TOTAL S.A.

ORGANIC-WALLED MICROFOSSILS and PETROLOGY of the HUAMAMPAMPA and LOS MONOS FORMATIONS

in

LA CANDELARIA and LA ESCALERA SECTIONS (MIDDLE DEVONIAN, SOUTHERN BOLIVIA)

FINAL REPORT

(October 25, 2003)

Research & Development Contract

Ref. TOTAL DGEP/TDO/CA/ACOMS CT N°. 13510
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CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

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by

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PREAMBLE

Palynological investigations have been already carried out on Devonian strata from Bolivia. Most of the published data concern surface samples collected in various sections located all along the eastern Cordillera and the Sub-Andean units (Racheboeuf et al. 1993, Grahn 2002). Additional subsurface data, generally based on cutting samples, are available in TOTAL S.A internal reports (e.g. Paris et al. 2001, Paris and le Hérissé 2002) and in several publications (e.g., McGregor 1984, Melo 2000, Ottone 1996, Perez-Leyton 1990, Vavrdova et al. 1994, Wood 1994). All these data demonstrate that during Devonian time, the present day eastern Cordillera as well as the Sub-Andean Bolivia were connected with the western Gondwana palaeobiogeographic province documented in Brazil, Paraguay, and Northern Argentina (see Melo 1988, for further references).

The present study is the third part of a three-fold project, financed by TOTAL S.A, and dealing with the biostratigraphy and palaeoenvironments of the Devonian of southern Bolivia. Two first studies concerned sub-surface samples, respectively from the PARAPETTI and INAU-X2 boreholes (Paris, Le Hérissé and Streel, 2001), and from the INIGUAZU-X4 and ITAU-X2 boreholes (Paris and Le Hérissé, 2002). Unfortunately, most of the organic-walled microfossils recorded in these subsurface samples were recovered from cuttings. Consequently the range of the identified taxa might be biased by down-well contaminations (caving).

The present investigations deal with samples from outcrops. In order to benefit of a well-established sedimentological succession and to avoid contaminations, the «La Candelaria» and «La Escalera» sections, have been selected. They are located south of Sucre, at about 25 kms south of Tarabuco (south Bolivia) (Fig. 1). The lithological succession was established by Jacques DURAND (TOTAL S.A), Walter MARQUEZ and Miguel PEREZ LOPEZ in December, 2002. Because of lithological constrains (shaly and silty sediments are more favourable for the occurrence of organic-walled microfossils), they concentrated the sampling respectively on the boundary beds of the Huamampampa Formation *stricto sensu*, and on the Los Monos/Iquiri? formations (Figs. 2-5).

AIMS OF THE STUDY

The Middle Devonian sandy formations proved to be one of the main hydrocarbon reservoir in Southern Bolivia where they constitute an important target for gas exploration. However, the age assignment of various Devonian sandy bodies recorded all along the eastern Cordillera and the Sub-Andean units remains a problem: the palaeontological and palynological data from outcrops are too sparse and the sub-surface data, mostly based on cutting samples, may have suffered important down-well contamination due to caving processes.

The available age assignments are in some cases contradictory. This may result from: 1) an incomplete record and description of the endemic Bolivian species, 2) lumping and/or confusion in taxa identification (e.g. various species with a different range are sometime grouped under the same specific name because of poor taxonomic descriptions), 3) a poor cover of the palynomorph diversity through time, 4) an environmental control on the occurrence of some species regarded as key taxa. However, the conflicting ages may as well be due to a diachronic setting of the Middle Devonian sandy bodies over Southern Bolivia. Consequently, a detailed biostratigraphic study, not affected by sampling or environmental biases, was hardly needed.

It appeared that a local biostratigraphic standard was missing for the accurate datation of the Middle Devonian sandy sedimentation and for controlling its possible diachronism over southern Bolivia. TOTAL S.A. management has decided therefore to investigate in great detail, both for biostratigraphical and sedimentological purposes, the type section of the Huamampampa Formation *stricto sensu*. A special attention is paid to the boundary beds with the underlying strata regarded as part of the «Argentinean type of the Huamampampa Formation» (termed here as «Argentinean Huamampampa») and with the overlying Los Monos Formation because their accurate age assign-

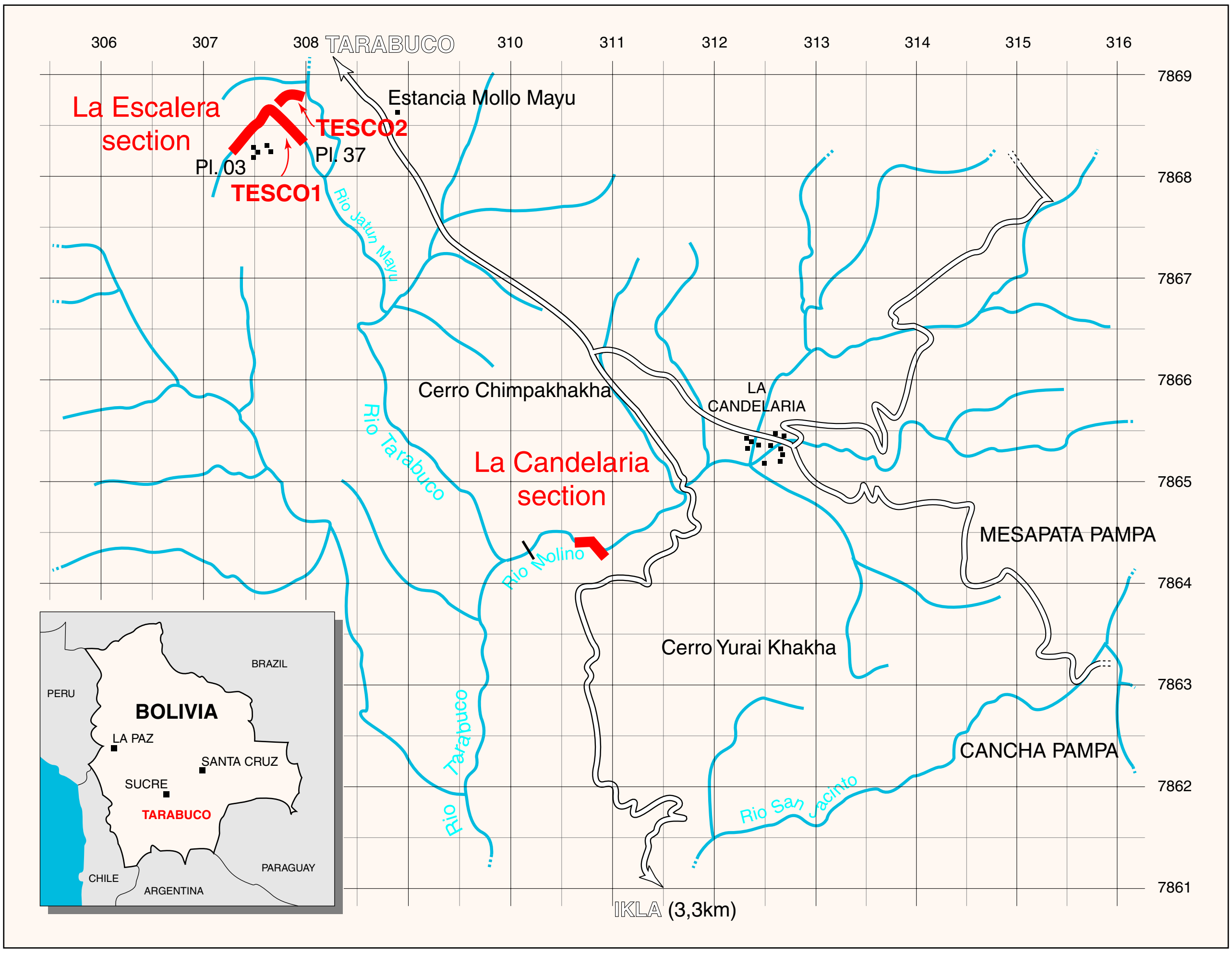

Fig. 1: Location map of the «La Candelaria» and the «La Escalera» sections in southern Bolivia (adapted from Marquez and Perez 2003)

ment constitute the best «tool» for documenting a regional diachronism.

Our aim is to inter-calibrate the range of the different organic-walled microfossils (i.e. acritarchs, chitinozoans and miospores) recorded in the type section and to use the range chart of each group in the type section for correlation with the subsurface data. Quantified palynological investigations are carried out during this study. Indeed, a very high abundance of some species in thin horizons may constitute a source of contamination due to caving in subsurface cutting samples. These quantified data should allow documenting such caving and even restoring the actual range of the taxa in the previously investigated wells (correction of the FAD). Moreover, the quantified data proved to be of great interest for evaluating the setting palaenvironments.

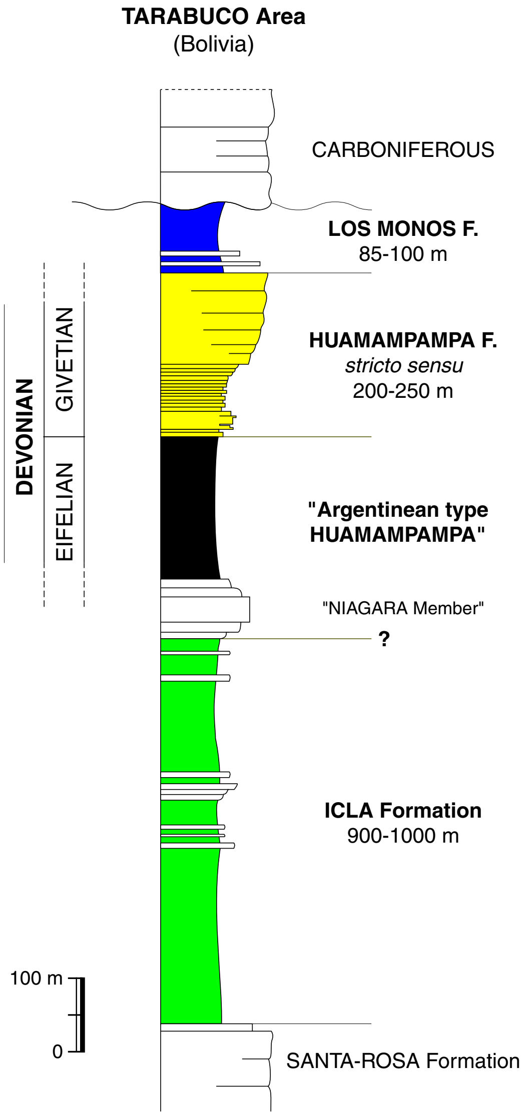

Fig. 2: Schematic lithological succession of the Devonian of the Tarabuco area (from Marquez and Perez 2003; lithostratigraphic subdivisions from TOTAL S.A. October 2003)

MATERIAL

A total of 51 samples from the **La Candelaria** and **La Escalera** sections have been investigated for chitinozoans (Figs. 6-8), acritarchs (Figs. 11-13) and miospores (Figs. 15-17). The occurrence and the abundance of other organic microfossils, (i.e., land derived plant remains such as cuticles, tracheids, woody debris, or marine metazoan remains, e.g. scolecodonts) and peculiar lithological features (e.g., pyrite, heavy minerals, graphite), have been pointed too (Tabl. 1-3).

The investigated palynological material comprises:

- 9 samples from **La Candelaria** section, including 6 samples (**TO1-PL.01** to **TO1-PL.06**) from the uppermost part of the «Argentinian Huamampampa» (formally regarded as the upper part of the Icla Formation), and 3 samples (**TO2-PL.07, TO2-LM.01** and **TO3-PL.08**) from the lowermost part of the Huamampampa Formation *stricto sensu* (Fig. 3). All these samples provided workable organic residues, except TO3-PL.8, which is totally barren (Tabl. 1).

NB: At the moment, the status of the silty sequence underlying the sandy body representing the base of the Huamampampa Formation, stricto sensu in La Candelaria locality (known formely as «Hamampampa village», and therefore representing the type locality of the formation) is not yet formally fixed. It possibly represents the so-called «Huamampampa Formation» in Argentina and southermost Bolivia.

- 6 samples (**TESCO2-PL.01** to **TESCO2-PL.06**) from the «lower» **La Escalera** section corresponding to the upper part of the Huamampampa Formation *s.s.* (Fig. 4). Only the two oldest samples contain organic-walled microfossils (Tabl. 2)

- 36 samples (**TESCO1-PL.37** to **TESCO2-PL.03**) from the «upper» **La Escalera** section corresponding to the Los Monos Formation (Fig. 5). The youngest samples (**TESCO1-PL.15** to **TESCO2-PL.03**), probably belonging to the Iquiri Formation, have not yielded any identifiable organic-walled microfossils (Tabl. 3). The section ends below a basalt layer.

The petrological studies are made by M.P. DABARD (MPD) on specific samples (labelled LM.). The aim of these petrographical investigations is the identification of possible different sources for the Middle Devonian sediments of southern Bolivia. In addition to the study of classical petrographical thin sections, heavy mineral residues (mostly oxides as most of the silicates were destroyed by HF) obtained during the extraction of the organic-walled microfossil by acid maceration have been observed. They have been concentrated and then mounted in Canada balsam. They are used here for defining the heavy mineral cortege in the type area of the Huamampampa Formation.

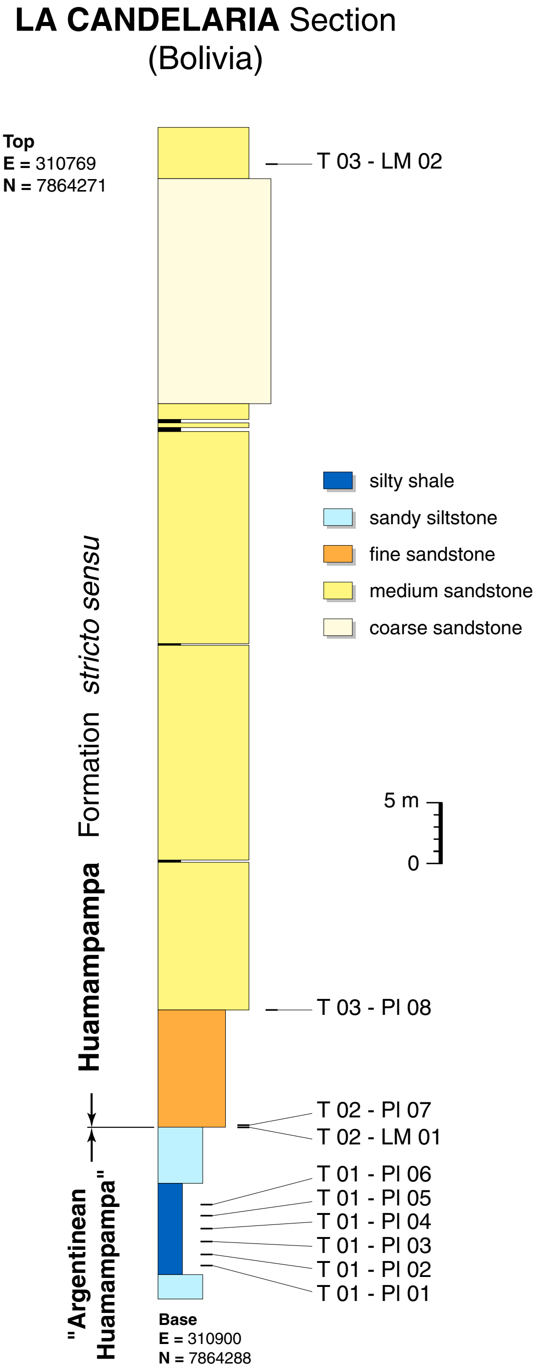

Fig. 3: Schematic lithological column and position of the investigated samples in the «La Candelaria» section (adapted from Marquez and Perez 2003) (lithostratigraphic sub divisions from TOTAL S.A. October 2003)

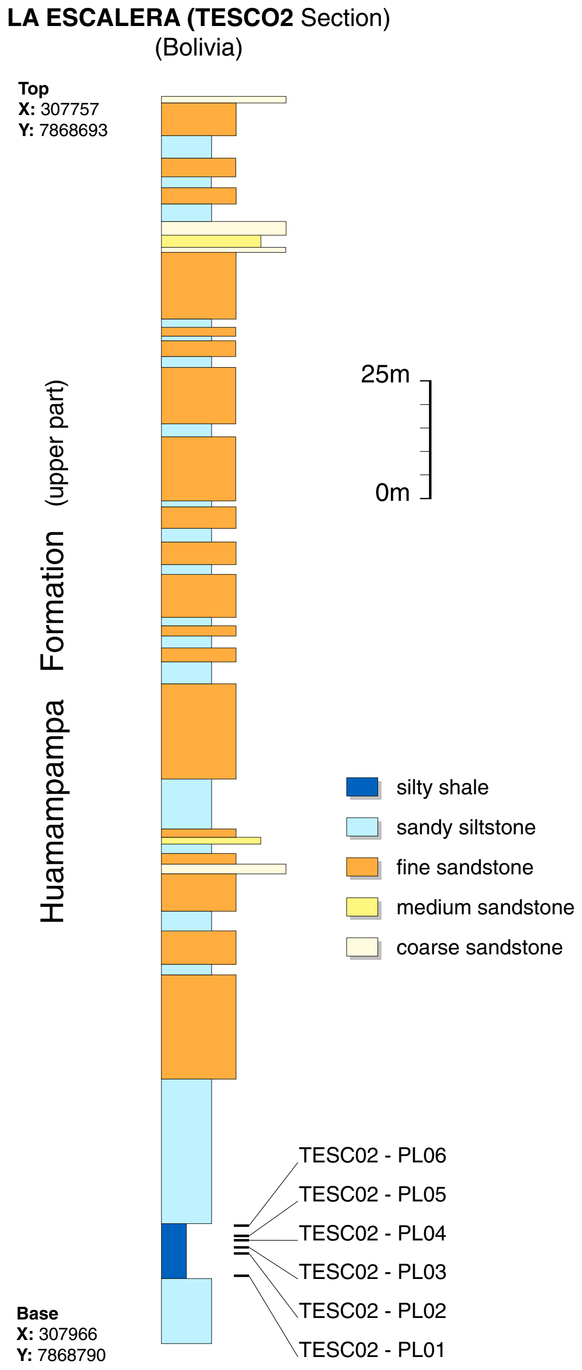

Fig. 4: Schematic lithological column of the lower «La Escalera» section (TESCO2) and position of the investigated samples (TESCO2-PL.01 to TESCO2-PL.06) (adapted from Marquez and Perez 2003

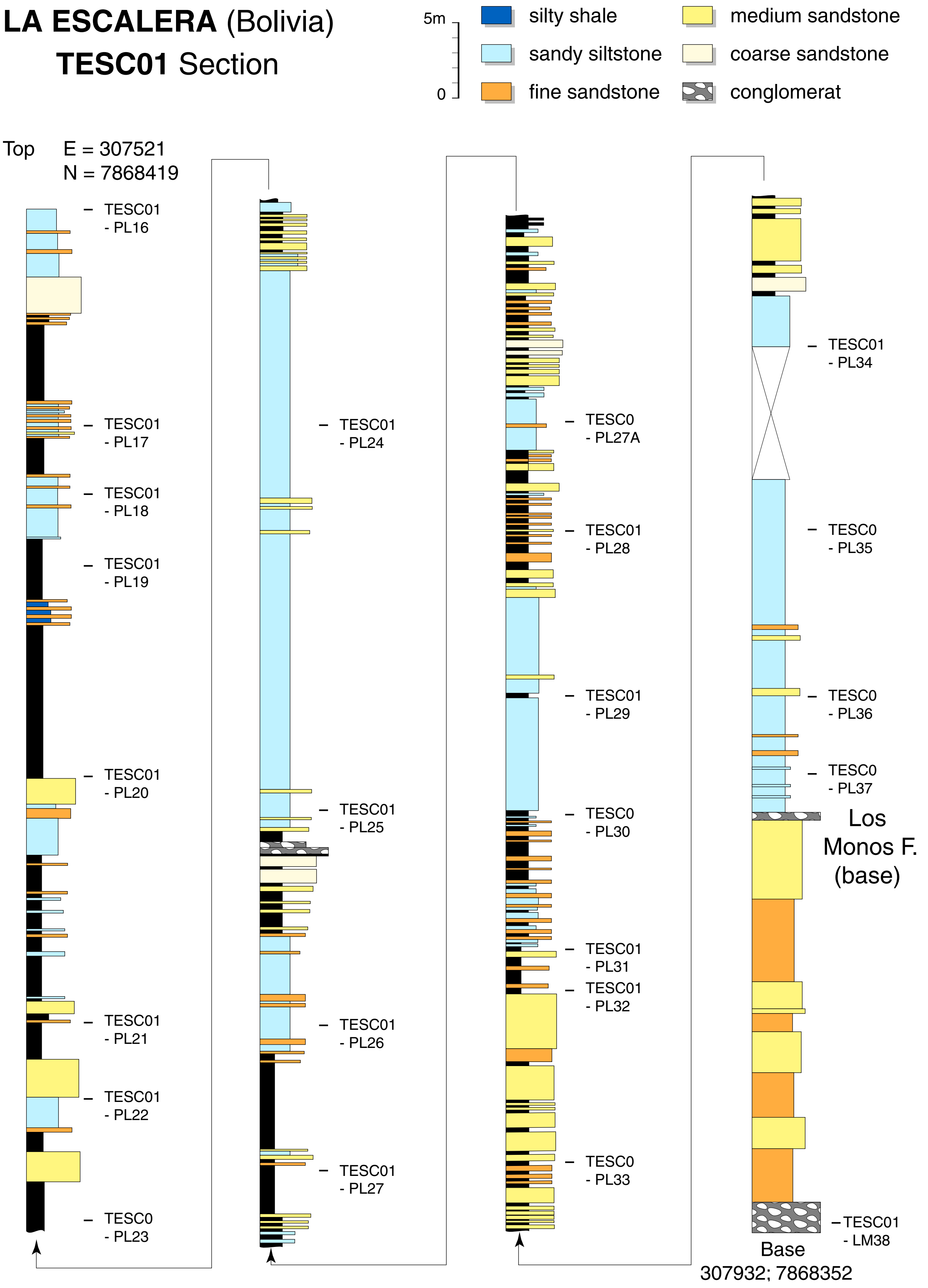

Fig. 5: Schematic lithological column of the upper «La Escalera» section (TESCO1) and position of the investigated samples (TESCO1-PL.37 to TESCO1-PL.16) (adapted from Marquez and Perez 2003)

TECHNICAL PROCEDURE

1- Acid treatment and microfossil sorting (DB)

The destruction of the mineral matrix is realised, first with HCL (removing of the carbonate and of the ferruginous minerals), then with HF (destruction of the silicates) until the rock disaggregates totally. The remaining residue contains heavy minerals (e.g. zircons, tourmaline, rutile, graphite), and the organic fraction (organic-walled fossils and microfossils, amorphous organic matter and plant remains). This residue is «gently cleaned» with HNO3 at 65% (destruction of the remaining clay minerals and of part of the finest amorphous organic matter). Several washings and decantations are made for a total removing of the acid. The organic residue is screened using a 53 microns mesh in order to sort the larger organic-walled microfossils, i.e. in the present case, chitinozoans, scolecodonts, large leiospheres, and plant fragments. The residue minor to 53 microns is screened a second time, using a 20 microns mesh. The fraction between 20 and 53 microns is kept and stored, whereas the lower fraction is eliminated (however, it may contain a few minute spores and/or acritarchs). The organic-walled microfossils of the fraction higher than 53 microns are handpicked with a micropipette under the binocular microscope (X 40 magnification). Then, the organic residue ranging between 53 and 20 microns is mixed with the residue remaining after the sorting of the chitinozoans and of the larger organic-walled microfossils from the fraction higher than 53 microns. This organic residue (minor all or a fraction of the chitinozoans and some selected scolecodonts) containing acritarchs, leiospheres, miospores, and plant remains is mounted in permanent palynological slides, in Canada balsam.

For the present study, a peculiar attention is paid to the evaluation of the palaeoenvironments through the composition of the organic residue. Consequently, numerous sifting at different mesh-sizes, and bleaching are avoided as they should result in a biased composition of the land-derived elements versus the true marine palynomorphs. In addition, for each sample, in order to have comparable quantified information for the acritarchs, and for the spores, 3 permanent slides are mounted from exactly the same amount of organic residue. This procedure gives certainly less «clean» slides but, on the other hand, it allows a strict comparison between the respective abundance of each investigated group. For close examination, or for good illustrations of the taxa, either under transmitted light microscope or with a Scanning Electron Microscope (MEB), a specific sorting of miospores or acritarchs by handpicking is possible as a large amount of residue is still available after the preparation of the 3 permanent palynological slides for most of the samples.

2- Counting

For the chitinozoans (FP), the classical procedure described by Paris (1981), based on handpicking (with a glass micropipette) of the specimens present in the palynological residue, is used. Usually, the chitinozoans are picked and counted from the whole residue. However, they may be too numerous (e.g. several thousands in 10 g of sample). In such a case, the picking and the counting are made on 10% of the initial residue (see Tabl. 4-6). The chitinozoan abundance is expressed in number of specimens per gram of rock. Their relative frequency, based on the identified specimens only, is calculated also, (Figs. 6-8; Tabl. 4-6). The unidentified specimens may reach up to 50% in a few samples (Tabl. 5-6).
Extensive illustrations of the recorded species are made by SEM (Pl. 1-2) and by transmitted light micro-photos (Pl. 3-4). In addition, a database of colour micro-photos, including the main related information (genus and species name, sample number, locality, age assignment, England-Finder coordinates...) is build under FILE MAKER PRO.

A counting of the acritarchs (ALH), and of the miospores (PS and MS) is made too. In order to have quantified data, for each sample, the volume of the total organic residue (stored in an Eppendorf tube) is measured using an automatic pipette. Then, a precisely measured volume of this residue is used to prepare a permanent palynological slide. A set of 3 palynological slides, using the same amount of residue, has been prepared for each productive sample (DB). The first slide is for the acritarch counting, the second for the spore counting and the third is regarded as a witness-slide. For the spores, only the abundance is calculated (Tabl. 13 and 14). The reasons that prevented the evaluation of the relative frequencies of the recorded spore species are given in the chapter corresponding to this group (PS and MS).

CHITINOZOANS

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The chitinozoans are extracted, sorted and counted according to the procedure described above (see chapter Technical Procedure). The abundance (expressed in number of specimens per gram of rock; see Figs. 6-8; Tabl. 4-6), the diversity (relative frequency of the identified taxa in the recorded assemblages), and the percentage of the unidentified individuals have been calculated for each sample yielding chitinozoans. The preservation is fairy correct with amber to brown coloured vesicles (moderate thermal alteration). However, the chitinozoan walls are very brittle. This is fairly unusual for amber to brownish coloured specimens. These vesicles probably suffered bacterial attack.

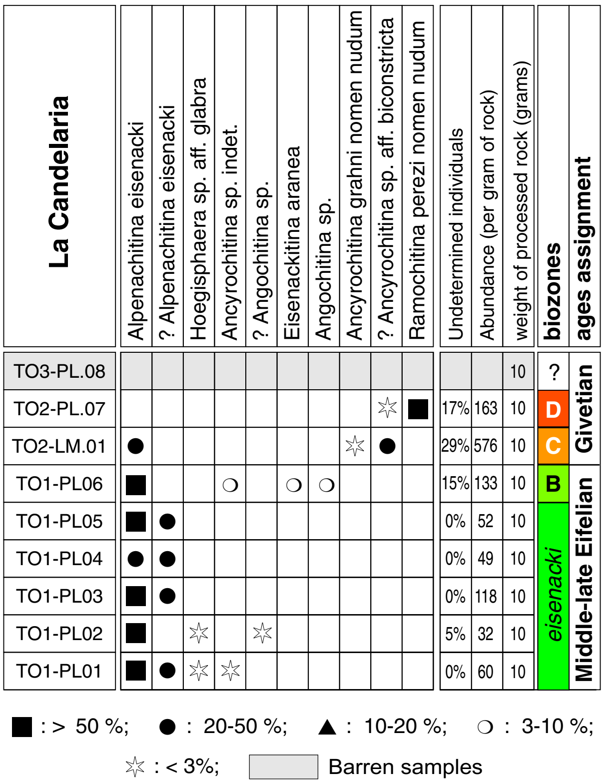
The chitinozoans display normal abundances in the uppermost part of the silty interval referred to the «Huamampama of Argentinean type» in the La Candelaria section, according to the information provided by TOTAL S.A. The recorded values range from about 32 (TO1-PL.02) to 133 specimens per gram of rock (TO1-PL.06). However, the chitinozoans assemblages are virtually monospecific in these samples as the poorly preserved individuals recorded in TO1-PL.01 to PL.05 in all likelihood belong also to *Alpenachitina eisenacki*. (Tabl. 4; Fig. 6).

Surprisingly, in the lowermost part of the Huamampampa Formation (s.s.) in the La Candelaria section, sample TO2-LM.01, which was originally collected for petrological analyses, yields numerous chitinozoan specimens (576 specimens per gram of rock), but a poorly diversified assemblage (Fig. 6).

In the upper part of the Huamampampa Formation (s.s.) sampled in the «lower La Escalera» section (TESCO2), the abundance (about 30 specimens per gram of rock) and the diversity (4 different taxa in TESCO2-PL.02) are low with regard to the values usually observed in open marine Devonian deposits.

The greatest variations are recorded in the Los Monos Formation in the «upper La Escalera» section (Tabl. 6; Fig. 8). The highest values occur in the lowermost part of the formation (e.g., 2916 specimens per gram of rock in TESCO1-PL.36, or 1250 specimens per gram of rock in TESCO1-PL.37). This abundance decreases rapidly upward in the section and does not exceed 100 specimens per gram of rock from TESCO1-PL.28 to TESCO1-PL.16, which is the last fertile sample in this section. Abundances as low as 1 or even less are recorded in the middle part of the Los Monos Formation (e.g., 1 specimen per gram of rock in TESCO1-PL.26, TESCO1-PL.22; <1 in TESCO1-PL.28 and TESCO1-PL.24; barren samples in TESCO1-PL.27 and TESCO1-PL.24). The very low diversity of the chitinozoan assemblages must be stressed too (Tabl. 6). The mean diversity is about 3 species per fertile assemblage, with a maximum of 4 species in TESCO1-PL.20 (48% of undetermined forms), and several monospecific assemblages (TESCO1-PL.28, TESCO1-PL.22, TESCO1-PL.17).

The new species names recently created by Grahn and Melo (in press A and B) for Brazilian chitinozoan forms have been used in the present report thanks to the courtesy of these authors who accepted to give the preprint of their publications in press. This allows the replacement of the taxa kept in open nomenclature in the previous reports (see. Paris et al. 2001; Paris and Le Hérissé 2002) by specific names. Nevertheless, beside these newly des-



La Candelaria	Alpenachitina eisenacki	? Alpenachitina eisenacki	Hoegisphaera sp. aff. glabra	Ancyrochitina sp. indet.	? Angochitina sp.	Eisenackitina aranea	Angochitina sp.	Ancyrochitina grahni nomen nudum	? Ancyrochitina sp. aff. biconstricta	Ramochitina perezi nomen nudum	Undetermined individuals	Abundance (per gram of rock)	weight of processed rock (grams)	**biozones**	**ages assignment**
TO3-PL.08													10	?	**Givetian**
TO2-PL.07									☆	■	17%	163	10	**D**	
TO2-LM.01	●							☆	●		29%	576	10	**C**	
TO1-PL06	■			❍		❍	❍				15%	133	10	**B**	**Middle-late Eifelian**
TO1-PL05	■	●									0%	52	10	*eisenacki*	
TO1-PL04	●	●									0%	49	10		
TO1-PL03	■	●									0%	118	10		
TO1-PL02	■		☆		☆						5%	32	10		
TO1-PL01	■	●	☆	☆							0%	60	10		

■ : > 50 %; ● : 20-50 %; ▲ : 10-20 %; ❍ : 3-10 %;
☆ : < 3%; ▨ Barren samples

Fig. 6: Range, relative frequencies, abundance, and age assignment of the chitinozoan taxa recorded in «La Candela ria» section (TO1-TO3)

cribed species are several other forms I believe to be new species too. Consequently, new chitinozoan species names are used as *nomen nuda* (e.g. *Ramochitina durandi* nomen nudum; *Ancyrochitina grahni* nomen nudum) in order to prevent the proliferation of identification such as «*Ramochitina* sp. 1, *Ramochitina* sp. 2, or *Ancyrochitina* sp. A, *Ancyrochitina* sp. B», which began to be confusing after several studies. All these *nomen nuda* need rapidly a detailed description and illustration in a scientific journal in order to get a full taxonomic status.

1- Chitinozoan Biostratigraphy

When fully documented in the recorded assemblages the global Devonian Chitinozoan Biozones, as defined by Paris et al. (2000), are used in the present report. The correspondence with the local chitinozoan zonation proposed in the 2 previous reports (Paris et al. 2001; Paris and Le Hérissé 2002) is given below.

Alpenachitina eisenacki Biozone

- Definition and range.

This biozone is defined by the interval range between the FAD of A. *eisenacki* and the FAD of *Eisenackitina aranea*, which is the index species of the succeeding global Devonian chitinozoan biozone. The *eisenacki* biozone is clearly present in the upper part of the silty sediments referred according to J. DURAND, to the «South Bolivian/Argentinean Huamampampa» in the La Candelaria section, in samples TO1-PL.01 to PL.05 (Fig. 6). It must be noted that the index species dominates totally the chitinozoan assemblages in these 5 samples because the numerous broken individuals observed (referred as ? A. eisenacki in the diagrams), in all likelihood, belong also to *A. eisenacki*. Therefore, the index species may represent 92 to 100% of the recorded chitinozoan assemblages in the upper part of the «Argentinean Huamampampa»). The morphology of the recorded *A. eisenacki* individuals (i.e., highly branched processes) is very similar to that illustrated by Wood (1980) from the Jeffersonville Limestone of Indiana. When present, the very rare other species belong to *Hoegisphaera* sp. aff. glabra and to unidentified *Angochitina* species.

- Age assignment.

Monospecific assemblages, or assemblages highly dominated by *A. eisenacki* are characteristic of the middle/late Eifelian (Wood 1980; see Paris et al. 2000). In term of conodont Zones, the present assemblage corresponds roughly to the *costatus-angustus* Zones (see Wood 1980, fig. 2). Consequently, **a mid/late Eifelian age is assigned to the uppermost part of the «South Bolivian/Argentinean Huamampampa» in the La Candelaria section, i.e. just below the base of the Huamampampa Formation** *stricto sensu* (see remark above)

- Remarks.

The investigated interval assigned to the *eisenacki* Biozone in La Candelaria section corresponds obviously to the acme of the index species (Tabl. 4, Fig. 6). In previously investigated subsurface samples from southern Bolivia (Paris and le Hérissé 2002; Paris et al. 2001), as well as in more remote localities (e.g., Wood 1980, Tabl. 1), the relative frequency of *A. eisenacki* fades away in the younger part of its range. This is not documented in La Candelaria section and therefore, a short hiatus should be envisaged in the local lithological succession.

It must be keep in mind that in subsurface, monospecific *A. eisenacki* assemblages, with good abundances (i.e. several tens of specimens per gram of rock) are susceptible to generate important down-well contamination in cuttings from virtually barren older levels. This will be used for a reappraisal of the age assignment of the cutting samples previously studied in south Bolivia boreholes.

Eisenackitina aranea Biozone

- Definition and range.

This biozone is defined as the interval range between the FAD of the index species and the FAD of *Ancyrochitina cornigera*, which is the index species of the succeeding global chitinozoan biozone (see Paris et al. 2000). A few *Eisenackitina aranea* specimens (3% of the identified chitinozoan individuals) occur in sample TO1-PL.06, in the uppermost part of the silty sequence i.e., not yet belonging the basal part of the Huamampampa Formation *stricto sensu* in La Candelaria section. In spite *A. eisenacki* is still dominating with 70% of the identified specimens, this sample must be considered as documenting the base of the *aranea* Biozone. The other subordinate taxa are *Angochitina* sp. and *Ancyrochitina* sp. (too poor preservation to allow firm identifications).

- Age assignment.

The *aranea* Biozone is representative of the upper Eifelian/lower Givetian (see discussion in Paris et al. 2000). Because the assemblage observed in sample TO1-PL.6 corresponds obviously to the early part of the biozone, **a late Eifelian age is the most likely for what is regarded as the topmost part of the «south Bolivian Argentinean Hamampampa facies «**. *A. aranea* is known in other Bolivian localities (Grahn, 2002; Paris unpublished data)

Local biozone of *Ancyrochitina grahni* nomen nudum

- Definition and range.

Ancyrochitina grahni nomen nudum is restricted to sample TO2-LM.01, collected at the base of the Huamampampa Formation in the La Candelaria section, according to the lithostratigraphic boundary adopted for this study (i.e., the base of the sandy body overlying silty fine sandstone; Figs. 2 and 3). *A. grahni* nomen nudum is a species closely related to *Ancyrochitina cornigera*, which is the index species of the global chitinozoan biozone succeeding to the *aranea* Biozone (see definition in Paris et al. 2000). *A. grahni* nomen nudum might be confused with *A. cornigera* in former studies. However, *A. cornigera* does not possess the hook-like short branching exhibited by *A. grahni* nomen nudum (Pl. 2, fig. 10; Pl. 3, Figs. 4, 6-7).

A. eisenacki is still well represented in this biozone (45% of the identified taxa), and a form very tentatively compared to *Ancyrochitina biconstricta* in spite a very poor preservation (basal processes absent, very short vesicle) represents 24 % of the assemblage. A similar form was observed in a chitinozoan assemblage from the Parana Basin, in Brazil (Burjack and Paris 1989).

- Age assignment.

The *grahni* local biozone does not provide any direct possibilities of datation as it is a new taxon. However, because its coexistence with numerous *A. eisenacki*, a very diagnostic species, which has its LAD in the lower part of the middle Givetian (Urban 1972; see discussion in Paris et al. 2000), and because the location of sample TO2-LM.01 above the FAD of *E. aranea*, **an early Givetian age is likely for the lowermost part of the Hamampampa Formation stricto sensu**. Grahn (2002, fig. 6D) illustrated a broken specimen he called *Ancyrochitina* sp. from the upper part of the «Icla Formation» in the Tarabuco section, which is very similar to *Ancyrochitina grahni* nomen nudum..

Local biozone of *Ramochitina perezi* nomen nudum

- Definition and range.

This biozone corresponds to the total range of *Ramochitina perezi* nomen nudum (Pl. 2, figs. 8, 11-12; Pl. 4, Figs. 15-16, 19) (= *Ramochitina* sp. B in Grahn 2002, possibly *Angochitina callawayensis* in Wood 1980, pl. 3, figs. 7-9, and *Angochitina* cf. *capillata* in Lange 1967, pl. 1, figs; 10-11). This taxon constitutes a virtually monospecific assemblage, so far restricted to sample TO2-PL.07, which is located in the lowermost part of the Huamampampa Formation *stricto sensu* in the La Candelaria section (see remarks on this lithological boundary above). Only a few fragments of undetermined chitinozoan recalling *Ancyrochitina biconstricta* coexist with *R. perezi*

La Escalera TESCO2	Ancyrochitina moroni nomen nudum	Ramochitina sp. aff. ramosi	Angochitina sp.A	Angochitina sp.	Undetermined individuals	Abundance (per gram of rock)	weight of processed rock	**biozones**	**ages assignment**
TO2-PL06	▨	▨	▨	▨	▨	▨	10	**?**	**Givetian**
TO2-PL05	▨	▨	▨	▨	▨	▨	10		
TO2-PL04	▨	▨	▨	▨	▨	▨	5		
TO2-PL03	▨	▨	▨	▨	▨	▨	5		
TO2-PL02	■	☆	▲		50%	33	5	**E**	
TO2-PL01	■	❍			53%	32	5		

■: > 50 %; ●: 20-50 %; ▲ 10-20 %;
❍ : 3-10 %; ☆ : < 3%; ▨ Barren

Fig. 7: Range, relative frequencies, abundance, and age assignment of the chitinozoan taxa recorded in the lower «La Escalera» section (TESCO2)

numen nudum in this sample. Based on the column of Marquez and Perez (2003), this sample overlies immediately sample TO2-LM.01.

- Age assignment.

This new species is not yet chronostratigraphically diagnostic. However, Grahn (2002, fig. 5B) has illustrated under the name *Ramochitina* sp. B a similar form from the upper part of the Huamampampa Formation in the Angosto de Huacareta section.

Local biozone of *Ancyrochitina moroni* nomen nudum

- Definition and range.

This biozone corresponds to the total range of *Ancyrochitina moroni* nomen nudum (Pl. 3, Figs. 13-14), in the «lower» La Escalera section. *Ancyrochitina moroni* nomen nudum was reported in open nomenclature under the name *Ancyrochitina* sp. 8, in Paris et al. 2001 (pl. 4, fig. 18). This new species is abundant (about 40% of the identified forms) in samples TESCO2-PL.01 and TESCO2-PL.02 (33 specimens per gram of rock) (Tabl. 7). These 2 samples are from the upper part (but not the uppermost part) of the Huamampampa Formation (Fig. 2). Among the subordinate taxa are *Ancyrochitina* sp. 1 (Pl. 3, Figs. 11-12) (10% of the identified specimens in sample TESCO2-PL.02), very rare (less to 1%), *Ramochitina ramosi* (P. 3, Fig. 10) and *Angochitina* sp. (Tabl. 5).

- Age assignment.

Because it is in open nomenclature, *Ancyrochitina moroni* nomen nudum cannot be fully used for chronostratigraphical purpose. It must be noted that this form is reported from cuttings at 2300-2316 m to 2345-2355 m in well PARAPETTI-X2 (Paris et al. 2001), in levels where it coexists with *R. ramosi*. Both taxa seem to be caved in this well (see discussion below).

Local biozone of *Ancyrochitina biconstricta*

- Definition and range.

This biozone corresponds mostly to the concurrent range of *Ancyrochitina biconstricta* (Pl. 3, Figs. 15-17) and of *Ramochitina tarabucoensis* nomen nudum (Pl. 1, Figs. 6, 11; Pl. 2, Fig. 1; Pl. 3, Figs. 8, 19; Pl. 4, Figs 1, 3-4). This new species was called *Ramochitina* ? sp 3 in Paris et al. (2001). In the «upper» La Escalera section, *R. tarabucoensis* nomen nudum is dominating (59% of the identified forms; Tabl. 6) in sample TESCO1-PL.37 situated in the lowermost part of the Los Monos Formation (2.50 m above the conglomeratic bed ending the more sandy part of the section; see Fig. 5). The proportions are inverted in the succeeding sample (TESCO1-PL.36), which was collected 5 m higher in the sequence, and where *A. biconstricta* represents 81% of the identified species (Tabl. 6) in an extremely abundant chitinozoan assemblage (2916 specimens per gram of rock). The succeeding sample (TESCO1-PL.35), collected 18.75 m above the last conglomeratic bed has not yielded *Ramochitina tarabucoensis*, However, it is referred to the same assemblage as it contains also a few *Ramochitina* sp. aff. *ramosi* (see Tabl. 6). This assemblage is equivalent to the lower part of Ass.3 of Paris et al. (2001) of INAU-X2 (cuttings 1340-1350 and 1358-1366 m) and PARAPETTI-X2 (2224 to 2265 m), and of Paris and Le Hérissé (2002) in ITAU-X2 (cuttings at 3860-3880 m).

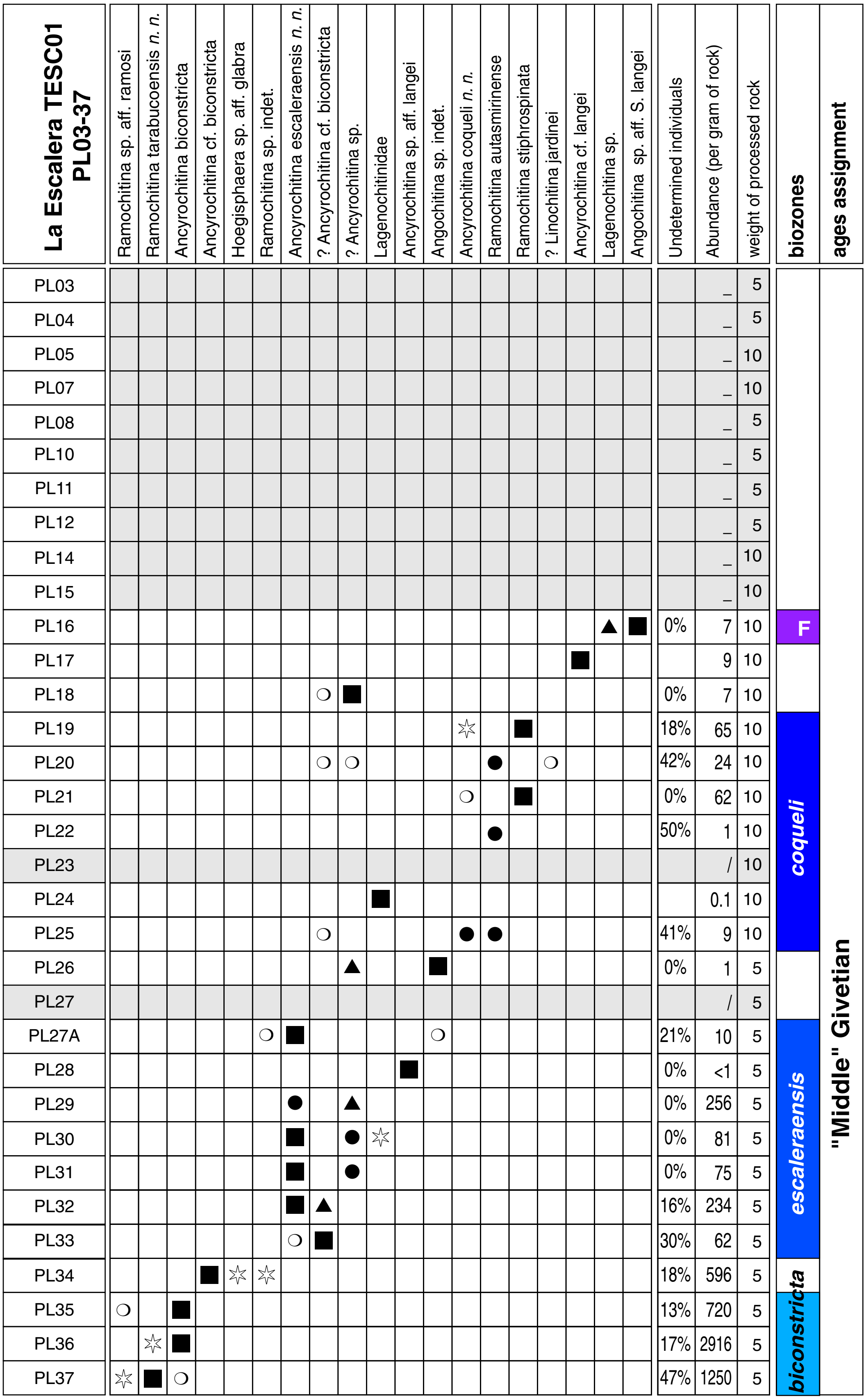
- Age assignment.

None of the species recorded in this 18.75 m interval (TESCO1-PL.37 to ESCO1-PL.35) allows a direct correlation with the standard Devonian chronostratigraphy, mainly because of the endemic characters of this Bolivian «Middle Devonian» fauna. Nevertheless, because *A. eisenacki* and *E. aranea*, which have respectively their LAD in the early middle *varcus* and in the late *varcus* conodont Zone, are no longer present, **a «middle» Givetian age** (broadly the *ansatus/hermanni/cristatus* conodont zones) is proposed for this biozone.

Local biozone of *Ancyrochitina escaleraensis* nomen nudum

- Definition and range.

This biozone corresponds to the total range of *Ancyrochitina escaleraensis* nomen nudum (Pl. 1, Figs. 1-4; Pl. 4, Figs. 5-8) in the «lower» La Escalera section, from sample TESCO1-PL.33 to sample TESCO1-PL.27A (Tabl. 6, Fig. 8), i.e. at least within an interval of 48.75 m (Fig. 5). It dominates the chitinozoan assemblages recovered from the lower part (but not the basal part of the Los Monos Formation. In the previous reports (Paris et al. 2001; Paris and Le Hérissé 2002) *Ancyrochitina escaleraensis* nomen nudum was included within the *Ancyrochi-*



La Escalera TESC01 PL03-37	Ramochitina sp. aff. ramosi	Ramochitina tarabucoensis *n. n.*	Ancyrochitina biconstricta	Ancyrochitina cf. biconstricta	Hoegisphaera sp. aff. glabra	Ramochitina sp. indet.	Ancyrochitina escaleraensis *n. n.*	? Ancyrochitina cf. biconstricta	? Ancyrochitina sp.	Lagenochitinidae	Ancyrochitina sp. aff. langei	Angochitina sp. indet.	Ancyrochitina coqueli *n. n.*	Ramochitina autasmirinense	Ramochitina stiphrospinata	? Linochitina jardinei	Ancyrochitina cf. langei	Lagenochitina sp.	Angochitina sp. aff. S. langei	Undetermined individuals	Abundance (per gram of rock)	weight of processed rock	**biozones**	**ages assignment**
PL03																					_	5		**"Middle" Givetian**
PL04																					_	5		
PL05																					_	10		
PL07																					_	10		
PL08																					_	5		
PL10																					_	5		
PL11																					_	5		
PL12																					_	5		
PL14																					_	10		
PL15																					_	10		
PL16																		▲	■	0%	7	10	**F**	
PL17																	■				9	10		
PL18								❍	■											0%	7	10		
PL19													☆		■					18%	65	10	***coqueli***	
PL20								❍	❍					●		❍				42%	24	10		
PL21													❍		■					0%	62	10		
PL22														●						50%	1	10		
PL23																					/	10		
PL24										■											0.1	10		
PL25								❍					●	●						41%	9	10		
PL26									▲			■								0%	1	5		
PL27																					/	5		
PL27A						❍	■					❍								21%	10	5	***escaleraensis***	
PL28											■									0%	<1	5		
PL29							●		▲											0%	256	5		
PL30							■		●	☆										0%	81	5		
PL31							■		●											0%	75	5		
PL32							■	▲												16%	234	5		
PL33							❍	■												30%	62	5		
PL34				■	☆	☆														18%	596	5		
PL35	❍		■																	13%	720	5	***biconstricta***	
PL36		☆	■																	17%	2916	5		
PL37	☆	■	❍																	47%	1250	5		

■ : > 50 %; ● : 20-50 %; ▲ : 10-20 %; ❍ : 3-10 %; ☆ : < 3%; ▨ Barren

Fig. 8: Range, relative frequencies, abundance, and age assignment of the chitinozoan taxa recorded in the lower «La Escalera» section (TESCO1)

tina biconstricta complex of Lange (1948). Intermediate forms between *A. biconstricta* and *A. escaleraensis* exist in sample TESCO1-PL.34. *Ramochitina durandi* nomen nudum (Pl. 1, Figs. 7, 8, 10a-b, 12a-b), a new chitinozoan species with a very discriminating morphology, coexists with *A. escaleraensis* in the lower part of this biozone

- Age assignment.

Because it is a new species, *Ancyrochitina escaleraensis* nomen nudum cannot be directly used for chronostratigraphical purpose. This form is present in well PARAPETTI-X2 in the cuttings from 1940-1960 m, where it was included in the *A. biconstricta* complex. Because no typical Frasnian, nor even late Givetian species, occur in these samples, **a «middle» Givetian age is likely** (i.e., corresponding broadly with the *ansatus/hermanni/cristatus* conodont zones as for the underlying *biconstricta* biozone).

Local biozone of Ancyrochitina coqueli nomen nudum

- Definition and range.

This biozone corresponds to the total range of *Ancyrochitina coqueli* nomen nudum (Pl. 4, Figs. 14 and 18) in the «lower» La Escalera section, from sample TESCO1-PL.25 to sample TESCO1-PL.19 (Tabl. 6, Fig. 8), i.e. at least within an interval of 82.50 m (Fig. 5). The index species is only frequent in the lowermost par of the biozone, in sample TESCO1-PL.25, where it represents 28% of the identified chitinozoans (within a fairly poor population of 9 specimens per gram of rock, and with numerous indetermined individuals). This local biozone extends over most of the upper part of the productive interval of the Los Monos Formation. *Ancyrochitina coqueli* nomen nudum (= *Ancyrochitina* sp. *A sensu* Paris) was reported in open nomenclature in PARAPETTI-X2 (cuttings from 1940-1960 m) under the name *Ancyrochitina* sp. 3 (see Paris et al., pl. 4, fig. 15). This new species is well known in southeastern Algeria, where it has its FAD at the base of the regional Givetian transgression in the Illizi Basin (Algerian Sahara).

Among the associated species are *Ramochitina autasmirinense* Grahn and Melo (in press B) and *Ramochitina stiphrospinata* Grahn and Melo (in press A). The latter is highly dominating the fairly abundant (up to 65 specimens per gram of rock) chitinozoan assemblages recovered from samples TESCO1-PL.21 and PL.19 (Tabl. 6). Specimens of *R. stiphrospinata* were reported in open nomenclature in chitinozoan assemblages from PARAPETTI-X2 under the name *Ancyrochitina* sp. 4 (see Paris et al., pl. 3, fig. 6).

- Age assignment.

Because it is a new species, *Ancyrochitina coqueli* nomen nudum cannot be directly used for chronostratigraphical purpose. However, this new species is well known in several core samples from southeastern Algeria where it is associated with miospore assemblages assigned to the *lemurata* biozone (Boumendjel, unpublished). The associated taxa are present in the Ererê Formation in the Amazonas Basin in Brazil. *Ramochitina stiphrosinata* Grahn and Melo (in press A) is even, in Brazil, the index species of a local biozone correlated with the Lli miospore biozone (*Geminospora lemurata-Chelinospora* ex. gr. *ligurata*) as defined by Melo and Loboziak (2003). This Lli miospore biozone is referred to the early Givetian by Melo and Lobozoiak (2003).

Because no typical Frasnian, nor even late Givetian species occur in these samples, a **«middle» Givetian age is likely** (i.e., (corresponding broadly to the *ansatus/hermanni/cristatus* conodont zones as for the underlying *biconstricta* biozone).

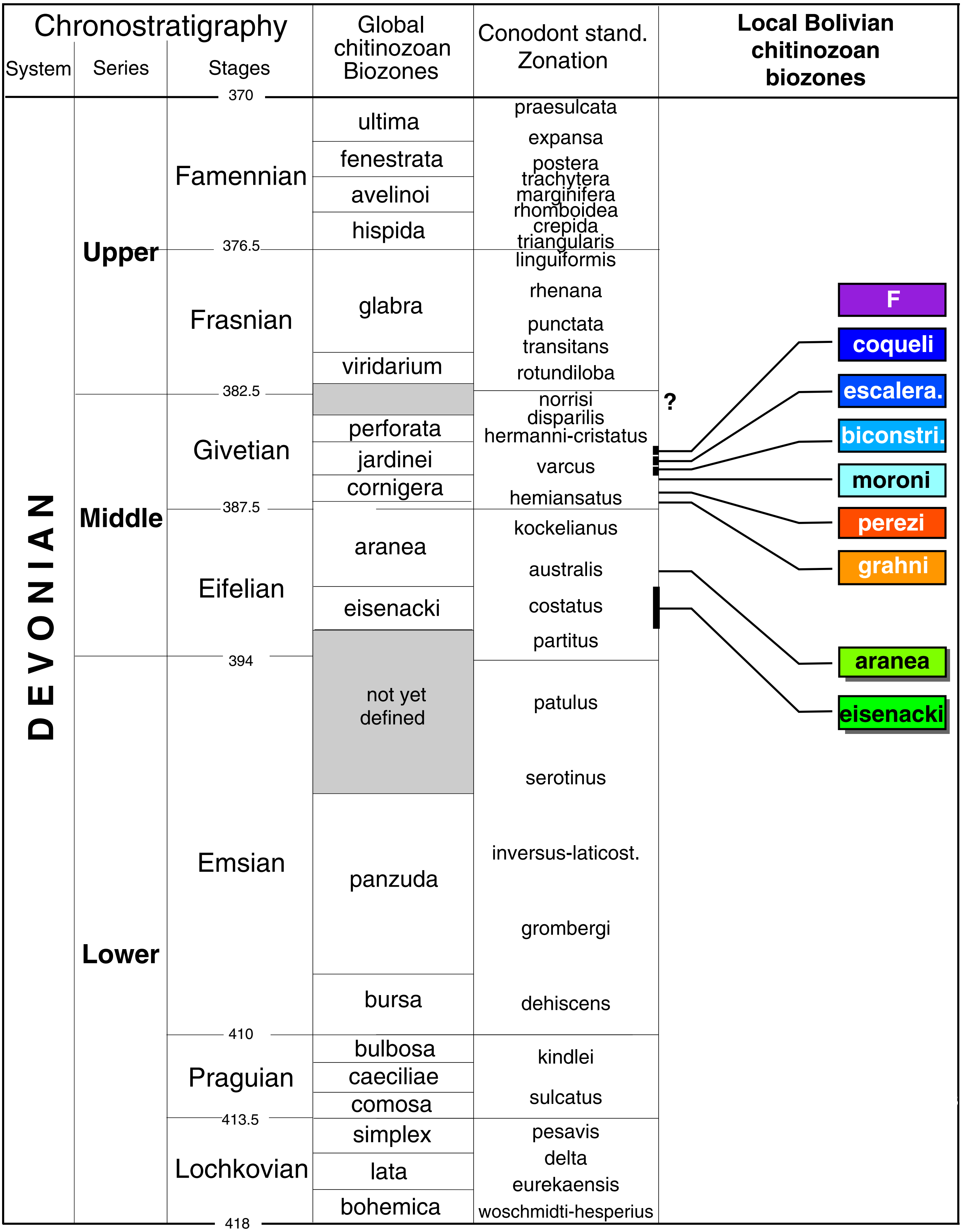
Local biozone of *Angochitina* sp. aff. *Sommerochitina langei*

- Definition and range.

This biozone is restricted to sample TESCO1-PL.16, which is the last fertile sample referred to the Los Monos Formation in the «upper» La Escalera section. The preservation is poor and the chitinozoan abundance low (7 specimens per gram of rock). However, the recovered chitinozoan assemblage is significantly different from the former ones, which all contain forms recalling *Ancyrochitina biconstricta* (labelled here as ? *Ancyrochitina* cf. *biconstricta*). Consequently, this peculiar assemblage is individualised here.

- Age assignment.

Sommerochitina langei is a Famennian taxon (see Grahn and Melo in press A). However, chitinozoan individuals referred to *Sommerochitina* cf. *langei* by Grahn and Melo (pl. 7, figs. 8-9, in press A) have a morphology fairly close to those of *Angochitina* sp. aff. *S. langei*. According to Grahn and Melo (in press A), in Brazil, these indivi-



F. PARIS (10/2003)

Fig. 9: Age assignment of the recorded chitinozoan assemblages with regard to the Devonian chronostratigraphy and to the global chitinozoan zonation of Paris et al. 2000)

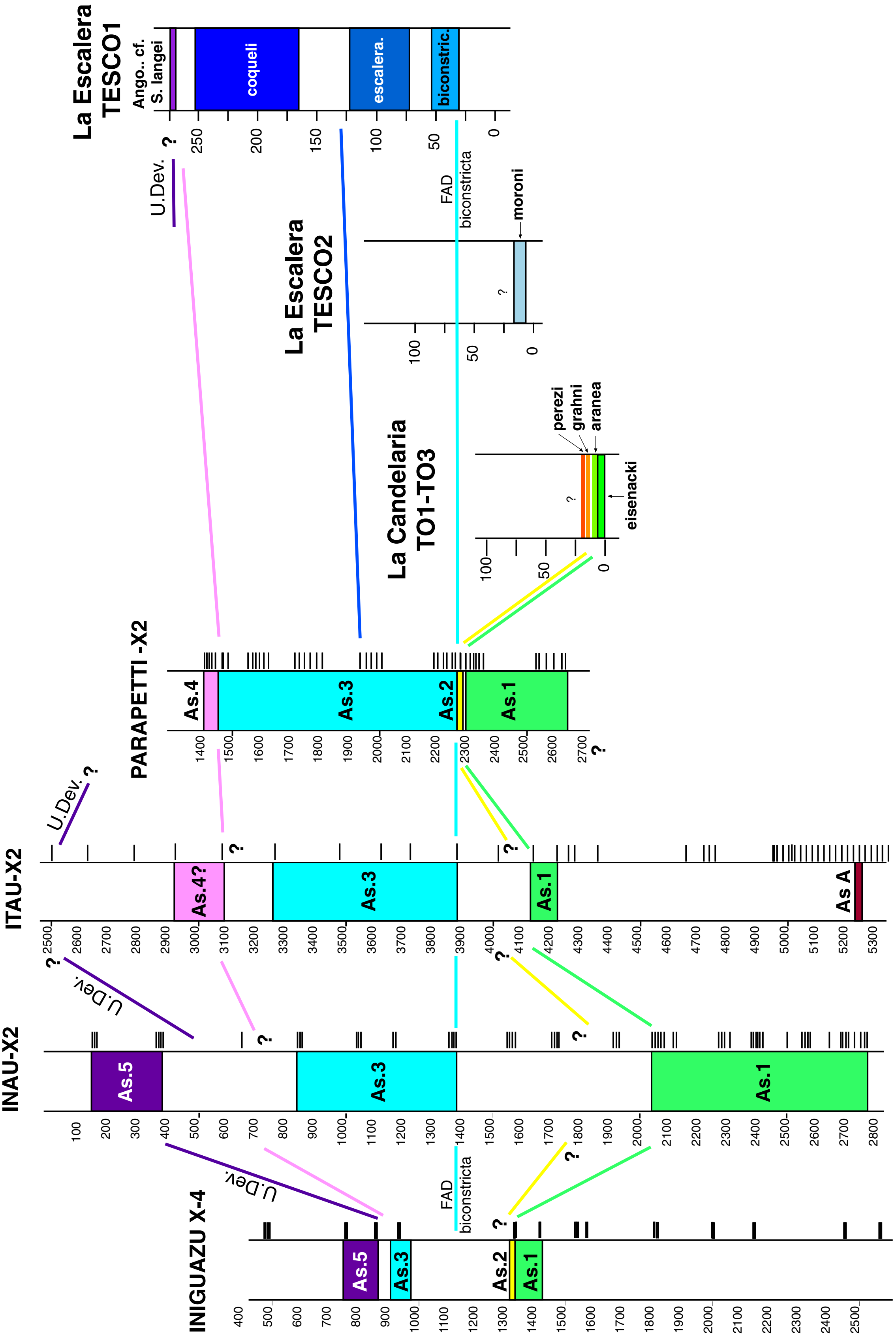


Fig. 10: Correlation between the Devonian outcrops (La Escalera and La Candelaria sections) and the subsurface (PARAPETTI-X2, INAU-X2, INIGUAZU-X4 and ITAU-X2) in southern Bolivia, based on the updated chitinozoan data.

duals occur in the upper part of the Pimenteira Formation of late Frasnian age.

2- Chronostratigraphic conclusions

The main goal of the present biostratigraphic study carried out on the Middle Devonian strata of southern Bolivia is to provide biomarkers that are precise enough, at regional scale, for documenting a possible diachronism of the setting of the sandy deposits referred to the Huamampampa Formation *sensu lato*. For that reason, a very detailed biostratigraphic time slicing is proposed, based both on the range and on the quantification of the recorded acritarch, chitinozoan and miospore taxa.

As far as chitinozoans are concerned, the present study clearly indicates that a succession of bioevents (i.e. acme, FAD and LAD of various species) allows an accurate time slicing of the Middle Devonian strata of southern Bolivia. The most significant result is that, in the Rio Tarabuco area (La Candelaria and La Escalera sections), the Huamampampa Formation *stricto sensu* is bracketed by 2 important bioevents. These are: 1) the disappearance of *Alpenachitina eisenacki* at the base of the formation; 2) the appearance of the typical elongate forms of *Ancyrochitina biconstricta*, in association with *Ramochitina tarabucoensis*, just above the top of the formation. The first event indicates that the total range of *A. eisenacki* is not fully recorded in the investigated section. Indeed, its upper part, i.e., the interval corresponding to the fading away of the *A. eisenacki* above its acme zone, is missing here. The thin argillaceous intercalation (sample T02-PL.07) seems to play an important role as it yields a chitinozoan assemblage dramatically different from the preceding ones. This indicates a total renewing of the chitinozoan microfauna at the base of the Huamampampa Formation *stricto sensu*, probably in relation with a hiatus (gap ?). An additional sampling of the lower part of the Huamampampa Formation *stricto sensu* is, however, necessary as sample T03-PL.08 is barren.

For the chitinozoan microfauna recovered from the basal part of the Los Monos Formation in section TESCO1, once again, an additional sampling is necessary, as the thickness of the interval separating the productive samples collected in section TESCO2 from the top of the Huamampampa Formation is not documented yet.

In addition, it must be stressed that important chitinozoan species, with a very discriminating morphology, have not been recorded in the provided samples. These species, such as *Ancyrochitina langei*, *Ancyrochitina postdesmea*, *Ramochitina ramosi* are well represented in the previously investigated wells and have been reported in several papers (see Grahn 2002). This suggests that *A. langei* and *A. postdesmea* are taxa restricted to the Huamampampa Formation *stricto sensu*. Their absence in the chitinozoan assemblages recorded in the present study is simply related to a too incomplete sampling of the Huamampampa Fornation (6 samples only available from the upper part of the formation in section TESCO2).

3- Correlation with the wells and influence of the caving processes

Based only on the productive samples bracketing the Huamampampa Formation *stricto sensu* in the Tarabuco area, a reappraisal of the chitinozoan assemblages recovered from cutting samples in the 4 previously investigated Bolivian wells (i.e., PARAPETTI-X2, INAU-X2, INIGUAZU-X4 et ITAU-X2) is proposed.

In **PARAPETTI-X2**, caving is responsible of the too early occurrence of *Ramochitina ramosi*, *Ramochitina durandi* nomen nudum (= *Ramochitina* ? sp. 3 in Paris et al. 2001), *Ancyrochitina langei* and *A.* cf. *langei*. Indeed neither *R. ramosi* nor *A. langei* have been recorded in La Candelaria section. Then, in the cutting samples, these species should be regarded as caved from younger strata and therefore deleted from the chitinozoan list of Ass. 1 in PARAPETTI-X2. When these caved species are deleted, the relative frequency of *A. eisenacki* increases significantly, and then their occurrences are more consistent with the range of these species as recently documented in Brazil by Grahn and Melo (2002, in press A and B). In INAU-X2 the caving seems less important as *Ancyrochitina biconstricta* (typical form) and *Ramochitina tarabucoensis* do not coexist with *A. eisenacki*, which relative abundance is much higher than in PARAPETTI-X2, and more consistent with the values observed in La Candelaria section. The range of *Ancyrochitina moroni* numen nudum suggests that the cuttings from 1540-1548 m in INAU-X2 are more or less equivalent to the fertile samples of the «lower La Escalera section» (samples TESCO2-PL.01 and PL.02 belonging to the upper part, but not the uppermost part of the Huamampampa Formation *stricto sensu*).

In **ITAU-X2** (southern Bolivia), where caving seems very limited (see Paris and Le Hérissé, fig. 1), the acme of *A. escaleraensis* in cuttings from 3240-3260 m (the species was labelled *A. biconstricta* in Paris and Le Hérissé 2002, pl. 3, figs 6,7, 9) indicates that the corresponding strata are contemporaneous with the lower part, but not the lowermost part of the Los Monos Formation in the La Escalera section (TESCO1, PL.33 to PL.27A). However, it should be noted that the elongate *A.* cf. *cyrenaicensis* coexisting with *A. escaleraensis* in cuttings from 3240-3260 m in ITAU-X2, has not been recorded in the La Escalera section. In well ITAU-X2, the position of *R. tarabucoensis* nomen nudum (= *Ramochitina*? sp. 3 in ITAU-X2; see Paris and Le Hérissé, pl. 4, figs. 5 and 13) is consistent with the respective range of *A. escaleraensis* and of *R. tarabucoensis* in the La Escalera section. However, in the La Escalera section the two species are separated only by some tens of meters, whereas 600 m separate the respective occurrences of these two species in ITAU-X2, when only close to 300 m separates *R. tarabucoensis* from a questionable occurrence of *A. eisenacki* (see Paris and Le Hérissé 2002, fig. 1). The lack of information on the dipping of the strata in ITAU-X2, however, does not allow a strict comparison in term of thickness between the La Escalera section and ITAU-X2.

In well **INIGUAZU-X4** (southern Bolivia) caving is much more important. This is peculiarly obvious in Ass. 1 where very abundant *Ancyrochitina langei* coexist with *A. eisenacki*. If one considers the range and the relative frequency of *A. eisenacki* in the La Candelaria section as a local standard, then, its concurrent range with *A. langei* in the upper part of Ass. 1 in INIGUAZU-X4 (see Paris and Le Hérissé 2002, fig. 2) should be regarded as representative of the missing interval in La Candelaria. However, the occurrence of *A. eisenacki* is discontinuous in INIGUAZU-X4 and thus, possible scarce occurrences may also exist higher up in the lower Huamampampa Formation *stricto sensu* e.g., in strata not sampled in the La Candelaria section. The domination of *A. langei* (in term of relative frequency) in Ass. 1 in INIGUAZU-X4 is probably due to down-hole caving of this species from its very productive horizon at 1326-1328 m (250 chitinozoans per gram of rock) (see Paris and Le Hérissé 2002, fig. 2). In INIGUAZU-X4, the absence of *A. biconstricta* and of *A. escaleraensis* nomen nudum in the assemblage referred to Ass. 3 must be stressed. Thus, the correlation of this assemblage with the lower part of the Los Monos Formation in section La Escalera is not clearly documented yet.

List of the recorded chitinozoan taxa and their synonymy with the chitinozoan reported in the wells

* ? *Alpenachitina* sp. 1
* *Alpenchitina eisenacki* ? Dunn and Miller 1964
* *Ancyrochitina langei* Sommer and van Boekel 1964
* *Ancyrochitina* sp. 3 in Paris and Le Hérissé 2002
* *Ancyrochitina* sp. 4 in Paris and Le Hérissé 2002
* *Ancyrochitina* sp. 6 in Paris and Le Hérissé 2002
* *Ancyrochitina* sp. 9 in Paris et al. 2001
* *Ancyrochitina* sp. B in Paris and Le Hérissé 2002
* *Ancyrochitina* sp. C in Paris and Le Hérissé 2002
* *Ancyrochtina* sp. J Wood (1986) = *Ramochitina autasmirinense* Grahn and Melo in press B
* *Angochitina* cf *comosa* (Taugourdeau and de Jekhowsky 1960)
* *Angochitina mourai* Lange 1952
* *Angochitina* sp. 1 in Paris et al. 2001
* *Angochitina* sp. A in Paris and Le Hérissé 2002
* *Fungochitina* cf. *pilosa* (Collinson and Scott)
* *Fungochitina* sp. 1 in Paris and Le Hérissé 2002
* *Ramochitina boliviensis* Grahn 2002
* *Ramochitina* cf. *boliviensis* Grahn 2002
* *Ramochitina* cf. *cyrenaicensis* Paris 1988
* *Ramochitina* sp. 1 in Paris et al. 2001
* *Ramochitina* sp. in Paris and Le Hérissé 2002
**Angochitina* cf. *hispida* (Taugourdeau and de Jekhowsky 1960)
? *Alpenachitina eisenacki* Dunn and Miller 1964
? *Ancyrochitina* cf. *biconstricta* (Lange 1949)
? *Ancyrochitina* sp.
? *Linochitina jardinei* Boumendjel 1985
Alpenachitina eisenacki Dunn and Miller 1964
Ancyrochitina biconstricta (Lange 1949)
Ancyrochitina cf. *biconstricta* (Lange 1949)
Ancyrochitina cf. *langei* Sommer and van Boekel 1964
Ancyrochitina coqueli nomen nudum = *Ancyrochitina* sp. 6 in Paris et al. 2001
Ancyrochitina escaleraensis nomen nudum
Ancyrochitina grahni nomen nudum
Ancyrochitina moroni nomen nudum= *Ancyrochitina* sp. 8 and sp. 7 in Paris et al. 2001
Ancyrochitina postdesmea Grahn 2002 = *Ancyrochitina* sp. 5 in Paris et al. 2001
Ancyrochitina sp. A
Ancyrochitina sp. aff. langei Sommer and van Boekel 1964
Ancyrochitina sp. indet.
Angochitina sp.
Angochitina sp. aff. *Sommerochitina langei* Da Costa and Quadros 1985
Angochitina sp. indet.
Eisenackitina aranea (Urban 1972)
Hoegisphaera sp. aff. *glabra* Staplin 1960
Lagenochitina sp.
Lagenochitinidae indet.
Ramochitina autasmirinense Grahn and Melo in press B
Ramochitina durandi nomen nudum = *Ramochitina* sp. in Paris and Le Hérissé 2002 (pl. 6, fig. 10)
Ramochitina perezi nomen nudum = *Ramochitina* sp. in Paris and Le Hérissé 2002 (Pl. 6, figs. 4-5)
Ramochitina sp. aff *ramosi* Lange
Ramochitina sp. indet.
Ramochitina stiphrospinata Grahn and Melo in press A = *Ancyrochitina* sp. 4 in Paris et al. 2001
Ramochitina tarabucoensis nomen nudum = ? *Ramochitina* sp. 3 and sp. 2 in Paris et al. 2001; *Ancyrochitina* sp. 3 in Paris and Le Hérissé 2002

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CHITINOZOANS

PLATES

Plate 1

Chitinozoans from La Escalera section (Bolivia)

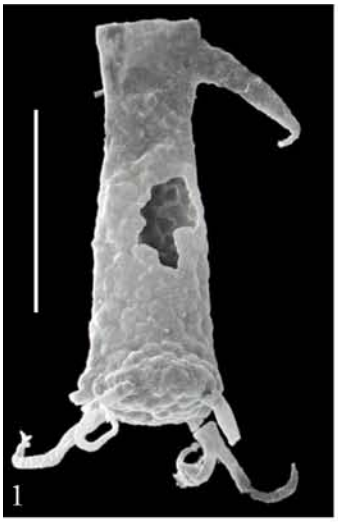
The bar represents 100 microns

Figs 1-4: *Ancyrochitina escaleraensis* nomen nudum. La Escalera section, TESCO1-Pl.31. Note the elongate peri-apertural spines (figs. 1, 2 and 5) and the granular surface of the chamber (figs 2-3). The antiapertural processes may branch (figs. 1 and 5)

Figs. 6 and 11: *Ramochitina tarabucoensis* nomen nudum. La Escalera section, TESCO1-Pl.37. (note the scare of a broken process on the tilted margin). Note the robust ornamentation in vertical rows (e.g. fig. 11)

Figs 7, 8, 10a-b and 12 a-b: *Ramochitina durandi* nomen nudum. La Escalera section, TESCO.1-Pl.32. Note the vertical rows of multi-rooted spines resembling irregular crests in some cases (e.g. fig. 8). Note also the peculiar mesh-like pattern of the ornamentation on the margin (figs. 7, 10 a-b)

Fig. 9: Fragment of cuticle from land plan remains; La Escalera section, TESCO1-Pl.37. The central structure may represent the scar of the attachment of the sporangium.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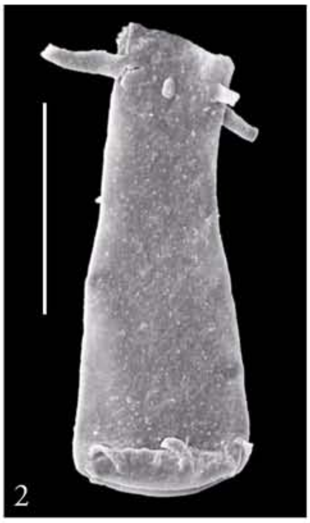
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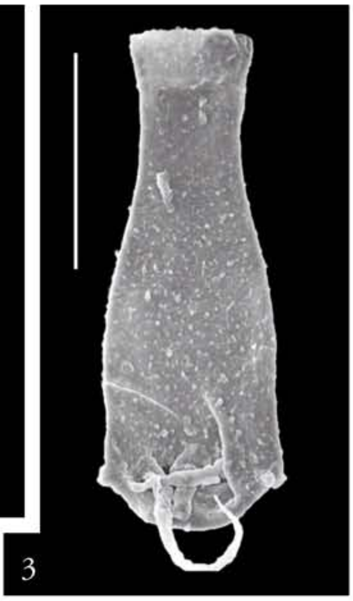
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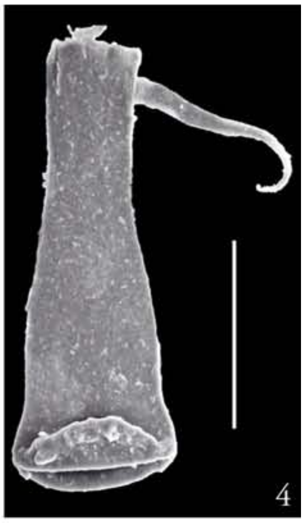
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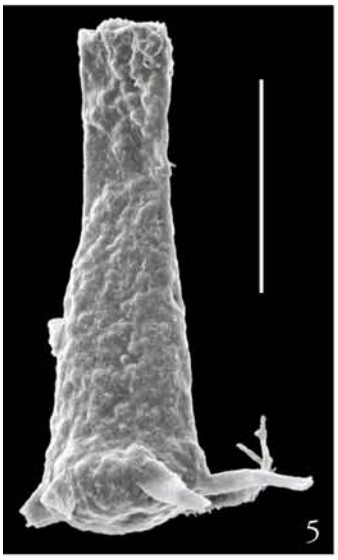
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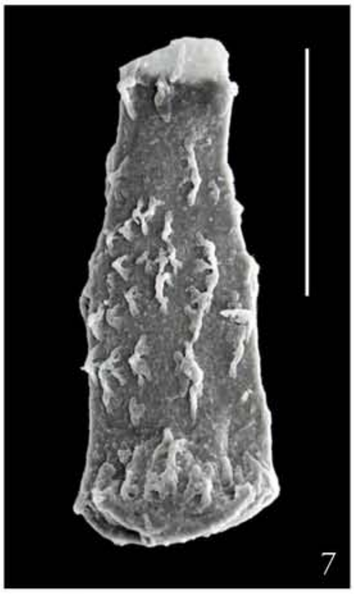
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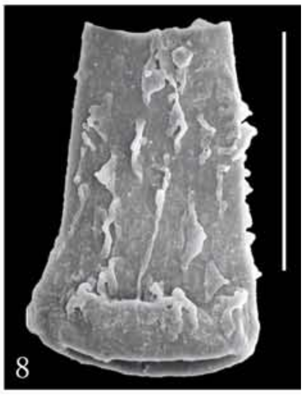
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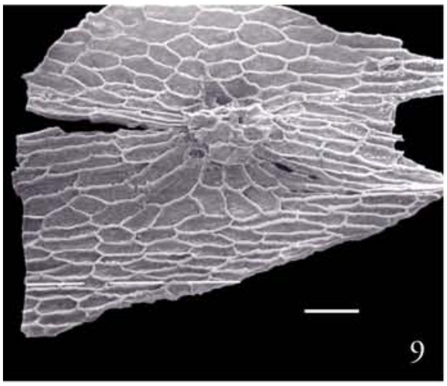
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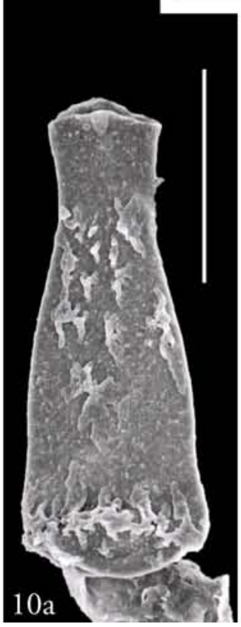
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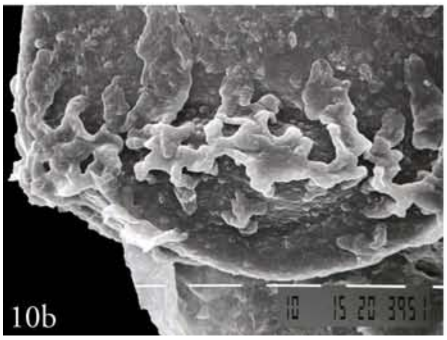

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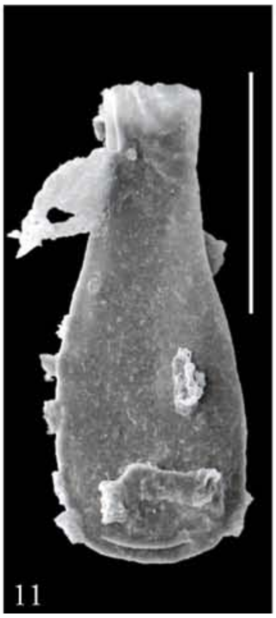
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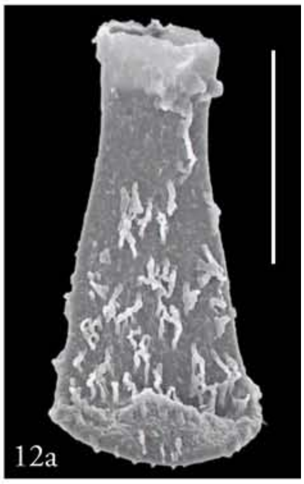
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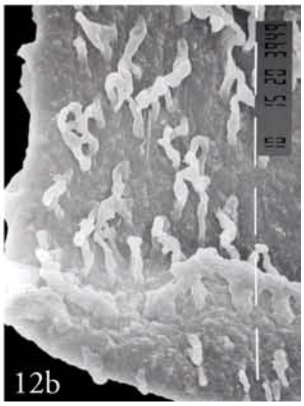
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Plate 2

Chitinozoans from La Candelaria and La Escalera sections (Bolivia)

The bar represents 100 microns, except for figs. 11b and 13 b (10 microns)

Fig 1: *Ramochitina tarabucoensis* nomen nudum. La Escalera section, TESCO1-Pl.37. Specimen with few spines.

Fig. 2: *Ancyrochitina biconstricta* (Lange); La Escalera section, TESCO1-Pl.37. (poorly preserved specimen but in full relief)

Figs. 3-4: *Ramochitina autasmirinense* Grahn and Melo (in press B). La Escalera section, TESCO1-Pl.25. The bottom is evaginated in the specimen of fig. 3. The rows of spines are not obvious when numerous (e.g. fig. 3). Note the stronger and branched spines on the margin (recalls A. ferquensis Paris)

Fig. 5, 6, 7 and 9: *Ramochitina stiphrospinata* Grahn and Melo (in press A). La Escalera section, TESCO1-Pl.19. Note the well branched distal part of the spines on these stubby individuals

Figs. 8, 11 a-b and 12: *Ramochitina perezi* nomen nudum, La Candelaria section, TO3-PL.07. Note the slender spines (fig. 11 b)

Fig. 10: *Ancyrochitina grahni* nomen nudum. La Candelaria section, TO2-LM.01. Note the very large conical processes (larger diameter close to 30 microns) with a hook-like branching in their very distal part

Figs. 13 a-b: *Alpenachitina eisenacki* Dunn and Miller. La Candelaria section, TO1-PL.01

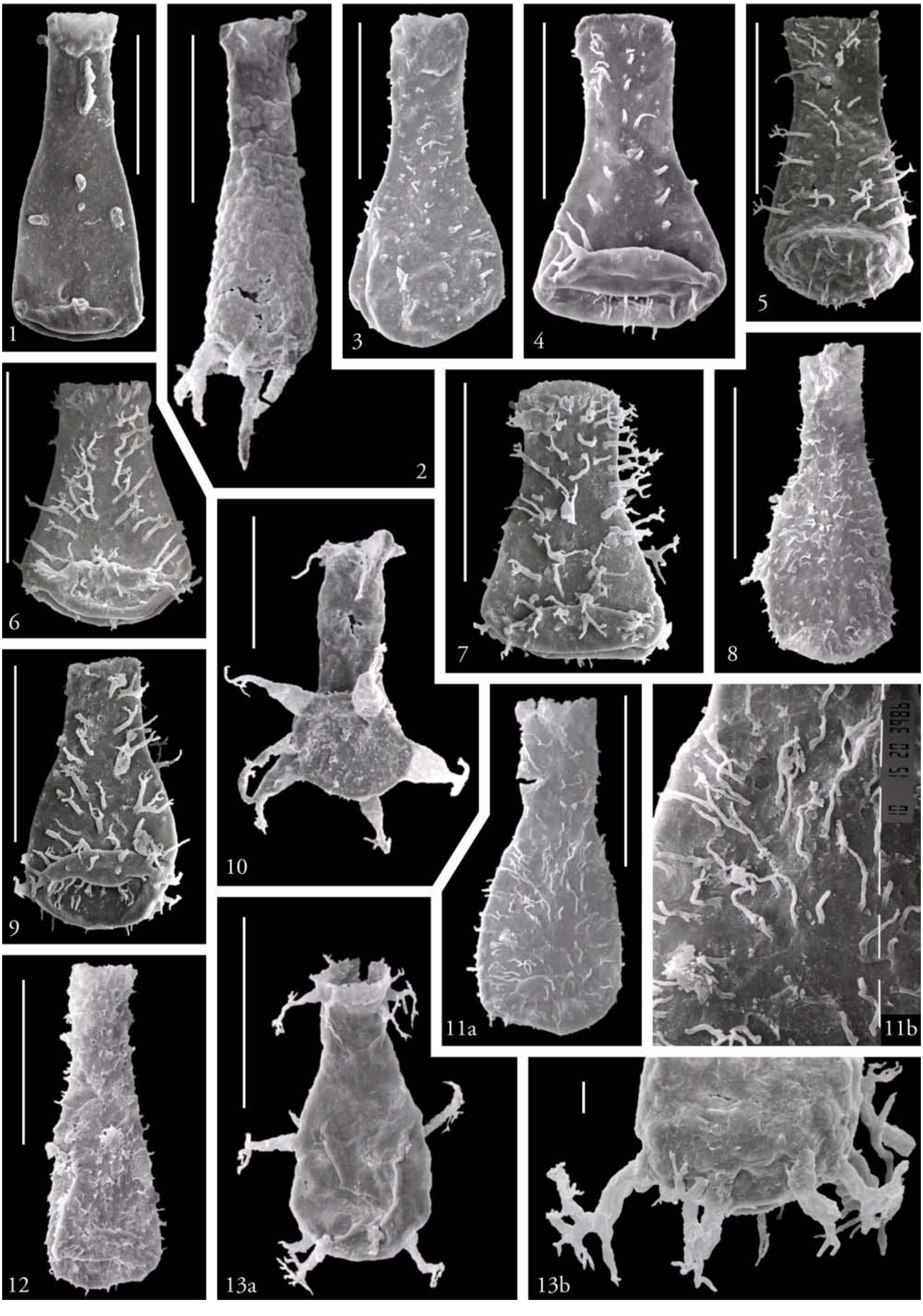
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Plate 3

Chitinozoans from La Candelaria and La Escalera sections (Bolivia)

Enlargement: x 200 for figs. 1-2, 4-5, 8-10, 14-19 and x 320 for figs. 3, 6-7, 11-13
(The location of the specimen in the slide is indicated with the England Finder coordinates)

Figs. 1 and 3: *Angochitina* sp. La Candelaria section, TO2-LM.01 (note the very long and slender processes on fig. 1)

Figs. 2 and 18: *Alpenachitina eisenacki* Dunn and Miller; La Candelaria section, TO1-06 (R53/1) (fig. 2 represents an incomplete specimen with highly branched processes)

Figs 4, 6-7: *Ancyrochitina grahni* nomen nudum. La Candelaria section, TO2-LM01
4- lateral view (L.49/4)
6- antiapertural view (R40)
7- antiapertural view (P38)

Fig. 5: *Ancyrochitina* sp. aff. *moroni* nomen nudum (sensu Paris et al. 2001). La Candelaria section, TO2-LM01 (P38)

Figs. 8 and 19: *Ramochitina tarabucoensisi* nomen nudum; La Escalera section, TESCO1-PL.37. Note the brohen ornamentaion on fig. 8.

Fig. 9: *Angochitina* sp. La Escalera section, TESCO2-PL.2. Broken specimen with a dense spiny ornamentation

Fig. 10: *Ramochitina ramosi* Lange. La Escalera section, TESCO2-PL.2. Broken specimen with a dense spiny ornamentation

Figs. 11-12: *Ancyrochitina* sp. A; La Escalera section, TESCO2-PL.2. Stubby specimens with a very short neck.
11- (N36/4)
12- (N52/3)

Figs. 13-14: *Ancyrochitina moroni* numen nudum; La Escalera section, TESCO2-PL.2. Slender specimens with long slender processes around the margin.
13- (P45/3)
14- (Q44)

Figs. 15-17: *Ancyrochitina biconstricta* (Lange). La Escalera section, TESCO1-PL.36.
15- (O43/3)
16- (S58/1)
17- (P42/4), specimen with broken processes.


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Plate 4

Chitinozoans from La Candelaria and La Escalera sections (Bolivia)

Enlargement: x 200 for figs. 4-8, 13-16, 18-19 and x 320 for figs. 1-3, 9-12, 17
(The location of the specimen in the permanent slide is indicated with the England Finder coordinates)

Figs. 1, 3 and 4: *Ramochtina tarabucoensis* nomen nudum; La Escalera section, TESCO1-PL.36
- 1- (J36/2); Note the vertical crest on the more or less transparent wall
- 3- (K31/4); Note the vertical row of ornaments anastomosed at their distal end
- 4- (P48)

Fig. 2: *Ramochtina boliviensis* Grahn; La Escalera section, TESCO1-PL.37, (J42/1)

Figs. 5, 6, 7 and 8: *Ancyrochitina escaleraensis* nomen nudum. La Escalera section,
- 5- TESCO1-PL.32 (G43), short specimen with long and branched processes
- 6- TESCO1-PL.32 (L43/3), specimen with long robust spines on the base of the neck
- 7- TESCO1-PL.34 (G48)
- 8- TESCO1-PL.30 (Q41), short specimen with long spines on the base of the neck

Figs. 9 and 12: ?*Linochitina jardinei* Boumendjel, La Escalera section, TESCO1-PL.20 (P40)
- 9- TESCO1-PL.20 (W40/4). No mucron is visible on this poorly preserved individual which can belong as well to a reworked Cingulochitina species
- 12-TESCO1-PL.20 (P40). The scar of a mucron is visible on the apex of this specimen. However, the occurrence of a carina cannot be excluded and therefore, this individual can belong as well to a reworked Cingulochitina species.

Figs. 10-11: *Ramochitina stiphrospinata* Grahn and Melo (in press A). La Escalera section, TESCO1-PL.19. Note the short neck and the highly branched spines
- 10- (O54)
- 11- (N46/1)

Fig. 13: *Angochitina* sp. aff. *Sommerochitina langei* La Escalera section, TESCO1-PL.16 (G36/4)

Figs. 14 and 18: *Ancyrochitina coqueli* nomen nudum. La Escalera section.
- 14- TESCO1-PL.25 (M42)
- 18- TESCO1-PL.21 (P46)

Figs. 15, 16 and 19: *Ramochitina perezi* nomen nudum, La Candelaria section, TO3-07
- 15- (R48/3)
- 16- (P47/3)
- 19- (G49/4)

Fig. 17: *Ramochitina autasmirinense* Grahn and Melo (in press B), TESCO1-PL.22 (N47/1)


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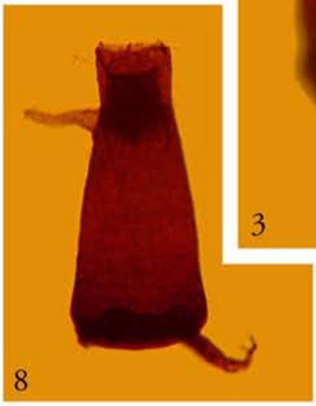
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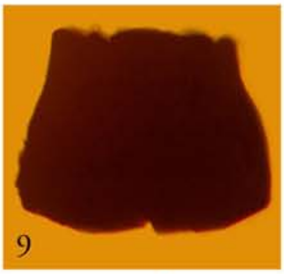
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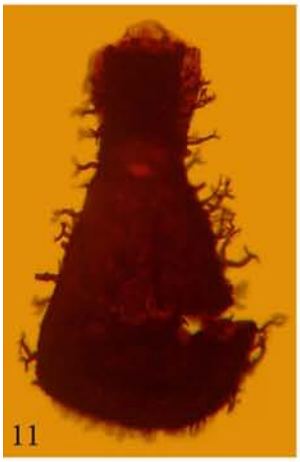
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Plate 5

Exemples of spores, plant debris, and scolecodont recorded in La Candelaria and La Escalera sections (Bolivia)

The location of the specimen in the permanent slide is indicated with the England Finder coordinates

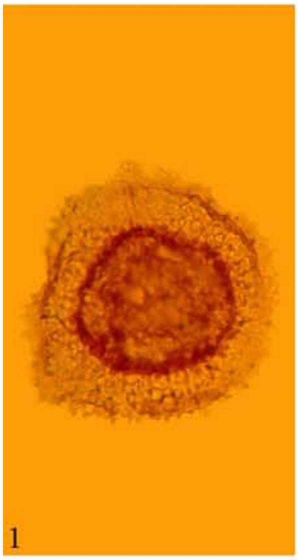
Fig. 1: Velate spore, La Candelaria section, TO1-04 (M38/2)

Fig. 2: Spiny spore, La Candelaria section, TO1-04 (S47)

Figs. 3, 5, 6-8: fragments of cuticle of land plants, La Escalera section
    3- TECO1-PL.31, note the stomate (upper part of the fragment)
    5- TECO1-PL.27A (P43)
    6- TECO1-PL.27A (R51/1)
    7- TECO1-PL.31 (N55)
    8- TECO1-PL.31 (T49/1)

Fig. 4: Fragment of land plant, La Escalera section, TESCO1-PL.27A (K44/4)

Fig. 9: Scolecodont, La Escalera section, TESCO1-PL.26 (O38/3)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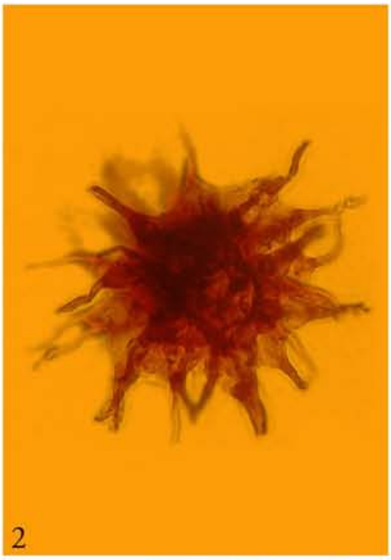
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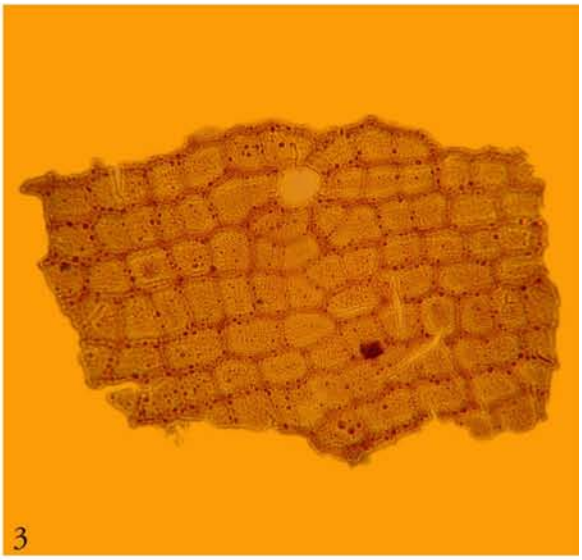
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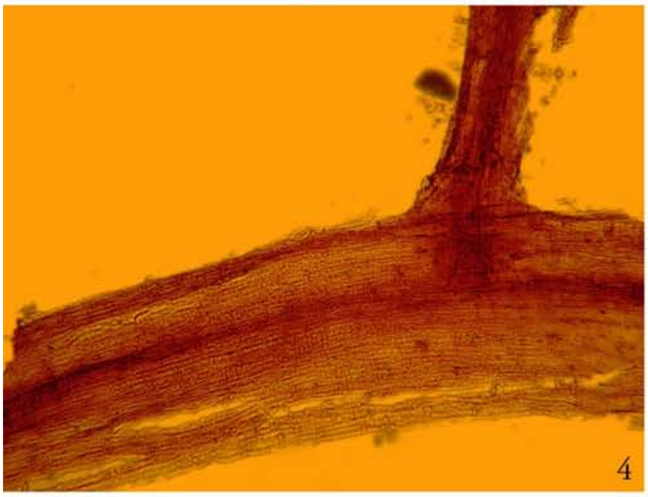
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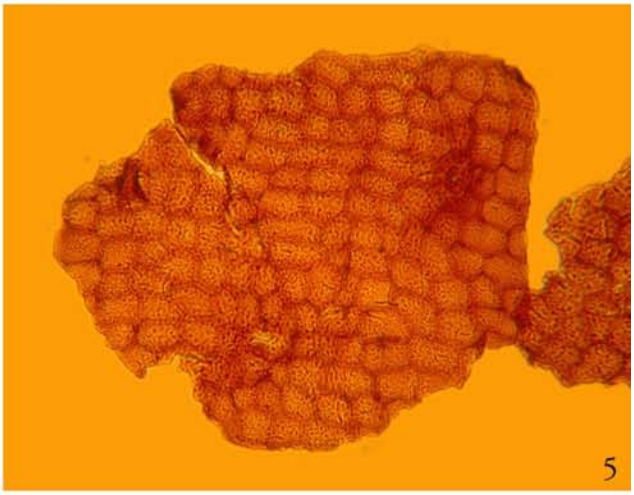
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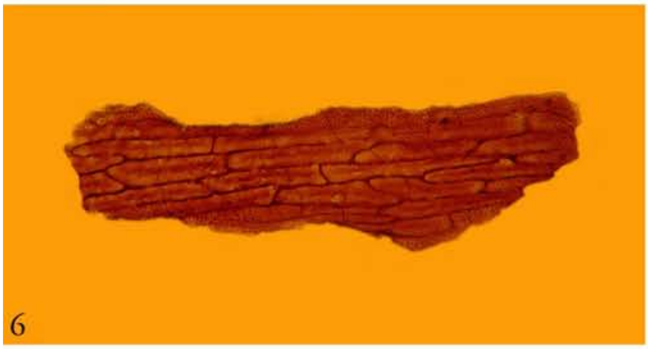
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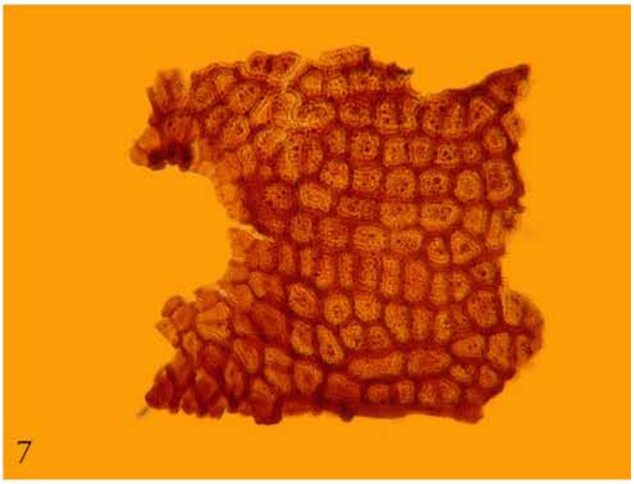
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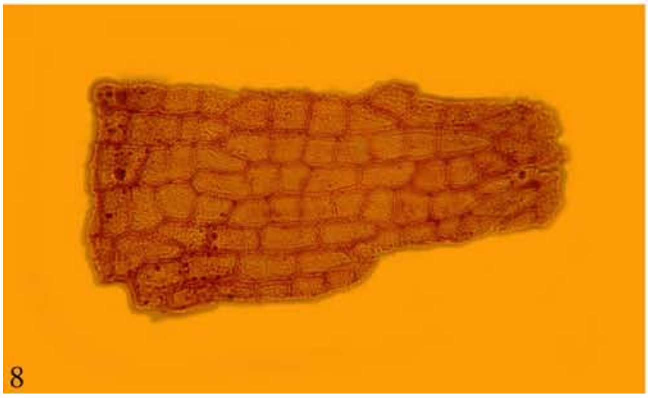
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9

— ACRITARCHS and PHYCOMATA

Alain LE HÉRISSÉ

The present report deals with the acritarch and prasinophycean phycomata assemblages of the Huamampampa (*sensu lato*, see explanations in the introduction chapter) and the Los Monos formations, from the La Candelaria and La Escalera sections exposed in the South of Bolivia, in the western sector (Fig.1).

Among the palynomorphs, acritarchs and the prasinophycean phycomata are the two major elements of the phytoplankton subgroup, commonly found in marine sediments. Although they are of uncertain and probably varied affinities the acritarchs are included within the phytoplankton subgroup. They were the dominant forms of the marine organic-walled microplankton during the Palaeozoic.

The objectives of the study are : (1) to investigate the phytoplankton assemblages for their biostratigraphical and palaeoenvironmental significance, (2) to integrate in a final report the qualitative and quantitative information, together with spore and chitinozoan data, for improving the local biostratigraphy and the facies interpretation, and (3) to understand the microfossil distribution in terms of the depositional setting and sea-level variations.

LA CANDELARIA section

For the present study, samples productive of phytoplankton remains were collected in the section under the following references : TO1-PL01, TO1-PL02, TO1-PL03, TO1-PL04, TO1-PL05, TO1-PL06, TO2-LM.01 and TO2-PL07 (Figs. 3 and 11)

The organic residues corresponding to these samples consisted of more or less rich assemblages of acritarchs, prasinophycean phycomata (*Pterospermopsis* spp., tasmanitids, leiospheres, etc…), spores, chitinozoans and structured kerogen composed mostly of plant and wood remains (Tabl. 1). The preservation of the palynomorphs is quite good, compared to others sections or boreholes from the Altiplano or from the the Subandean zone (e.g. the Presto section, which is quite close to the La Candelaria locality) dealing with contemporaneous levels.

1- Characterization and age of the acritarch microfloras

A selection of about 40 species is presented in the range chart (Fig. 11 and Tabl. 7). Some of them are kept in open nomenclature because we have too few specimens available at the moment for appreciating their morphological limits and for evaluating their global importance.

The quantitative analysis (Fig. 11 and Tabl. 7) revealed a limited abundance of acritarchs ranging between 25 and 4983 specimens per gram of rock (mean of 1674 by gram of rock for the 8 samples). Nevertheless, this quantitative analysis shows an interesting over-representation of the species *Evittia sommeri* (relative frequencies ranging between 41 to 58% of the total microflora), between T01.02 and T01.05.

Based on the evolution of the acritarch assemblages, a subdivision of the studied interval into 2 biozones is proposed.

- The first one corresponds to the acme-biozone of *E. sommeri*.
- The second one corresponds to changes in the microflora diversity, from the succeeding samples T01.06 to T02.07. It fits with the appearance of new diagnostic forms, such as *Horologinella horologia* or the *Hapsidopalla* spp.

The interval with over-representation of *E. sommeri*, below the base of the Huamampapa Formation stricto sensu in the La Candelaria section (interval from T01.01 to T01.05), seems to correspond to the upper part of the Zudaneziano stage in the local stratigraphy of the cordilleran cycle as proposed by Suarez-Soruco and Lobo-Boneta in 1986 (cf . Tabl. 10), and to their *Emphanisporites annulatus-Evittia sommeri* zone.

Evittia sommeri is not only abundant in this interval but it is also highly polymorph (cf. Plate 6) in these levels. This species is therefore regarded as diagnostic of a local or regional bioevent. *E. sommeri* ranges up to the Frasnian, e.g. in Brazilian material (Oliveira, 1997). However, in these younger strata, it is less abundant, and never so polymorph. When creating the species, Brito (1967) illustrated 3 specimens showing the same instability of morphology as documented here. In Brazil, Brito reported that the species was common in palynological Zone R in the

Maranhao Basin, tentatively referred to the Lower Devonian. This zone is presently referred to the Middle Devonian (cf. Melo 2000).

TO1-PL01	TO1-PL02	TO1-PL03	TO1-PL04	TO1-PL05	TO1-PL06	TO2-LM-01	TO2-PL07	**LA CANDELARIA: List of acritarchs**
○	○	○	○					**Navifusa cf. exilis**
○								Duvernaysphaera tenuicingulata
○	○	○					○	Duvernaysphaera angelae
○	○	○	○	○	○		○	**Evittia sommeri**
○				○			○	Exochoderma arca/geometrica
○	○		○	○				Gorgonisphaeridium sp. 1
○	○	○	○					Polyedryxium simplex
○	○	○			○		○	Multiplicisphaeridium ramusculosum
○	○				○			Veryhachium trispinosum s. l
○	○				○		○	Veryhachium lairdi
○		○	○	○	○		○	Navifusa bacillum
○					○		○	Palacanthus ledanoisi
○								Ozotobrachion furcillatus
○	○	○						Muraticavea munificus
○	○							Polyedryxium cf. cuboides
○								Baltisphaeridium sp.
	○	○						Pterospermopsis aff. onondagaensis
	○		○					Tunisphaeridium tentaculaferum
	○							Oppilatala sp. 1
	○			○	○			Polyedryxium fragosulum
		○						Veryhachium pastore
		○			○			? Advenasphaeridium sp.
				○			○	? Palacanthus sp. 1
				○				Tyligmasoma alargada
				○				Stellinium sp. 1
					○			Leiofusa cf. fastidonia
					○			Cymatiosphaera cornifera
					○			Polyedryxium cubus
					○			Schizocystia pilosa
					○			**Horologinella horologia**
					○			**Hapsidopalla exornata**
					○			**Estiastra spinireticulata**
					○			Pterospermopsis cf. carminae
					○			Pterospermopsis cf. rajada
							○	Hapsidopalla chela
							○	Evittia spicifera
							○	Ammonidium sp.
							○	Veryhachium sp. 1
							○	Veryhachium sp. 2

Fig. 11: Range of the acritarchs and prasinophycean phycomata taxa recorded in «La Candelaria» section (TO1-TO3)

Remarks :

Limachi et al. (1998), placed the entire Huamampampa Formation in the *E. annulatus/E. sommeri* zone, attributed by them to the Emsian. Here I suggest that the *E. sommeri* acme Zone is of late Eifelian age (not lates?).
We do not have acritarchs characteristic of the Emsian (or more exactly of the Pragian-Emsian(?)-early Eifelian interval) as we known elsewhere, e.g. in Algeria or in Libya, but also as documented in the Sirari borehole, drilled north of the Bolivian «boomerang» (Le Hérissé, unpublished data). These assemblages include for example *M. escobaides*, some *Eisenackidium* spp, a diversity of *Polyedryxium*, the large forms of *O. assymmetrica* , and abundant *Tylygmasoma alargada*.
The wrong age assignment given by Limachi et al. (1998) results probably from the presence of Pragian-early Eifelian (s.l) acritarch taxa we suppose to be reworked (in T01.06 particularly), just below the sandy beds of the Hamampampa Formation *stricto sensu* (Fig. 3).

The second local acritarch local biozone (interval T01.06 to T02.07) is based on acritarch and prasinophytes characteristics such as the FAD of *Horologinella horologia*, the *Advenasphaeridium* morphology, the development of the *Hapsidopalla* group, the recurrence of the small *Pterospermopsis* (disaster species for Tappan 1980) etc. Correlations are possible with some material known in Algeria, Libya (e.g., A1-69) and Tunisia (e.g., MG-1), and the upper part of the miospore zone AD, i.e. the *lemurata* Zone (Loboziak and Streel 1989). These levels were attributed to the upper Eifelian, now it seems that the lemurata Zone is considered to be early Givetian (Loboziak and Melo 2000).

Remarks:

Here the species *Daillydium pentaster/quadridactylites* has not been observed, but it could be first appearing in the interval, based on the results obtained in North Africa.

To conclude, sample T02.07 shows also the incoming of new forms, with for example some Veryhachids in open nomenclature (indicating new instability of the environment), or *H. chela* and *E. spicifera*, which are 2 species announcing an evolution of the Devonian assemblages, with some morphologies that continue up to the Frasnian

2- Paleoenvironmental significance

The distribution of Palaeozoic acritarchs shows some strong similarities with dinocyst trends, with abundance and diversity primarily reflecting a proximal-distal trend, following variations in hydrodynamic energy, water depth and availability of nutrients. In reality the production and distribution of acritarchs is more complex and need to be detailed to the specific, generic or group level.

The distribution of prasinophycean phycomata, known from Cambrian to Quaternary studies, shows that they are particularly abundant in shelf or oceanic environments in sediments deposited under dysoxic to anoxic conditions. They can be significant components of the kerogen in black shales formations. Here we use the ratio of acritarchs/ prasinophycean phycomata (e.g. leiosphaerids, *Tasmanites*, *Pterospermopsis*, *Cymatiosphaera* etc.) as an index of hydrographic stability, even though the number of studied samples is insufficient for allowing definitive conclusions.

In the La Candelaria section, acritarchs are never really abundant. The samples studied are certainly not from the neritic marine environment, which is the most favourable environment for production of cysts (and for high diversity). The difference between the base of the section (between T01.01 and T01.05) and the top (T01.06-T02.07) is significant in terms of stacking patterns, with the top of the section maybe indicating a surface of transgression (a top lowstand surface), and a situation somewhat more remote from the coastline, possibly on the mid-shelf.

LA ESCALERA section

Samples TESCO1-PL.37, PL.29, PL.28, PL.27, PL.27A, PL.21, PL.17, PL.16 from the «upper» section and TESCO2-PL.1 from the «lower» section produced acritarchs. However, Prasinophycean phycomata (e.g. leiosphaerids) occur in several other samples from this section (Tabl. 2 and 3).

In most of the samples, acritarchs are poorly represented compared to the spores and to the chitinozoans (Tabl. 2 and 3). Over-representation of spores in these marine sediments can result of a particularly good productivity during this period, but probably also of important transport in suspension, from land.

At the base of the section, from TESCO1-PL.37 to TESCO1-PL.27, we have a good representation of the group *“ Veryhachium ” exasperatum/ “ V. ” libratum*, which announces the *Estiastra rhytidoa* of Wicander and Wood (1981) described in the Silica Formation (Givetian of Ohio). These species are well represented in A1-69 borehole in Libya (see Loboziak and Streel 1989) in some levels that are now referred to the lower Givetian. Some others species are well represented, such as *T. tentaculiferum*, *Muraticavea munificus* or some *Oppilatala* that will be interesting to detect also in others sections.

From TESCO1-PL.21 to TESCO1-PL.16, new species appear, such as *Iroistella* nov sp. A, that we know in the base of PARAPETTI-X2 borehole, few specimens of *Shizocystia saharica* (Middle Devonian form, see remarks), and others Givetian forms, e.g. *Oppilatala sparsa*, *Baltisphaeridium distentum* that are described in the Silica Formation (USA)

LA ESCALERA TESCO2	Duvernaysphaera tenuicingulata	Duvernaysphaera angelae	Navifusa bacillum	Pterospermopsis cf. onondagaensis
TO1 - PL06				
TO1 - PL05				
TO1 - PL04				
TO1 - PL03				
TO1 - PL02				
TO1 - PL01	❍	❍	❍	❍

Fig. 12: Range of the acritarchs and prasinophycean phycomata) taxa recorded in the «lower» La Escalera section (TESCO2)

LA ESCALERA TESCO1	**"V" Librtum/exasperatum**	Lophospaeridium sp.	Tunisphaeridium tentaculaferum	Polyedryxium fragosulum	Gorgonisphaeridium sp. 1	Polyedryxium simplex	Muraticavea munificus	Veryhachium polyaster	Veryhachium lairdi	Veryhachium trispinosum	Veryhachium pastore	Cymatiosphaera cornifera	Cymatiosphaera sp. 1	Baltisphaeridium sp. 1	**Multiplicisphaeridium gladiatorum n. sp.**	Elektroriskos sp. 1	Oppilatala sp. 1	Duvernaysphaera angelae	Duvernaysphaera tenuicingulata	Stellinium octoaster	Veryhachium trispininflatum	Evittia sommeri	Stellinium sp. 2	**Schizocystia saharica**	**Iroistella nov sp. A**	Ammonidium sp.	Exochoderma triangulata	**Baltisphaeridium distentum**	Polyedryxium sp.	**Chomotriletes vedugensis**	**Oppilatala sparsa**	**Estiastra rhytidoa**	Navifusa bacillum
PL.03 to PL.15	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
PL.16										○																							○
PL.17																			○											○	○	○	
PL.18																																	
PL.19																																	
PL.20																																	
PL.21			○		○																			○	○	○	○	○	○				
PL.22																																	
PL.23																																	
PL.24																																	
PL.25																																	
PL.26																																	
PL.27					○																○	○	○										
PL.27A																																	
PL.28		○																															
PL.29					○	○	○							○				○	○	○													
PL.30																																	
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PL.34																																	
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PL.36																																	
PL.37	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○															

Fig. 13: Range of the acritarchs species and of prasinophycean phycomata in the «upper» La Escalera section (TESCO1)

1- Systematic remarks

Chomotriletes vedugensis Naoumova 1953

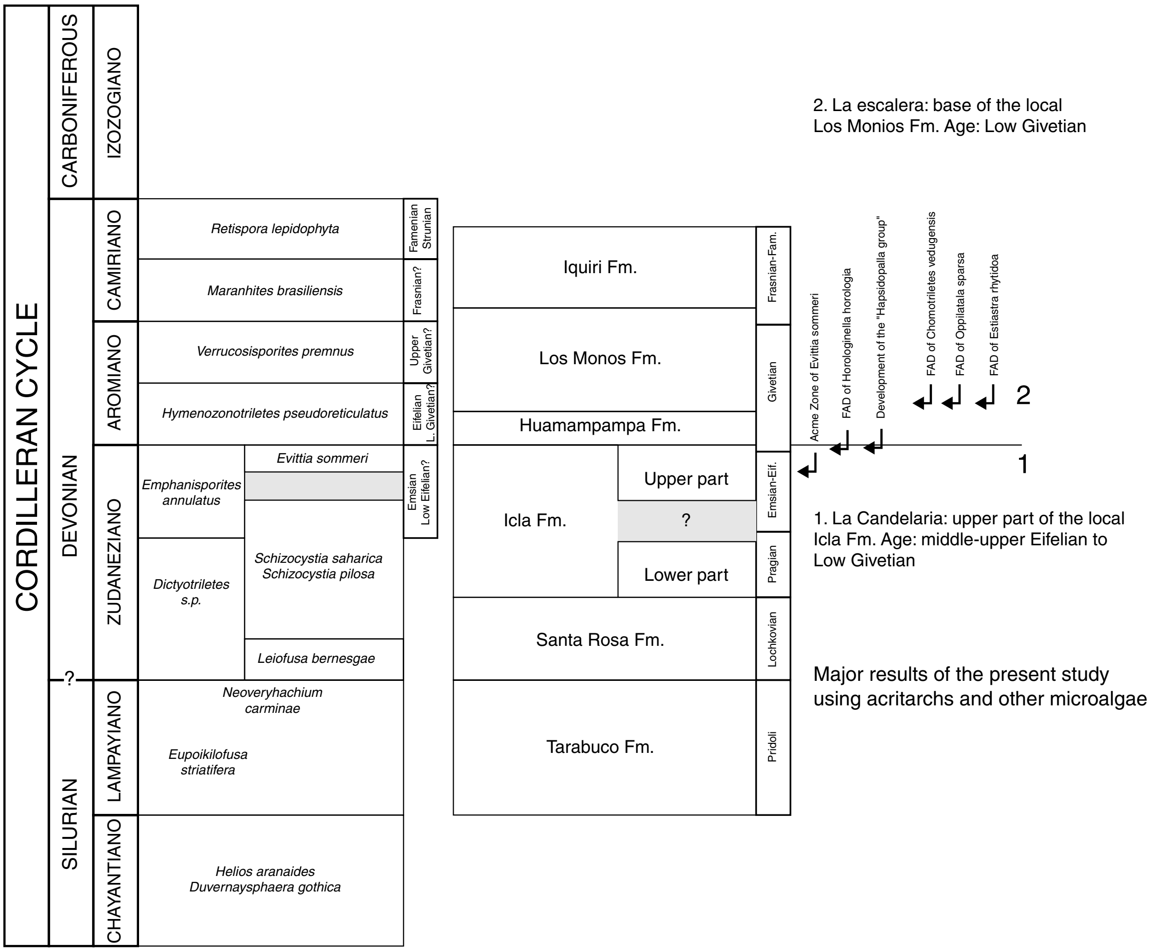
The occurrence of this form in sample TESCO1-PL.17 is of interest. Such forms, with concentric ornamentation, can be considered as algal palynomorphs rather than miospores. They appear in the Devonian and have, in my opinion, two taxonomic junior synonyms : *Concentricystes* Rossignol 1962, and *Circulisporites* de Jersey 1962 that are known in more recent sediments up to the Holocene
C. vedugensis was described in Frasnian deposits of the Russian platform, and reported from the Frasnian of Australia (Gneudna Formation: Balme 1962; Playford and Dring 1981). However, now it is known to appear earlier, as demonstrated by Turnau and Racki (1999), with some specimens found in Givetian samples from the Holy Cross Mountains, Central Poland. In Poland, the samples containing *C. vedugensis* are assigned to the Upper Lower or Middle *varcus* conodont sub-zone of the lower Givetian.

Schizocystia saharica Jardiné et al. 1974

As indicated by Jardiné et al. (1972) when defining this species, it is possible to distinguish two morphotypes: some specimens with well developed processes occur in the Lower Devonian (we have equivalent of that in the Lochkovian part of the Sirari well, north of the Bolivian «boomerang»), and some specimens with poorly developed processes (equivalent of the material present in TESCO1-PL.21) are characteristic of the Middle Devonian

2- Paleoenvironmental significance

In the La Escalera section, sporomorphs and phytoclasts dominate the palynomorph assemblages. This may reflect pulses of freshwater influx and indicate a well-oxygenated inner shelf depositional environment. It would be



2. La escalera: base of the local
Los Monios Fm. Age: Low Givetian

1. La Candelaria: upper part of the local
Icla Fm. Age: middle-upper Eifelian to
Low Givetian

Major results of the present study
using acritarchs and other microalgae

Fig. 14: Age assignment of the recorded acritarch taxa in term of the standard Devonian chronostratigraphy.

interesting to have data on the macrofauna (e.g. shell beds, trilobites, etc.) to support this interpretation.

Fluctuations in the abundance and in percentages of the main acritarchs groups indicate also a near-shore setting, may be in a delta front setting taking into account of the abundance of terrestrial kerogen.

3- Correlations

The acritarch results, particularly on the «upper» La Escalera section, allow some correlations with the previously studied boreholes of INAU-X2 and PARAPETTI-X2 (Paris et al., 2001).

The interval studied in the «upper» La Escalera section is partly equivalent to the interval 1966-2014 to 2386-2394 m, with some species in common such as *Iroistella* nov. sp. A, or *Estiastra rhytidoa*, which are characteristic of the Givetian and of the lower part of the Los Monos Formation.

The acritarchs from the deeper part of the INAU-X2 borehole, between 2766-2768.35 to 2494-2495.5 m, show also some equivalence with the acritarch assemblages recorded in the lower part of the Los Monos Formation. We can confirm that the *Maranhites* are reworked in the base of the INAU-X2 borehole.

List of acritarch and prasinophycean phycomata cited in the text

?*Advenasphaeridium* sp
Ammonidium sp.
Baltisphaeridium distentum Playford 1977
Baltisphaeridium sp.
Baltisphaeridium sp.1
Chomotriletes vedugensis Naoumova 1953
Cymatiosphaera cornifera Deunff 1955
Cymatiosphaera sp.1
Duvernayspahera angelae Deunff 1964a
Duvernaysphaera tenuicingulata Staplin 1961
Elektoriskos sp.1
Exochoderma arca Wicander & Wood 1981
Exochoderma triangulata Wicander & Wood 1981
Estiastra spinireticulata Oliveira & Burjack, in press
Estiastra rhytidoa Wicander & Wood 1981
Evittia sommeri Brito 1967
Evittia spicifera (Deunff) Lister 1970
Gorgonispaheridium sp.1
Hapsidopalla chela Wicander & Wood 1981
Hapsidopalla exornata (Deunff) Playford 1977
Horologinella horologia (Staplin) Jardiné et al. 1972
Iroistella nov. sp. A (cf. PARAPETTI-X2)
Leiofusa cf. *fastidonia* Cramer and Diez 1976
Multiplicisphaeridium gladiatorum n. sp.
Muraticavea munificus Wicander & Wood 1981
Navifusa bacillum (Deunff) Playford, 1977
Navifusa cf. *exilis* Playford in Playford & Dring 1981
Oppilatala sp.1
Oppilatala sparsa Wicander & Wood 1981
Palacanthus ledanoisi (Deunff) Playford 1977
?*Palacanthus* sp.1
Polyedryxium cf. *cuboides* Deunff 1955
Polyedryxium fragosulum Playford 1977
Polyedryxium simplex Deunff 1955
Pterospermopsis aff. *onondagaensis* Deunff 1955
Pterospermopsis cf. *rajada* Cramer, 1964
Pterospermopsis cf. *carminae* Cramer 1964
Oppilatala sparsa Wicander & Wood 1981
Ozotobrachion furcillatus (Deunff) Playford 1977
Schizocystia pilosa Jardiné et al. 1972
Schizocystia saharica Jardiné et al. 1974
Stellinium octoaster (Staplin) Jardiné et al. 1972
Stellinium sp.1
Stellinium sp.2
Tunisphaeridium tentaculaferum (Martin) Cramer 1971
Tyligmasoma alargada (Cramer) Playford 1977
“ *Veryhachium* ” *exasperatum* Deunff 1955
“ *Veryhachium* ” *libratum* Deunff 1966 (=*Estiastra rhytidoa* Wicander & Wood 1981)
Veryhachium lairdi Deflandre ex. Deunff 1959
Veryhachium pastore Deunff, 1966
Veryhachium polyaster Staplin 1961
Veryhachium trispinosum (Eisenack) Deunff 1954
Veryhachium sp.1
Veryhachium sp.2

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ACRITARCHS AND PRASINOPHYCEAN ALGAE

PLATES

ACRITARCHS AND PRASINOPHYCEAN ALGAE

Plate 6

Figs. 1-5, 8. *Evittia sommeri* Brito, 1967. 1. La Candelaria, T01.02 (L46.1) x1000 ; 2. La Candelaria, T01.06 (M37.1), x1000 ; 3. La Candelaria, T01.03 (H.40), x1000 ; 4. La Candelaria, T01.04 (S50.1), x500 ; 5. La Candelaria, T01.04 (N37.2), x500 ; 8. La Candelaria, T01.05 (F53.2), x500.

Figs. 6-7. *Gorgonisphaeridium* sp.1. : a dense ornamentation of short processes, heteromorphic. Central body 25-28µm, proces length 2.5-3.5µm. 6. La Candelaria, T01.02 (H45), x1000 ; 7. La Candelaria, T0.01 (F53), x1000

Fig. 9. *Exochoderma arca* Wicander and Wood, 1981. La Candelaria, T01.01 (H34.1), x500

Figs. 10, 11. *Duvernaysphaera angelae* Deunff, 1964. 10. La Candelaria, T01.02 (F45.4), x1000 ; 11. La Candelaria, T01.02 (G43.3), x1000.

Fig.12. *Duvernaysphaera tenuicingulata* Staplin, 1961. La Escalera, TESCO2 (S52.3), x1000


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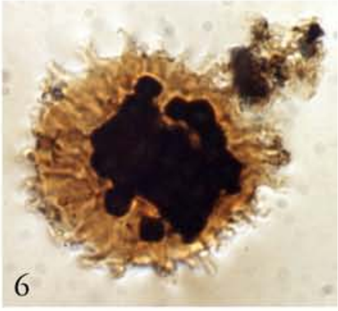
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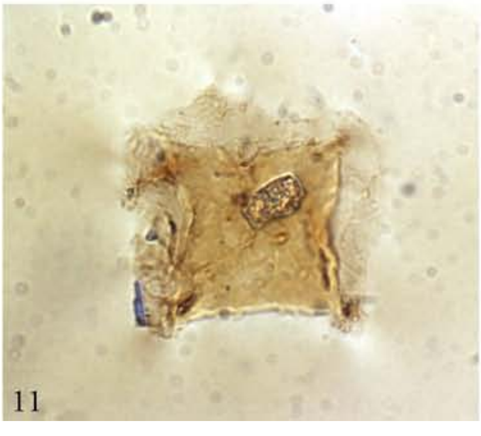
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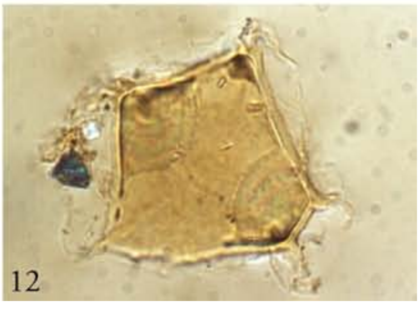
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ACRITARCHS AND PRASINOPHYCEAN ALGAE

Plate 7

Fig. 1. *Polyedryxium simplex* Deunff, 1955. 1. La Candelaria, T01.02 (E41) x1000

Figs. 2, 4. *Polyedryxium* cf. *cuboides* Deunff, 1955 . : 2. La Candelaria, T01.01(F54.1), x1000 ; 4. La Candelaria, T0.02 (H37.2), x1000

Fig. 3. *Navifusa* cf. *exilis* Playford in Playford and Dring, 1981. La Candelaria, T01.01 (P41.4), x1000

Figs. 5. *Polyedryxium fragosulum* Playford, 1977. La Candelaria, T01.01 (M32), x1000

Fig.6. *Multiplicisphaeridium* sp.1, La Candelaria, T01.02 (H46.4). A specimen with subtriangular body, 4 processes with branching composed of thin strips , x1000

Fig.7. ?*Advenasphaeridium* sp. La Candelaria, T01.03 (050.3), x1000

Fig.8. *Veryhachium trispininflatum* Cramer, 1964, La Candelaria, T01.01 (M32), x1000

Fig.9. *Tunisphaeridium tentaculiferum* (Martin) Cramer, 1971. La Candemaria T01.06 (K46), x1000

Fig . 10. *Multiplicisphaeridium ramusculosum* (Deflandre) Lister, 1970. La Candelaria, T01. 06 (G45), x1000

Fig.11. ?*Palacanthus* sp.1. La Candelaria, T01.05 (M46.1). The affinities with Palacanthus are suggested by the form of the processes with a stellate arrangement, but it is not definitively concluded. Central body 33µm in diameter, process length 13.5µm.

Fig.12. *Palacanthus ledanoisi* (Deunff) Playford, 1977. La Candelaria, T01.06 (J50.3), x1000


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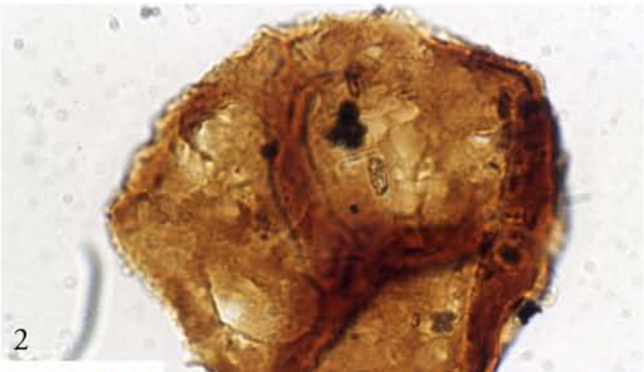
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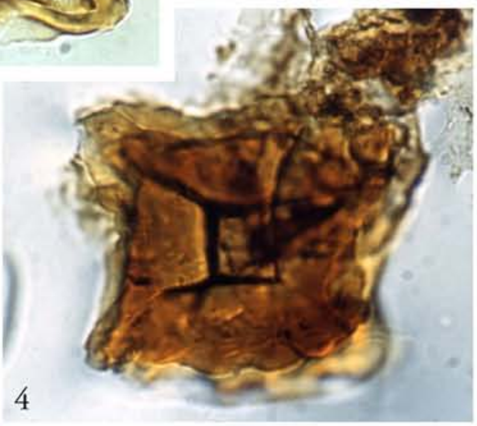
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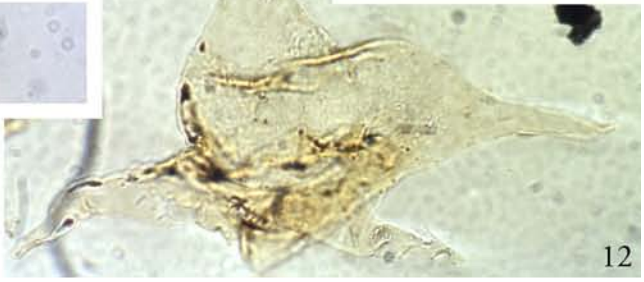
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ACRITARCHS AND PRASINOPHYCEAN ALGAE

Plate 8

Fig. 1 *Pterospermopsis* cf. *onondagaensis* Deunff, 1955. La Candelaria, T01.06 (M37.1) x1000

Fig. 2. *Pteospermopsis* cf. *rajada* Cramer, 1964 : La Candelaria, T01.06 (H53.4), x1000

Fig. 3. *Tyligmasoma alargada* (Cramer) Playford, 1977. La Candelaria, T01.05 (J49.4), x500. Remark : it could be good to isolate may be these morphons with rounded apex of the vesicle in a sub-species " *dilatata* ", because they are different from the Silurian forms

Fig. 4. *Pteospermopsis* cf. *hermosita* Cramer, 1964. La Candelaria, T01.06 (G48), x1000

Figs. 5, 6. *Schyzocistia pilosa* Jardiné et al., 1972. 5. La Candelaria, T01.06 (K41), x1000 ; 6. La Candelaria, T01.06 (N41.4), x1000.

Fig.7. *Leiofusa* cf. *fastidonia* Cramer and Diez, 1976. La Candelaria, T01.06 (S39.3), x1000

Fig.8, 9. *Estiastra spinireticulata* Oliveira and Burjack in press. 8. La Candelaria, T01.06 (S41), x1000 ; 9. La Candelaria T0.06 (V42), x1000. The processes are not clearly differentiated from the vesicle as for E. sommeri.

Fig. 10. ?*Advenasphaeridium* sp.1. La Candelaria T01.06 (R43), x1000

Fig.11. *Hapsidopalla chela* Wicander and Wood, 1981. La Candelaria, T01.06 (048), x1000

Fig.12. *Horologinella horologia* (Staplin) Jardiné et al., 1972. La Candelaria, T01.06 (N40.3), x1000


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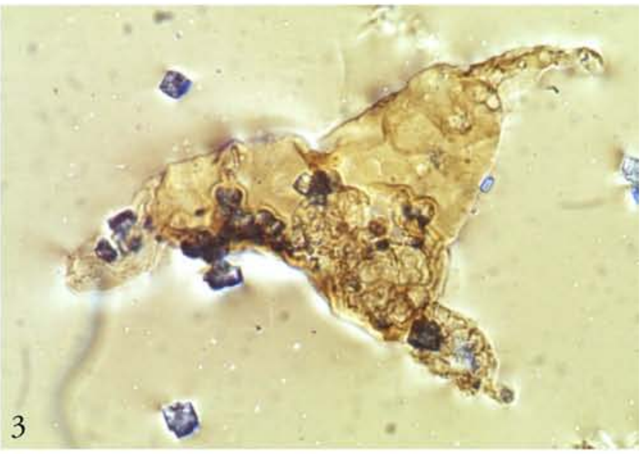
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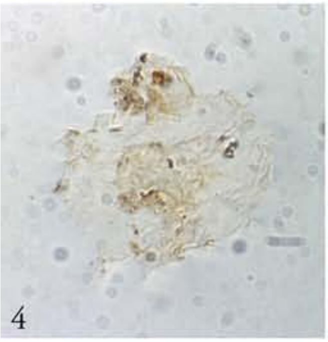
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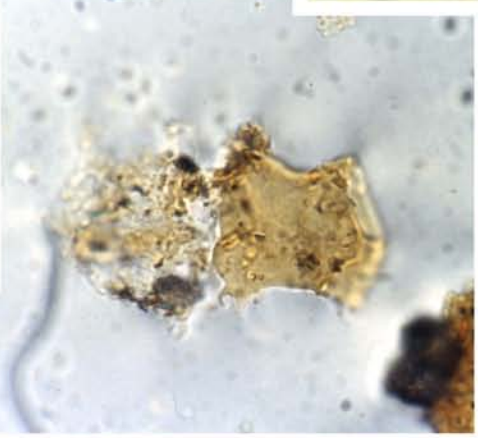
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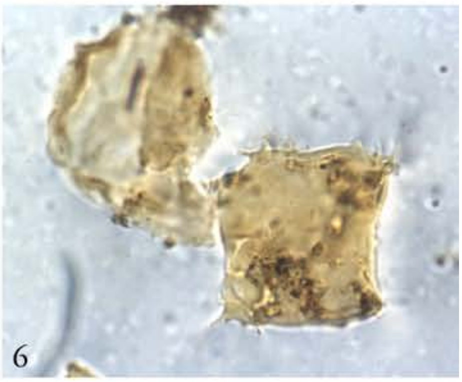
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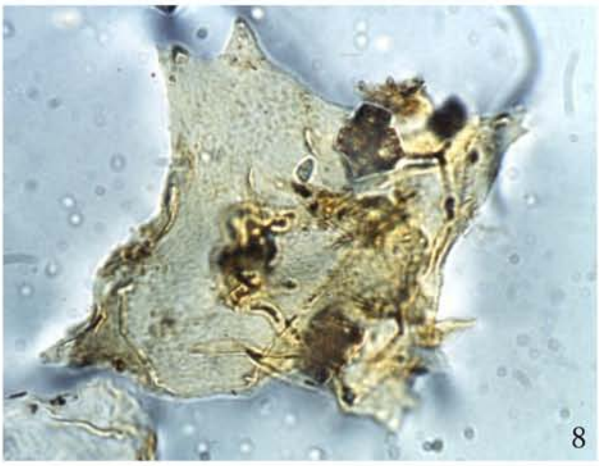
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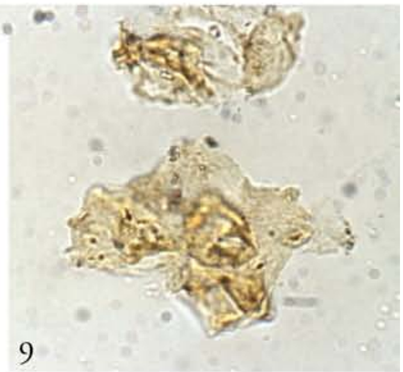
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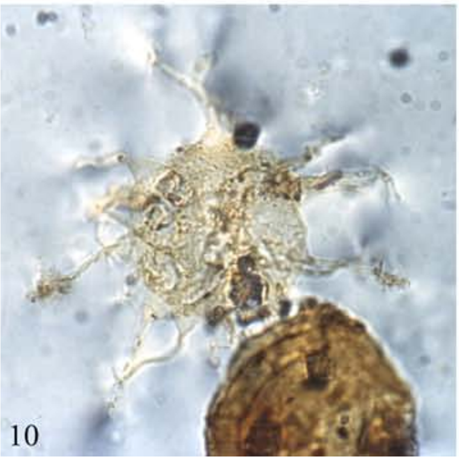
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ACRITARCHS AND PRASINOPHYCEAN ALGAE

Plate 9

Fig. 1 *Cymatiosphaera cornifera* Deunff, 1955. La Candelaria, T01.06 (P43) x1000

Fig. 2. ?*Crassiangulina tesselita* Jardiné et al., 1972. La Candelaria, T01.05 (J49.4), x500. Remark : it could be good to isolate may be these morphons with rounded apex of the vesicle in a sub-species " *dilatata*", because they are different from the Silurian forms

Fig. 3. *Coenobial algae*. La Escalera, PL37 (P46), x1000. This form is different from Petrovina connata known stratigraphically above in others localities. It could indicate in term of environment some freshwater influx or conditions of brackish environment.

Fig. 4. *Navifusa bacillum* (Deunff) Playford, 1977 : La Candelaria, T01.06 (J43), x1000

Fig. 5. *Multiplicisphaeridium gladiatorus* n.sp.La Escalera, Pl37 (Q38.3), x1000 . A species of Multiplicis phaeridium also known in the Presto section to the base of the " Huamampampa "Formation, with processes, large, conical, noit very well differentiated from the vesicle , with some heterogenous ramifications

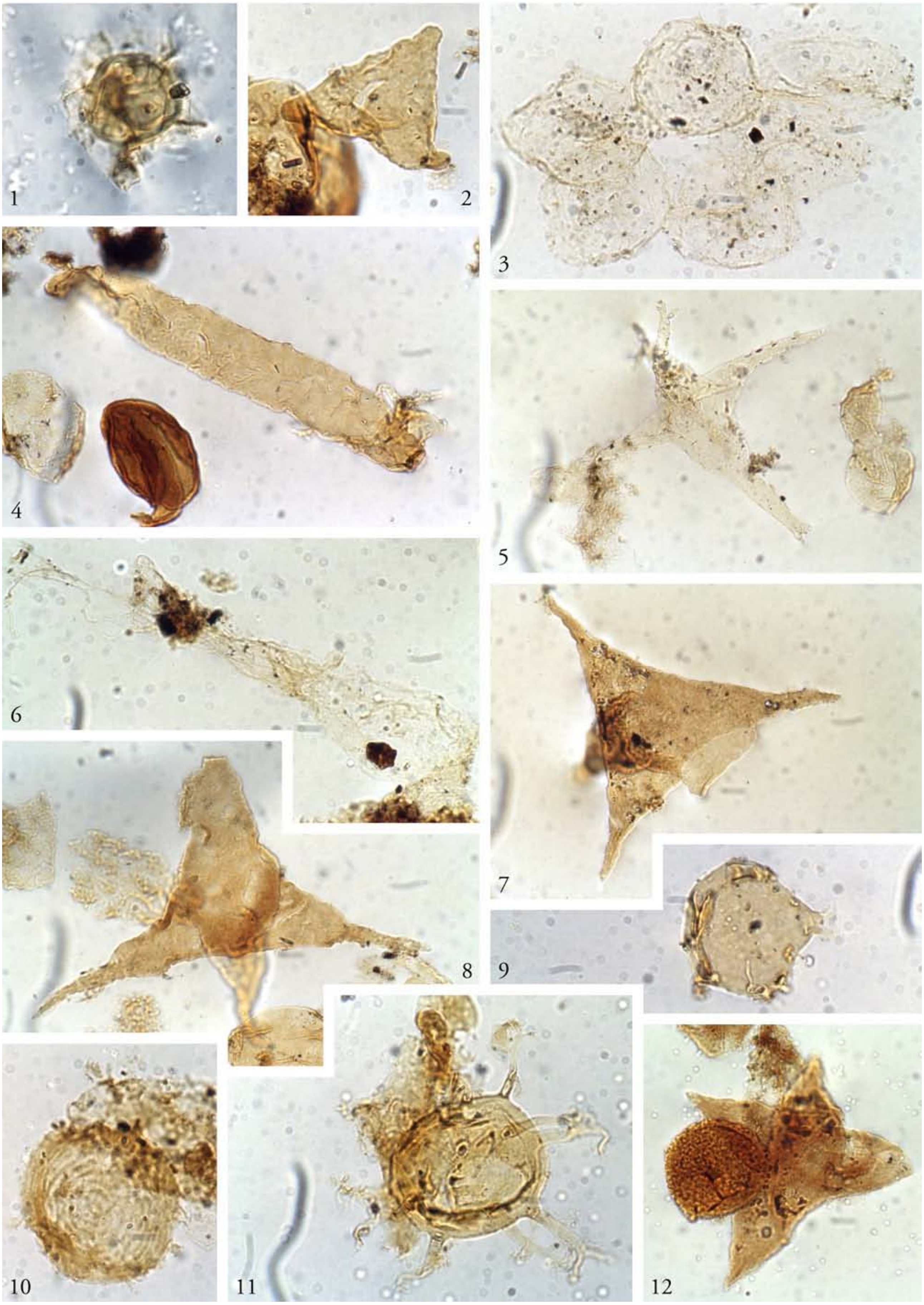
Figs.7, 8. " *Veryhachium* " *exasperatum* Deunff, 1955. La Escalera. 7. Pl.37 (F43.4), x1000, 8. PL37 (N46.2), x1000

Fig. 9. *Duvernayspahaera tenuicingulata* Staplin, 1961. La Escalera, Pl29 (056.1), x1000

Fig. 10. *Chomotriletes vedugensis* Naoumova, 1953. La Escalera, Pl17 (040), x1000

Fig.11. *Oppilatala sparsa* Wicander and Wood, 1981. La Escalera, Pl17 (R43.4), x1000

Fig.12. *Estiastra rhytidoa* Wicander and Wood, 1981. La Escalera, Pl17 (K50.3), x1000 . Remark : this form was named " *Veryhachium* " *libratum* by Deunff in 1957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MIOSPORES

Philippe STEEMANS and Maurice STREEL

The present report deals only with miospores.

We have only a few comments to make on these quantitative results.
The number of miospores / gram is often about ten time lower in La Candelaria (Tabl. 11) than in La Escalera (Tabl. 12). This might be interpreted as a more distal position in the basin of Candelaria samples compared to the Escalera ones. This is corroborated by the presence of acritarchs only in the La Candelaria samples.
The relative frequencies of the miospores in the investigated assemblages is of limited use because 80% of the specimens are species with a simple morphology belonging to *Retusotriletes*, *Punctatisporites*, and *Apiculiretusispora* genera. These species have no biostratigraphical interest and therefore they have been ignored.
The diagnostic miospores recorded in each slide are not numerous enough (Tabl. 11, 12) to allow counting with a statistical value (the preparations made in Liège University in similar material contain several thousand spore per slide). Moreover, many slides contain aggregated miospores preventing their detailed counting. For quantification purpose, the slides must be mounted from a well-washed residue, filtered several times, and using a dispersing agent.

Comments of F. Paris:

*the purpose was not to quantify the spores only. The actual goal of the quantification was to have the closest idea of the full composition of the organic residue. For that reason, and even if it is far to be perfect, the same standard procedure was used for all the processed samples. A specific treatment, concentrating selectively a single palynomorph group, may have introduced biases preven*ting *a correct application of the counting for palaeoenvironmental purposes.*

It must be stressed that many of the recovered organic residues contain more than 95% of cuticles and other plant remains

La Candelaria	Nb miosp./slide	Weight/slide	nb miosp./gram
T01-01	258	0,059	4377
T01-02	520	0,206	2524
T01-03	408	0,588	694
T01-04	133	0,196	676
T01-05	163	0,222	735
T01-06	182	0,172	1058
T02-LM.01	82	0,238	343
T03-07	88	0,034	2590

Tabl. 13: Abundance of the miospore taxa recorded in the La Candelaria section (TO1-TO3)

La Escalera	Nb miosp./slide	Weight/slide	nb-miosp./ gram
TESC01 PL.16	517	0,021	24596
TESC01 PL.17	781	0,032	24395
TESC01 PL.18	599	0,03	19957
TESCO1 PL.19	628	0,035	17944
TESCO1 PL.20	904	0,025	36157
TESCO1 PL.21	411	0,021	19565
TESCO1 PL.22	305	0,135	2261
TESCO1 PL.23	475	0,031	15337
TESCO1 PL.24	634	0,095	6673
TESCO1 PL.25	329	0,029	11334
TESCO1 PL.26	822	0,059	13928
TESCO1 PL.27	475	0,13	3657
TESCO1 PL.27A	153	0,014	10901
TESCO1 PL.28	452	0,085	5317
TESCO1 PL.29	182	0,111	1639
TESCO1 PL.30	158	0,018	8804
TESCO1 PL.31	434	0,036	12065
TESCO1 PL.32	200	0,034	5870
TESCO1 PL.33	276	0,033	8360
TESCO1 PL.34	200	0,017	11739
TESCO1 PL.35	200	0,033	6047
TESCO1 PL.37	393	0,018	21848
TESCO2 PL.03	10	0,926	11
TESCO2 PL.2	133	0,104	1275
TESCO2 PL.1	265	0,122	2173

Tabl. 14: Abundance of the miospore taxa recorded in the La Escalera section (TESCO1 and TESCO2)

1- Quantitative analysis

The number of miospores per gram in each sample is given above (Tabl. 13 and 14).

2- Qualitative analysis

Miospores are well preserved (the colour is yellow – brown) but the material is often folded or broken, making sometimes identification difficult.

All characteristic taxa* belong to the Eifelian / Givetian and adjacent stages.
The alphabetic list of these taxa is given below (tabl. 13) with their author(s) and stratigraphic significance (see Streel et al. 1987, Streel et al. 2000 and Loboziak and Melo 2002)

*Many specimens belonging to different species of the genera *Retusotriletes*, *Punctatisporites* and *Apiculiretusispora* are present. They have no stratigraphic significance other than Silurian to Devonian. They have not been taken into account.

The miospore biozones are explained below and their age assignment given.

Genera	Species	Biozones	Authors
Acinosporites	*acanthommamillatus*	AD preLem-TA	Richardson 1965
Acinosporites	*apiculatus*	AP-TA	(Streel) Streel 1967
Acinosporites	*lindlarensis*	FD-TA	Riegel 1968
Camarozonotriletes?	*concavus*	AD preLem-»Fr»	Loboziak & Streel 1989
Chelinospora	*ligurata*	AD Lem-»Fr»	Allen 1965
Chelinospora	*timanica*	AD Lem-»Fr»	(Naumova) Loboziak & Streel 1989
Diatomozonotriletes	*franklinii*	AB-TA	McGregor & Camfield 1982
Dibolisporites	*echinaceus*	BZ-»Fr»	(Eisenack) Richardson 1982
Dibolisporites	sp. A	(TA in Arabia)	
Geminospora	*lemurata*	AD Lem-»Fr»	(Balme) Playford 1983
Geminospora	*punctata*	AD preLem-»Fr»	Owens 1971
Grandispora	*daemonii*	(BM- «IV» but TA in Arabia)	Loboziak et al 1988
Grandispora	*douglastownense*	AP-AD Lem	McGregor 1973
Grandispora	*gabesensis*	AD preLem-»Fr»	Loboziak & Streel 1989
Grandispora	cf *inculta*	AD Lem-»Fr»	Allen 1965
Grandispora	*libyensis*	AD preLem-»Fr»	Moreau-Benoit 1980
Grandispora	*permulta*	uppermost AP-»Fr»	(Daemon) Loboziak et al. 1999
Grandispora	*protea*	AP Pro-»Fr»	(Naumova) Moreau-Benoit 1980
Grandispora	*tabulata*	(Tco - «IV» but AD lem in Arabia)	Loboziak et al 1988
Grandispora	*velata*	AP Vel-« Fr »	(Eisenack) McGregor 193
Hystricosporites	*mitratus*	AD Lem-« Fr »	Allen 1965
Rhabdosporites	*minutus*	FD-TA	Tiwari & Schaarschmidt 1975
Rhabdosporites	*parvulus*	?AP - «Fr»	Richardson 1965
Samarisporites	*eximius*	AP-ADLem	(Allen) Loboziak & Streel 1989
Samarisporites	*triangulatus*	TA-»IV»	Allen 1965
Verrucosisporites	*premnus*	AD preLem-»Fr»	McGregor & Camfield 1982
Verrucosisporites	*scurrus*	AD preLem-»Fr»	McGregor & Camfield 1982

Tabl. 15: Range of the most diagnostic miospores species recorded in the La Candelaria and La Escalera sections with regard to the global Devonian spore zonation.

“Fr” undefined Frasnian	
“Eif” undefined Eifelian	
“IV” Late Frasnian undefined zone	
BM Zone (*Verrucosisporites bulliferus-Lophozonotriletes media*)	Middle Frasnian
TCo Zone (*Samarisporites triangulatus–Chelinospora concinna*)	Givetian to Lower Frasnian
TA Zone (*Samarisporites triangulatus – Ancyrospora ancyrea ancyrea*)	Middle Givetian
AD Zone (*Acinosporites acanthomammillatus – Densosporites devonicus*)	
Lem (Interval Zone with *Geminospora lemurata*)	Early Givetian
Pre-lem (below the *Geminospora lemurata* Interval Zone)	Late Eifelian to basal Givetian
AP Zone (*Acinosporites apiculatus-Grandispora protea*,	
Vel (Interval Zone with *Grandispora velata*)	Middle Eifelian
FD Zone (*Emphanisporites foveolatus- Verruciretusispora dubia*)	Late Emsian
AB Zone (*Emphanisporites annulatus- Brochotriletes bellatulus*)	Middle Emsian
BZ Zone (*Breconisporites breconensis-Emphanisporites zavallatus*)	Early Emsian

Their stratigraphic extensions are also compared to the Devonian stages on figure 17.

The distribution of species/samples is given on diagrams (Figs. 15-16)

We have selected in the upper part of this (see) chart(s) the 11 taxa present in the La Candelaria section. None of these taxa occurs more recently than the AD pre-lem Zone. Therefore all these samples should belong to the Late Eifelian (or basal Givetian) .

Except *Acinosporites apiculatus*, they are also present in the La Escalera section.

In addition to these taxa, 18 other taxa are only present in the La Escalera section (TESCO 1). If we accept that some taxa (*G. daemonii* and *G. tabulata*) have the same stratigraphic distribution as in Arabia, none of these 18 taxa occurs more recently than the TA Zone. Therefore all these samples should belong to the Middle Givetian.

Material of TESCO2 might be very tentatively subdivided into an Eifelian PL.1 and a Givetian PL.2. but it should be noticed that this material is very poor making such conclusion almost hazardous.

In term of the conodont zonation, calibrated with the miospore zones in Western Europe, we suggest that the base of the Late Eifelian more or less correspond to the base of the *Tortodus australis* FOB (First occurrence biohorizon) and the base of the Middle Givetian more or less to the base of the *Polygnathus ansatus* FOB.

3- Comparison with the PARAPETTI-2 well

17 on the 25 species recorded in the PARAPETTI-2 well are also present in the La Candelaria and La Escalera sections (considering that the taxa *Samarisporites praetervisus* in PARAPETTI-2 should be better assigned to Samarisporites eximius).

LA CANDELARIA	*Acinosporites acanthomammillatus*	*Grandispora protea*	*Grandispora gabesensis*	*Dibolisporites echinaceus*	*Verrucosisporites premnus*	*Grandispora douglastownense*	*Samarisporites eximius*	*Emphanisporites rotatus*	*Acinosporites lindlarensis*	*Acinosporites apiculatus*	*Camarozonotriletes ?concavus*	*Diatomozonotriletes franklinii*	*Geminospora punctata*	*Grandispora velata*
TO3 - 07		❍		❍			❍						❍	❍
TO2 - LM-01	❍										❍	?		
TO1 - PL06	❍	❍	❍	❍			❍	❍	❍	❍	❍			
TO1 - PL05	❍	❍		❍	❍									
TO1 - PL04	❍	❍	❍											
TO1 - PL03		❍			❍	❍								
TO1 - PL02	❍		❍	❍										
TO1 - PL01	❍	❍	❍											

Fig. 16: Range of the miospore taxa recorded in La Candelaria section (TO1-TO3)

LA ESCALERA **TESCO1**	*Geminospora lemurata*	*Samarisporites eximius*	*Grandispora daemonii*	*Grandispora gabesensis*	*Acinosporites lindlarensis*	*Acinosporites acanthomammillatus*	*Emphanisporites rotatus*	*Dibolisporites echinaceus*	*Camarozonotriletes ?concavus*	*Geminospora punctata*	*Rhabdosporites parvulus*	*Diatomozonotriletes franklinii*	*Grandispora libyensis*	*Grandispora protea*	*Grandispora douglastownense*	*Chelinospora timanica*	*Rhabdosporites minutus*	*Samarisporites triangulatus*	*Grandispora velata*	*Dibolisporites sp. A*	*Grandispora permulta*	*Chelinospora ligurata*	*Hystricosporites mitratus*	*Grandispora cf inculta*	*Camarozonotriletes sp. A*	*Verrucosisporites scurrus*	*Grandispora tabulata*
PL. 16	❍									❍				❍	❍	❍			❍			❍				❍	❍
PL. 17														❍								❍				❍	
PL. 18																❍					❍					❍	
PL. 19	❍	❍				❍					❍					❍			❍			❍	❍			❍	
PL. 20		❍			❍									❍	❍	❍						❍	❍				
PL. 21						❍	❍	❍	❍	❍						❍	❍		❍		❍					❍	
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PL. 25	❍	❍						❍		❍		❍			❍	❍			❍					❍			
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PL. 27A	❍	❍								❍				❍				❍									
PL. 28	❍						❍			❍				❍						❍							
PL. 29	❍	❍					❍												❍								
PL. 30		❍	❍	❍			❍		❍	❍	❍			❍	❍	❍	❍	❍									
PL. 31		❍			❍								❍														
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TESCO2																											
PL. 1				❍						❍				?													
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Fig. 17: Range of the miospore taxa recorded in the lower «La Escalera» section (TESCO2) and in the upper «La Escalera» section (TESCO1)

On the 21 samples studied in PARAPETTI-2, only 4 were core samples, all the other being from cuttings. None of the miospores present in these 4 core samples occurs more recently than the AD pre-lem Zone and should correspond therefore to a Late Eifelian (or basal Givetian) age, being correlable with the La Candelaria section. Taxa of Givetian age are only present in the cuttings and should correspond to caving material.

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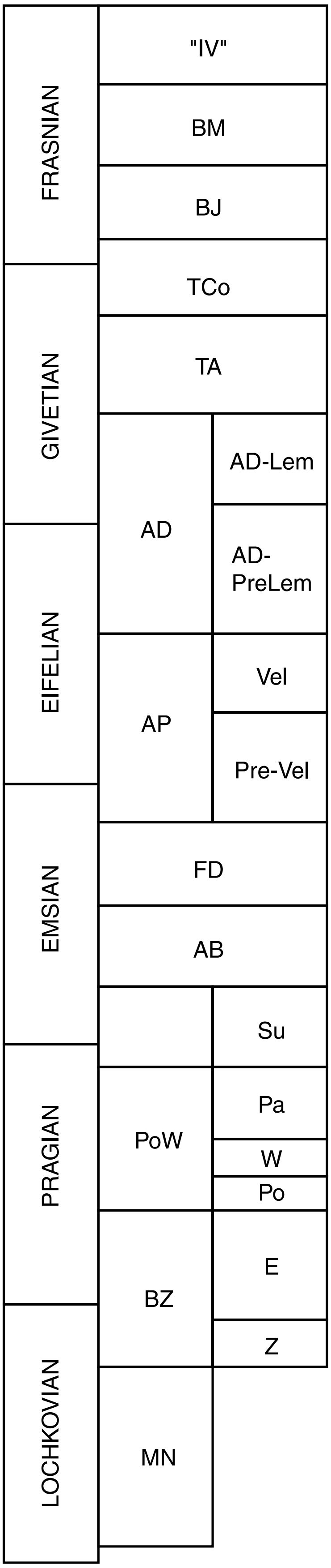


Fig. 18: Age assignment of the recorded miospore taxa in term of the standard miospore zonation

MIOSPORES

PLATES

Miospores from the La Candelaria (TO1-TO3) and La Escalera (TESCO1 and TESCO2) sections

Plate 10

The simple bar corresponds to 10 microns and the double one to 20 microns

Fig. 1: *Acinosporites acanthomammillathus*, T02-LM.01, (M39)

Fig. 2: *Acinosporites acanthomammillathus*, T01-PL.01, (K44)

Fig. 3: *Acinosporites lindlarensis*, TESCO1-PL.31, (F37/1)

Fig. 4: *Acinosporites lindlarensis*, TESCO1-PL.34, (O58/3)

Fig. 5: *Camarozonotriletes concavus*, TESCO1-PL.32, (G55/1)

Fig. 6: *Diatomozonotriletes franklinii*, TESC01-PL.35, (M46)

Fig. 7: *Geminospora lemurata*, TESC01-PL.37,(O53/3)

Fig. 8: *Grandispora* cf. *protea*, TESC02-PL.1, (M44/2)

Fig. 9: *Grandispora daemoni*, TESC02-PL.2, (R47)

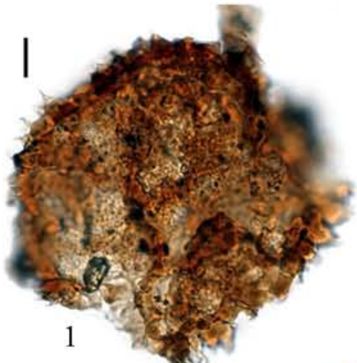
Fig. 10: *Grandispora daemoni*, TESC01-PL.37, (C44)

Fig. 11: *Grandispora gabesensis*, TESC01-PL.34, (S36/1)

Fig. 12: *Grandispora libyensis*, TESC01-PL.31, (E46)

Fig. 13: *Samarisporites eximiu*s, TESCO1-PL.31, (N46)

Fig. 14: *Samarisporites eximius*, TESCO1-PL.31, (K43/1)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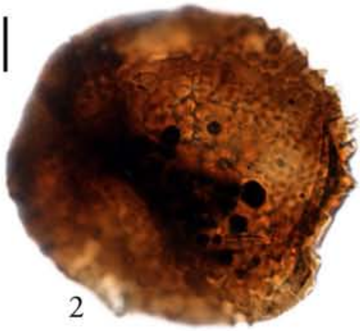
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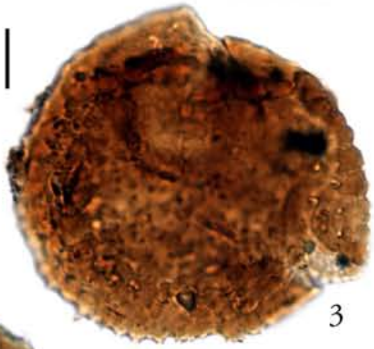
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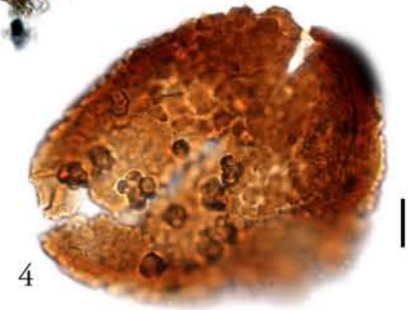
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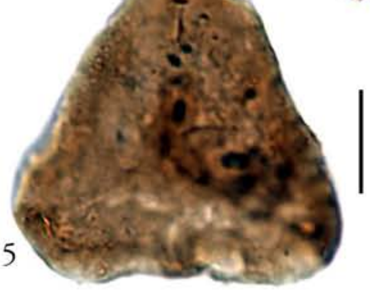
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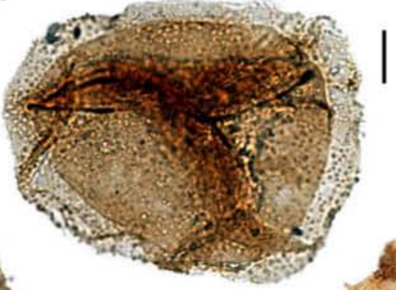
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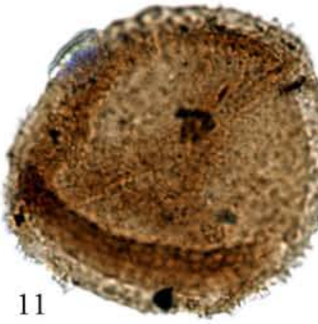
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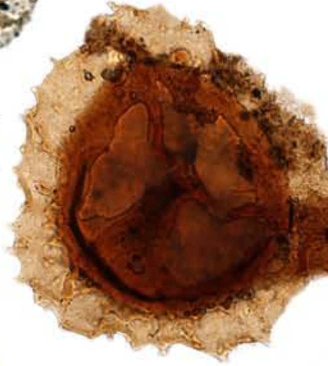
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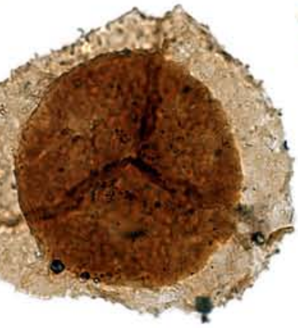
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Miospores from the La Escalera section (TESCO1)

Plate 11

The simple bar corresponds to 10 microns and the double one to 20 microns

Fig. 1: *Camarozonotriletes concavus,* TESC01-PL.30, (H30/1)

Fig. 2: *Chelinospora ligurata* , TESC01-PL.26, (O38/2)

Fig. 3: *Dibolisporites* sp. A , TESC01-PL.28, (G56)

Fig. 4: *Geminospora punctata*, TESC01-PL.27A, (T45/1)

Fig. 5: *Grandispora douglastownense*, TESC01-PL.20, (P39/2)

Fig. 6: *Grandispora gabesensis*, TESC01-PL.30,(K49)

Fig. 7: *Grandispora inculta*, TESC01-PL.25, (47/3)

Fig. 8: *Grandispora daemoni*, TESC01-PL.30, (D42/4)

Fig. 9: *Grandispora*, TESC01-PL.24, (R36/4)

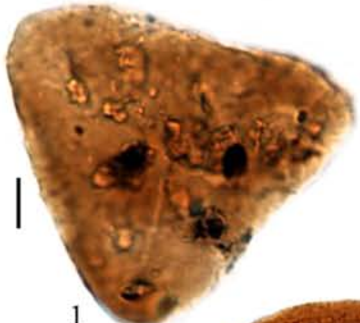
Fig. 10: *Grandispora*, TESC01-PL.24, (R36/4)

Fig. 11: *Hystricosporites mitratus*, TESC01-PL.20, (O51)

Fig. 12: *Hystricosporites mitratus*, TESC01-PL.26, (K38)

Fig. 13: *Samarisporites triangulatus*, TESC01-PL.27A, (Q51)

Fig. 14: *Samarisporites triangulatus*, TESC01-PL.30, (U38)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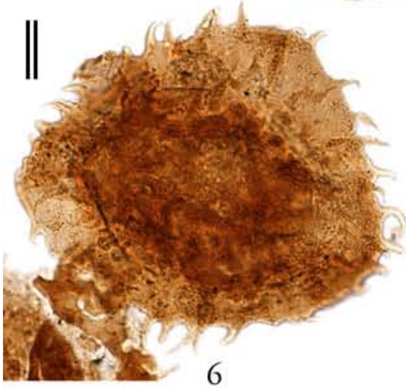
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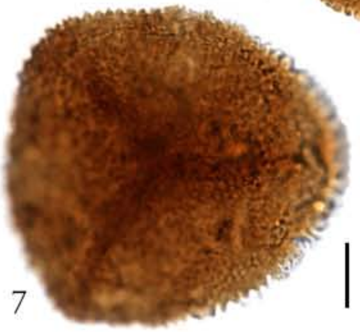
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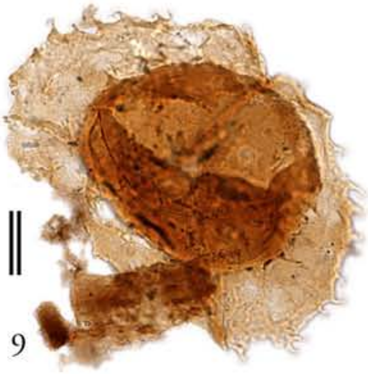
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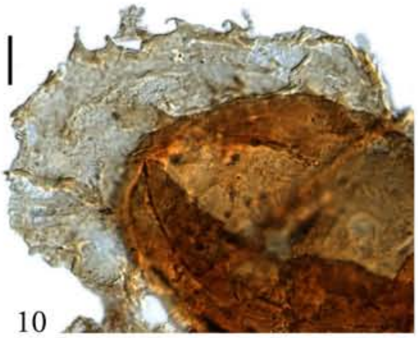
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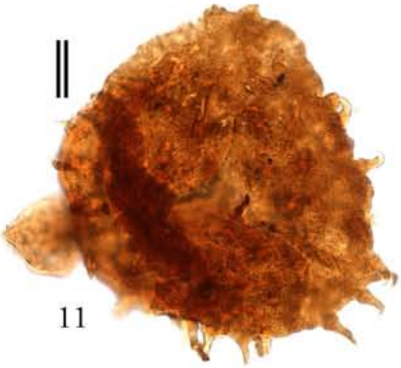
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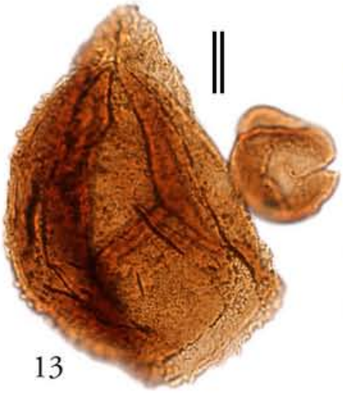
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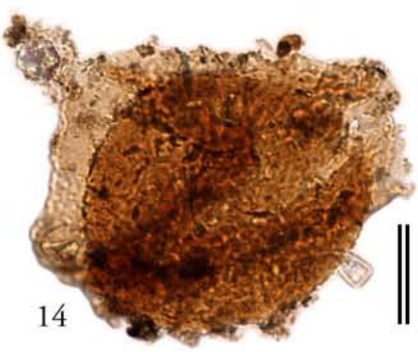
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Miospores from the La Escalera section (TESCO1)

Plate 12

The simple bar corresponds to 10 microns and the double one to 20 microns

Fig. 1: *Chelinospora ligurata*, TESC01-PL.17, (W41/3)

Fig. 2: *Chelinospora timanica*, TESC01-PL.18, (41)

Fig. 3: *Chelinospora timanica*, TESC01-PL.18, (41)

Fig. 4: *Geminospora lemurata*, TESC01-PL.16, (R45/3)

Fig. 5: *Geminospora pnuctata*, TESC01-PL.16, (T54/4)

Fig. 6: *Grandispora permulta*, TESC01-PL.18, (M43/3)

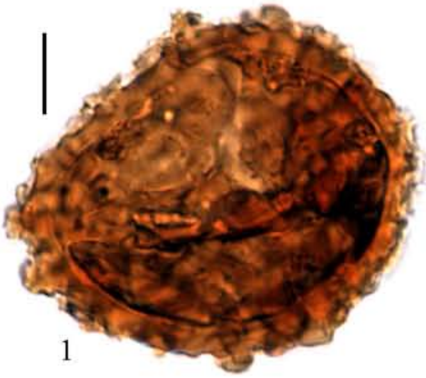
Fig. 7: *Grandispora protea*, TESC01-PL.16, (G40/2)

Fig. 8: *Grandispora tabulata*, TESC01-PL.16, (S54/1)

Fig. 9: *Grandispora velata*, TESC01-PL.16, (K40/2)

Fig. 10: *Verrucosisporites scurrus*, TESC01-PL.16, (P51/4)

Fig. 11: *Verrucosisporites scurrus*, TESC01-PL.18, (S47/4)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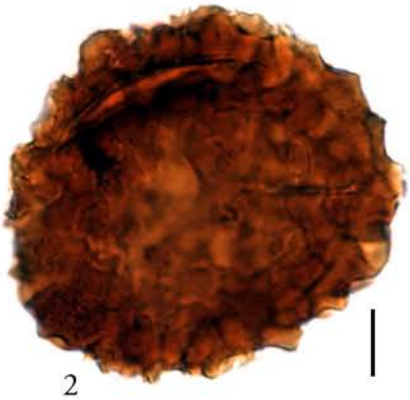
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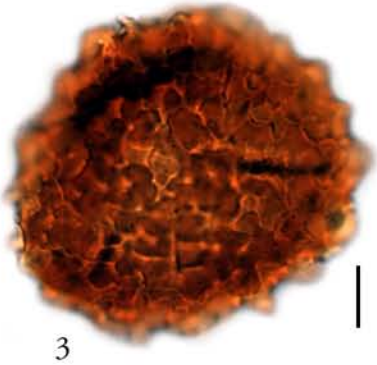
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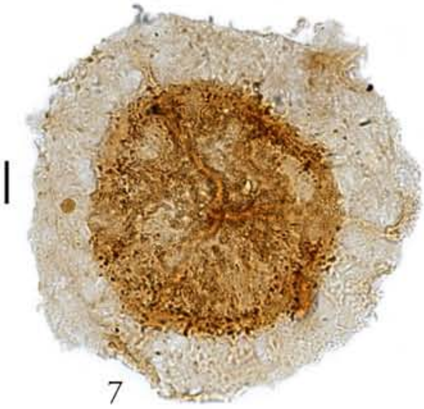
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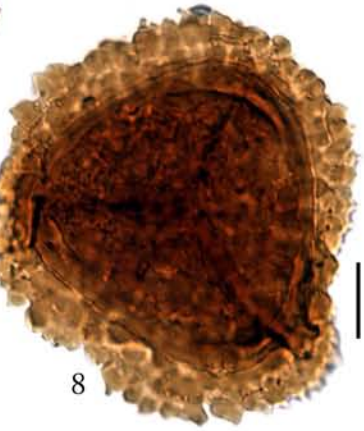
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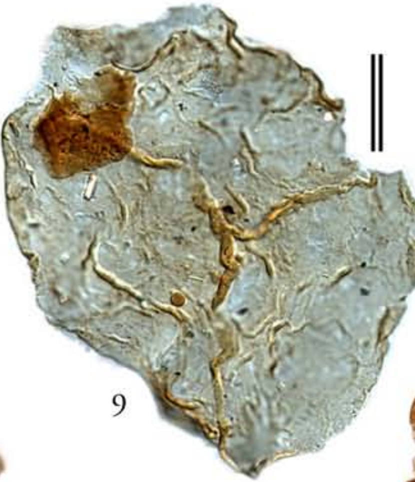
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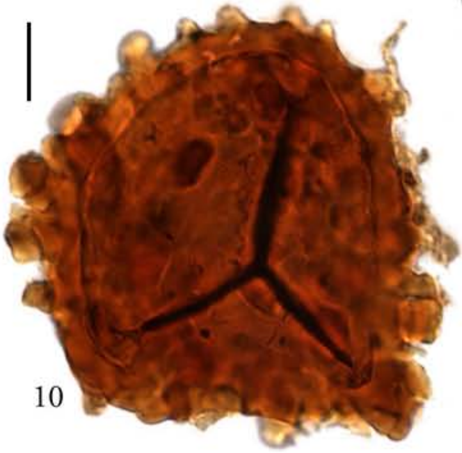
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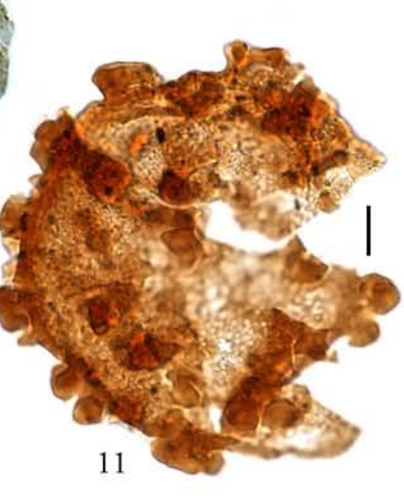
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TERRIGENOUS FACIES STUDY:

Identification of source materials.

Marie Pierre DABARD

1- Introduction

The purpose of this study is to characterize the mineralogical composition of terrigenous sediments located in the Escalera section and in the Candelaria section and to compare them. In a second time, the identification of the source areas is investigated.

The work is based on analyses of 33 whole-rock thin sections (26 from the Escalera and 7 from the Candelaria) and 18 sections of heavy minerals residus from palynological analyses (15 from the Escalera and 3 from the Candalaria). Samples were chosen according to granulometric factor, and are mainly represented by sandstones, coarse siltstones and laminated siltstones (see list in table 15). Only more significative results have been listed in tables 18 and 20. Modal analyses have been performed of the three coarser sandstones on 500 points according to the method of Dickinson and Suczek (1979).

2- Mineralogical compositions

(Tables 16, 17 and 18, and plate 13)

The mineralogical composition of studied sediments is dominated by terrigenous elements, carbonated contribution is poorly represented (Table 18) and only as cement.

Main detrital grains

In the Escalera section, studied samples are from the TESCO1 section, TESCO1-PL.01 to TESCO1- PL.29, with one part (PL.16 to PL.29) located in the stratigraphic log (see Fig. 5). The detritic grains of sandstones and coarse siltstones are monocrystallin quartz, feldspar, mainly orthoclase sometimes pertithic, microcline and plagioclase and some black feldspars, and micas (muscovite and biotite) with minor amounts of lithic fragments (quartz and feldspar, quartz and micas) and polycristalline quartz. Locally myrmekite (e.g. TESCO1 PL.11 and 13) and clasts with microcristalline texture (e.g. TESCO1-PL.05, LM.09) have been observed. In the TESCO1-PL.04 sample, these clasts are associated with euhedral quartz.
Modal analyses performed on 3 sandstones (Table 17) confirm the quartz enrichment (75 to 78% of detrital grain) and the prevalence of potassic feldspar (11 to 14%) on the plagioclase (4 to 7%). These coarse facies can be related to subarkoses according classification of Pettijohn et al. (1973).

In the Candelaria section, studied samples are from the base of the section (2m to 13,6m) and are represented by coarse siltstones and very fine sandstones. The main detritic grains are monocrystallin quartz, muscovite, biotite more or less chloritized, and minor amounts of feldspar (orthoclase sometimes pertithic, microcline, plagioclase).

Heavy minerals

In the two sections, the more abundant heavy minerals are tourmaline and zircon (Table 18). Main of the tourmaline grains are brown, green to yellow and can be related to ferromagnesian tourmaline (dravite and schorlite). In numerous samples, some blue grains of indicolite have been observed. Zircon grains are also ubiquist but a little less abundant. The minerals are various, some have sharp edges, others are rounded. Some are transparent and devoid of internal features, others show anatectic cores, inclusions... Many of them could be linked to K-calc-alkaline and subalkaline series granites according to the typologc classification of Pupin (1985). Zircons from crustal anatectic origin seem less frequent.

The second group of heavy minerals is composed of titaneous minerals, rutile, brookite and anatase. Some rare monazite, epidote and staurotide have been observed in the Escalera section.

Cement/Matrix

Cements, authigenic minerals and fine-grained matrix have also been observed in the two sections samples. Different types of cement have been observed. Quartz overgrouth is the most common silica ciment, the shape of the original grain is delineated by a clay or an oxide coating between the overgrowth and the grain (TESCO1-LM.13). Feldspar overgrouths occur on detrital feldspar grains (TESCO1-PL.9), especially around potash feldspars. Hematite can be abundant in some sandstones from the Escalera section. The absence of hematite coatings at grains contacs indicates a diagenetic origin. Carbonate cement is locally observed (TESCO1-LM.06, PL.09, PL.13, TO2-LM.01). Some clays (authigenic ?, detrital ?) are also present.

3- Comparison between the two sections

The compositions of detritic grains are relatively homogeneous along and between the two sections with the prevalence of monocrystallin quartz, potassic feldspars, plagioclase and micas. Presence of lithic fragments in the La Escalera section and their absence in the La Candelaria section could be related to the grain-size of studied samples. In fact, the detritic mineral composition is strongly size dependent and rock fragments abundance is rapidly decreasing in the very fine sandstones specially lithic fragments made of polycristalline quartz and micas plus quartz assemblages. So, there is no evidence of difference in the detritic grains composition between the two sections.

4- Source areas and tectonic settings

The relative abundance of monocristallin quartz in the studied sandstones is typical of provenance from a continental block and/or mature recycled orogen. In fact two types of source area can be invoked. Presence of feldspar such as orthoclase and microcline, as well as polycristalline quartz, lithic fragments of quartz plus feldspar or quartz plus micas, all indicate the participation of plutonic and/or metamorphic source areas. Moreover, the quartz-prevalence suggests also the contribution of older sedimentary terrigenous rocks. The heavy minerals, with the tourmaline-zircon-Ti oxydes assemblage, confirms the influence of mature recycled orogen. Rare clasts with microcristalline texture may indicate a discrete volcanic contribution but it must be confirmed.

In the surrounding geology, two potential source-areas could be invoked. At the north-east of studied sections (Pareja et al. 1978), the central Brazil shield and specially the Rondonian belt (1,3 Ga - 1.0 Ga), which contains granulites, gneiss and schist belts with extensive younger granitoid intrusions (Goodwin 1996), could have contribued to the plutonic/metamorphic material supply; the numerous quartz-grains observed in the studied samples could be derived from the mid-proterozoic sedimentary rocks. Nevertheless, this quartz-enrichment could also be linked to the contribution of Ordovician-Silurian sedimentary formations located at the west of the studied sections.

5- Conclusion

Mineralogical study of the La Escalera and Candelaria sections shows that terrigenous sediments have homogeneous compositions dominated by monocristalline quartz and potassic feldspars. The clastic supply is derived from the reworking of an old basement which could be related to the central Brazil shield, contribution of early Palaeozoic sediments however cannot be ruled out.

For tables 18 to 21, see the annex.

Recommendations

Here are some recommendations for identifying and locating more precisely of the source-areas of the studied sediments.

* The detritic mineral composition is strongly size dependent and rock fragments abundance is rapidly decreasing in the fine facies. So, it would be preferable to sample coarse facies, like sandstones, with constant granulometry.

* Microcrystalline textures are developped in rocks of different compositions (e.g. lavas, chert) so it could be interesting to use defocused beam microprobe analysis to precise chemical composition of microcrystalline texture fragments.

* In this work, contribution of early Palaeozoic sedimentary formations is invoked. A sampling of their terrigenous facies could provide informations on their composition.

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Mineralogical composition of the sandstones

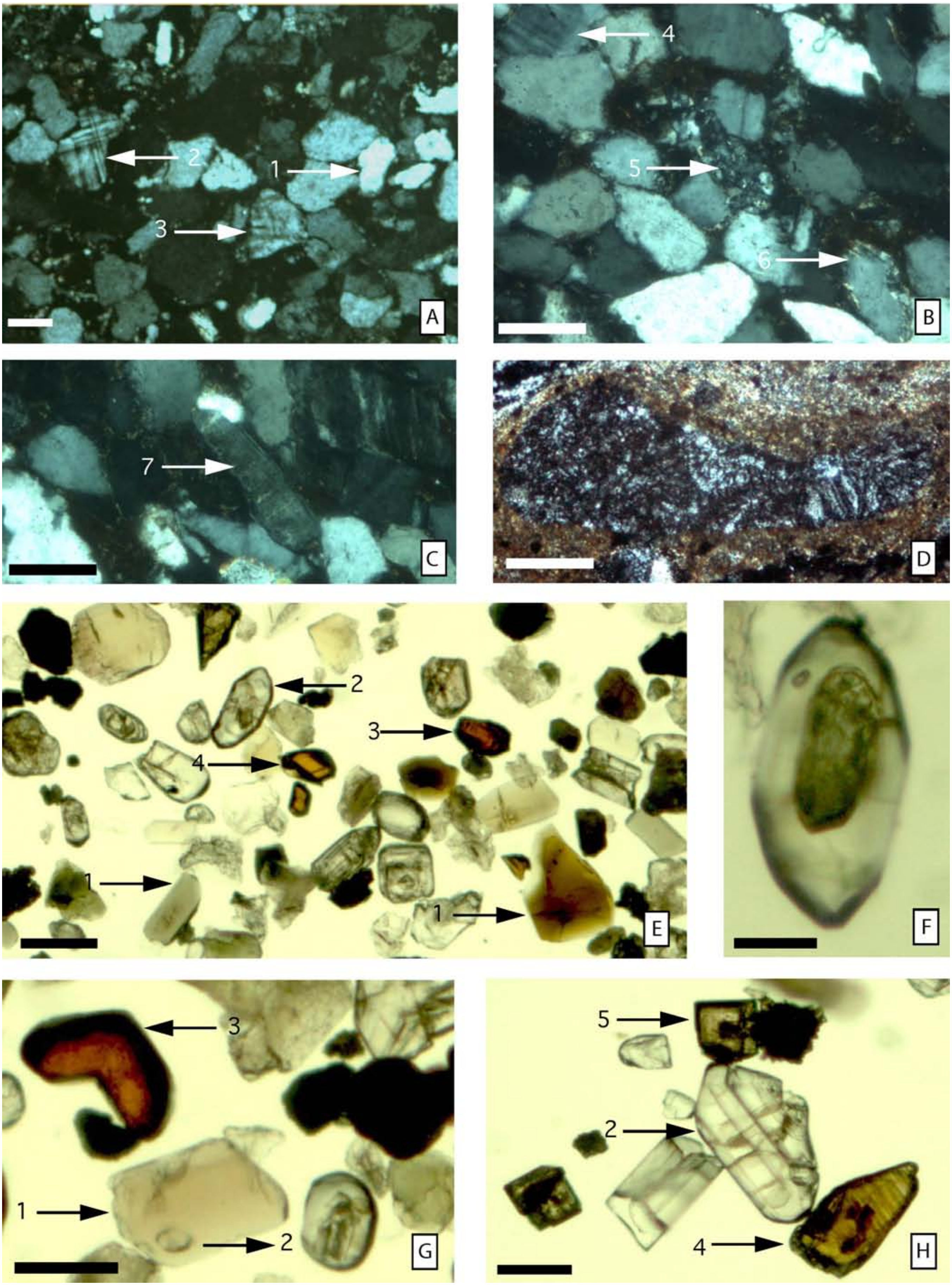
Plate 13

A, B, C: Common aspect of the sandstone. Quartz (1), microcline (2), orthoclase perthitic (3), plagioclase (4), lithic fragment with quartz and micas (5), quartz grain with clay coating (6), orthoclase with feldspar overgrowth (7).

D: silcrete (?) or volcanic (?) fragment (XPL, scale bar = 100_m).

E, G, H: Example of tourmaline (1), zircon (2), rutile (3), brookite (4) and anatase (5).

F: zircon grain with anatectic core (PPL, scale bar = 50__m)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PALAEOENVIRONMENTS

The organic-walled microfossils recovered from the La Candelaria and La Escalera samples have been quantified. The abundance of each group, expressed in number of specimens per gram of rock (Figs. 6-8, 11-13, Tabl. 13-14), and the relative frequencies at species level for the chitinozoans (Tabl. 4-6), and at generic level for the acritarchs (Tabl. 7-9) have been calculated.

The ratio of marine elements (acritarchs, chitinozoans) versus land-derived palynomorphs (miospores, plant debris) gives a fairly close idea of the environment of the setting area. The use of organic-walled microfossils as palaeoenvironment indicators during Palaeozoic time is based on some simple (obviously too simple when compared to the numerous implicated factors!) principles.

1) The abundance of land-derived elements (i.e., spores, cuticles, leaves, stems and/or woody fragments) in a sedimentary rock is regarded as a criterium of the proximity of emerged lands. During the Early-Middle Devonian, plants were likely growing in swamps along the sea-shore and along rivers. Thus the transport to the sea was mainly realized in suspension in water. The distribution of the plants remains in the marine sediment was made by coastal currents and through the seaward progradation of deltas fronts. In shallow basins the land-derived elements were concentrated near the shore, whereas in deep marine basins, the collapsing of the delta fronts was susceptible to transport them in a distal and deep environment position.

2) The acritarchs *stricto sensu* (i.e. excluding green algae such as tasmamites and probably a large number of the leiospheres) proliferate on the platform when nutriment supply was sufficient. Then the greatest diversity and abundance of the acritarchs is concentrated in the upper offshore, but in environments quite enough to allow their setting (silty to shaly deposits). Too high energy (e.g., storm, waves on the shoreface) provokes the winnowing of the light particles including the acritarchs and their transportation in deeper environment.

3) Chitinozoans are regarded as pelagic elements. Their distribution is not tightly linked to the depth of the marine environment. They occur in shallow environments (upper offshore) as well as is distal and deep environment e.g., lower offshore, slope (distribution similar to those of the graptolites). Their abundance is mainly controlled by the rate of sedimentation (e.g., starving sedimentation either during transgressions, or because of a setting far from the terrigenous sediment supply, are favourable for high abundances of chitinozoans; a selective winnowing under moderate hydrodynamic energy can concentrate the chitinozoans too).

4) Green algea such as tasmanites, prasinophytes, and most of the leiospheres develop in the lighted upper layer of the sea. They have a pelagic way of distribution and they grow as far as nutriment is available. Consequently, they may be very abundant in distal position where they coexist with chitinozoans only (e.g. early Devonian deposits of Bohemia), as well as in very near-shore environment.

The application of these palynological parameters to palaeoenvironmental reconstructions has been explained and tested on Early Devonian sequences by Baudu (1994), and by Baudu and Paris (1995).

La Candelaria

In the La Candelaria section, the oldest samples (T01-01 to T01-06) are referred to the «Argentinean Huamampampa type» (alternatively referred to the uppermost Icla Formation by Bolivian geologists).

The ratio acritarchs/miospores abundances ranges from 1.14 in T01-01 to 2.84 T01-06, whereas lower values close to 0.40 are obtained in T01-03 to T01-05. In the first and in the last sample, the abundance of the acritarchs exceeds those of the miospores and therefore suggests an open marine environment, probably middle to upper part of the upper offshore as plant remains are moderately present. The abundance of the chitinozoans, ranging from 32 to 133 is consistent with such environment. The high acritarchs/miospores ratio added to a significant increase of the number of the chitinozoans supports a short-lived sea-level rise in T01.06. A more distal position, or alternatively a selective winnowing of the lighter palynomorphs may explain the sudden and significant increase of the chitinozoan abundance in T02-LM.01 (argillaceous fine sandstone) with a concomitant drop of both the acritarch and the spore abundances (see Tabl. 22 in annex). A more «classical» assemblage is recorded immediately above, in the more silty T02-07sample (see Tabl. 1).

In conclusion, the palaeoenvironment, just below the base of the type Huamampampa Formation *stricto sensu*, **corresponded to the (middle ?) upper offshore**, with moderate land-derived plant remains and a fairly low abundance of the acritarchs (see Le Hérissé, above). A sea **level rise is likely in the basal part of the Huamampampa Formation**. This would be consistent with the dramatic change in the composition of the acritarchs and chitinozoan assemblages in sample T02-07.

La Escalera

The section termed here as «lower» La Escalera section (TESCO2) concerns a sequence within the Huamampampa Formation, and probably in it upper part. Only the oldest samples (TESCO2-PL01 and PL.2) have yielded both marine and land-derived microfossils (see Tabl. 2 and 22). Very limited palaeoenvironmental conclusion can therefore be drawn from the organic walled microfossils alone. The environment was quite similar to those depicted in the lower part of the La Candelaria section, i.e. corresponding to **an upper offshore setting**. The cuticle fragments were more numerous indicating either a closer location from the shore or an increased productivity of the land plants. The lack of marine palynomorphs in the younger samples collected in this section is due to a regressive trend (poor, or a lack of marine influence), to a coarser granulometry of the rock samples, and possibly to the recent weathering of the rock (see Tabl. 2).

The «upper» La Escalera section is much better documented, both in term of marine and of land-derived organic-walled microfossils (see Tabl. 3 and 22).

The most striking feature of the organic residues is the very high amount of well-preserved plant cuticles (see Pl. 5, figs. 3,5, 6-8). Another important feature is the very high chitinozoan abundance in the lower part of the section together with a very high abundance of the acritarchs and of the spores in sample TESCO1-PL.037 (respectively close to 12000 and to 22000 specimens per gram of rock (Tabl. 22). These samples correspond to the lower part of the Los Monos Formation (Fig. 5). Consequently, open marine conditions existed in this area during the lowermost part of the Los Monos Formation. The high amount of spores and cuticles in such marine environment is probably due to the existence of a delta bringing the land-derived elements far in the sea (to our knowledge, no evidence of a real oceanic domain has been documented on the south American craton). **The base of the Los Monos Formation corresponds to a significant but short-lived sea level rise with regard to the Huamampampa Formation. Higher up in the formation, the marine influence fades away progressively**. This is documented by the lowering of the chitinozoan abundances, by the very low abundances of the acritarchs (see Tabl. 9, and 22), and by the concomitant increase of the cuticle remains and of the spores ranging around 20000 to 30000 specimens per gram of rock in the upper part of the Los Monos Formation (Tabl. 14). It is worthy to note that the acritarchs/spores ratio is much below 0.1 all along the section. **This evolution of the composition of the palynomorph assemblages is representative of a general regressive trend**.

Rennes October 2003

List of the figures and tables

Tables in annexes

(Excel files, excepted *: WORD tables)

tions on the organic and mineral content of the investigated samples from the upper «La Escalera» section (TESCO1)

Tabl. 4: Range, relative frequencies, and abundance of the chitinozoan taxa recorded in «La Candelaria» section (TO1-TO3) (Bolivia)

Tabl. 5: Range, relative frequencies and abundance of the chitinozoan taxa recorded in the lower «La Escalera» section (TESCO2) (Bolivia)

Tabl. 6: Range, relative frequencies and abundance of the chitinozoan taxa recorded in the lower «La Escalera» section (TESCO1) (Bolivia)

Tabl. 7: Range, Abundance and relative frequencies of the main acritarch and prasinophycean phycomata genera recorded in the La Candelaria section (TO1-TO3)

Tabl. 8: Range, relative frequencies, and abundance of the acritarchs genera recorded in the «lower» La Escalera section

Tabl. 9: Range, relative frequencies, and abundance of the acritarch taxa recorded in the «upper» La Escalera section

Tabl. 10: Range of species of acritarchs and prasinophycean phycomata in La Candelaria section (T01-T03)

Tabl. 11: Range of species of acritarchs and prasinophycean phycomata in the «lower» La Escalera section (TESCO2)

Tabl. 12: Range of species of acritarchs and prasinophycean phycomata in the «upper» La Escalera section (TESCO1)

Tabl. 13*: Abundance of the miospore taxa recorded in the «La Candelaria» section (TO1-TO3)

Tabl. 14*: Abundance of the miospore taxa recorded in the «La Escalera» section (TESCO1 and TESCO2)

Tabl. 15*: Range of the most diagnostic miospores species recorded in the La Candelaria and La Escalera sections with regard to the global Devonian spore zonation

Tabl. 16: Range of the miospores recorded in the «La Candelaria» section

Tabl. 17: Range of the miospores recorded in the «La Escalera» sections (TESC01, and TESC02)

Tabl. 18*: List of the studied samples

Tabl. 19a-c*: Petrology and main constituents of the investigated samples

Tabl. 20*: Ratio cement/matrix and detrital grains in 3 samples from the La Escalera section

Tabl. 21*: Nature and relative abundance of heavy minerals in some selected samples from the La Escalera and La Candelaria sections (++: abundant, +: present, -: rare)

Tabl. 22*: Compared abundances (expressed as number of specimens per gram of rock) of the chitinozoans, the acritarchs and the miospores recorded in the Candelaria and in the La Escalera («lower» and «upper») sections. The abundance of the associated land plant cuticles is broadly evaluated as extremely abundant (++++), abundant (++), or present (+).

ANNEXES

Tabl. 1-12, 16 and 17 (Excel files)
and
Tabl. 18-22 (WORD documents)