordillera Argentina. In: Asociación Geológica Argentina. Eds., *10º Congreso Geológico Argentino, Actas 3*, 73–76. San Miguel de Tucumán.

BENEDETTO, J. L., SÁNCHEZ, T. M., CARRERAS, M. G., BRUSSA, E. D. and SALAS, M. J., 1999. Paleontological constraints on successive paleogeographic positions of Precordillera terrane during the early Paleozoic, In: Ramos, V.A. and Keppie, J.D., Eds., *Laurentia-Gondwana connections before Pangea*, 21–42 Boulder, Colorado: Geological Society of America. Special Paper 336.

BERGSTRÖM, S. M., CHEN, X., GUTIÉRREZ–MARCO, J. C. and DRONOV, A., 2009. The new chronostratigraphic classification of the Ordovician System and its relations to major regional series and stages and to $\delta^{13}C$ chemostratigraphy. *Lethaia*, 42: 97–107.

BUTCHER, A., 2009. Early Llandovery chitinozoans from Jordan. *Palaeontology*, 52: 593–629.

CARTER, C. and LAUFELD, S., 1975. Ordovician and Silurian fossils in well cores from the North Slope of Alaska. *American Association of Petroleum Geologists Bulletin*, 59: 457–464.

COCKS, L. R. M. and TORSVIK, T. H., 2004. Major terranes in the Ordovician. In: Webby, B. D., Paris, F., Droser, M. L. and Percival, I. G., Eds., *The great Ordovician biodiversification event*, 61–67. New York: Columbia University Press.

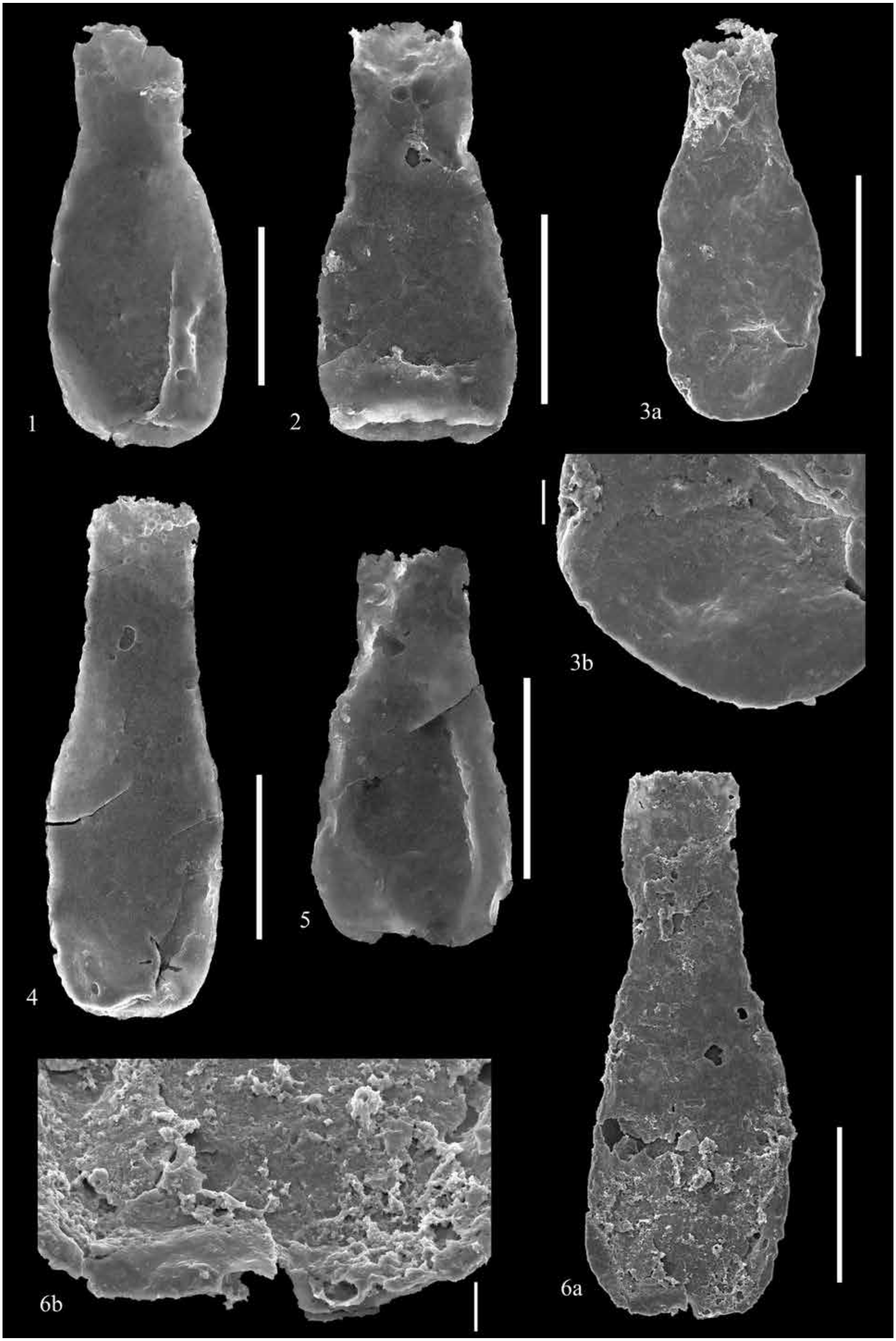
COLBATH, G. K. and GRENFELL, H. R., 1995. Review of biological affinities of Paleozoic acid-resistant, organic-rich eukaryotic algal microfossils (including “acritarchs”). *Review of Palaeobotany and. Palynology*, 86: 287–314.

PLATE 3

Middle to Upper Ordovician chitinozoans from the eastern Argentine Precordillera. Scale bars represent 50µm.

Lagenochitina sp. cf. *baltica* Eisenack 1931

1-6 Sample 10202; lower part of the Las Vacas Formation (Member A).


1
2
3a
3b
4
5
6b
6a

CUERDA, A., CABALLÉ, M. and ALFARO, M., 2004. Bioestratigrafía de la Formación Las Vacas (Ordovícico–Precordillera Argentina) basada en graptofaunas. Relaciones con el diastrofismo guandacólico. *Ameghiniana*, 41: 25–44.

DA COSTA, N. M. 1971. Quitinozoários silurianos do Igarapé da Rainha, Estado do Para. Belém: Departamento Nacional da Produção Mineral. Divisão de Geologia e Mineralogia. Boletim 255, 101 pp.

DE LA PUENTE, G.S. and RUBINSTEIN, C.V., 2013. Ordovician chitinozoans and marine phytoplankton of the Central Andean Basin, northwestern Argentina: A biostratigraphic and paleobiogeographic approach. *Review of Palaeobotany and Palynology*, 198: 14-26.

DERENNE, S., LARGEAU, C., BRUKNER-WEIN, A., HETENYI, M., BARDOUX, G. and MARIOTTI , A, 2000. Origin of variation in organic matter abundance and composition in a lithologically homogeneous maar-type oil shale deposit (Gérce, Pliocene, Hungary). *Organic Geochemistry*, 31: 787–798.

EISENACK, A., 1931. Neue Mikrofossilien des baltischen Silurs. 1. *Palaeontologische Zeitschrift*, 13: 74–118.

———, 1934. Neue Mikrofossilien des baltischen Silurs III und Neue Mikrofossilien des böhemischen Silurs I. *Palaeontologische Zeitschrift*, 16: 52–76.

———, 1958. Mikrofossilien aus dem Ordovizium des Baltikum. I. Markasitschicht, Dictyonema–Schlefer, Glaukonitsand, Glaukonitkalk. *Senckenbergiana lethaea*, 39: 389–405.

———, 1962 Mikrofossilien aus dem Ordovizium des Baltikums. 2. *Senckenbergiana lethaea*, 43: 349–366.

ELAOUAD-DEBBAJ, Z., 1984. Chitinozoaires Ashgilliens de l'Anti-Atlas (Maroc). *Geobios*, 17: 45–68.

FINNEY, S. C., 2007. The parautochthonous Gondwana origin of the Cuyania (greater Precordillera) terrane of Argentina: a re-evaluation of evidence used to support an allochthonous Laurentian origin. *Geologica Acta*, 5: 127–158.

FINNEY, S., GLEASON, J., GEHRELS, G., PERALTA, S. and ACEÑOLAZA, G., 2003. Early Gondwanan connection for Argentina Precordillera terrane. *Earth and Planetary Science Letters*, 205: 349–359.

———, 2004. Corrigendum to "Early Gondwanan connection for Argentina Precordillera terrane". *Earth and Planetary Science Letters*, 218: pp. 413.

FURQUE, G., 1963. *Descripción geológica de la Hoja* 17b–Guandacol. Buenos Aires: Dirección Nacional de Geología y Minería. Boletín 92, 72 pp.

GOSEN, W. VON, 1992. Structural evolution of the Argentine Precordillera: the Rio San Juan section. *Journal of Structural Geology*, 14: 643–667.

GRAHN, Y. 1982. Caradoc and Ashgillian Chitinozoa from the subsurface of Gotland. *Severiges Geologiska Undersökning, Serie C*, 788: 1–66.

GRAHN, Y. and BERGSTRÖM, S. M., 1984. Lower Middle Ordovician chitinozoan from the Southern Appalachians, United States. *Review of Paleobotany and Palynology*, 43: 89–122.

GUY-OHLSON, D., 1992. *Botryococcus* as an aid in the interpretation of palaeoenvironment and depositional processes. *Review of Paleobotany and Palynology*, 71: 1–15.

JANSONIUS, J., 1964. Morphology and classification of some Chitinozoa. *Bulletin of Canadian Petroleum Geology*, 12: 901–918.

JENKINS, W. A. M., 1967. Ordovician Chitinozoa from Shropshire. *Palaeontology*, 10: 436–488.

———, 1969. Chitinozoa from the Ordovician Viola and Fernvale Limestones of the Arbuckle Mountains, Oklahoma. *Special Papers in Palaeontology*, 5: 1–44.

———, 1970. Chitinozoa from the Ordovician Sylvan Shale of the Arbuckle Mountains, Oklahoma. *Palaeontology*, 13: 261–288.

JORDAN, T. E., ALLMENDINGER, R. W., DAMANTI, J. F. and DRAKE, R. E., 1993. Chronology of motion in a complete thrust belt: The Precordillera, 30–31°S, Andes Mountains. *Journal of Geology*, 101: 135–1 56.

JORDAN, T. E., ISDCKS, B. L., ALLMENDINGER, R. W., BREWER, J. A., RAMOS, VA. and ANDO, C. J., 1983. Andean tectonics related to geometry of subducted Nazca plate. *Geological Society of America Bulletin*, 94: 341–361.

KELLER, M., 1999. Argentine Precordillera: sedimentary and plate tectonic history of a Laurentian crustal fragment in South America.

PLATE 4

Upper Ordovician chitinozoans from the eastern Argentine Precordillera. Scale bars represent 50µm for 1-6 and 7-9.

Cyathochitina sp. cf. *Cy. kuckersiana* (Eisenack 1934)

1 Sample 9921; upper part of the Las Vacas Formation (Member D).

2 Sample 9922; upper part of the Las Vacas Formation (Member D).

Cyathochitina sp. aff. *Cy. macastyensis* Achab 1978a

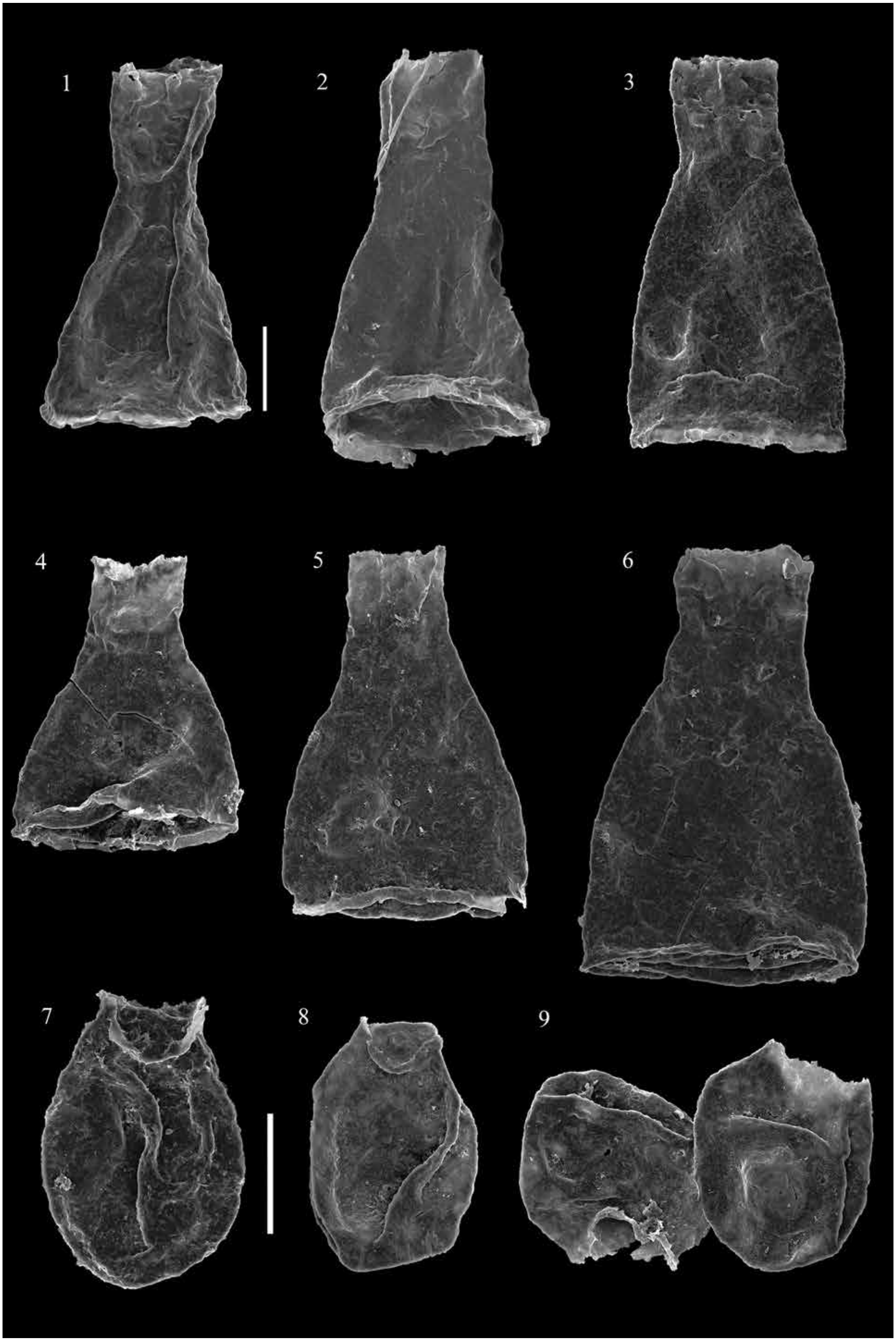
3, 6 Sample 9922; upper part of the Las Vacas Formation (Member D).

4-5 Sample 9923; upper part of the Las Vacas Formation (Member D).

Desmochitina minor form *typica* Eisenack 1958

7 Sample 9921; upper part of the Las Vacas Formation (Member D).

8-9 Sample 9923; upper part of the Las Vacas Formation (Member D).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Boulder, Colorado: *Geological Society of America*. Special Paper, 341, 131 pp.

LAUFELD, S., 1967. Caradocian Chitinozoa from Dalarna, Sweden. *Geologiska Föreningens i Stockholm Förhandlingar*, 89: 275–349.

LILLE, U., 2003. Current knowledge on the origin and structure of Estonian kukersite kerogen. *Oil Shale*, 20: 253–263.

MALO, M., COUSINEAU, P. A., SACKS, P. E., RIVA, J. F. V., ASSELIN, E. and GOSSELIN, P., 2001. Age and composition of the Ruisseau Isabelle Mélange along the Shickshock Sud fault zone: constrains on the timing of mélanges formation in the Gaspé Appalachians. *Canadian Journal of Earth Sciences*, 38: 21–42.

MARTIN, F., 1975. Sur quelques Chitinozoaires ordoviciens du Québec et de l'Ontario, Canada. *Canadian Journal of Earth Sciences*, 12: 1006–1018.

———, 1978. Lower Paleozoic Chitinozoa and acritarchs from Newfoundland. *Geological Survey of Canada Current Research, part B*. 78–1B: 73–81.

———, 1983. Chitinozoaires et acritarches ordoviciens de la Plate-forme du Saint-Laurent (Québec et sud-est de l'Ontario). Ottawa: *Geological Survey of Canada*. Bulletin 310, 65 pp.

NESTOR, V., 1980. New chitinozoan species from the lower Llandovery of Estonia. *Proceedings of the Estonian Academy of Sciences, Geology*, 29: 98–107.

NEVILLE, R. S. W., 1974. Ordovician chitinozoan from western Newfoundland. *Review of Palaeobotany and Palynology*, 18: 187–221.

ORTEGA, G. and BRUSSA, E. D., 1990. La subzona de *Climacograptus bicornis* (Caradociano temprano) en la Formación Las Plantas en su localidad tipo. *Ameghiniana*, 27: 281–288.

ORTEGA, G. and MÁSPERO CASTRO, B. 2002. La Zona de *Pterograptus elegans* (Ordovícico Medio) en la Formación Gualcamayo, quebrada Corridita, Precordillera de San Juan. In: Gallego, O., Ed., *VIII Congreso Argentino de Paleontología y Bioestratigrafía, Corrientes, Resúmenes*, p. 88. Corrientes

ORTEGA, G., TORO, B. and BRUSSA, E. D., 1993. Las Zonas de graptolitos de la Formación Gualcamayo (Arenigiano tardío–Llanvirniano temprano) en el norte de la Precordillera (Provincias de La Rioja y San Juan) Argentina. *Revista Española de Paleontología*, 8: 207–219.

ORTIZ, A. and ZAMBRANO, J. J., 1981. La Provincia Geológica Precordillerana Oriental. In: Asociación Geológica Argentina, Eds., *8° Congreso Geológico Argentino, Actas 3*, 59–74. San Luis.

OTTONE, E. G., ALBANESI, G. L., ORTEGA, G. and HOLFELTZ, G. D., 1999. Palynomorphs, conodonts and associated graptolites from the Ordovician Los Azules formation, Central Precordillera, Argentina. *Micropaleontology*, 45: 225–250.

OTTONE, E. G., HOLFELTZ, G. D., ALBANESI, G. L. and ORTEGA, G., 2001. Chitinozoans from the Ordovician Los Azules Formation, Central Precordillera, Argentina. *Micropaleontology*, 47: 97–110.

PARIS, F., 1979. Les chitinozoaires de la Formation de Louredo, Ordovicien supérieur du synclinal de Buçaco (Portugal). *Palaeontographica A*, 164: 24–51.

———, 1981. Les Chitinozoaires dans le Paléozoïque du sud-ouest de l'Europe (cadre géologique – étude systématique-biostratigraphie). *Mémoire de la Société géologique et minéralogique de Bretagne*, 24: 1–496.

———, 1990. The Ordovician chitinozoan biozones of the Northern Gondwana Domain. *Review of Palaeobotany and Palynology*, 66: 181–209.

PARIS, F., BOURAHROUH, A. and LE HÉRISSÉ, A., 2000. The effects of the final stages of the Late Ordovician glaciation on marine palynomorphs (chitinozoans, acritarchs, leiospheres) in well Nl-2 (NE Algerian Sahara). *Review of Palaeobotany and Palynology*, 113: 87–104.

PARIS, F., GRAHN, Y., NESTOR, V. and LAKOVA, I., 1999. A revised chitinozoan classification. *Journal of Paleontology*, 73: 549–570.

PARIS, F., LE HÉRISSÉ, A., MONOD, O., KOZLU, H., GHIENNE, J. F., DEAN, W. T., VECOLI, M. and GÜNAY, Y., 2007. Ordovician chitinozoans and acritarchs from southern and southeastern Turkey. *Revue de Micropaléontologie*, 50: 81–107.

PARIS, F., THUSU, B., RASUL, S., MEINHOLD, G., STROGEN, D., HOWARD, J. P., ABUTARRUMA, Y., ELGADRY, M. and WHITHAM, A. G., 2012. Palynological and palynofacies analysis of early Silurian shales from borehole CDEG-2a in Dor el Gussa, eastern Murzuq Basin, Libya. *Review of Palaeobotany and Palynology*, 174: 1–26.

PERALTA, S. H. and FINNEY, S. C., 2003. The Upper Ordovician graptolite faunas of the Cuyania Terrane: Their biostratigraphic and paleogeographic significance in the western margin of Gondwana.

PLATE 5

Upper Ordovician chitinozoans from the eastern Argentine Precordillera. Scale bars represent 50µm for 1-11 and 12.

Kalochitina multispinata Jansonius 1964

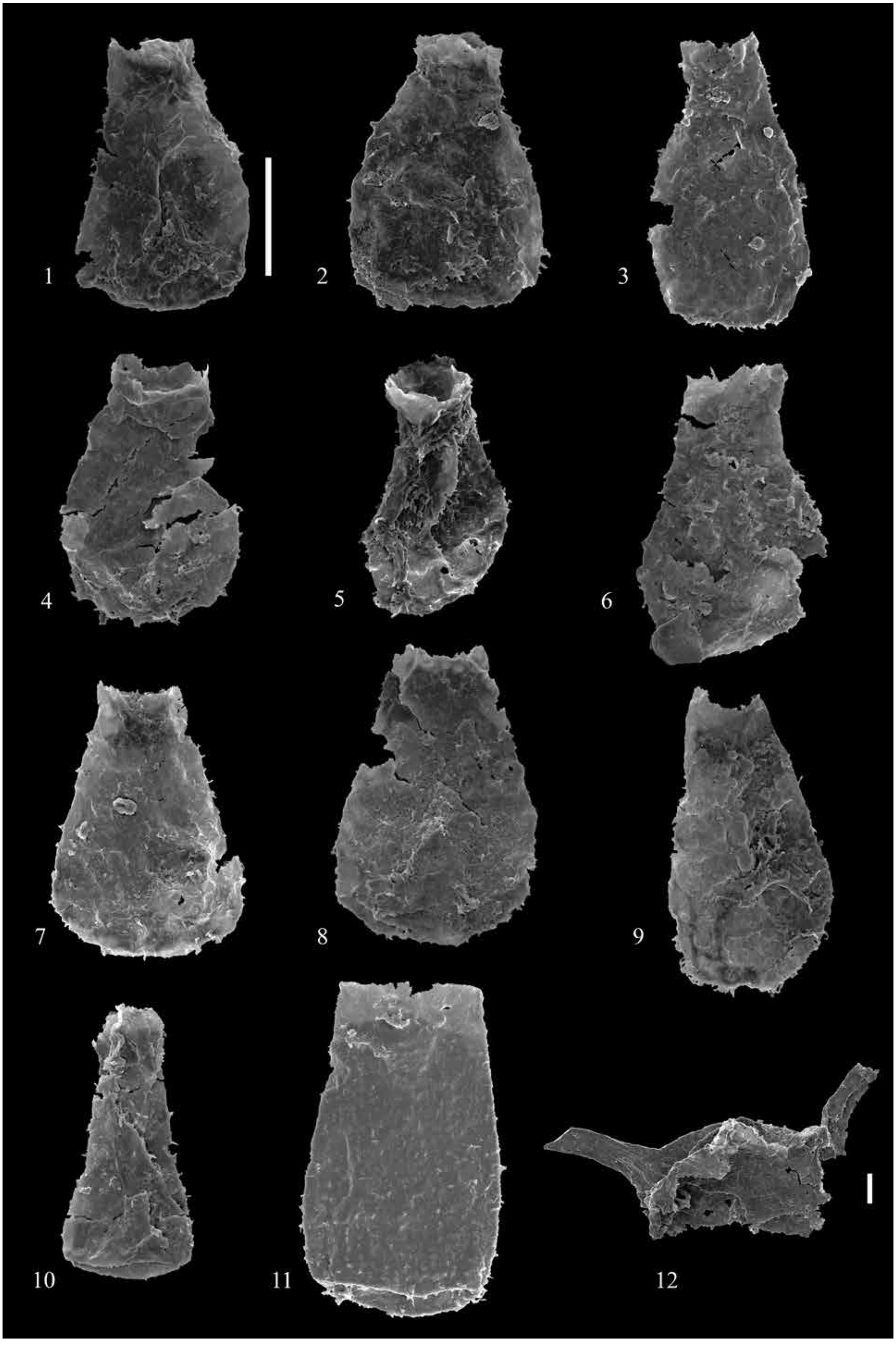
1-10. Sample 9923; upper part of the Las Vacas Formation (Member D).

Belonechitina sp.

11. Sample 9923; upper part of the Las Vacas Formation (Member D).

Acritarch (giant).

12. Sample 9923; upper part of the Las Vacas Formation (Member D)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In: Aceñolaza, F. G., Ed., *Aspects of the Ordovician System in Argentina*, 41–74. San Miguel de Tucumán: Universidad Nacional de Tucumán. Serie Correlación Geológica, 16.

RAMOS, V. A., 1988. Late Pretorozoic–Early Paleozoic of South America–a collisional history. *Episodes*, 11: 168–174.

———, 2004. Cuyania, an exotic block to Gondwana: review of a historical success and the present problems. *Gondwana Research*, 7: 1009–1026.

RAMOS, V. A., DALLMEYER, R. D. and VUJOVICH, G., 1998. Time constraints on the Early Palaeozoic docking of the Precordillera, central Argentina. In: Pankhurst, R. J. and Rapela, C. W., Eds., *The proto-Andean margin of Gondwana*, 143–158. London: The Geological Society. Special Publication 142.

RAMOS, V. A., JORDAN, T. E., ALLMENDINGER, R. W., MPODOZIS, C., KAY, S. M., CORTKS, J. M. and PALMA, M., 1986. Paleozoic terranes of the Central Argentine–Chilean Andes. *Tectonics*, 5: 855–880.

RAPALINI, A. E., 2012. Paleomagnetic evidence for the origin of the Argentine Precordillera, fifteen years later: what is new, what has changed, what is still valid? *Latinmag Letters*, 2: 1–20.

RUBINSTEIN, C. V. and VACCARI, N. E., 2004. Cryptospore assemblages from the Ordovician–Silurian boundary in the Puna, northwest Argentina. *Palaeontology*, 47: 1037–1061.

RUBINSTEIN, C. V., GERRIENNE, P., DE LA PUENTE, G. S., ASTINI, R. A. and STEEMANS, P., 2010. Early Middle Ordovician evidence for land plants in Argentina (eastern Gondwana). *New Phytologist*, 188: 365–369.

RUBINSTEIN, C. V., VECOLI, M. and ASTINI, R. A., 2011. Biostratigraphy and paleoenvironmental characterization of the Middle Ordovician from the Sierras Subandinas (NW Argentina) based on organic-walled microfossils and sequence stratigraphy. *Journal of South American Earth Sciences*, 31: 124–138.

SOUFIANE, A. and ACHAB, A., 2000. Upper Ordovician and Lower Silurian chitinozoans from central Nevada and Arctic Canada. *Review of Palaeobotany and Palynology*, 113: 165–187.

TAPPAN H., 1980. *The paleobiology of plant Protista*. San Francisco: Freeman, 1028 pp.

THOMAS, W. A. and ASTINI, R. A., 1996. The Argentine Precordillera: a traveler from the Ouachita embayment of North American Laurentia. *Science*, 273: 752–757.

———, 1999. Simple–shear conjugate rift margins of the Argentine Precordillera and the Ouachita embayment of Laurentia. *Geological Society of America Bulletin*, 111: 1069–1079.

———, 2003. Ordovician accretion of the Argentine Precordillera terrane to Gondwana: a review. *Journal of South American Earth Sciences*, 16: 67–79.

———, 2007. Vestiges of an Ordovician west-vergent thin-skinned Ocloyic thrust belt in the Argentine Precordillera, southern Central Andes. *Journal of Structural Geology*, 29: 1369–1385.

THOMPSON, C. K., KAH, L. C., ASTINI, R. A., BOWRING, S. A. and BUCHWALDT, R., 2012. Bentonite geochronology, marine geochemistry, and the Great Ordovician Biodiversification Event (GOBE). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 321–322: 88–101.

VANDENBROUCKE, T. R. A., ANCILLETTA, A., FORTEY, R. and VERNIERS, J., 2009a. A modern assessment of Ordovician chitinozoans from the Shelve and Caradoc areas, Shropshire, and their significance for correlation. *Geological Magazine*, 146: 216–236.

VANDENBROUCKE, T. R. A., ARMSTRONG, H. A., WILLIAMS, M., PARIS, F., SABBE, K., ZALASIEWICZ, J. A., NÕLVAK, J., VERNIERS, J., 2010. Epipelagic chitinozoan biotopes map a steep latitudinal temperature gradient for earliest Late Ordovician seas: implications for a cooling Late Ordovician climate. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 294: 202–219.

VANDENBROUCKE, T. R. A., GABBOTT, S. E., PARIS, F., ALDRIDGE, R. J. and THERON, J. N., 2009b. Chitinozoans and the age of the Soom Shale, an Ordovician black shale lagerstätte, South Africa. *Journal of Micropalaeontology*, 28: 53–66.

VANDENBROUCKE, T. R. A., VERNIERS, J. and CLARKSON, E. N. K., 2003. A chitinozoan biostratigraphy of the Upper Ordovician and Lower Silurian strata of the Girvan area, Midland Valley, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, 93: 111– 134.

VOLKHEIMER, W., CUERDA, A. and MELENDI, D. L., 1980. Quitinozoos ordovícicos de la Formación Gualcamayo en su localidad tipo al sudoeste de Guandacol, Precordillera de La Rioja, República Argentina. In:Asociación Paleontológica Argentina, Eds., *II Con-*

PLATE 6

Upper Ordovician phytoplankton and spores from the eastern Argentine Precordillera. Scale bar represents 20μm.

1- cf. *Tetrahedraletes medinensis* (Strother and Traverse) Wellman and Richardson 1993. 3C- S40-4

2- cf. *Rimosotetras problematica* Burgess 1991. 3C-M29-2-1

3- Tetrad sp. 3A- X38-3

4- *Leiosphaeridia* sp. 3E-F27-0

5- cf. *Veryhachium* sp. 3B-Y29-3

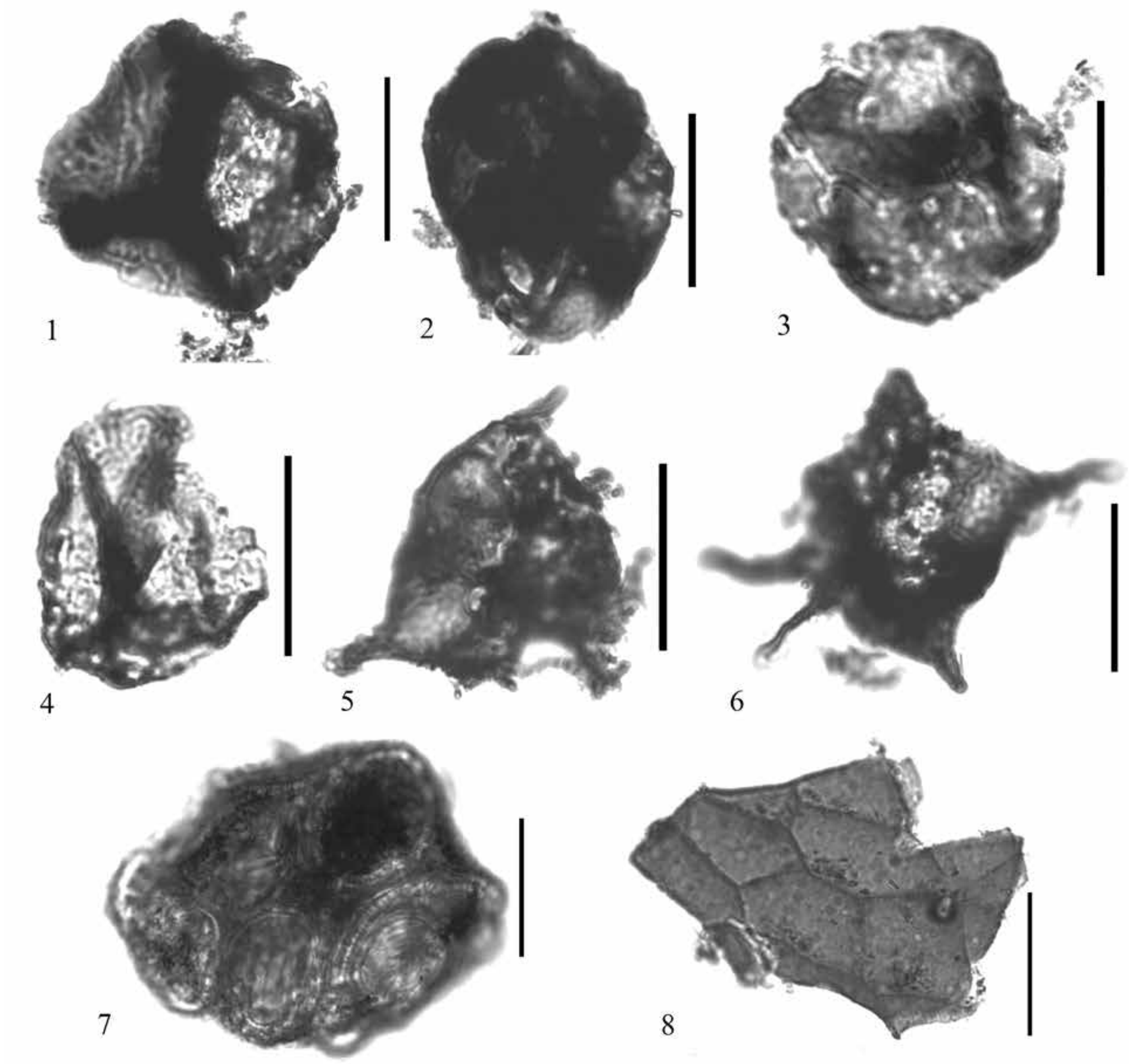
6- Acritarch indet. 3E-X27-0-1

7- cf. *Gloeocapsomorpha* sp. A-V30-0

8- Fragment of a coenobial algae? C-D23-0

1-6. Sample 9923; upper part of the Las Vacas Formation (Member D).

7-8. Sample 9924; Trapiche Formation.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WICANDER, R., FOSTER, C. B. and REED, J. D., 1996. Green and blue-green algae Gloeocapsomorpha. In: Jansonius, J. and McGregor, D. C., Eds., *Palynology: principles and applications*, 215–225. Salt Lake City: AASP Foundation.

ZALESSKY, M. D., 1917. Sur le sapropélite marin d'âge Silurien formé par une algue cyanophycée. Ezhegodnik Vsesoyuznogo Paleontologicheskogo Obshchestva, 1: 25–42.