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CAN FLUORESCENCE BE HELPFUL TO DISCRIMINATE BETWEEN INDIGENOUS TAXA OF CARBONIFEROUS AGE FROM THOSE REWORKED OF MID-UPPER DEVONIAN ROCKS?

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ABSTRACT

Terrestrial spores and pollen grains and microplankton of fresh- to marine water environments may exhibit bright yellow to weak orange, red and brown colors of autofluorescence. When palynomorphs fluoresce with good intensities, usually associated to well- preserved specimen, fluorescence microscopy is a useful tool for their morphologic characterization revealing features not visible with light microscopy. On the contrary, the lack of fluorescence in palynomorphs exposes preservation effects linked to their taphonomic history. On the other hand, reworked palynomorphs are those that have been eroded from older sedimentary rocks and then deposited in younger sedimentary basins. They are useful in deciphering base-level variation, diastrophism, and provenance. Several authors have suggested the use of autofluorescence as a tool to recognize reworked palynomorphs. In this work, the power of fluorescence microscopy is evaluated as a tool to differentiate indigenous from reworked palynomorphs in samples of Late Famennian age from USA bearing indigenous *Retispora lepidophyta,* and in samples of Carboniferous age from Bolivia and northern Argentina bearing Devonian reworked taxa (including *R. lepidophyta*). Additionally, a sample of Miocene age from Peru bearing reworked taxa of Late Famennian age is analyzed. Standard palynologic methodologies were applied. Selected residues were also oxidized in order to test the effects of oxidation on fluorescence. The performance of fluorescence in slides mounted in permanent, semi-permanent and temporary conditions with different mounting media (e.g. jelly-glycerin, UV-curable acrylateTrabasil NR2, Cellosize/Entellan, Canadian Balsam, Norland NOA60, glycerin sealed with paraffin, and water) was also tested. This study reveals that *R. lepidophyta* exhibits autofluorescence colors from yellow to orange up to black (non-fluorescent) independently of its **indigenous** or **reworked** (**I-R**) condition. Besides, microplankton species generally yielded lighter colors with higher intensities of autofluorescence than that of monosaccate pollen grains and spores, in this order. This observation does not depend of the I-R nature of taxa. The

results of this contribution confirm that autofluorescence depends on the original composition of the exine, as well as their source and taphonomic history, as previous studies indicate. Moreover, oxidation does not affect the fluorescence of palynomorphs, whether they are indigenous or reworked. Concerning the performance of different mounting media, we recommend the use of non-fluorescent Cellosize and Norland in permanent slides, glycerin in semi-permanent slides, and water in temporary slides. The jelly-glycerin, very used in many countries due to its accessibility, fluoresces with green color and hence, its use is not recommended. Our observations indicate that fluorescence microscopy is not an appropriate tool to differentiate indigenous and reworked palynomorphs. Instead, their differentiation must be based on the accurate taxonomic identification, and the most probable stratigraphic range of palynomorphs.

1 Introduction

Terrestrial spores and pollen grains, and fresh to marine microplankton may exhibit bright yellow to weak orange, red and brown color of autofluorescence, as the result of a photochemical reaction produced by the presence of specific compounds in the organic matter called "fluorophores" or "chromophores". Three factors may affect the intensity of primary fluorescence in palynomorph: 1- their biological nature, 2- their taphonomic history, and 3- their range of maturity (Lin and Davis, 1988). The biological nature of palynomorphs imprints an original response of color and intensity to ultraviolet (UV) (or blue light) depending on the different chemical compositions of their walls: sporopollenin in plant spores and pollen exines (e.g. carotenoids), dinosporin and other variants (e.g. telalginite, polysaccharides) in dinoflagellates, and chitin in other groups of palynomorphs, such as chitinozoans and scolecodonts (e.g. Brooks, 1971; Brooks and Shaw, 1978; Tyson, 1995; Traverse, 2008). The oldest chemical compound attributed to eukaryotic acritarchs documented in Precambrian rocks of c. 1.2–1.4 billion years old. Initially, the exine has probably played the role of protector of the protoplasm against ultraviolet radiation and oxygen (Traverse, 2008). The eukaryotic green algae are presumably responsible for the development of sporopollenin and for its introduction into the armament of higher green plants, where the principal functions are structural integrity, and protection against oxidation and desiccation. The natural color of the wall of palynomorphs is generally whitish and the intensity and color of autofluorescence is barely green to yellow but it changes to dark yellow, orange, reddish brown, and finally black mainly due to organic thermal maturity, and taphonomic processes also play an important role (Brooks and Shaw, 1978; Tyson, 1995; Traverse, 2008). Similarly, the structure of sporopollenin may undergo irreversible changes associated with the loss of hydroxyl group by dehydration and increasing aromaticity, producing a progressive red shift in fluorescence (Obermajer et al., 1999). Despite all changes suffered by fossil palynomorphs, their auto**fl**uorescence may persist for a long time, even at a geological time scale (Yang and Grote, 2018).

On the other hand, Hunt et al. (2007) postulated the autofluorescence color and intensity of palynomorphs could be affected by laboratory processes. Although, a full range of fluorescence colors could still be observed after applying cold HCl and HF in many studies (El Diasty et al., 2014; Ströther et al., 2017; Yang and Grote, 2018; Hoyle et al., 2018, and more references therein). Di Pasquo et al. (2016a) developed a study of spores from modern ferns living in the El Palmar National Park (Colón, Entre Ríos, Argentina). Depending on the species of fern and lycophyte analyzed, autofluorescence varied between yellow and dark orange, and no significant difference in the autofluorescence between acetolized and non-acetolized

specimens of the same species were reported (Fig. 1). Fluorescence microscopy can be applied with certainty for morphologic characterization of palynomorphs when they have good intensities, being a useful tool to reveal features not observed under white light microscopy, especially when they have thin walls (Traverse, 2008). Another application of fluorescence microscopy was proposed by some authors in order to recognize reworked palynomorphs (e.g. Batten, 1980; Traverse, 2008). The process of reworking of organic matter results from the erosion, transport, and redeposition of sediments bearing organic matter into younger sedimentary basins. This process may result in mixed assemblages of palynomorphs of different ages (Streel and Bless, 1980; Batten, 1991). Therefore, indigenous palynomorphs, also called autochthonous, are coetaneous to sedimentation while those coming from the erosion of older sedimentary rocks that are incorporated into younger deposits are called reworked. Both **autochthonous** and **reworked** (**I-R**) palynomorphs suffered different taphonomic processes that are preserved along with the thermal maturation suffered during diagenesis (fossilization process). Hence, their color and intensity of autofluorescence can be somewhat different in a single sample. Several authors have applied this technique with negative outcomes (e.g. Hoyle et al., 2018).

In this contribution, autofluorescence of palynomorphs is explored to find out its potential application to discriminate between: 1- indigenous species of Carboniferous age and reworked species of Middle and Late Devonian age in samples from Bolivia and northern Argentina; 2. Indigenous species of Late Famennian (Devonian) age, especially bearing *in situ Retispora lepidophyta* and allied spores and phytoplankton, in samples from USA; 3. Indigenous species of Miocene age and reworked taxa (*R. lepidophyta* and *U. saharicum*) of late Famennian age in a sample from Peru. The performance of palynomorph's fluorescence is analyzed in non-oxidized and oxidized residues, and in slides that were mounted employing different mounting media (e.g. jelly-glycerin, Trabasil NR2, Cellosize/Entellan, Canadian Balsam, Norland NOA60, glycerin sealed with paraffin, and water for temporary slides). Final recommendations are addressed.

2 Materials and methods

Autofluorescence of indigenous and reworked palynomorphs was explored in selected samples mainly of Mississippian and Pennsylvanian units from Bolivia and northern Argentina, and from latest Devonian units of USA and one sample of the Miocene from Peru. A more detailed information of materials studied in this work are given in the following sections. Equipment used for palynologic analysis and test of autofluorescence in this contribution are housed in the Laboratory of Palynostratigraphy and Paleobotany at the CICYTTP (CONICET-ER-UADER). Standard palynologic maceration of the samples was followed, applying HCl (25%) and HF (40%). Several washes with distilled water allowed the neutralization of residues. After a first revision of residues under the microscope, a small portion of HCl (10%) was added to productive residues to be boiled directly over a flame for 5-10 minutes. This is useful to remove clumps of organic matter and release palynomorphs and other components of the kerogen. Residues were then, sieved using 10 µm and 25 µm meshes. Fluorescence essays were performed in: 1- permanent slides employing jelly-glycerin (Traverse, 2008), Trabasil NR2 (see Noetinger et al., 2017), Cellosize/Entellan, Norland NOA60 and, Canadian Balsam as mounting media, 2- semi-temporary slides using glycerin as mounting media, and sealed with paraffin, and 3- temporary slides mounted in water. Few residues were also oxidized with HNO_3 (3 minutes) and ammonia to test the effects of oxidation under

fluorescence. The microscopic analysis was performed using a light microscope Leica DM500 bearing a fluorescence device (LED lamp, filter block for fluorescein ca. 450 nm). Microphotographs were taken with a Leica EC3 (3 Mp) video camera between years 2011 and 2015, and with an AmScope 14 Mp video camera since year 2015 till present. The AmScope software allows changing the time of exposition up to 2000 milliseconds and the gain between 1 and 3. In order to better illustrate the autofluorescence, these parameters were modified at the moment of capturing the specimens. In many cases, a filter BG38 included in the microscope was used to avoid authomatic modifications in the time of exposition and gain. It should be noted that the highest time of exposition and gain are required to photograph the highest level of autofluorescence, especially when palynomorphs have low intensities and dark color of fluorescence, as occurred with some spores. In extreme cases, it was necessary the combination of fluorescence and white light to get a good illustration of the specimens. In contrast, time of exposition and gain need to be reduced in order to allow morphologic observations when palynomorphs have high intensities of autofluorescence, as occurred with prasinophytes and acritarchs. These parameters are indicated in captions of illustrations. Additionally, selected pieces of rock of each sample were also processed using Sodium Hexametaphosphate. After few weeks, each residue composed of minerals and released palynomorphs were observed in a Petri dish. The palynomorphs were selectively picked under the Leica EC3 stereomicroscope using a steel needle or a very thin pipette (see description in di Pasquo et al., 2022). Selected specimens, especially megaspores, were mounted in slides with water and illustrated under the stereomicroscope with a Leica video camera (3 Mpx), as well as under the microscope with both white and fluorescence lights, before being transferred to stubs for SEM images in a Phenom Pro microscope (non metallized samples under low vacuum energy, see di Pasquo and Vilá, 2019). Studied samples are housed at the CICYTTP (CONICET-ER-UADER), labeled under the acronym CICYTTP-Pl for residues and slides of the rock samples (Paleopalynology collection), and CICYTTP-M for the collection of mega-microspore specimens picked from residues (see di Pasquo and Silvestri, 2014). England Finder (EF) coordinates were used to indicate the location of the illustrated specimens in permanent slides. A list of the taxa cited with their authorities is included after the list of references.

3 Brief geologic/paleontologic information of studied samples and its results

A brief geologic and palynologic background of each locality (Figure 2), as well as additional information of the studied materials, such as sampling and repository, along with the results obtained testing fluorescence of palynomorphs are described below.

3.1 Bolivia

In 1998 and 2000, Mercedes di Pasquo (MdP) and Dr. Jaime Oller from Pluspetrol S.A. carried out a palynostratigraphic survey of Devonian and Carboniferous units of the Tarija Basin in several localities in central and southern Bolivia (e.g., Balapuca, Alarache, Yesera norte, Canaletas, Samaipata, Angosto del Pilcomayo and Bermejo and Caigua, Los Monos, Taputá and Macharetí). They also sampled the Pando X-1 borehole (c. 80 samples) drilled in the Madre de Dios Basin. In 2007 and 2008, Devonian to Permian units were sampled at several localities across Bolivia with the finantial support of Spain (project IGME-Q2820007-I given to E. Díaz Martínez). In 2009, the responsible of the repository of the University of Idaho (Moscow, USA), Peter Isaacson, made a more detailed sampling of the Devonian-Carboniferous (DC) interval in the Pando x-1 borehole, based on the information aforementioned. These samples were

then delivered to MdP. In 2011, the whole Manuripi X-1 was sampled by MdP along with P. Isaacson and G. Grader during her stay at the University of Idaho (see di Pasquo et al., 2019a), where Pando and Manuripi X-1 boreholes are housed since 2001 till now. All the mentioned samples were processed and studied (see localities and references in Figure 2). A test of autofluorescence of Mississippian and Pennsylvanian indigenous palynomorphs and those from reworked rocks of Devonian age including *Retispora lepidophyta* was carried out in selected samples (surface and subsurface) from northern Argentina and Bolivia aforementioned (see di Pasquo, 2022, Figure 3).

3.1.1 Pando X-1 and Manuripi X-1 boreholes, Beni plain

A previous study of the Pando X-1 by Vavrdová et al. (1996) assigned the interval 1167 m - 1123 m to the Latest Devonian *Retispora lepidophyta* Zone (*R lep* Zone), and the interval 1095 m- to the Tournaisian *V. vallatus-R. incohatus* Zone, despite some doubts of the authors due to the recognition of older Devonian reworked palynomorps in the analyzed samples. Somewhat different ages were also given to similar interval samplings in unpublished reports for petroleum exploration summarized by Suárez Soruco (2000).

Di Pasquo et al. (2015b, see di Pasquo et al., 2019a) provided a new interpretation of the DC boundary in the Pando X-1 and Manuripi X-1 boreholes, considering the occurrence of exclusive Tournaisian and Visean taxa in the same samples bearing reworked *Retispora lepidophyta* and other Devonian palynomorphs (spores and microplankton). Therefore, from its base, the Manuripi X-1 was assigned to the mid-late Tournaisian between 1541-1387 m depth, based on the occurrence of spores *Anapiculatisporites ampullaceus, Cordylosporites papillatus, Crassispora scrupulosa, Cristatisporites echinatus, Dibolisporites setigerus, Foveosporites hortonensis, Raistrickia ponderosa, Reticulatisporites waloweekii, Secarisporites undatus, Spelaeotriletes balteatus,* and *Vallatisporites ciliaris.* This interval partially correlates with the *Spelaeotriletes pretiosus-Colatisporites decorus* Zone of Brazil and with the *S. pretiosus-Raistrickia clavata* and *Schopfites claviger-Auroraspora macra* Zones of Europe. Moreover, abundant reworked Devonian palynomorphs characterize this interval.

The 1328-1315 m interval of the Manuripi X-1 is composed of the persistent occurrence of *Cristatisporites menendezii* and *C. stellatus,* and the appearance of *Crassispora kosankei, Cristatisporites peruvianus, Indotriradites viriosus, Lycospora noctuina*, *Verrucosisporites morulatus* and few recycled Devonian palynomorphs. The indigenous taxa are diagnostic of the Tournaisian–early Visean in Bolivia, Peru, Argentina, North America, Europe, and Australia. The overlying interval c. 1300-1151 m is late Visean in age, based on the first appearance of *Reticulatisporites magnidictyus* (*Mag* Zone of Brazil). *Retispora lepidophyta* (reworked) is abundant in the 1432-1387 m interval, and persists up to 1151 m. Other reworked Devonian forms include *Ammonidium garrasinoi, Bimerga bensonii, Evittia sommeri, Grandispora pseudoreticulata, Hystricosporites porrectus, Kraeuselisporites explanatus, Maranhites* spp., *Samarisporites triangulatus,* and *Umbellasphaeridium saharicum.*

The interval between 1351-1240 m of the Pando X-1 is correlated to the mid-late Tournaisian interval 1541-1387 m depth of the Manuripi X-1, sharing similar palynologic features (di Pasquo et al., 2019a). Immediately below, from 1404 to 1360 m, the FAD (first appearance datum) of *Umbellasphaeridium saharicum* together with the absence of *Retispora lepidophyta* allow the attribution of an early Famennian age and the definition of a gap (hiatus) in between akin to the late Famennian *R lep* Zone. For more information about palynostratigraphic description of the Manuripi and Pando X-

1 boreholes and illustrations of selected I-R palynomorphs see di Pasquo et al. (2019a) and di Pasquo and Streel (2022, see Figure 4).

Till now, anyone tested autofluorescence as a tool to discriminate possible reworked palynomorphs from indigenous ones in samples from these boreholes. Hence, some intervals palynologically analyzed and published (see di Pasquo et al., 2019a and references), are studied in this work.

Results: The presence of abundant and diverse groups of recycled species (acritarchs, prasinophytes, spores, chitinozoans, and others), frequently well-preserved (many specimens not fragmented), and thermally immature to mature characterizes Mid- Tournaisian to late Visean samples from both Manuripi and Pando X-1 boreholes. Indigenous spores and some fresh/brackish water algal remains are the indigenous components, mostly well-preserved as well. The process of reworking in the palynologic organic matter from these units can be explained by the action of glacio-fluvial processes that eroded Devonian rocks during approximately mid- Tournaisian to late Visean in this region. A fast transport and deposition under low energy or even fast events of deposition (like hyperpicnites) under appropriate anoxic bottom condition at depocenters occurred allowing a good preservation of the organic matter.

From the Manuripi X-1, both indigenous and reworked specimens in slides mounted with jelly – glycerin and water yielded flourescence ranging from yellow to dark orange (Figs. 5-8). Some specimens picked from residues mounted in non-permanent slides with water were also pictured under fluorescence microscope before being transferred to stubs for SEM illustration (see Quetglas et al., 2017, 2019; Quetglas, 2021).

From the Pando X-1, autofluorescence analyses attempted in 2011 (unpublished information) mainly corresponded to samples from the Early Visean following di Pasquo et al. (2019a). In this contribution, new analyses were done in samples of the underlying mid-late Tournaisian interval. Selected slides mounted with jelly-glycerin, Cellosize/Entellan, Norland, glycerin, and water were explored for autofluorescence.

It is interesting to note that fluorescence of both well- preserved I-R taxa from the Mississippian intervals in Pando X-1 is very variable. Reworked acritarchs, like *Umbellasphaeridium saharicum* and prasinophytes of the genera *Maranhites* and *Tasmanites,* exhibit very high yellow autofluorescence, similar to that of indigenous chlorophycean *Botryococcus*. Some indigenous spore species of *Cordylosporites* and *Verrucosisporites* yielded yellow-orange colors whereas specimens of reworked *R. lep* reveal low fluorescence intensity, with dark color or black. Moreover, fluorescence was tested in oxidized residues mounted in 2022 with Trabasil and Norland (Figs. 9-14).

3.1.2 Encañada de Beu section, Rio Alto Beni

Azcuy and Ottone (1987) published the first palynologic study of the Kaka Formation at Encañada de Beu, North Subandean (Fig. 3). They illustrated some indigenous (e.g. *Apiculiretusispora semisenta, Granulatisporites frustulentus, Verrucosisporites cerosus*) and reworked taxa from the Devonian *sensu lato* (e.g. *Retispora lepidophyta, Grandispora pseudoreticulata, Emphanisporites rotatus, Maranhites mosesi, Umbellasphaeridium saharicum, Chomotriletes* sp., *Navifusa bacila*). Fasolo et al. (2006) published a detailed revision of their samples from the upper part of this unit. The autochthonous assemblage composed of 80 well-preserved species, yielded principally trilete miospores and few pollen grains (one praecolpate and two saccate pollen species)**,** and the green algae *Botryococcus*. Due to few pollen grains and *Cordylosporites magnidictyus* found in the association, Fasolo et al. (2006) tentatively assigned the unit to the Serpukhovian. This unit partly correlates

with the late Visean *Cordylosporites magnidictyus* palynozone defined in the Amazon basin (Brazil), and also correlated with the Ambo Formation assemblage from Peru (Azcuy and di Pasquo, 2005). Although, the presence of few pollen grains would indicate a better correlation to mid-late Serpukhovian assemblages in South America (e.g. di Pasquo et al., 2019a; Milana and di Pasquo, 2019).

Results: The samples herein analyzed correspond to the material studied by Azcuy and Ottone (1987), named under the catalogue number BAFC-Pl 506 (catalogue number corresponds to FCEN, UBA, see di Pasquo and Ottone, 2009). Fluorescence color of several indigenous taxa herein documented were illustrated from slides mounted with jelly-glycerin (Figs. 15-16). The indigenous spores bear a variable autofluorescence color, mostly ranging from orange to red and somewhat black, whereas *Botryococcus* yielded a yellow color. The bright green fluorescence color of the still well-preserved jelly-glycerin (not dried), prevented a clear observation of the fluorescence of several embedded palynomorphs, as well as the use of the maximum time of exposition and gain to take pictures. It is highlighted the presence of *Rotaspora fracta* found herein because it reinforces an age not older than late Visean, a diagnostic spore in palynofloras from North Hemisphere (e.g. Owens et al., 2004).

3.1.3 Macharetí section

Di Pasquo (2008a) presented the results of the palynological analysis of the only two fertile samples, collected in the Iquirí and Itacua Formations in the Macharetí creek (63º 24' 09" W, 20º 47' 50" S), Aguaragüe range, southern Bolivia (Fig. 3, appendix 1). On a fault appears an intercalation of ca. 50 m thick, with decimetric to metric banks of fine and medium sandstones (with current and bioturbation structures) and centimetric to decimetric shales, laminated or massive, assigned to the Iquirí Formation. From this section, 6 samples were collected, of which the one located in the last layer of gray-greenish pelite was fertile. In pseudoconcordance, the Itacua Formation (ca. 60 m) begins with a layer of greenish diamictites with a sandy matrix (ca. 3 m) followed by another (ca. 5 m) of gray clayey matrix from which the second fertile sample comes, located at 4 meters from the other productive one. The unit continues with a succession of whitish sandstones, black claystones, greenish-violet diamictites and grayish-violet shales; three samples were taken resulting sterile. The association 1 was obtained from the Iquirí Formation. It comprises abundant, diverse and well-preserved palynomorphs (80% spores and microplankton) and phytoclasts (20% charcoal, logs and cuticles), with yellow to orange colors. Among the species of stratigraphic importance, it is highlighted the presence of *Acinosporites eumammillatus*, *Verrucosisporites bulliferus*, *Pseudolunulidia imperatrizensis*, and *Umbellasphaeridium companulatum*. These taxa support a Frasnian age for the association. The association 2 was obtained from the Itacua Formation. It is composed of phytoclasts (50% charcoal, logs and cuticles) and abundant and diverse palynomorphs (50%) with notable differences in their preservation (e.g., whole, fragmented, pyritized) and color (from orange to black). An early Visean age is supported by diagnostic species such as *Foveosporites appositus*, *Secarisporites undatus*, *Retusotriletes mirabilis*, *Densosporites triangularis*, and *Lophozonotriletes dentatus*. Some of these species were recorded in the Itacua Formation at Balapuca (see di Pasquo, 2007b), which is correlated with the Malimán Formation in Precordillera Argentina (Amenábar et al., 2009). This information confirmed the existence of the DC unconformity in the Macharetí creek, and the absence of Famennian and Tournaisian rock- interval. A detailed study of palynomorphs potentially reworked from older units, present in association 2, would provide more information on the aforementioned hiatus.

Results: The non- oxidized and oxidized slides analyzed correspond to the Itacua

Formation (CICYTTP-Pl 2702 (BAFC-Pl 1666) mounted with jelly-glycerin and Trabasil. The fluorescence of indigenous and reworked specimens varied between yellow to orange in most phytoplankton, and dark orange to black in spores, except for few ones with lighter orange to yellow as can be seen in Fig. 17, 4-5. No direct link between fluorescence and I-R precedence was recognized and, in the oxidized residue no effects on the intensity and color of fluorescence was detected (Fig. 17).

3.2 Northern Argentina

The main work carried out by di Pasquo (2002, 2003) allowed the recognition of 165 indigenous species from numerous samples (84 productive) of several sections (six outcrops and two boreholes, Fig. 18) of the Macharetí (Itacua, Tupambi, Itacuamí, Tarija), and Mandiyutí (Escarpment, San Telmo) groups from Tarija Basin (northern Argentina and southern Bolivia). In many of the studied samples, the presence of two groups of palynomorphs with different age ranges was recognized. The indigenous group (including pollen grains, spores and algal remains) allowed the establishment of a Pennsylvanian age for these rocks, based on their comparison with palynofloras from Neopaleozoic basins of South America, Gondwana and elsewhere. The first appearance of selected taxa was proposed to establish a biostratigraphic chart. It is composed of a Superzone named *Kraeuselisporites volkheimeri-Circumplicatipollis plicatus*, divided into five First Appearance Interval Palynozones. The three oldest zones, *Crassispora kosankei - Cystoptychus azcuyi, Raistrickia radiosa – Apiculatasporites spinulistratus* and *Dictyotriletes bireticulatus – Cristatisporites chacoparanensis*, were attributed to an early-middle Late Carboniferous age, and the other two ones, named *Converrucosisporites (Granulatisporites) micronodosus – Reticulatisporites reticulatus* and *Marsupipollenites triradiatus – Lundbladispora braziliensis*, are akin to the late Late Carboniferous. The age was based on the biostratigraphic range of several key-species and the place of each palynozone within the lithostratigraphic succession. The abundant presence of common species with other palynofloras from the Late Carboniferous of South America, especially from Argentina and Brazil, also supports this age. The reworked group is composed of more than 150 reworked palynomorphs, including spores, acritarchs, prasinophytes, chitinozoans, and others, all derived from the erosion of Devonian and Lower Mississippian deposits (Figs. 2-4, 18), which were mountain ranges along western and south-eastern boundaries of the Tarija Basin during the Late Carboniferous (di Pasquo and Azcuy, 1997 b; Starck and del Papa, 2006). A test of autofluorescence of indigenous Mississippian and Pennsylvanian palynomorphs and Devonian reworked ones including *Retispora lepidophyta* was carried out in selected samples from Macharetí Group. For more information and illustrations see di Pasquo (2022, this volume).

3.2.1 San Antonio X-1 borehole

The San Antonio X-1 well (Fig. 18) drilled to a depth of ca. 3.700 meters, was sampled for palynology in 2006. di Pasquo and Noetinger (2008) analyzed the palynologic organic matter of 53 cutting samples obtained of the section between 2,544 and 1,293 m depth 14 samples. Most of palynomorphs are poorly preserved and show a variable degree of thermal maturation color, dominantly dark brown (Thermal alteration index- TAI 2+ to -3 according to the scale of Utting and Wielens, 1992) to almost black color (TAI 3+ to -4) , while some spores and acritarchs are somewhat lighter (TAI -2 to 2). Based on the vertical distribution of species and considering the local biostratigraphic scheme proposed by di Pasquo (2003), di Pasquo and Noetinger (2008) outlined the main results and interpretations (see appendix 2), summarized as follows:

1) The section between 2.544 and 2.510 m depth cannot be attributed with certainty to the Pennsylvanian, since the few

monosaccate pollen grains found could be caved elements, and considering that the spores and phytoplankton correspond to species known mainly from the Givetian-Frasnian (Middle-Late Devonian, see Noetinger and di Pasquo, 2011).
2) The early Pennsylvanian *C. kosankei-C. azcuyi* (KA) Zone di Pasquo is documented in sample at depth 2.504-2.502 m, based on the record of *Crassispora kosankei*, although with doubts due to the lack of other diagnostic elements.
3) The section between 2.374 and 1.831 m has successively provided several species of spores and pollen grains exclusive to the Moscovian *Dictyotriletes bireticulatus–Cristatisporites chacoparanensis* Zone (BC), including as well *Microreticulatisporites punctatus, Apiculatisporis hericinus, Didecitriletes ericianus* and *Densipollenites* sp. In the sample at depth 1834-1831 m, *Crassispora kosankei, Cystoptychus azcuyi, Granasporites medius* and *Schopfipollenites ellipsoides* are interpreted as reworked from the KA Zone (Tupambi Formation) deposited in the Tarija Formation, in agreement with di Pasquo (2003) and del Papa and di Pasquo (2007) at Zanja Honda.
4) A gap between the late Devonian and earliest Pennsylvanian is located between 2.548 and 2.528 m that covers at least part of the Frasnian and the Late Mississippian.
5) In most of the samples analyzed, Devonian reworked spores including the late Famennian *Retispora lepidophyta*, and microplankton species such as *Umbellasphaeridium saharicum* confirm the stratigraphic gap as part of a complex geological history in this region (see Figs. 3-4) of Argentina (see di Pasquo and Azcuy, 1997; di Pasquo, 2003; Noetinger and di Pasquo, 2011).

Results: From both oxidized and non-oxidized residues of two selected samples (Figs. 19-20, see appendix 2), phytoplankton yielded a lighter yellow color more intense than monosaccate pollen grains and spores in this order. This gradation does not depend of their I-R condition.

3.2.2 Zanja Honda section

Del Papa and di Pasquo (2007) carried out a sedimentologic and palynologic study of thick diamictitic layers interbedded with sandstones and mudstones of the Tarija Formation (Macharetí Group), at Zanja Honda creek (Fig. 18) and Zanja Honda X-1 well. This study allowed to reconstruct the palaeoenviromental and palaeoclimatic evolution of the southern portion of the Tarija Basin. According to the stratigraphic distribution of Late Carboniferous species (indigenous) found in the Tarija Basin, samples from the Zanja Honda are attributed to the *Dictyotriletes bireticulatus-Cristatisporites chacoparanensis* (BC) Biozone (di Pasquo, 2003). The following indigenous species are documented: *Endosporites zonalis, E. rhytidosaccus, Velamisporites autraliensis, Reticulatisporites polygonalis, Cristatisporites crassilabratus, C. scabiosus, Vallatisporites ciliaris, Dibolisporites disfacies, Spelaeotriletes ybertii, Crucisaccites latisulcatus*, including those homonymous of the zone. *Botryococcus* and other indigenous fresh water algae (e.g. *Brazilea, Tetraporina*) are found along with a great number of reworked species from Siluro-Devonian deposits (e.g. *Laevolancis divellomedium, Quadrisporites variabilis, Eupoikilofusa striatifera*, *Dactylofusa maranhensis*, *Retispora lepidophyta*, *Umbellasphaeridium saharicum*, *Maranhites* spp.), and from the Early Carboniferous (e.g. *Colatisporites decorus, Cordylosporites marciae, Densosporites annulatus*). In general, palynomorphs bears an exine with varied maturation colors, related to the thermal history originally attained by the different layers. Some differences in the state of preservation of I-R palynomorphs was detected. For example, some acritarchs and spores of Devonian age have pyrite in their exines, while indigenous spores and pollen grains and algal remains are non-pyritized. The presence of abundant phytodetritus, with a general good preservation of non-pyriritized indigenous material, and the great volume of relatively well-preserved reworked material, are correlated to the

palaeoenvironmental interpretation for this region of the Tarija Basin, as expressed by del Papa and di Pasquo (2007) and other authors (e.g. di Pasquo and Azcuy, 1997; Azcuy and di Pasquo, 2000; di Pasquo, 2003, 2009b; Starck and del Papa, 2006; di Pasquo et al., 2015b, 2017a, 2019a). Reworked palynomorphs from Siluro-Devonian and Early Carboniferous rocks were re-sedimented mainly through the erosion by fluvial drainages during interglacial periods along the Late Carboniferous. Moreover, some Late Carboniferous species such as *Crassispora kosankei*, *Cristatisporites rollerii* and *Cystoptychus azcuyi*, exclusive of the KA Biozone and *Raistrickia radiosa* of the RS Biozone di Pasquo (lower Tupambi and Itacuamí formations), are also interpreted as reworked when they are found in the overlying Tarija Formation and Mandiyutí Group (see di Pasquo, 2003). This is supported by the existence of tectonic events that exposed new areas subjected to erosive processes related to glacier dynamics, and deposited in palaeovalleys and lacustrine environments (di Pasquo and Azcuy, 1999b). At Zanja Honda, a fluvio-lacustrine setting is interpreted for the Tarija Formation based on the presence of glacial varves, continental algae such as *Botryococcus braunii* and the overall facies associations. The organic matter would have reached a nearby lacustrine depocenter and rapidly settled from debris flows, which favoured their preservation. Also, the presence of different types and sizes of well-preserved *Botryococcus* colonies may suggest that they were settled *in situ*, confirming the terrestrial (lacustrine) characteristics of the depocenter.

Results: Autofluoresence of palynomorphs from the Zanja Honda section was tested in sample CICYTTP-Pl 2705(BAFC-Pl 1476). Oxidized and non-oxidized residues from this sample were mounted using Trabasyl as mounted media. Phytoplankton yielded lighter yellow color and more intense fluoresence than monosaccate pollen grains and spores in this order, independently of their I-R origin (Figs. 21-22).

3.3 Peru

The Neogene evolution of the Amazonian landscape is still under debate especially concerning the number of marine incursions in Western Amazonia. A multidisciplinary paleontologic, biostratigraphic, sedimentologic and isotopic analysis carried out in the Pebas-Nauta Formations, Madre de Dios Basin (Sub-Andean zone and foredeep depozone) yielded enough evidence for Parra et al. (2016) to suggest for the first time an episode of marine influence in the late Early Pliocene in Peru. The results were obtained from 15 productive sand and shale samples of four stratigraphic sections from base to top, Puerto Maldonado (MD-325/MD-51), Santa Rosa (MD-208/MD-13), Inambari (MD-204C), and Pongo de Coñeq (Section 1: MD 244/MD-246), SE-NW oriented across the Madre de Dios Basin, which are summarized herein (see Parra et al., 2016). Thirteen of the 15 analyzed samples have revealed autigenic pyrite, and facies with foraminifers such as *Miliammina*, *Bathysiphon, Trochammina* and *Haplophragmoides*, which suggest marginal marine sedimentation and oligohaline - lower mesohaline (about 2-16 ppt) environment, common in salt marshes and most mangroves. All samples show the same palynofacies containing abundant cuticles among the phytoclasts and palynomorphs dominated by Poaceae and pteridophytes spores (*Cyathidites, Equisetum, Laevigatosporites, Polypodiisporites*), fungi spores, and bryophytes. Additionally, some samples revealed specific features such as: MD-325/MD-51 present crabs (ichnofacies), *Oedogonium* algae, *Tetraploa* and *Potamomyces* (fungi, see ecologic details in Nuñez et al., 2017) and some proximate dinoflagellate morphotypes related to estuarine tidal type environment. MD-13/MD-208 contains *Oedogonium* algae, *Tetraploa* and *Potamomyces* (fungi) and pyrite in the spore-pollen specimens. MD-244/MD-246 yielded *Deltoidospora* aff.

adriensis that suggests a mangrove swamp with anoxic bottom (see ecologic details in Parra et al., 2020), and *Potamomyces.* MD-204C yielded *Verrucatotriletes*, *Deltoidospora adriensis*, *Pteridaceae* and algae (*Pediastrum, Oedogonium*) and angiosperms (*Cecropia* and *Poaceae*). The first record of chironomidae and species of *Potamomyces* and *Tetraploa* in MD-51/MD-325, MD-13/MD-208, MD-244/MD-246 outcrops, support a Neogene age. The recovered marker species in these sections (*e.g. Cyatheacidites annulatus, Cingulatisporites laevigatus, Nijssenosporites fossulatus, Grimsdalea magnaclavata* and *Bombacacidites baculatus*) indicate a late Miocene to early Pliocene (7.15-3.4 Ma) age. However, the presence of *Alnipollenites-Echitricolporites* association (*Alnipollenites verus* and *Echitricolporites mcneillyi* in MD13/208 and *Alnipollenites* forms (Pliocene-Pleistocene), in MD-51/MD-325 and MD-204C, as well as a dating in MD-204C (biotite Ar/Ar 3.45 Ma) indicate a late Early Pliocene. This multidisciplinary analysis of the sections allowed Parra et al. (2016) to document a marine incursion into a Neogene cycle. Additionally, reworked palynomorphs from the Devonian (*Retispora lepidophyta, Umbellasphaeridium saharicum*) and Mesozoic were found in MD-204C, evidencing the Andean range was the subject of erosive processes and the influence of its mountainous flora (*Clavainaperturites microclavatus*, *Cecropia*, *Podocarpus*), is also documented in almost all samples.

Results: The fluorescence of selected I-R palynomorphs documented in MD-204 are compared and illustrated in Figures 23-25 with the aim to reinforce the results found in this research. Slides were mounted with Canadian Balsam from the oxidized residue of MD-204, and from the revision of this residue in a Petri dish under the microstereoscope, selected specimens of I-R palynomorphs were hand-picked and mounted with water in a temporary slide. Different times of exposition (ms) and gain (G) parameters are applied to record varied intensities of fluorescence of each taxon. Note the green color of fluorescence of the Canadian Balsam similar to that of the jelly-glycerin, but in the former, a halo is created around the palynomorphs due to the effect of UV light. Independently of their I-R origin, and from slides mounted with Canadian Balsam and water, a bright-yellow color of fluorescence is yielded by specimens of *Umbellasphaeridium saharicum*, and yellow/orange for *Retispora lepidophyta*. The same occurs with indigenous specimens of *Ipomea*-like (Fig. 25. 11-13), a pantoporate echinate pollen grain (Convolvulaceae, see RCPol database), and poaceae (Fig. 25. 14-15), and algae *Oedogonium* and *Botryococcus,* which yielded bright yellow fluorescence, whereas it is orange in the spore *Cyatheacidiites annulatus.*

3.4 United States of America (USA)

Late Famennian palynomorphs analyzed herein were obtained from outcrop samples at the Apalachian Basin (Kentucky) and the Sappington Basin (Montana) (Fig. 26).

3.4.1 Logan Hollow section (Morehead-Kentucky), Appalachian Basin

During the Late Devonian, the Appalachian Basin and the mountains of the eastern United States was thought to be positioned in the subtropics between 30°S (Heckel and Witzke, 1979; Scotese, 2008) and 45°S (e.g., Scotese, 2002; Blakey, 2008, 2016). Within the Appalachian Basin, a glacigenic succession is recognized by a belt of *in situ* terrestrial diamictite 400 km long and 40 km wide. This interval is assigned to the lower Spechty Kopf Formation, the Rockwell Formation, and the Cussewago Sandstone of Pennsylvania and Maryland, and the Bedford Shale and Berea Sandstone of Ohio (cf. Brezinski et al., 2010). The diamictite was deposited during a single glacial advance and retreat sequence as parts of shallow, marginal-marine transgressive sequences, which inundated Hampshire/Catskill alluvial plains, and ended Late Devonian alluvial sediment accumulation across most of the area. In northeastern Kentucky, Upper Devonian–Lower Mississippian clastic

rocks evidence the Acadian alpine glaciation. Ice rafted dropstone boulders were also preserved in the contemporaneous Cleveland Shale Member of the Ohio Shale (Ettensohn et al., 2009). Palynology indicated that all the diamictites examined occur in the LE and LN miospore zones following Clayton et al. (2010, 2012). Ettensohn et al. (2020a, 2020b) interpreted that the Acadian orogeny not only generated high mountain source areas capable of supporting glaciation, but also through deformational foreland loading, led to regional subsidence and the incursion of shallow seas favoring mountain glaciers reach open sea.

In the framework of the AASP Annual Meeting held at Lexington in 2012 (see Mason et al., 2012 in Ettenson et al., 2020b, and references therein), a field trip was developed in Devonian-Carboniferous sections of Kentucky. The field trip included eight stops where the participants were able to collect samples for their own record and comparisons. In this opportunity, MdP collected a total of 20 samples from the eight stops. The stop 6 at Logan Hollow section (N38°11'36'', W83°29'37''), was visited to look at the Robinson boulder or "lonestone" (see Ojakangas, 1985) that is included in the upper Cleveland Member of the Ohio shale Formation. The Robison boulder is interpreted as a glacial dropstone removed from the Ordovician (Ettensohn et al., 2009, 2020a, 2020b).

In the depositional model proposed by Ettensohn et al. (2009), the Cleveland Member may have formed under anaerobic to dysaerobic, basin floor conditions, whereas the Bedford Shale may represent the slow accumulation of muddy sediments at distal margins of a mud-rich turbiditic slope under more dysaerobic conditions. The overlying Bedford shales may reflect distal lowstand deposits related to alpine glaciation in Acadian/Neoacadian highland source areas located towards the east, whereas the Berea sandstone may represent a series of storm-dominated shelf deposits (Pashin and Ettensohn, 1987, 1992, 1995). The shale interval from Cleveland and Bedford and the Berea sandstone was dated as late Famennian due to the presence of the LN miospore Zone (Clayton et al., 2010, 2012) and the Sunbury Shale assigned to the early Tournaisian (Hastarian) HD Zone (see Heal et al., 2009, in Ettenson et al., 2020a).

Results: Three samples collected from Logan Hollow section (Fig. 27) were processed at the Laboratory of the CICYTTP (CONICET-ER-UADER), where they are housed in the Palynologic Repository under the acronym CICYTTP-Pl. The palynologic results of each sample are described from base to top. The sample Cleveland 1 (CICYTTP-PI 954) was taken from the black shale of Cleveland Member just beneath the dropstone aforementioned. This sample has abundant amorphous organic matter (AOM), a high frequency of *Leiosphaeridia*, and few poorly- preserved spores, like *R. lepidophyta* and *Tumulispora rarituberculata*. There are some differences in autofluorescece color between different palynomorphs. While specimens of *Leiosphaeridia* show a yellow fluorescence, spores *R. lepidophyta* and *T. rarituberculata* yield orange fluorescence (Figs. 28-30).

The grey shale sample Bedford 1 (CICYTTP-PI 958) was obtained from the Bedford Shale just c. 50 cm over above the Cleveland 1. This sample is characterized by abundant spores such as *R. lepidophyta, Vallatisporites hystricosus, V. drybrookensis, V. splendens, Retusotriletes incohatus, Velamisporites rugosus, Anapiculatisporites hystricosus,* almost all of them with orange fluorescence, and phytoplankton (*Leiosphaeridia, Tasmanites, Maranhites, Cymatiosphaera*) with bright yellow fluorescence.

The grey sample Bedford 2 (CICYTTP-PI 959) was collected c. one meter above the Bedford 1. This sample is composed of well- preserved palynomorphs with light yellow color (TAI +1 to -2). Spores such as *R. lepidophyta* and *K. explanatus,* both show yellow-orange fluorescence. Phytoplankton (acritarchs and

prasinophytes) yields yellow fluorescence.

3.4.2 Logan Gulch and Koch sections, Sappington Basin, Montana

The Sappington Formation of Montana spans the DC boundary. These strata are important for understanding global biotic events and for constraining depositional environments and sequence stratigraphic interpretations of the correlative Bakken Formation, a hydrocarbon reservoir in the Williston Basin, USA. Evaporitic, shallow through deep marine rocks of the Three Forks and Sappington formations in western Montana represent local intrashelf troughs inboard of active Devonian-Mississippian arches along the Montana-Idaho border. On the other hand, remarkably similar and widespread latest Famennian stacking patterns across the "more stable" part of the Montana craton (and other parts of the world) suggest primary global controls during abrupt late Famennian change in climate/eustasy and transition to a Carboniferous icehouse. Palynological surveys started in 2011 yielded results mainly from the Three Forks, Sappington and Logepole formations from Logan Gulch, later published by di Pasquo et al. (2012, 2017b, see appendix 3).

Fieldworks between 2013 and 2017 focused on palynology and conodont sampling within the upper Three Forks, Sappington, and lower Lodgepole formations of Devonian-Carboniferous age. The sampling was carried out at several locations including Antelope Valley, Beaver Creek, Dry Hollow, Moose Creek, Trident, and Storm Castle. The ages observed in preliminary studies presented by Rice et al. (2016, 2017) and di Pasquo et al. (2017b, 2019c, 2019d, 2021), agreed in general with previous studies in conodonts for the Three Forks Formation (Trident Member) to Lower Sappington (U1) dated as middle to late Famennian *marginifera/ trachytera/early expansa* Zones, Middle Sappington (Unit 4) to *praesulcata* Zone as previously found by Sandberg et al. (1972) in shales of the Unit 3 and 5?, interbedded Unit 4 bearing *Retispora lepidophyta* assemblage at Hardscrabble, Bridger Range (see discussion in di Pasquo et al., 2017b, 2019c; appendices 4-6).

Palynofacies analized reveal that palynomorphs from some locations include well- preserved spores and phytoplankton with lower thermal alteration (TAI c. 2 to -3 in Utting and Wielens 1992), consistent with other thermal maturity indicators (e.g. Conodonts, Ro vitrinite reflectance, HI values, e.g. Gaswirth and Marra, 2015). In other locations, palynomorphs show more fragmentation and corrosion with TAI c. 3+ -4, as illustrated in Figures 31-32. The high value of TAI in spores makes difficult their taxonomic identification, especially in those spores with intra to inter- species variation, and some new species as well. Besides, framboidal and euhedral pyrite are present in exines of palynomorphs at most locations, supporting the interpretation of a dysoxic marine depocenter with probably shallow brackish water. The high number of spores along with few acritarchs confirms proximity to a terrestrial environment (di Pasquo et al. 2017b; See appendix 3).

More than one hundred spore species were documented in the Sappington Formation, including *Anapiculatisporites* cf. *semicuspidatus, Bascaudaspora collicula, B. submarginata, Claytonisporites rarisetosus*, *Convolutispora fromensis, C. major, C. oppressa, Cordylosporites glumaceus, Cymbosporites loboziakii, Cyrtospora cristifera, Densosporites infacetus, Diaphanospora perplexa, Grandispora echinata, G. praecipua, Knoxisporites concentricus, Kraeuselisporites explanatus, Pustulatisporites dolbii, Reticulatisporites cancellatus, Retispora lepidophyta, Retusotriletes crassus, R. incohatus, Spelaeotriletes crustatus, Tumulispora rarituberculata, Vallatisporites drybrookensis, V. splendens, V. vallatus, and Velamisporites perinatus*. Twelve species of microphytoplankton were found, eight of which (*Dictyotidium*

cf. *araiomegarium*, *Gorgonisphaeridium absitum, G. evexispinosum, G. ohioense, G. plerispinosum, G. winslowiae,* and species of *Maranhites* and *Leiosphaeridia*) are present at multiple locations. Almost all these species and most of the microphytoplakton are also present in assemblages from the shale (U4) in the middle Sappington Formation at Logan Gulch, in the Horseshoe Hills of Montana (di Pasquo et al., 2017b), which is assigned to the latest Famennian *R. lep.* – *V. nitidus* Zone.

The other known *Retispora lepidophyta* assemblage of U4 at Hardscrabble (Peak 9559) in the Bridger Mountains (Sandberg et al., 1972) is composed of 34 spore and 3 acritarch species sharing 15 species with the U4 assemblages at multiple studied locations (e.g. *Cyrtospora cristifera, Grandispora echinata, Knoxisporites heredatus, Retusotriletes incohatus*, *Tumulispora rarituberculata, Velamisporites perinatus, Vallatisporites vallatus, V. drybrookensis*, *Gorgonisphaeridium winslowiae*). The global stratigraphic ranges of the species recorded in U4 assemblages mentioned above together with the co-occurrence of the diagnostic spores *Retispora lepidophyta* and *Vallatisporites vallatus,* among others, indicate a latest Famennian (Strunian) age akin to the *LN* Zone of Europe (Higgs et al., 1988) and LV (*lepidophyta*-*Vallatus*) Zone of Brazil (Melo and Loboziak, 2003). These are also correlated with late Famennian palynofloras of Middle Bakken Formation by Hogencamp and Pocknall (2018) and elsewhere (see e.g. Marshall, 2021 and other references in the special issue 101 "Global review of the Devonian-Carboniferous Boundary"). It should be noted that the rarely documented *Verrucosisporites nitidus* has been confirmed from Antelope Valley and Logan Gulch locations (cf. Rice, 2021).

From the Koch section, located in the Madison Range of southwestern Montana, a detailed palynological analysis of four samples from the latest Devonian Sappington Formation was developed. The whole association composed of dominant trilete spores (87 species) and scarce microphytoplankton (13 species) (di Pasquo et al., 2019d). Among most representative spore species, *Convolutispora oppressa, Cymbosporites loboziakii, Cyrtospora cristifera, Diaphanospora perplexa, Grandispora echinata, Knoxisporites concentricus, Knoxisporites literatus, Kraeuselisporites explanatus, Punctatisporites hannibalensis, Pustulatisporites dolbii, Retispora lepidophyta* (very abundant), *Retusotriletes incohatus, Spelaeotriletes crustatus, Tumulispora rarituberculata*, and *Vallatisporites drybrookensis* are documented (see Fig. 33). These species are diagnostic of the *LN* Zone yet documented in Unit 4 shale at Logan Gulch (di Pasquo et al., 2017b) and other locations in SW Montana (Rice, 2021). di Pasquo et al. (2019d) mentioned the first record of the megaspore *Lagenicula devonica* (Lepidocarpaceae, Lycophyta) in the U4 Sappington Formation associated to the microspore *LN* Zone of Montana. This gulate megaspore (110-150 μm), with a reticulate ornamentation on the distal surface, is known from the Frasnian-Famennian of Canada, as part of the megaspore *Magnifica* Zone Chi and Hills (Late Devonian). This zone is also characterized by megaspores *Grandispora magnifica, Lagenicula constricta* and *Ocksisporites maclarenii*, and large forms of *Leiosphaeridia*. Minor occurrences were documented in the late Devonian of USA and Siberia. The absence of this taxon in the overlying *Multiapicalis* Zone attributed to the earliest Tournaisian (Hills et al., 1971, 1984) helps to place constraints on the timing of extinction events across the DC boundary (Fig. 34). It also reinforces correlations with stratigraphic units from the Devonian-Carboniferous boundary in USA and Canada (di Pasquo et al., 2017b, 2019d).

The finding of early Tournaisian conodonts with nodose ornamentation and rostral ridges, identified as *Siphonodella* cf. *S. hassi*, occurs in a unique, fossiliferous channel sandstone at Antelope Valley in Montana, recently documented by Rice (2021). At least, this is an outcrop of

Montana where there is evidence of early Mississippian conodonts and blastoid fossils (echinodermata) to interpret the presence of *Retispora lepidophyta* and other Famennian taxa in the interbedded shales of this section as "likely" or "surely" reworked. This fact confirms previous documentation about the uncertainty of *R. lep´*s range extended to younger Tournaisian or, more likely as a reworked taxon, a more suitable interpretation given by di Pasquo et al. (2021, appendix 6).

Results: A fluorescence analysis carried out in samples from green shale (Unit 4) of the Sappington Formation at Logan Gulch (di Pasquo et al., 2017b) and at Koch, where a green shale sample 30 cm below the top of Unit 4 beneath shoreface sandstone facies of Unit 5A (Fig. 33). Most microplankton specimens show a bright yellow color of autofluorescence, while micro- and megaspores varied from yellow to orange, in general darker than that of microplankton (Figs. 35-36). Specimens without fluorescence were also observed but not illustrated.

4 Discussion

4.1 Discrimination of indigenous and reworked palynomorphs using autofluorescence

Variations in the autofluorescence property of palynomorphs (and other particles of organic matter in general) are related to both the nature of each taxon and taphonomic-diagenetic history (van Gijzel, 1971). The auto**fl**uorescence wavelengths emitted from palynomorphs range from 400 nm (blue) to 700 nm (red). In well- preserved specimens, fluorescence helps in taxonomic identification by improving their morphologic characterization. The degradation of sporopollenin in the pollen wall is indicated by a blue-green to red shift in **fl**uorescence, and eventually total extinction (van Gijzel, 1971).

Yang and Grote (2018) summarized main properties and applications of autofluorescence of pollen and other palynomorphs. They investigated the fluorescence spectra of indigenous (also called *in situ*) pollen from Pleistocene deposits in the Khorat Plateau (Thailand), and its implication of the relationship among fluorescence intensity (FI), pollen taxa and depositional conditions. They referred to the ability of palynomorphs to **fl**uoresce and to be able to maintain it for a long time at a geological time scale. Their study demonstrated that the disappearance of the **fl**uorescence spectrum (red, orange, green and violet) is correlated to the environment were palynomorphs are preserved. Irreversible changes in the structure of sporopollenin associated with the loss of hydroxyl group by dehydration and increasing aromaticity produce a progressive red shift in fluorescence (Obermajer et al., 1999).

Additionally, **fl**uorescence of organic material decays at different rates in layers of different depth due to thermal and pressure factors (e.g. Brooks and Shaw, 1978). Therefore, burial, soil type and pH have impact on pollen **fl**uorescence (Batten, 1991; Tyson, 1995). Hoyle et al. (2018) analyzed the late Miocene and early Pleistocene marine-influenced samples from the South Caspian Basin. They differentiated the latter palyno-assemblages showing predominantly unaltered assemblages, considered *in situ* respect to more variable Pliocene ones bearing relatively unaltered to highly altered palynomorphs. The fluorescence method was applied by these authors as a tool to characterise palynomorph properties and to discriminate their indigenous versus reworked condition. They found that pollen and prasinophytes yielded yellow fluorescence in most of the samples, although palynomorphs with dark orange fluoresence, and even without fluorescence were also recovered in some levels. One of the most likely means for alteration of palynomorph´s fluorescence over short time-scales is exposure to oxygen/microbial decay (Waterhouse, 1998) and in long time period potential causes are strong heating in subsurface. Hence, Hoyle et al. (2018) disclosed that low burial temperatures at the sites

sampled would suggest that exposure to oxygen during transport is likely the primary mechanism of change in fluorescence properties. These authors have also explained that the process of erosion from soils is conceptually similar to reworking from older rock units. However, in the case of palynomorphs reworked from unconsolidated sediments or soils, the length of time between source and archive would be shorter and still ill-defined. They are therefore, not necessarily suitable for being used in cyclostratigraphic or palaeoclimatic studies without a careful analysis to discard their reworked nature. Despite Hoyle et al. (2018) could not get support to the usage of fluorescence to discriminate reworked palynomorphs, they provided useful information of the fluorescence of palynomorphs obtained from unconsolidated sediments.

The study carried out by Hoyle et al (2018), testing the use of fluorescence as a tool to discriminate between indigenous and reworked palynomorphs in Miocene – Pliocene rocks, motivated this study to evaluate its utility when applied in Late Devonian and Early Carboniferous rocks. It was quite intriguing and valid to apply this methodology in a different time interval, in which different geological processes affected the rocks.

A comparison between the fluorescence of indigenous palynomorphs from samples of the Upper Famennian units from USA and from the Carboniferous of Bolivia and northern Argentina and Mio-Pliocene of Peru was carried out. From the former country, Cleveland (CICYTTP-PI 954) and Bedford 1 (CICYTTP-PI 958) and Bedford 2 (CICYTTP-PI 959) were compared. Autofluorescence of spores like *R. lepidophyta,* and microphytoplankton (*Leiosphaeridia, Tasmanites, Maranhites, Cymatiosphaera*) were orange (or light orange) and bright yellow, respectively. Instead, a lighter autofluorescence of yellow-orange color in spores like *R. lepidophyta* and *K. explanatus*, and light/intense yellow for acritarchs and prasinophytes observed in the sample Bedford 2 (CICYTTP-PI 959). Hence, palynomorphs from Late Famennian samples analyzed did not loose their fluorescence despite a variable range of colors and intensities recorded. This was mainly in concordance with a lower Thermal Alteration Index- TAI of the latter sample respect to the other two ones.

On the other hand, as it was mentioned, palynomorphs are feasible to resist the erosion of rock deposits in which they are embedded and can be deposited as "reworked palynomorphs" into a younger sedimentation cycle. From this work, a certain link between higher thermal maturation and degradation of exines with a change in fluorescence colors was also corroborated based on the analysis of the remaining samples of younger deposits afformentioned bearing indigenous taxa mixed with reworked ones from Mid-Upper Devonian eroded deposits. Therefore, it is demonstrated that fluorescence colors cannot be related with their indigenous or reworked nature.

In this sense, a general conclusion from this study revealed that in the same sample, microphytoplankton (i.e. from both marine like acritarchs and prasinophytes and fresh water environments), either indigenous or reworked, exhibited yellow to light orange colors and more intense color of fluorescence, respect to pollen grains and spores in this order. Spores, including *Retispora lepidophyta*, exhibited slightly darker colors from orange up to red and even loss of fluorescence (black) with lesser intensities, independently of their I-R nature. This is in agreement with the color of fluorescence of modern (*in situ*) spores obtained from fertile monilophytes (see example by di Pasquo et al., 2016a), and confirms its close relationship with the composition of the wall of each palynomorph (source/biological affinity). Later on, the change in color of autofluorescence is also, a consequence of different grades of degradation of sporopollenin during pre- and post-buried (= taphonomic and

diagenetic) processes as previous studies demonstrated (e.g. van Gijzel, 1971; Phillips, 1972; Batten, 1991; Tyson, 1995; Yang and Grote, 2018).

As the recognition of reworked palynomorphs is useful in deciphering base-level variation, diastrophism and provenance in agreement with many previous works (e.g. Streel and Bless, 1980; Gregory and Hart, 1992; Tyson, 1993, 1995; di Pasquo and Azcuy, 1997; di Pasquo, 2003; Azcuy and di Pasquo, 2005; Yeloff and Hunt, 2005; di Pasquo et al., 2015b, 2019a; Parra et al., 2016), their identification must be carefully established. The relevant criteria are mostly two, a careful systematic assignment to specific level and the more probable stratigraphic range (more consensual) of the identified species in agreement with Streel and Bless (1980) and di Pasquo and Azcuy (1997). There are other criteria, such as differences in their preservation, different degree of maturity of organic matter, relative abundance, which are somewhat difficult to apply. Among them, the potential use of paleoecological affinities of the palynomorphs is highlighted because it may happen that the reworked palynomorphs correspond to a depositional environment different from the depocenter where they were incorporated together with the indigenous palynomorphs (e.g. marine versus lacustrine environments). Hence, a correct establishment of their provenance in a sample makes possible a more accurate interpretation of the paleoenvironment of deposition and the effect of other factors that would have affected it (e.g. climate, tectonic, astronomic effects). Although debatable, among astronomic effects, Marshall et al. (2020) interpreted the extinction of spores of *R. lepidophyta* from terrestrial environments of late Famennian age (*R lep* zones) was due to anomalous higher UV radiations.

4.2 Observation of fluorescence versus methods applied and mounting media

We agree with Yang and Grote (2018) and Hoyle et al. (2018) that cold HCl and HF used to process samples do not affect palynomorph fluorescence properties. In this work, hot HCl and nitric oxidization methods were tested and no effects on fluorescence properties were detected.

Concerning the better mounting media for fluorescence exploration, this study agrees with Hoyle et al. (2018) in avoiding the use of jelly-glycerin since it is highly fluorescent, and due to palynomorphs are usually into this medium instead of being adhered at its upper surface (in contact with the cover slide), many are almost not seen under fluorescence light. Unfortunately, jelly-glycerin is very used due to it is affordable, obtainable, and easy to prepare despite this inconvenient feature. The same occurs with the Canadian Balsam and Trabasil (UV-curable acrylates gels), due to they are also fluorescent except for Trabasil somewhat lesser than jelly-glycerin. Their use is not as spread as jelly-glycerin because they are somewhat expensive or not easily available. The use of Trabasil as mounting media implies a previous centrifugation of few drops of residue in alcohol (see Noetinger et al., 2017).

Although Glycerol or glycerin used for a non-permanent slide, it is the best medium to prepare slides to explore autofluorescence as it is not fluorescent at all, beyond it is affordable and available in the market everywhere.

On the other hand, despite specimens picked and temporary mounted in slides with water allowed recording their autofluorescence very nicely, slides last a very short time till water evaporates and specimens are not able to be illustrated or even worse, they are feasible to be broken very easily. Therefore, specimens mounted in slides with glycerin sealed with paraffin can be reoriented allowing more accurate identifications and slides can last for many years somewhat fairly well if they are well-preserved/stored.

Cellosize (mixed with drops of residue) and Entellan (glue to seal the permanent slide) are not fluorescent, so a

good fluorescence of palynomorphs is observed highlighted by a black background, even in such cases of weird pattern of recrystallizations that can be observed after several years of storage.
Norland is completely non-fluorescent transparent glue useful to mount dry drops of residues in permanent slides sealed with a UV lamp (few minutes). Cellosize can be used to better disperse the drops of residue across the slide and must be well-dried (a hot plate can be helpful), before using Norland. This is important to avoid as much as possible the formation of bubbles, despite they do not disturb in general, the observation of palynomorphs.

5 Conclusions

In this work, the autofluorescence was tested as a tool to differenciate indigenous and reworked taxa in samples from Lower and Upper Carboniferous deposits of Bolivia and northern Argentina, Miocene deposits from Peru, and Upper Devonian deposits from USA.

This study confirms that indigenous and reworked taxa cannot be discriminated using autofluorescence, in agreement with previous studies developed with fossil palynomorphs from other ages.
The indigenous and reworked (I-R) taxa herein analized yielded autofluorescence colors from light yellow to black, with variations in their intensity and color between terrestrial and phytoplankton species, independently of their indigenous or reworked condition.

In agreement with previous researches, this study confirms that the autofluorescence is dependent on the original composition of the exine (and thus, on their biological nature), although their taphonomic (e.g. oxidation, corrosion, degradation) and diagenetic (e.g. thermal alteration) history also have an effect on the intensity of autofluorescence.

As autofluorescence is not a good technique to discriminate between reworked and indigenous palynomorphs, the most probable age (biochron) of palynomorph carefully determined at the species level is the most accurate criteria to identify and differentiate indigenous and reworked palynomorphs. This discrimination is also important to interpret the environment of deposition and the floristic/biologic composition using exclusively the indigenous palynomorphs.

Standard palynologic processing methods employing cold/ hot HCl, cold HF and oxidation did not affect palynomorph fluorescence properties.

To use fluorescence as a tool in the morphological characterization of palynomorphs, we recommend the use of Norland and Cellosize as mounting media in permanent slides, glycerin in semi-permanent, and water in temporary slides. The use of UV-curable acrylates, such as Trabasil, and particularly, jelly-glycerin and Entellan (due to its toxicity) should be avoided.

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scientific institutions of different countries (e.g. affiliations in Parra et al., 2016, 2020).

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LIST OF TAXA CITED IN THIS TEXT WITH THEIR AUTHORITIES

Spores

Acinosporites eumammillatus Loboziak, Streel & Burjack
Anapiculatisporites ampullaceus (Hacquebard) Playford
Anapiculatisporites hystricosus Playford
Apiculatasporites spinulistratus (Loose) Ibrahim
Apiculatisporis hericinus Menéndez
Apiculiretusispora semisenta (Playford) Massa, Coquel, Loboziak, Tagordeau-Lantz
Auroraspora macra Sullivan
Cingulatisporites laevigatus Silva-Caminha et al.
Colatisporites decorus (Bharadwaj & Venkatachala) Williams in Neves et al.
Converrucosisporites micronodosus (Balme & Hennelly) Playford & Dino (=*Granulatisporites micronodosus*)
Convolutispora oppressa Higgs
Cordylosporites glumaceus (Byvsheva) emend. Playford & Melo (= *Cordylosporites marciae*)
Cordylosporites magnidictyus (= *Reticulatisporites magnidictyus* Playford & Helby)
Cordylosporites papillatus Playford & Satterthwait
Crassispora kosankei (Potonié & Kremp) Bhardwaj emend. Smith & Butterworth
Crassispora scrupulosa Playford emend. Playford & Satterthwait
Cristatisporites chacoparanensis Ottone
Cristatisporites crassilabratus Archangelsky & Gamerro
Cristatisporites echinatus Playford
Cristatisporites menendezii (Menéndez & Azcuy) Playford emend. Césari
Cristatisporites peruvianus Azcuy & di Pasquo
Cristatisporites rollerii Ottone
Cristatisporites scabiosus Menéndez
Cristatisporites stellatus (Azcuy) Gutiérrez, Limarino
Cyatheacidites annulatus Cookson
Cymbosporites loboziakii Playford & Melo
Cyrtospora cristifera (Luber & Waltz) Van der Zwan
Deltoidospora adriensis (Potonié & Gelletich) Frederiksen
Densosporites annulatus (Loose) Smith & Butterworth
Densosporites subcrenatus Potonié & Kremp
Densosporites triangularis Kosanke
Diaphanospora perplexa Balme, Hassel emend. Evans
Dibolisporites disfacies Jones & Truswell
Dibolisporites setigerus Playford & Satterthwait
Dictyotriletes bireticulatus (Ibrahim) Potonié & Kremp emend. Smith & Butterworth, *morphon*
Didecitriletes ericianus Venkatachala & Kar
Emphanisporites rotatus McGregor emend. McGregor
Endosporites rhytidosaccus Menéndez & Azcuy
Endosporites zonalis (Loose) Knox
Foveosporites appositus Playford
Foveosporites hortonensis Azcuy
Granasporites medius (Dybová & Jachovicz) Ravn, Butterworth, Phillips & Peppers
Grandispora echinata Hacquebard
Grandispora libyensis Moreau-Benoit
Grandispora magnifica Chi & Hills
Grrandispora pseudoreticulata (Menéndez & Pöthe de Baldis) Ottone
Granulatisporites frustulentus Playford
Hystricosporites costatus Vigran
Hystricosporites porrectus Allen
Indotriradites viriosus Playford & Melo
Knoxisporites concentricus (Byvsheva) Playford & McGregor
Knoxisporites literatus (Waltz) Playford
Kraeuselisporites explanatus (Luber) Azcuy & di Pasquo
Kraeuselisporites volkheimeri Azcuy
Laevolancis divellomedium (Chibrikova) Burgess & Richardson
Lagenicula constricta Chi & Hills
Lagenicula devonica Chaloner
Lagenoisporites magnus C&ilier, Coquel & Loboziak
Lophozonotriletes dentatus Hughes & Playford

Lophozonotriletes appendices in Ravn
Lundbladispora braziliensis (Pant & Srivastava) Marques Toigo & Pons emend. M. Toigo & Picarelli
Lycospora noctuina Butterworth & Williams
Microreticulatisporites punctatus Knox
Murospora altila (Hacquebard & Barss) Braman & Hills
Nijssenosporites fossulatus Lorente
Ocksisporites maclarenii Chaloner
Punctatisporites hannibalensis Wicander & Playford
Pustulatisporites dolbii Higgs et al.
Raistrickia clavata Hacquebard emend. Playford
Raistrickia ponderosa Playford
Raistrickia radiosa Playford & Helby
Reticulatisporites magnidictyus Playford & Helby
Reticulatisporites polygonalis (Ibrahim) Loose
Reticulatisporites reticulatus (Ibrahim) Ibrahim
Reticulatisporites waloweekii Ravn
Retispora lepidophyta (Kedo) Playford
Retusotriletes incohatus Sullivan
Retusotriletes mirabilis (Neville) Playford
Rotaspora fracta Schemel
Samarisporites triangulatus Allen
Schopfites claviger (= *Raistrickia clavigera* (Sullivan) Playford & Satterthwait)
Secarisporites undatus Playford
Spelaeotriletes balteatus (Playford) Higgs
Spelaeotriletes crustatus Higgs
Spelaeotriletes pretiosus (Playford) Utting
Spelaeotriletes ybertii (Marques Toigo) Playford & Powis
Tumulispora rarituberculata (Luber) Potonié
Vallatisporites ciliaris (Luber) Sullivan
Vallatisporites drybrookensis Playford & McGregor
Vallatisporites hystricosus (= *Vallatisporites drybrookensis* morphon in Playford & McGregor)
Vallatisporites splendens Staplin & Jansonius
Vallatisporites vallatus Hacquebard
Velamisporites autraliensis (Playford & Helby) di Pasquo et al. (= *Rugospora* (*Wilsonites*) *australiensis* (Playford & Helby) Jones & Truswell)
Velamisporites rugosus Bharadwaj & Venkatachala
Verrucosisporites bulliferus (Taugourdeau-Lantz) Richardson & McGregor
Verrucosisporites cerosus Butterworth & Williams
Verrucosisporites congestus Playford
Verrucosisporites morulatus (Knox) Potonié & Kremp emend. Smith & Butterworth
Verrucosisporites nitidus Playford

Pollen grains

Bombacacidites baculatus Muller, di Giacomo, Erve, Van, Maraven
Cannanoropollis densus (Lele) Bose & Maheshwari
Cannanoropollis janakii Potonié & Sah
Cannanoropollis triangularis (Mehta) Bose & Maheshwari
Circumplicatipollis plicatus Ottone & Azcuy
Clavainaperturites microclavatus Hoorn
Crucisaccites latisulcatus Lele & Maithy
Cystoptychus azcuyi di Pasquo
Echitricolporites mcneillyi Hopping
Grimsdalea magnaclavata Germeraad et al.
Marsupipollenites triradiatus Balme & Hennelly
Plicatipollenites malabarensis (Potonié & Sah) Foster
Potonieisporites lelei Maheshwari
Schopfipollenites ellipsoides (Ibrahim) Potonié & Kremp

Microphytoplankton

Ammonidium garrasinoi Ottone
Bimerga bensonii Wood
Botryococcus braunii Kützing
Dactylofusa maranhensis Brito & Santos
Eupoikilofusa striatifera (Cramer) Cramer
Evittia sommeri Brito
Gorgonisphaeridium ohioense (Winslow) Wicander
Hemiruptia legaultii Ottone
Maranhites mosesi (Sommer) Brito emend. González
Maranhites perplexus Wicander & Playford (junior synonym of *Maranhites mosesii* in González 2009)
Navifusa bacila (Deunff) Playford
Pseudolunulidia imperatrizensis (Brito & Santos) Brito & Quadros
Petrovina connata Oliveira & Burjack
Pyloferites pentagonalis Quadros
Quadrisporites granulatus (Cramer) Ströther

Quadrisporites variabilis (Cramer) Ottone & Rossello
Umbellasphaeridium companulatum Oliveira & Burjack
Umbellasphaeridium saharicum Jardiné et al.

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Figure 1. Autofluorescence (epifluorescence) of modern spores from the El Palmar National Park (Entre Ríos province, Argentina). Pictures were taken with a Leica EC3 video camera in 2013. 1-5. *Anogramma chaerophylla* (CICYTTP-R49). 1-2. Sporangia and spores (non-acetolized, slide mounted in water). 3-5. Spores (acetolized, mounted in glycerin). 6-8. *Selaginella sellowii* (CICYTTP-R42, mounted in glycerin). 9-12. *Rhumora adiantiformis* (CICYTTP-R38, non-acetolized, mounted in water, figs. 9 and 12 are illuminated with both white and fluorescence light).

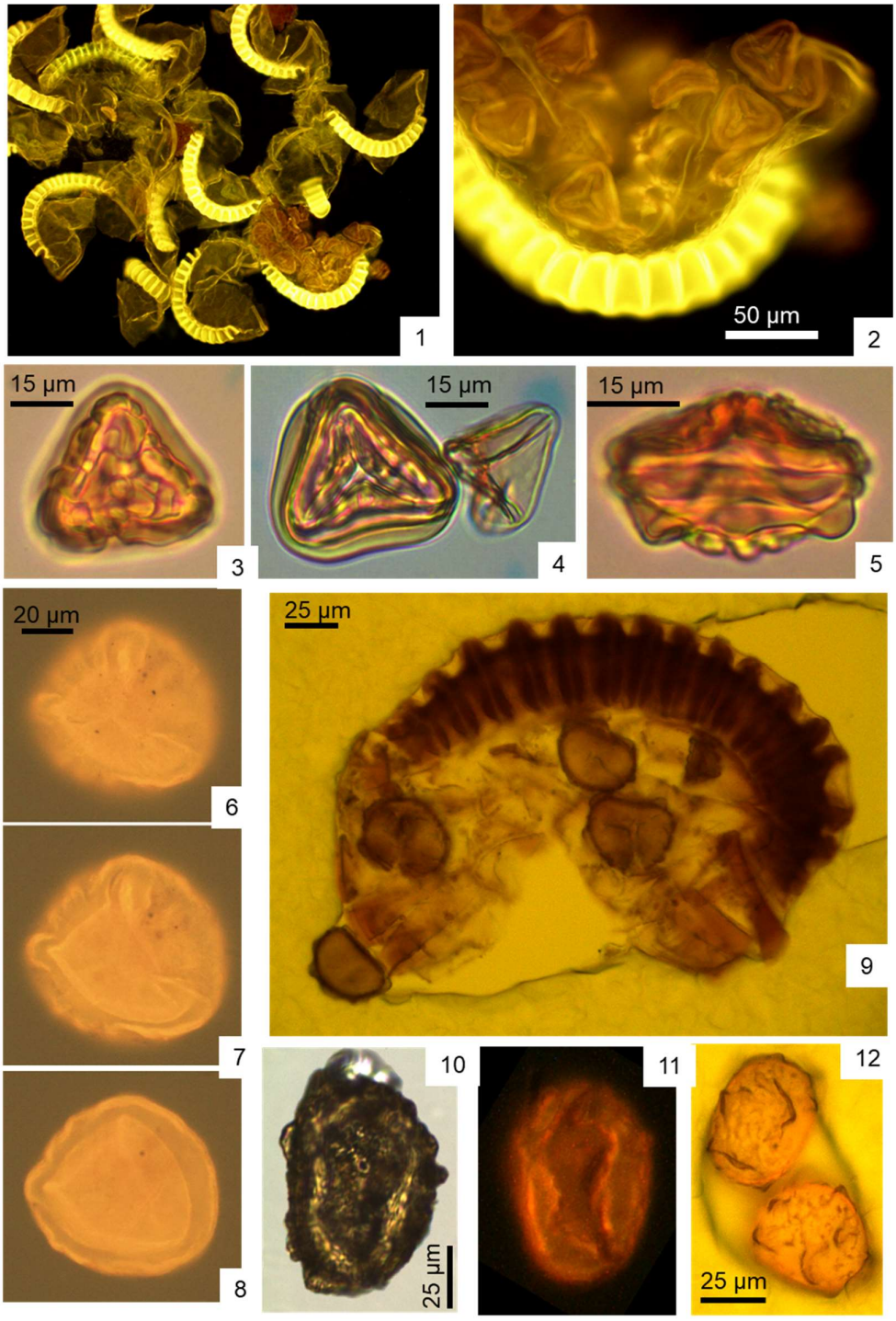


Figure 2. Upper Paleozoic Geological Provinces of Bolivia (after Suárez Soruco, 2000): 1- Madre de Dios, 2- Beni, 3- Chaco and Chaco-Salta plains, 4- Guaporé Craton, 5- Subandean Range, 6- Eastern Range, 7- Altiplane, 8- Pantanal, 9- Western Range. Devonian - Permian localities sampled by di Pasquo in 2000: a- Balapuca (di Pasquo, 2003, 2007 a, 2007b, 2007c; di Pasquo et al., 2009, 2017a), b- Alarache (di Pasquo and Noetinger, 2008), c- La Yesera (di Pasquo et al., 2015a; Noetinger et al., 2018), d- Canaletas, e- Los Monos (di Pasquo et al., 2015a; Noetinger et al., 2018), f- Angosto del Pilcomayo, g- Caigua, h- Macharetí (di Pasquo, 2008a), i- Taputá, j- río Bermejo, k- Samaipata. Devonian – Permian localities sampled in 2007-2008: a- Balapuca (di Pasquo et al., 2015a, 2017a; Noetinger et al., 2018), c- La Yesera (di Pasquo et al. 2015a; Noetinger et al., 2018), d- Canaletas, h- Macharetí, k-l - Samaipata-Mairana (di Pasquo and Anderson, 2012), m- Saipurú, n- Apillapampa (di Pasquo and Grader, 2012), o- Parapetí, p- Zudañez (di Pasquo et al., 2019b), q- Pasorapa, r- Yampupata, s- Via Molino, t- Siripaca, u- El Tunal, v- Narvaez. Boreholes (Core samples obtained by di Pasquo in 2000): w- Pando X-1 (di Pasquo, 2008b, 2009a), x- Lliquimuni X-1, y- Yapacani, z- Tacuaral, w- Pando X-1 and Manuripi X-1 (core samples collected by di Pasquo during her stays at Idaho in 2009 and 2011 along with Peter Isaacson and George Grader, see di Pasquo et al., 2015b, 2016b, 2019a).

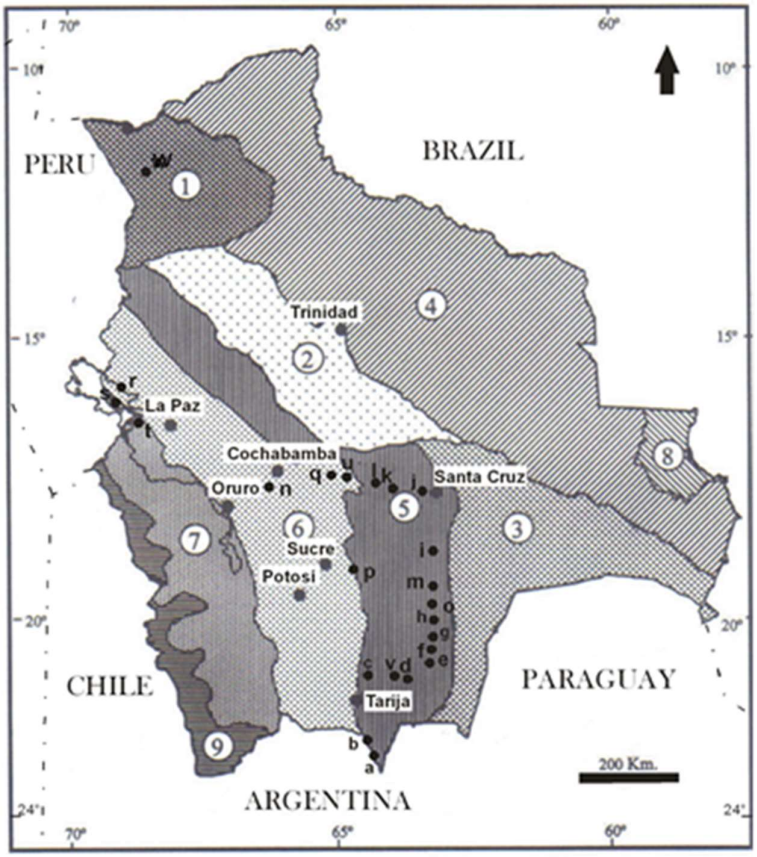


Figure 3. A. Stratigraphy of Devonian-Carboniferous northern Argentina and southern Bolivia, from the oral presentation given by di Pasquo (2022) at the AASP meeting (Manizales, 2022). **B**. Illustration included in the abstract.

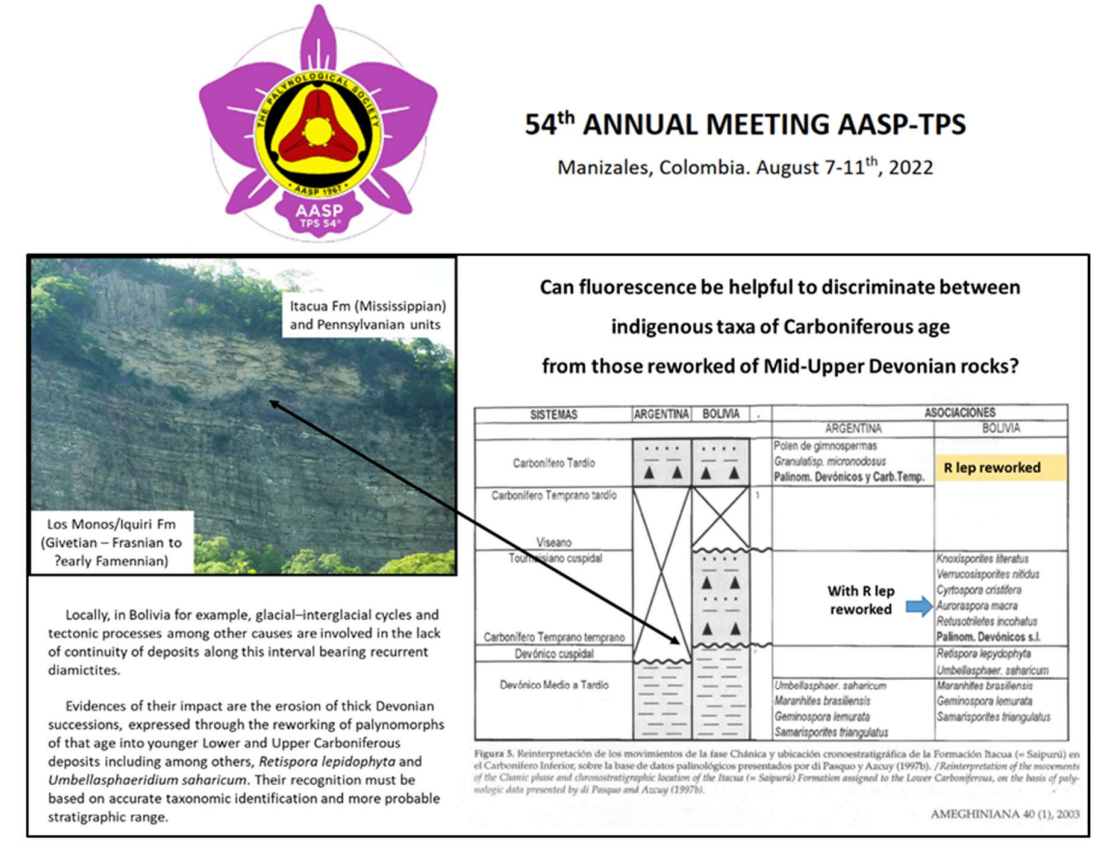


Figure. Fluorescence color exhibited by phytoplankton and spores like Retispora lepidophyta (lower left, x100 magnification), which are mostly reworked from Devonian strata. Sample from the Pando X-1 (core at 1132 m depth, slide mounted with Cellosize/Entellan), Early Visean in age.

Figure 4. Diagnostic taxa from Mid-Late Devonian and Carboniferous.

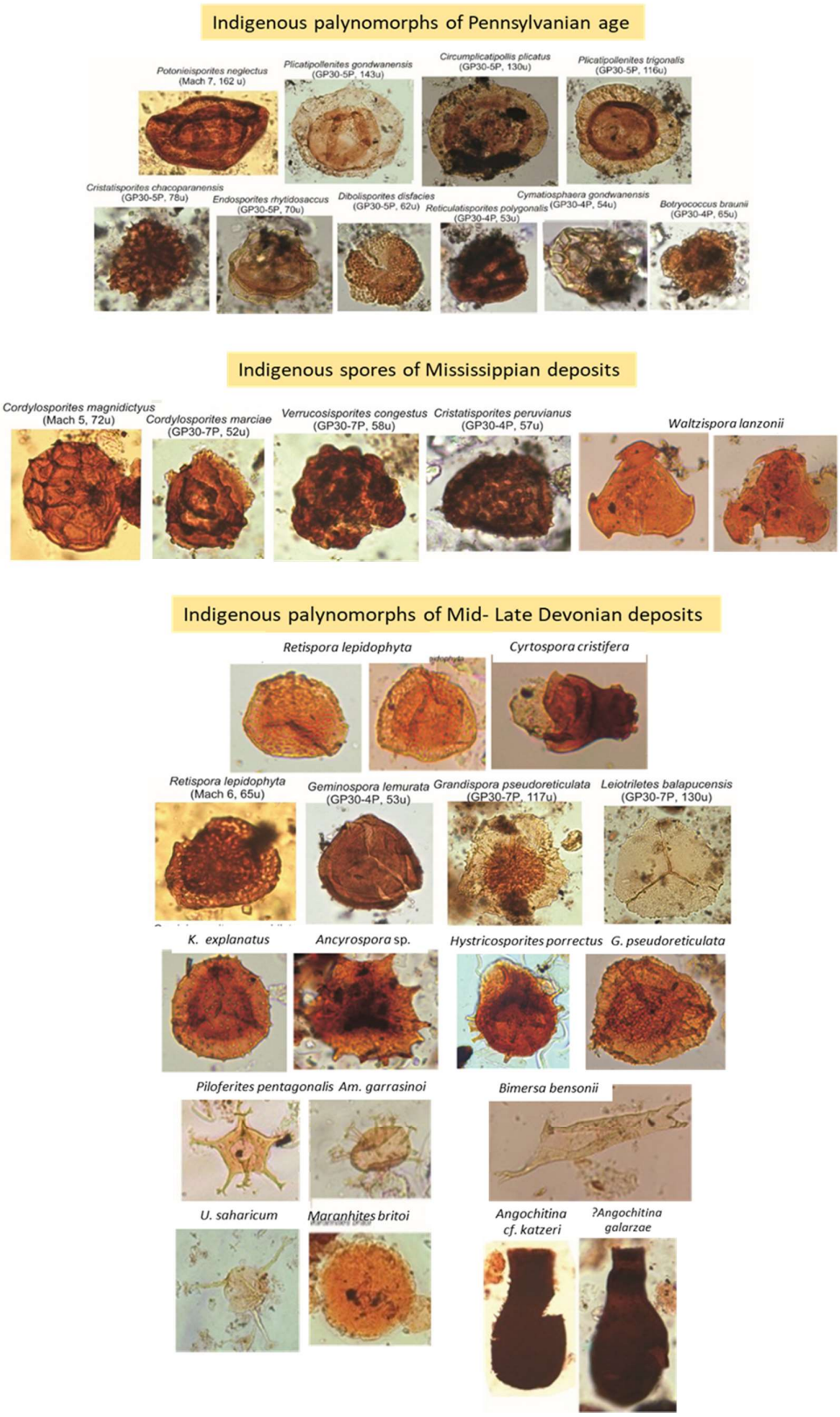


Figure 5. Manuripi X-1, sample CICYTTP-Pl 572-1-hf-GG, mounted with jelly-glycerin. 1-4. *Petrovina connata* (reworked) and *Reticulatisporites waloweekii* (indigenous). EF J68/0 (1-2, x40, 1114 ms, 3G. 3-4. x100, 1114 ms, 3G). 5-9. *Grandispora libyensis*, *Umbellasphaeridium saharicum* (both reworked) and many more spores and phytoplanktonic taxa with and without fluorescence, EF R67/3 (6. x40, 487 ms; 7. x100, 700 ms, 3G, BG38; 8-9. x10, 487 ms, 3G). 10-13. *Cristatisporites menendezii* (indigenous) and indeterminate spores and acritarchs. EF J68/0 (10. x40; 11. 2000 ms, 3G; 12. 1200 ms; 13. x100, 2000 ms).

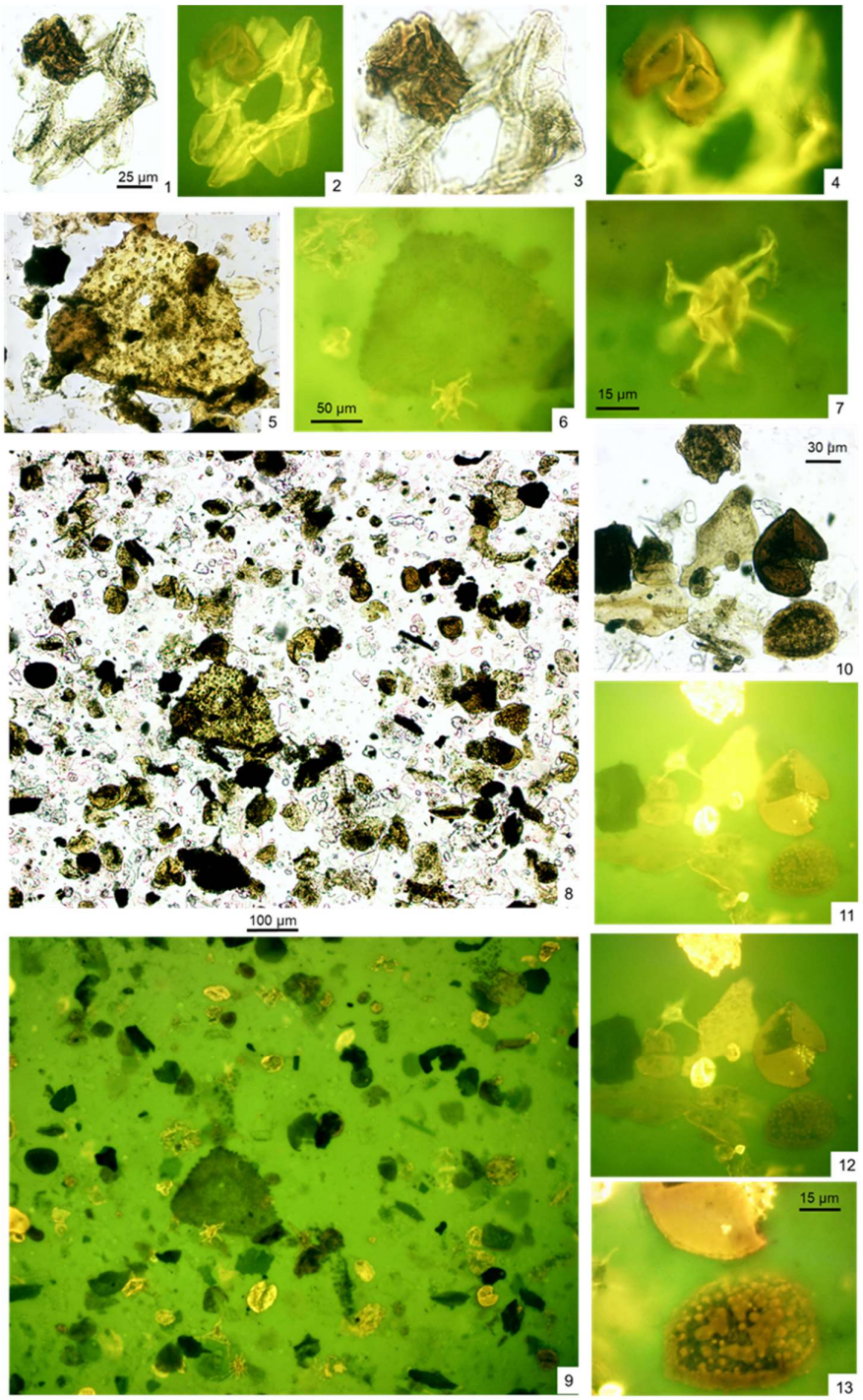


Figure 6. Manuripi X-1, sample CICYTTP-Pl 572-1-hf-GG, mounted with jelly-glycerin. 1-3. *Apiculiretusispora semisenta* (indigenous), EF N65/0 (2. x100, 2000 ms, 3G; 3. 2000 ms, 3G, BG38). 4, 7. *Retispora lepidophyta* (reticulum with small luminae, reworked specimen), EF J68/0 (7. x100, 2000 ms, 3G). 5. *Pterospermella maranhensis* (reworked), J68/0 (x40, 785 ms, 3G, BG38). 6. *Maranhites mosesi*, J68/0 (x40, 785 ms, 3G, BG38). 8-12. *Retispora lepidophyta* (reticulum with large luminae, reworked), *Verrucosisporites* sp., J68/1 (9. x40, 2000 ms, 3G; 11. x100, 2000 ms, 3G; 12. x100).

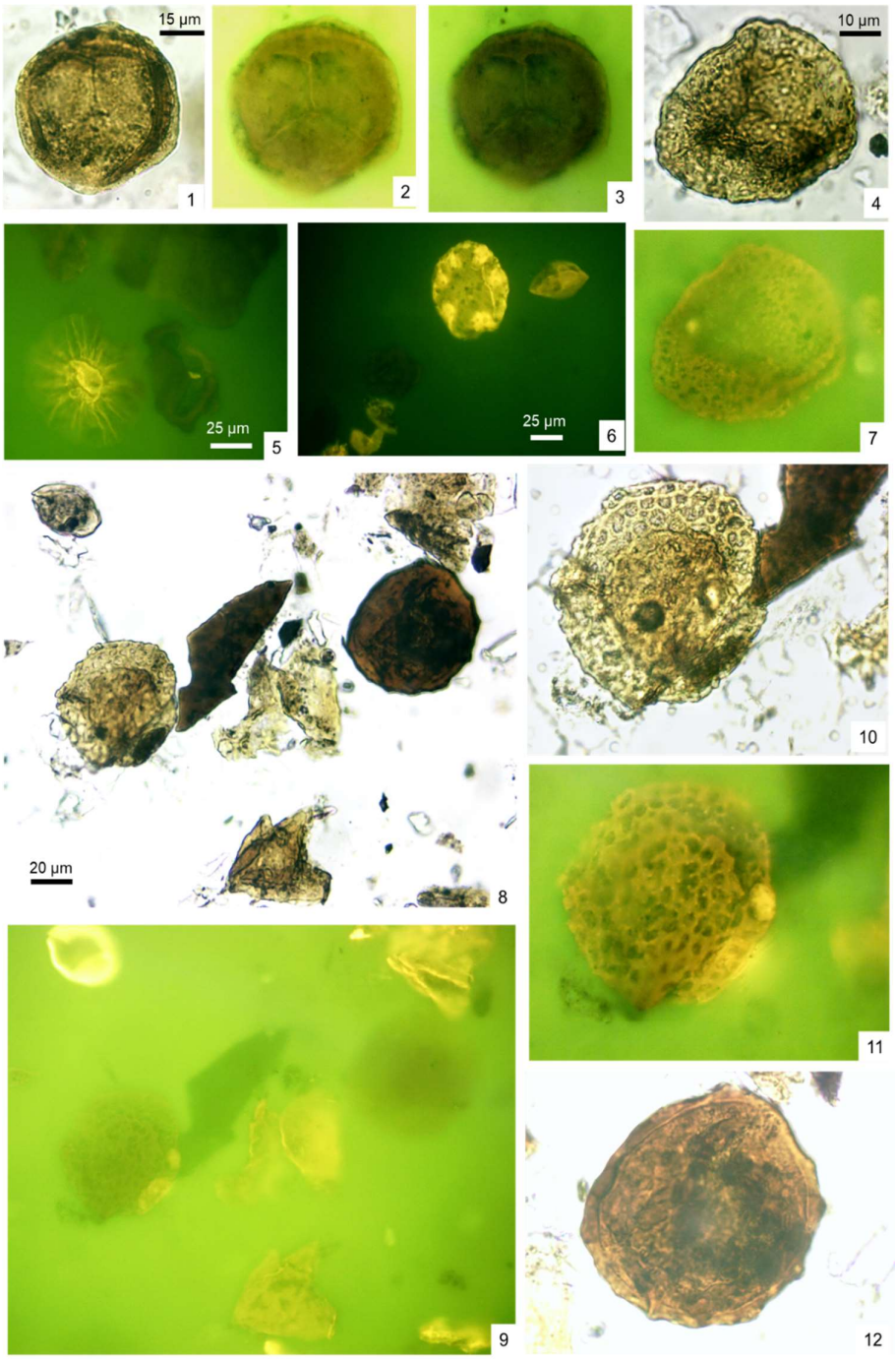


Figure 7. General view of palynomorphs in Manuripi X-1, sample 573-1+25-HF mounted with jelly-glycerin. 1-3. CICYTTP-Pl 573-1+25-HF-DMG P32/4. The differences in green intensity between 1 and 2-3 are the result of varying amounts of white light making use of the microscope diaphragm (i.e. less open in 1 than in 2-3). This procedure helps to observe palynomorphs without fluorescence (black) along with those having brilliant fluorescence (i.e. some acritarchs and prasinophytes like *Maranhites*) to orange in color (megaspore *Lagenoisporites magnus*). 4-11. Specimens picked and mounted in non-permanent slides with water. 4-5. Megaspore *Lagenoisporites magnus* (CICYTTP-Pl 576-M 144, see Quetglas et al., 2019). 6-7. *Multiplicisphaeridium* sp. (CICYTTP-Pl 572 picked). 8-9. *Spelaeotriletes balteatus* (indigenous, CICYTTP-Pl 572 picked). 10-11. *Ancyrospora* sp. (reworked, CICYTTP-Pl 572 picked).

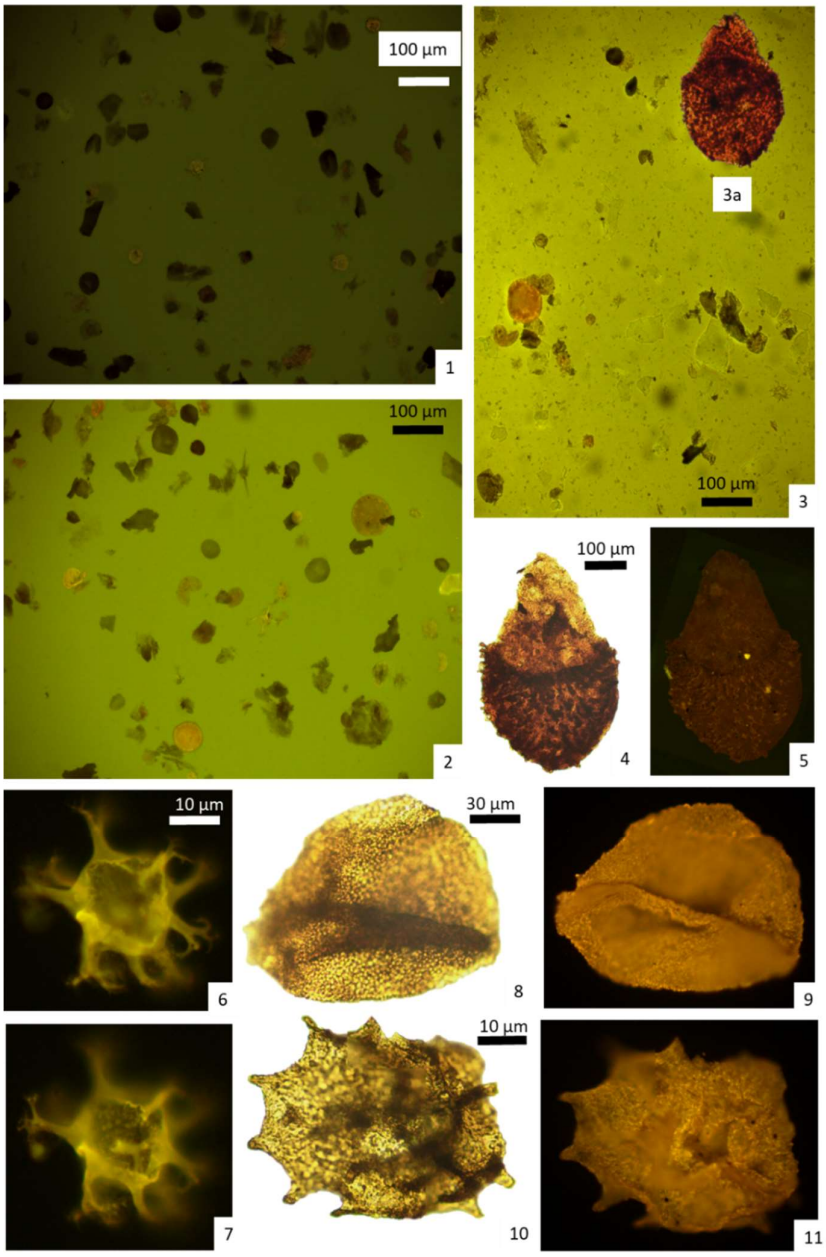


Figure 8. Manuripi X-1. All specimens of indigenous and possibly reworked species, picked from residue of sample CICYTTP-Pl 572(hexametaphosphate), mounted in non-permanent slides with water. 1. *Densosporites subcrenatus* (indigenous, see Playford, 1962), indigenous specimen lacking fluorescence. 2. *Retispora lepidophyta* (reworked) lacks fluorescence. 3-4 *Ancyrospora* sp. (reworked, CICYTTP-M 184, reworked). 5-12. Three different specimens of *Cordylosporites papillatus* (indigenous) illustrated. 13-15. *Lagenicula* sp. (CICYTTP-M 184, megaspore, in Quetglas et al., 2019, abstract). The combination of white light and fluorescence in fig. 15 helped to better illustrate the wall ornamentation of the spore.

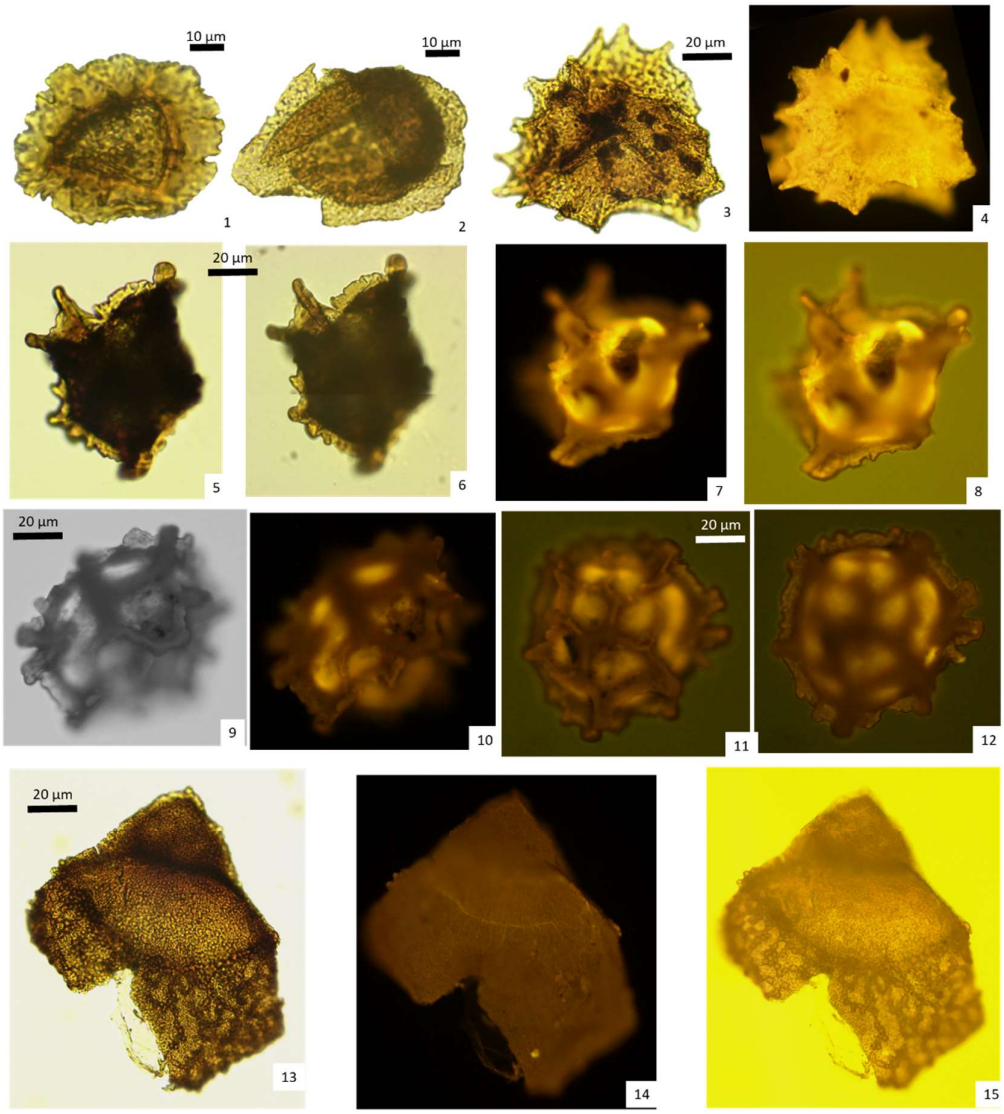


Figure 9. Pando X-1. Early Visean indigenous and Devonian reworked palynomorphs from a sample at 1132.66 m deep (CICYTTP-Pl 709, cellosize/Entellan, taken by di Pasquo in 2011 (unpublished information), see di Pasquo et al., 2019). 1-2. Reworked *Retispora lepidophyta* lacking fluorescence. 3-4. Acritarch *Umbellasphaeridium saharicum*, typical of Famennian and extinct at the end of Devonian, exhibiting a high yellow fluorescence like the indigenous chlorophycean *Botryococcus braunii* (b). 5-6. Indigenous specimens of *Verrucosisporites* sp. (a) and *Cordylosporites* sp. (b, both exhibiting orange fluorescence. Microphotograph in 6 was taken using white and fluorescence light in order to better differentiate specimens with orange fluorescence from black specimens (without fluorescence).

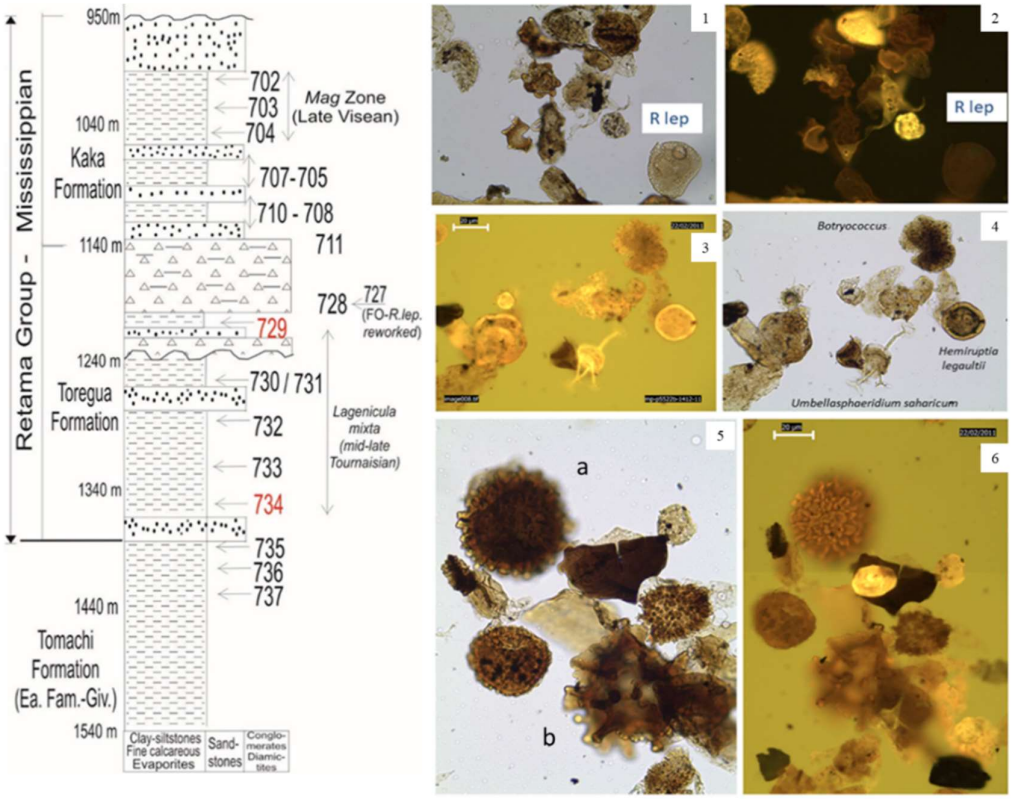


Figure 10. Pando X-1. Early Visean indigenous and Devonian reworked palynomophs from a sample at 1132.66 m deep (CICYTTP-Pl 709, cellosize/entellan). The microphotographs were taken with a Leica EC3 video camera by MdP in 2011. 1-3. Reworked acritarchs (*Umbellasphaeridium saharicum, Verhyachium, Gorgonisphaeridium),* prasinophytes (*Tasmanites*, *Maranhites, Cymatiosphaera*) and spores bearing fluorescence. 4-6. Reworked *Retispora lepidophyta* at the upper left margin in Fig. 4 (enlarged from fig. 5). The absence of fluorescence of *R. lepidophyta* is shown in fig. 6. Acritarchs such as *Umbellasphaeridium saharicum* exhibit a higher yellow fluorescence respect to an orange color of some indigenous and reworked spore taxa.

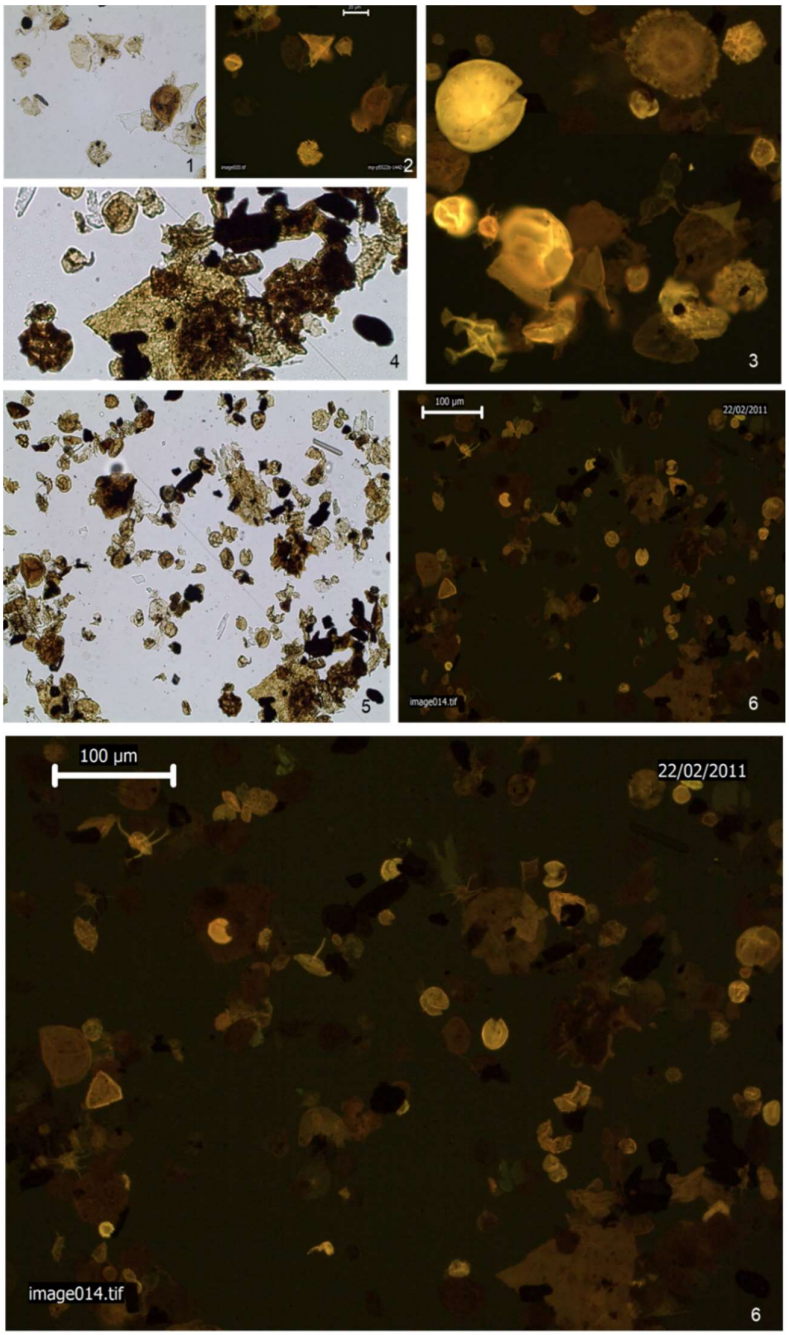


Figure 11. Pando X-1. Late Tournaisian/Early Visean indigenous and Devonian reworked palynomophs from a sample at 1182.81 m deep (CICYTTP-Pl 727, cellosize/entellan). The microphotographs were taken with an AmScope 14 Mp video camera by MdP in 2022. 1-2. Indigenous (see Figs. 3-4) and reworked taxa (see Fig. 5) are shown, EF O42/1 (1. x10, 2. x40, 2000 ms, 3 gain). 3-4. *Lophozonotriletes appendices* (indigenous, x100, 2000 ms, 3 gain). 5. *Retispora lepidophyta* (x100, 2000 ms, 3 gain). 6-8. *Murospora altila* (indigenous), EF O47/0 (7. x40, 2000 ms, 3 gain; 8. x40, 2000 ms, 3 gain, BG38). 9-12. *Retispora lepidophyta* and *Umbellasphaeridium saharicum*, EF R47/2 (10. x40, 2000 ms, 3 gain; 12. x100, 2000 ms, 3 gain). 13. *Botryococcus braunii* (CICYTTP-Pl 728, 1185 m deep, cellosize/entellan), EF J51/0 (x40, 900 ms, 1.4 gain).

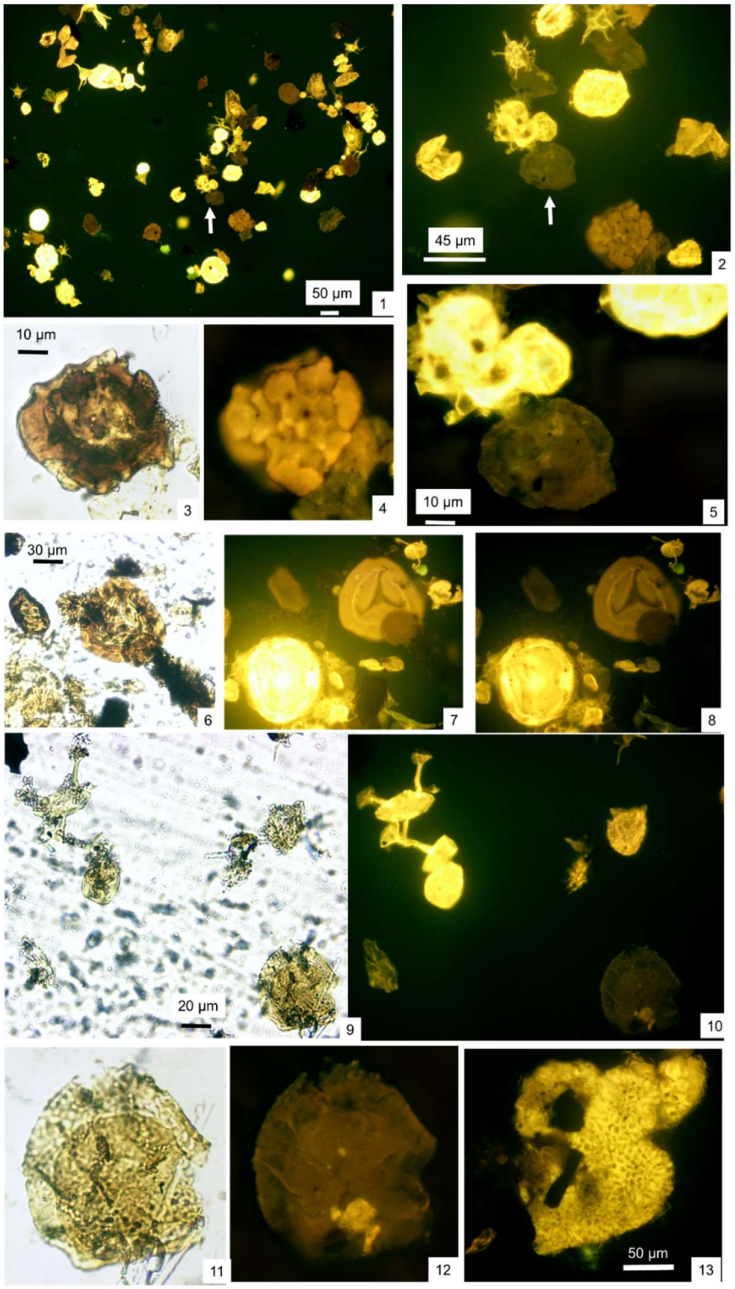


Figure 12. Pando X-1. Oxidized residues mounted with Trabasil in 2022. 1-4. *Hystricosporites porrectus* and *Grandispora pseudoreticulata* (reworked) among other palynomorphs and phytoclasts, CICYTTP-Pl 733(Wood)-1-OX-trab, EF J46/0 (2. X10, 2000 ms, 3 gain; 3.x10, 2000 ms, 2 gain; 4.x10, 2000 ms, 3G, BG38). 5-6. CICYTTP-Pl 735(Wood)-1-OX-trab, EF O22/1 (x10, 2000 ms, G1).

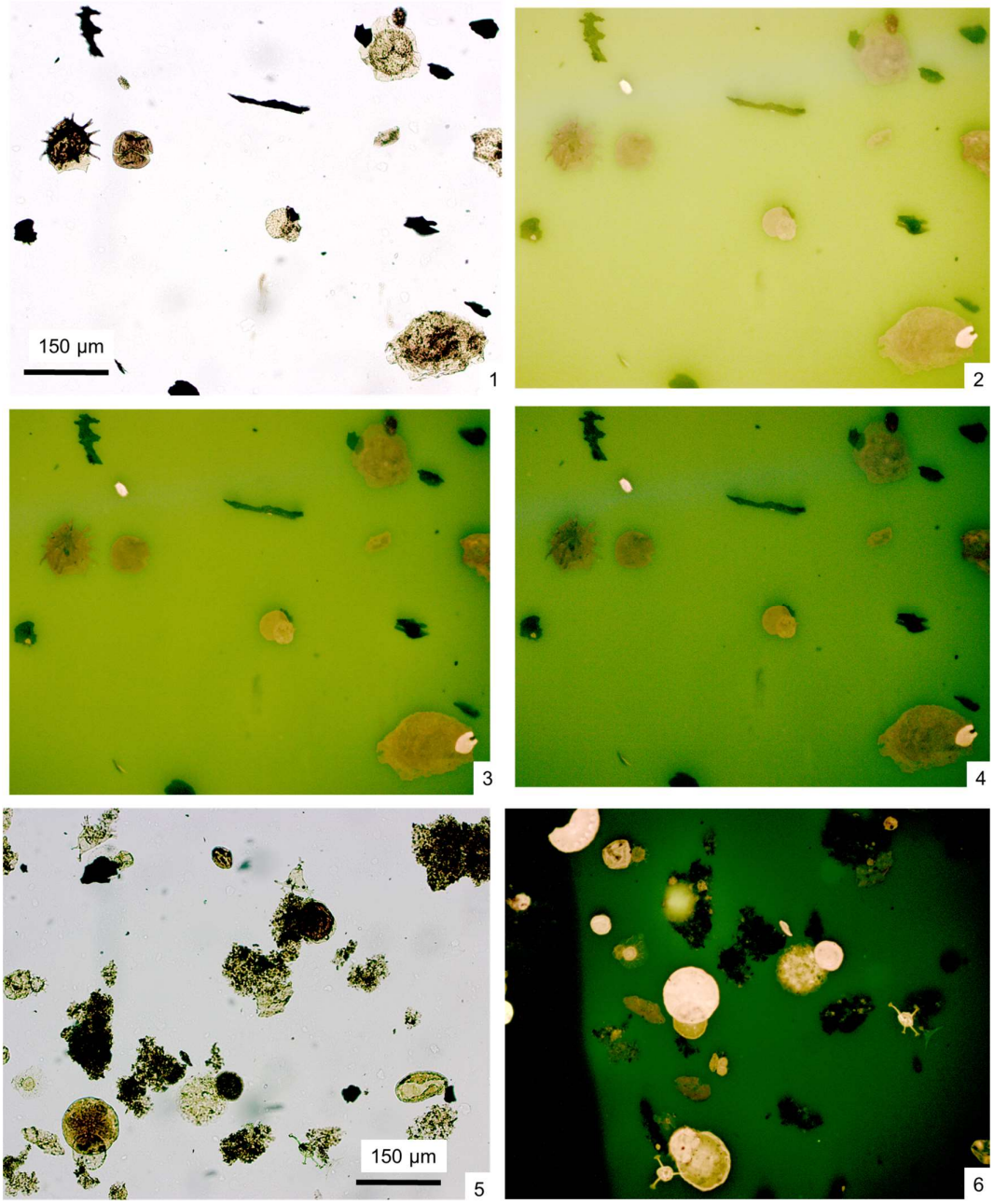


Figure 13. Pando X-1. 1-4. *Retispora lepidophyta* (without fluorescence), CICYTTP-Pl 728-1-jelly-glycerin, EF U50/3 (2. X40, 115 ms, 1 gain; 3-4.x100, overlapped palynomorphs). 5-6. *Umbellasphaeridium saharicum* and other palynomorphs, CICYTTP-Pl 734-hclte-1-jelly-glycerin, EF Q40/0 (x40, 430 ms, 3 gain). 7, 10. *Hystricosporites* sp. (reworked), CICYTTP-Pl 733(Wood)-1-OX-trab, EF D31/0 (x40, 2000 ms, 3 gain; 11. X40, 2000 ms, 3G, BG38). 8-9. *Lagenicula* sp., CICYTTP-Pl 733(Wood)-1-OX-trab, EF D25/0 (x10, 2000 ms, 3 gain, BG38). 12-14. *Hystricosporites* sp. (reworked), CICYTTP-Pl 733(Wood)-1-OX-trab, EF D33/0 (x10; 13. X40, 2000 ms, 3 gain; 14. 2000 ms, 3G, BG38). 15-17. *Spelaeotriletes balteatus* (indigenous) and *U. saharicum*, CICYTTP-Pl 735(Wood)-1-OX-trab, EF B45/4 (15. x40, 2000 ms, 1.5 gain, BG38; 16. x10, 2000 ms, 1.5 gain).

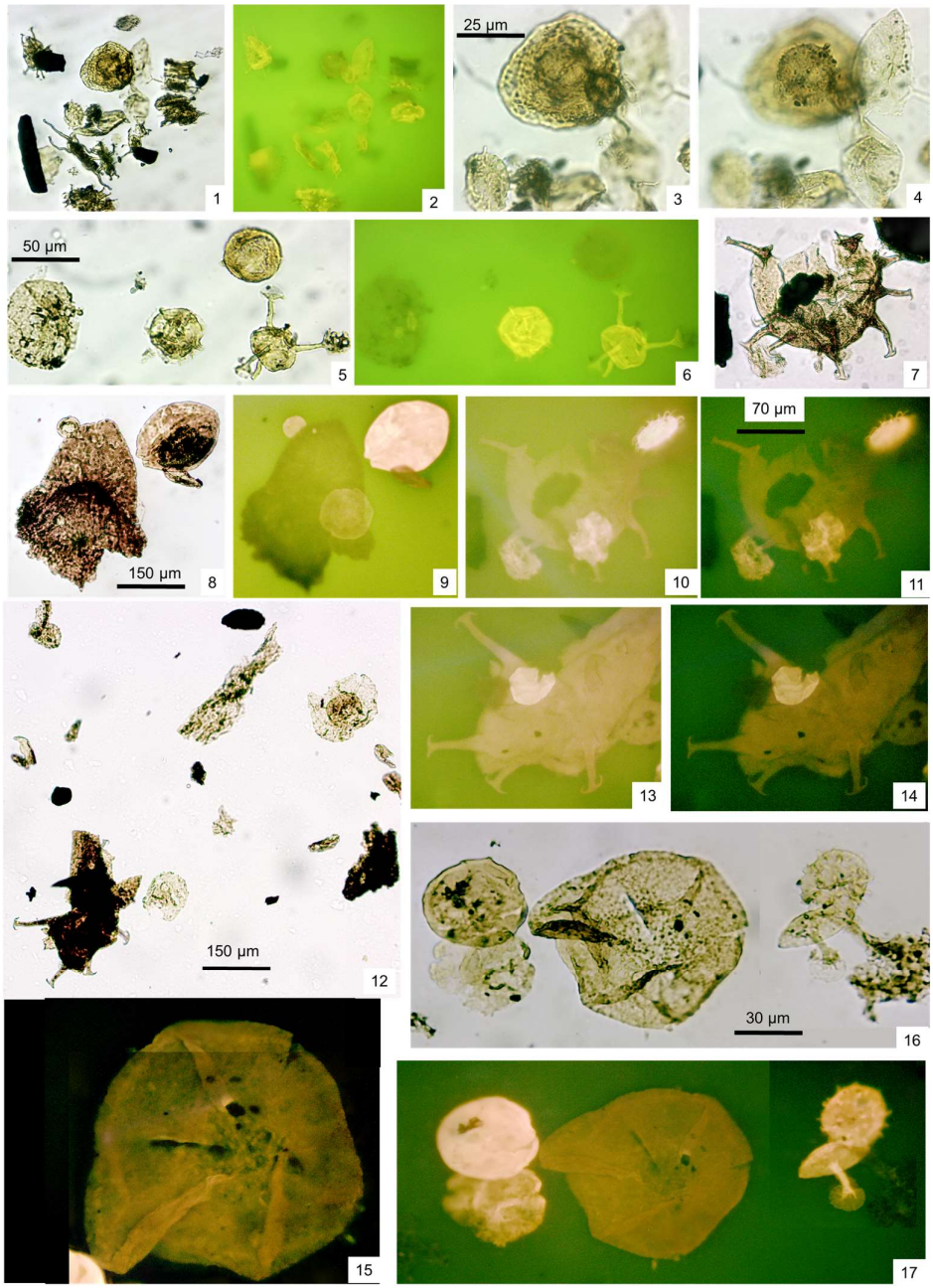


Figure 14. Pando X-1, CICYTTP-Pl 733(Wood)-1-OX (oxidized residue), 1-14. Slide mounted with Norland in 2022; 15. Slide mounted with Trabasil. 1-2. Most of the palynomorph are reworked from Devonian, EF P44/4 (x10, 2000 ms, 3 gain). 3-4. *Maranhites mosesi* and *Gorgonisphaeridium* sp. exhibiting intense yellow fluorescence (square in Fig. 1; x40, 2000 ms, 3 gain). 5-6. *Densosporites variomarginatus* (indigenous) and *Umbellasphaeridium saharicum* and other taxa, EF Q44/1 (x40, 2000 ms, 3 gain). 7-8. *Horologinella quadrispina* and *Grandispora* sp. (reworked) and megaspore, EF U46/0 (7. x40, 8. x10, 2000 ms, 3 gain). 9-12. *Maranhites mosesi* and other acritarchs, EF V46/0 (10. x40, 2000 ms, 3 gain; 11. 1777 ms, 1.8 gain; 12. 2000 ms, 3 gain, BG38). 13-14. *Reticulatisporites waloweekii* (indigenous), EF V47/0 (x100, 2000 ms, 3 gain). 15. *Umbellasphaeridium saharicum* and *Gorgonisphaeridium* sp., EF V48/0 (x40, 1465 ms, 3 gain, BG38).

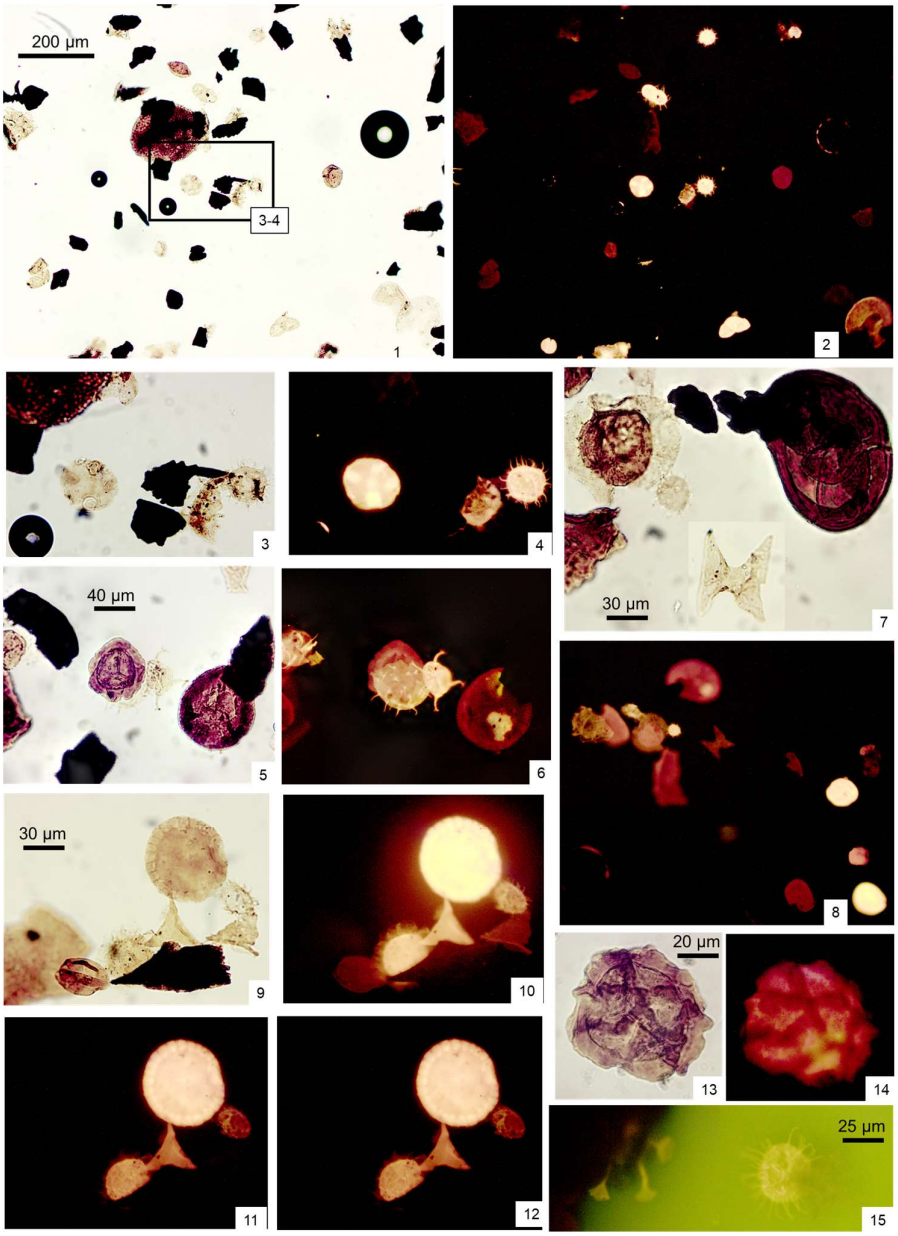


Figure 15. Indigenous spores of the Rio Alto Beni (BAFC-Pl 506, jelly-glycerin). 1-3. *Calamospora* sp. and 4-6. *Botryococcus* (2, 5. 350 ms, 1.2 gain; 3, 6. 630 ms, 1.4 gain) EF V48/4. 7-8. *Verrucosisporites congestus* (760 ms, 1.6 gain), EF R34/4. 9-10. *Cristatisporites peruvianus* (730 ms, 2.3 gain), EF M52/0. 11-13. *Cordylosporites magnidictyus* (11-12. x100, and x40, 1000 ms, 2.4 gain; 13. x10, 500 ms, 2.4 gain), EF V48/4.

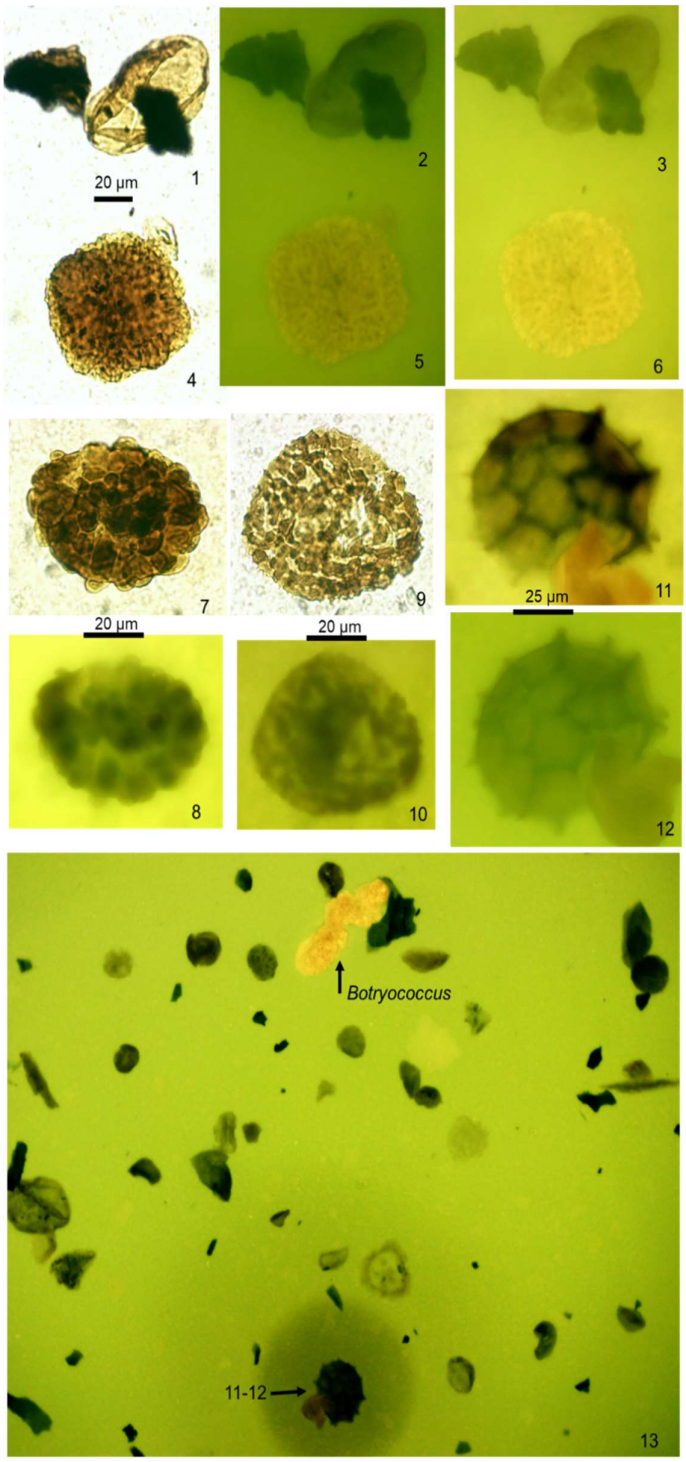


Figure 16. Indigenous spores of the Rio Alto Beni (BAFC-Pl 506, jelly-glycerin). 1-3. *Reticulatisporites magnidictyus* (1. x10; 2-3. x40, 268 ms, 1.7 gain; 4. x100, 784 ms, 1.7 gain), EF L24/1. 5-6. Several spore taxa, with dark orange to somewhat black color of fluorescence except for the spore at the upper right that shows a lighter orange color (x40, 757 ms, 2 gain), EF M52/0. 7-9. *Apiculiretusispora semisenta* (7) and *Cristatisporites peruvianus* (8-9), EF K53/4 (9. x100, 870 ms, 2 gain). 10-12. *Rotaspora fracta*, EF V43/0 (11. x100, 260 ms, 1.7 gain; 12. x40, 196 ms, 1.7 gain).

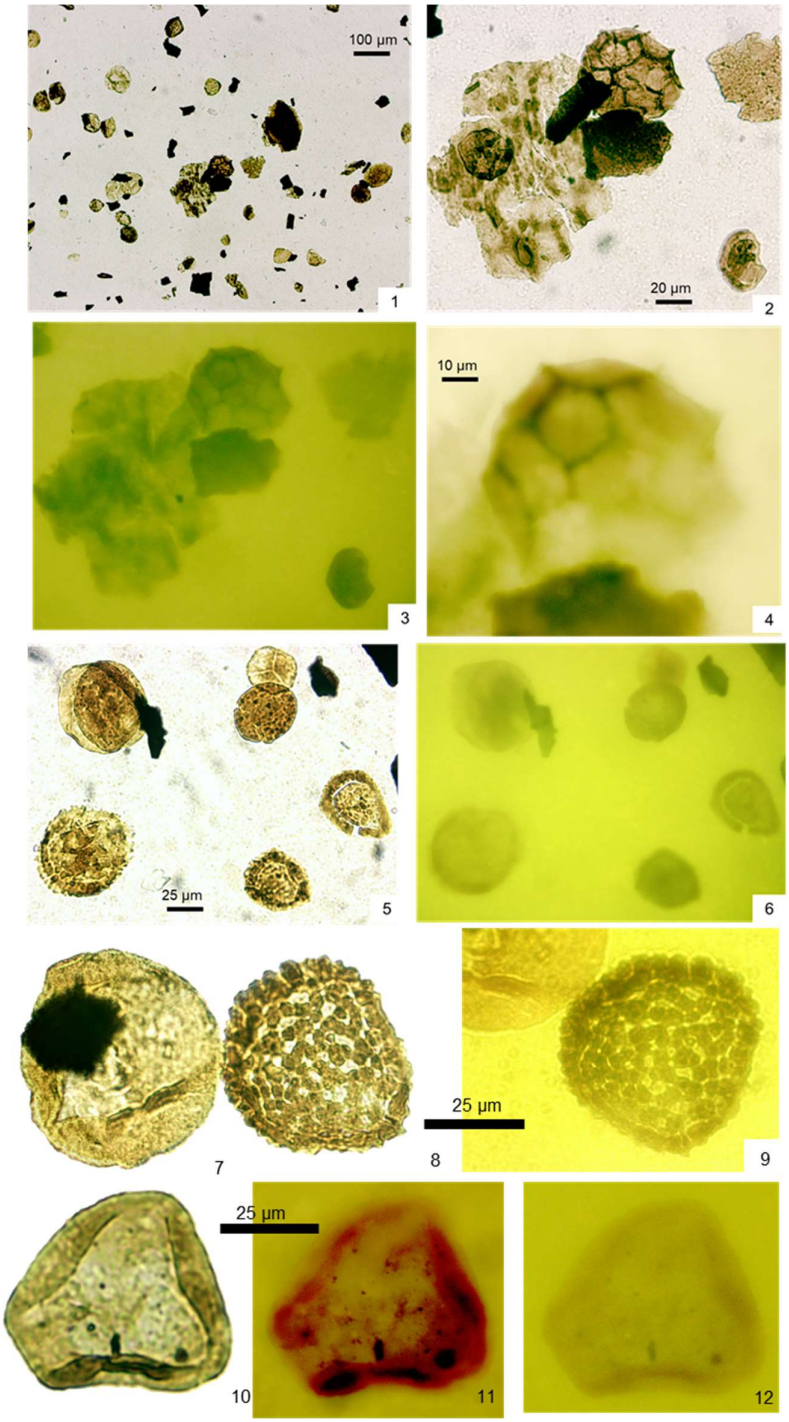


Figure 17. Macharetí creek. 1-5. Sample CICYTTP-Pl 2702-1-OX-trabasil (oxidized). 6-11. CICYTTP-Pl 2702-1-trabasil (non- oxidized). 1-3. *Polyedryxium* sp. (reworked), EF X33/0 (1-2. 2000 ms, 3 gain. 3. 2000 ms, 3 gain, BG38). 4-5. *Reticulatisporites waloweekii* (indigenous), EF W34/0 (2000 ms, 3 gain). 6-7. Prasinophycea (reworked), EF R32/0 (2000 ms, 3 gain). 8-9. *Quadrisporites granulatus* (reworked), EF R38/2 (8. 2000 ms, 3 gain, BG38, 9. 2000 ms, 3 gain). 10-11. Algal specimens (reworked) with orange fluorescence and other black palynomorphs without fluorescence, EF J42/2 (x10, 2000 ms, 3 gain).

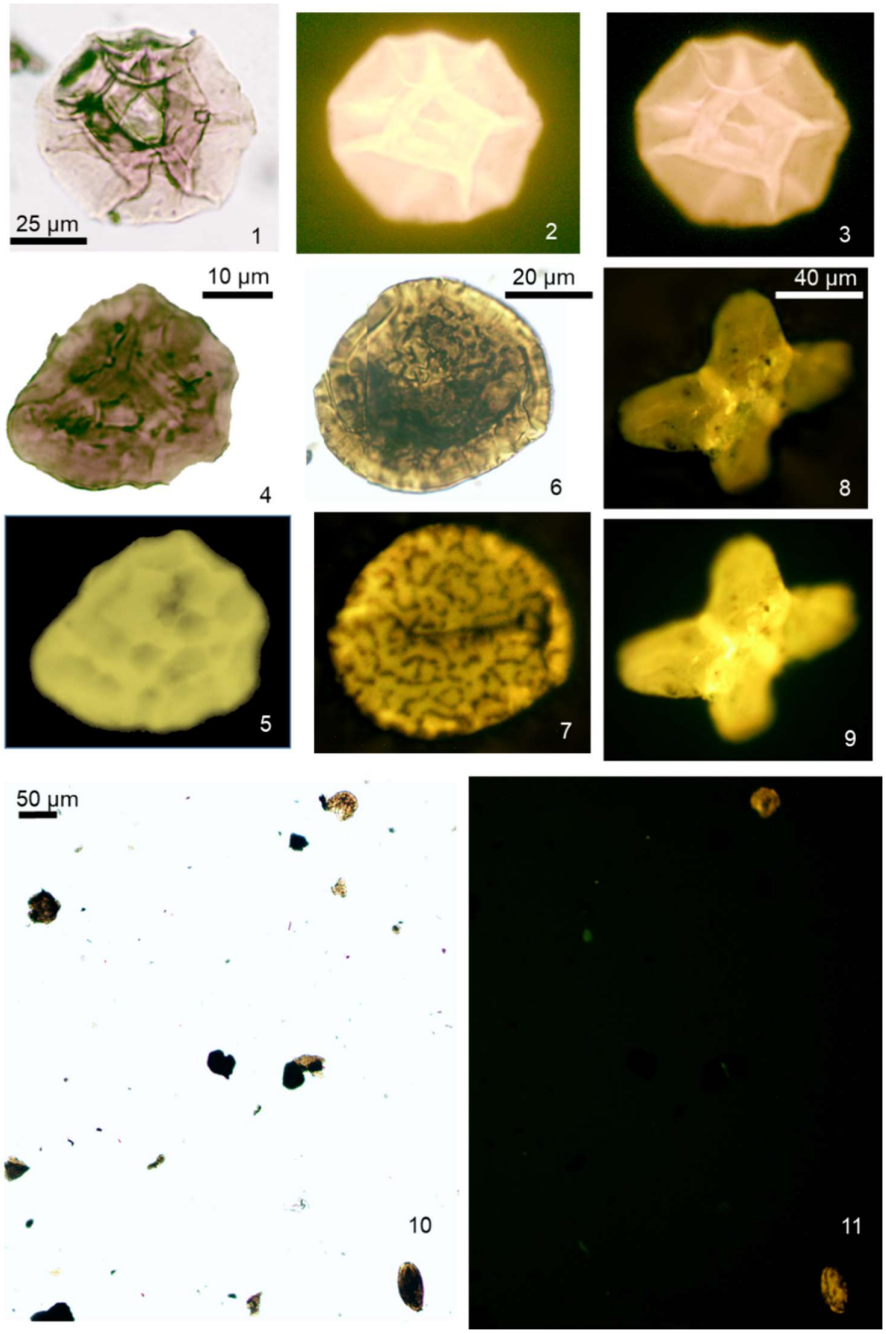


Figura 18. Map of northwestern Argentina showing Upper Paleozoic Geologic Provinces and location of San Antonio X-1 (SA, di Pasquo and Noetinger, 2008; Noetinger and di Pasquo, 2011) and Zanja Honda (del Papa and di Pasquo, 2007) studied setions herein among others carried out by di Pasquo from Devonian-Carboniferous units (see Azcuy and di Pasquo, 2000; di Pasquo, 2002, 2003, 2007a, 2007b, 2009b, 2022; di Pasquo and Azcuy, 1997, 1999a, 1999b; Noetinger et al., 2018).

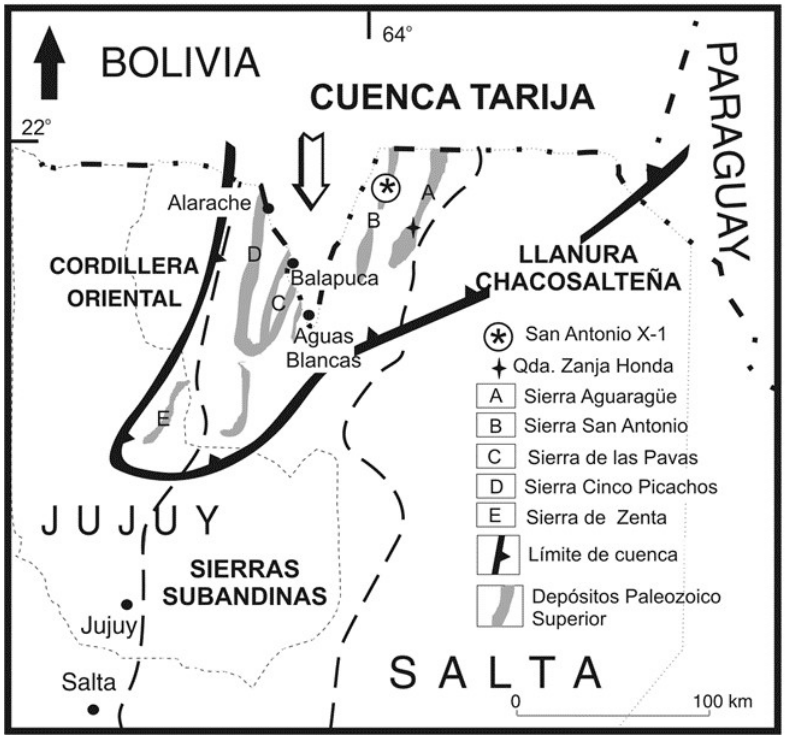


Figure 19. San Antonio X-1 borehole. 1-2. *Umbellasphaeridium saharicum* (reworked), CICYTTP-Pl 2704(BAFC-1994)-1-GG (non-oxidized, jelly-glycerin), EF R43/0 (x100, 2000 ms, 3 gain). 3-4. *Retispora lepidophyta* (reworked), CICYTTP-Pl 2703(BAFC-1968)-1-GG (non-oxidized, jelly-glycerin), EF V51/1 (x100, 2000 ms, 3 gain). 5. *Retispora lepidophyta*, CICYTTP-Pl 2703(BAFC-1968)-2-trab (non-oxidized, Trabasil), EF R50/4 (x100), without fluorescence. 6-7. *Retispora lepidophyta,* CICYTTP-Pl 2704(BAFC-1994)-1-OX-trab (oxidized, Trabasil), EF R45/1 (x100, 2000 ms, 3 gain). 8. *Retispora lepidophyta*, CICYTTP-Pl 2703(BAFC-1968)-1-trab (non-oxidized, Trabasil), EF S28/1 (x100), without fluorescence. 9-11. *Maranhites mosesi* (reworked), CICYTTP-Pl 2704(BAFC-1994)-1-trab (non-oxidized, Trabasil), EF F38/0 (10. x40, 2000 ms, 3 gain; 11. 2000 ms, 3 gain, BG38).

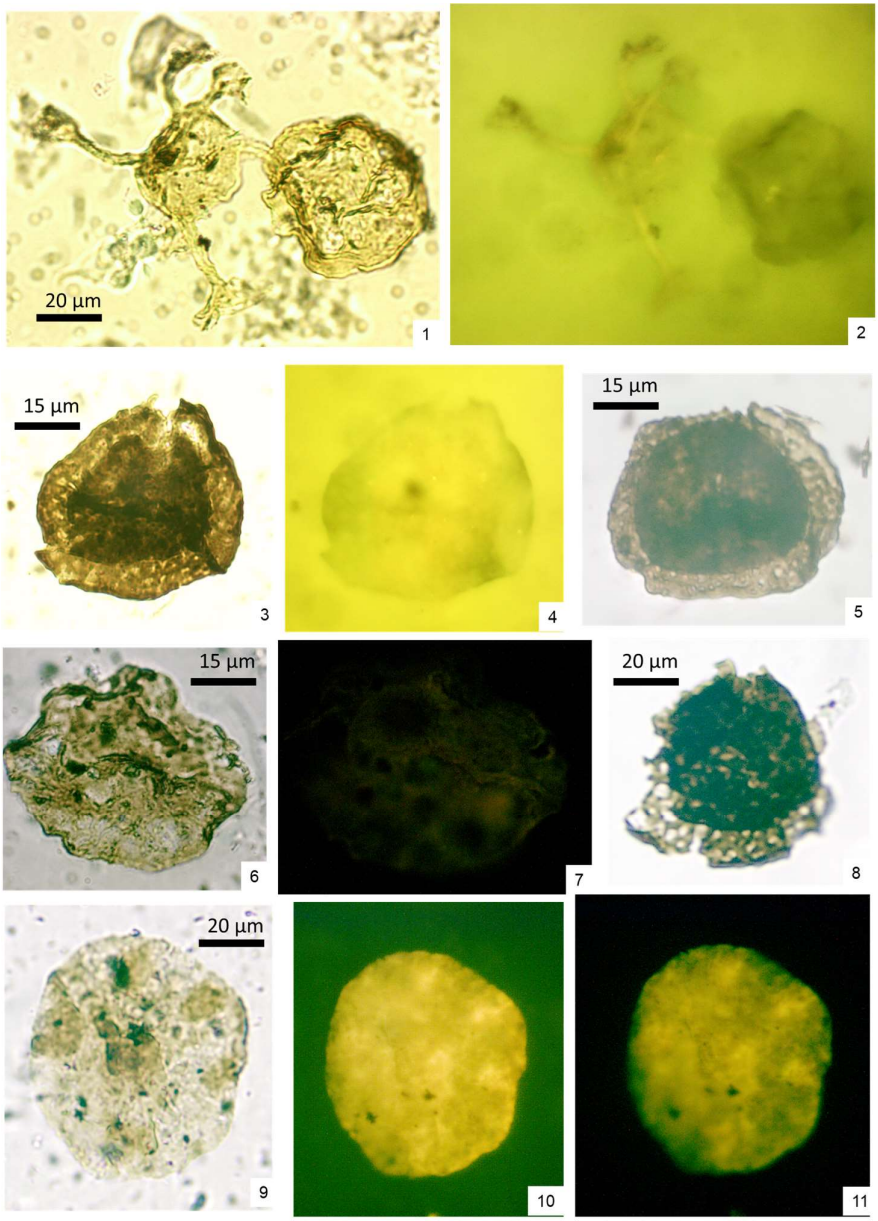


Figure 20. San Antonio X-1 borehole. 1-2. Chitinozoan, *Tasmanites* and other palynomorphs. CICYTTP-Pl 2704(BAFC-1994)-1-OX-trab (oxidized, Trabasil), EF L26/1 (x10, 2000 ms, 3 gain). 3-4, 8. *Potonieisporites lelei*, CICYTTP-Pl 2704(BAFC-1994)-1-OX-trab, EF Y29/0 (3. x10, 4, 8. x40, 2000 ms, 3 gain). 6-7. *Botryococcus braunii*, CICYTTP-Pl 2703(BAFC-1968)-1-OX-trab, EF D59/0 (x100, 2000 ms, 3 gain, BG38). 5, 9. *Maranhites mosesi*, CICYTTP-Pl 2704(BAFC-1994)-1-OX-trab, EF Y39/0 (x40, 2000 ms, 3 gain).

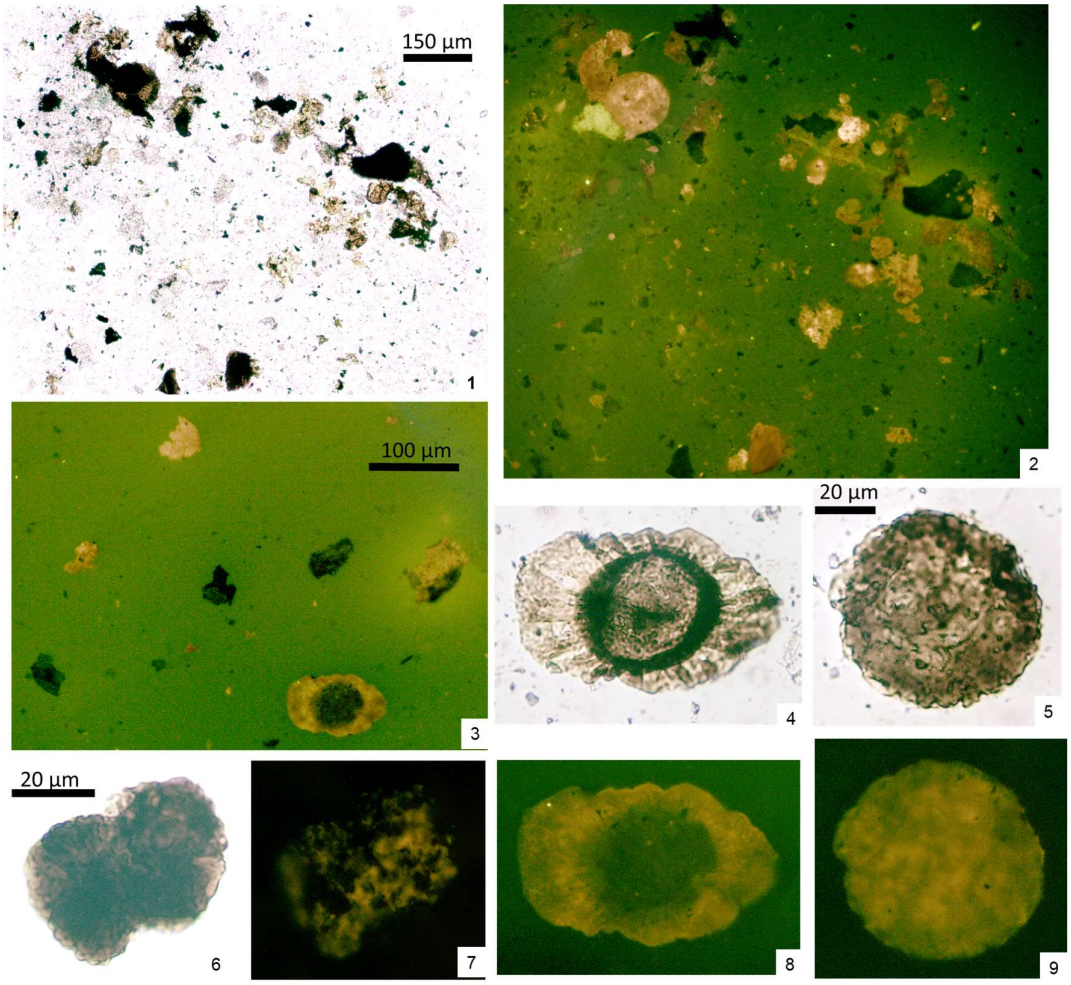


Figure 21. Zanja Honda. 1-13. CICYTTP-Pl 2705(BAFC-Pl 1476)-1-trab (non-oxidized, Trabasil). 1-4. *Cannanoropollis triangularis* (indigenous), EF Y57/0 (1. x10, 2000 ms, 3 gain; 2-3. x40, 2000 ms, 3 gain; 4. x100, 2000 ms, 3 gain). 5-6. *Plicatipollenites malabarensis*, EF O26/3 (6. x40, 2000 ms, 3 gain). 7, 11. *Cannanoropollis densus*, EF F28/1 (x40, 2000 ms, 3 gain). 8-9. *Retispora lepidophyta*, EF W53/0 (x100, 2000 ms, 3 gain). 10. *Grandispora pseudoreticulata* (distal face, reworked), EF N39/1 (x40, 2000 ms, 3 gain). 12-13. *Retispora lepidophyta* (with small reticulum, reworked), EF Y63/0 (x100, 2000 ms, 3 gain). 14-15. *Retispora lepidophyta* (with large reticulum), CICYTTP-Pl 2705(BAFC-Pl 1476)-2-GG (non-oxidized, jelly-glycerin), EF X64/0 (x100, 1380 ms, 2 gain).

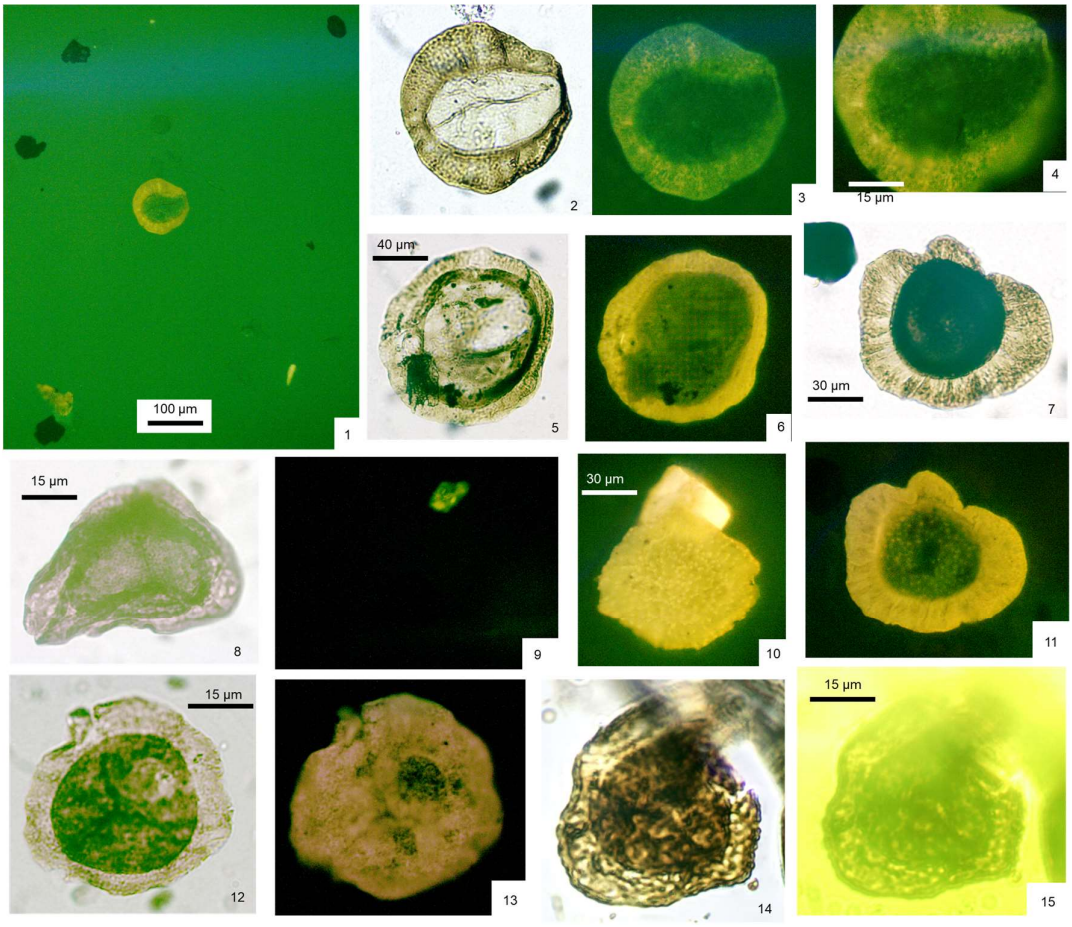


Figure 22. Zanja Honda. 1-12. CICYTTP-Pl 2705(BAFC-Pl 1476)-1-OX-trab (oxidized residue, Trabasil). 1-4. *Cordylosporites* sp., EF F23/2 (1. x40; 2-3. x100, 2000 ms, 3 gain, BG38; 4. x40, 2000 ms, 3G; it is seen in proximal face). 5-7. *Retispora lepidophyta* (reworked), EF C27/0 (5. x40; 6. x100; 7. x100, 2000 ms, 3 gain, without fluorescence, so white and fluorescence lights are showing the specimen). 8-12. *Cannanoropollis densus* (indigenous), EF D59/0 (8. x10, 2000 ms, 3 gain; 9. x40; 10. x40, 2000 ms, 3 gain; 11. x40, 2000 ms, 3 gain, BG38; 12. x100, 2000 ms, 3 gain; it is seen in distal face). 13-19. CICYTTP-Pl 2705(BAFC-Pl 1476)-1-trab (non-oxidized, Trabasil). 13-14. *Botryococcus braunii* (indigenous), EF B50/0 (13. x10, 2000 ms, 3 gain; 14. x40, 2000 ms, 3 gain). 15. *Botryococcus braunii*, EF D54/0 (x40, 2000 ms, 3 gain). 16-19. *Maranhites mosesi* (reworked), EF Z53/0 (17. x40, 540 ms, 1 gain; 18. x10, 2000 ms, 3 gain; 19. 2000 ms, 3 gain, BG38).

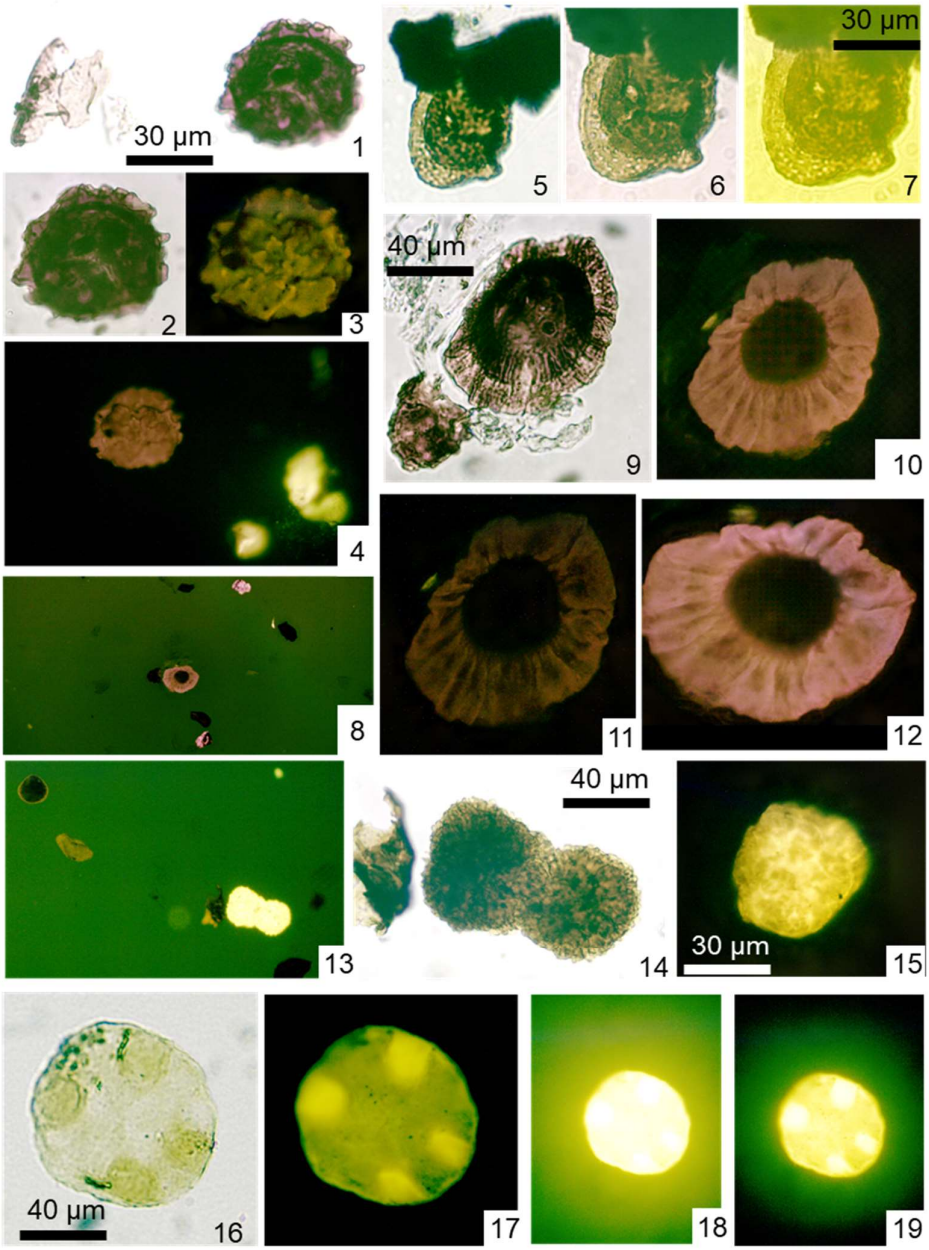


Figure 23. Inambari (MD-204C). 1-4. Oxidized residue mounted with Canadian Balsam (MD204-1B-B-oxid). 1. Palynomorphs and phytoclasts showing different intensities of fluorescence (1. x10, 2000ms, 2g). Indigenous monoporate pollen grain (Poaceae) are marked with (a), and *Retispora lepidophyta* (reworked) illustrated in Figs 2-4, EF S51/0 (3. x100, 2000 ms, 2g; 4. 2000 ms, 3g). 5-7. *Retispora lepidophyta* picked and mounted in slide with water (x100; 6. 2000 ms, 2g; 7. 2000 ms, 3g).

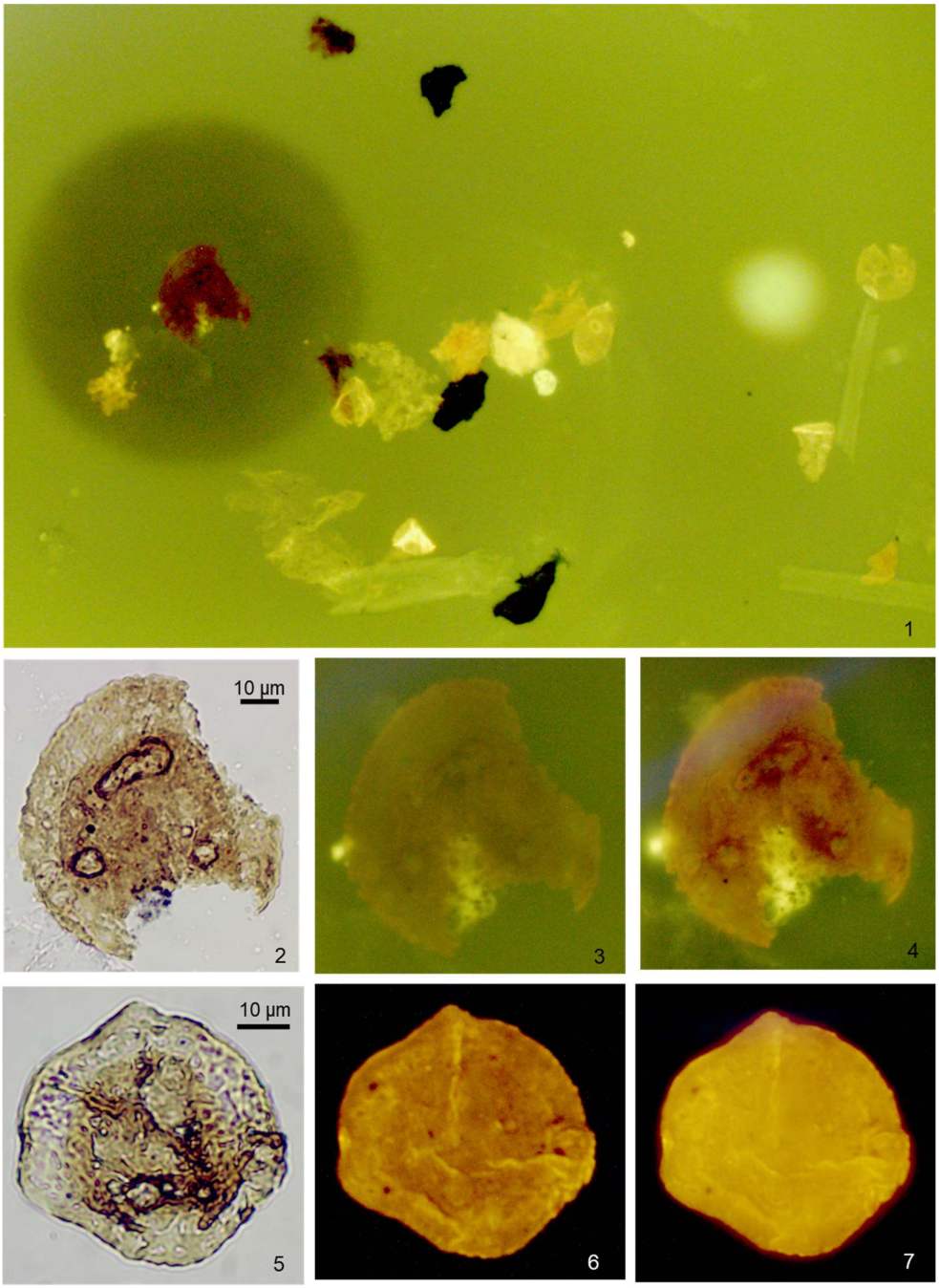


Figure 24. Inambari (MD-204C). 1-5. Oxidized residue mounted with Canadian Balsam (MD204-1B-B-oxid). 1-5. *Umbellasphaeridium saharicum* (reworked). EF O34/4. Pictures are illustrated with different magnifications and time of exposition and gain for comparison. 1. (x100, white light), 2 a-b. (x10, 2000 ms, 2g), 2c-d. (x40, 2000 ms, 2g), 3. (x100, 2000 ms, 2g), 4. (x100, 2000 ms, 3g). The delicate membrane of the distal part of processes is visible with fluorescent light, whereas poorly distinct with white light. 5-9. Specimen picked and mounted in slide with water. 5. (x10, 2000 ms, 3g), 6-7. (x40, 2000 ms, 3g), 9-10. (x100, 2000 ms, 3g).

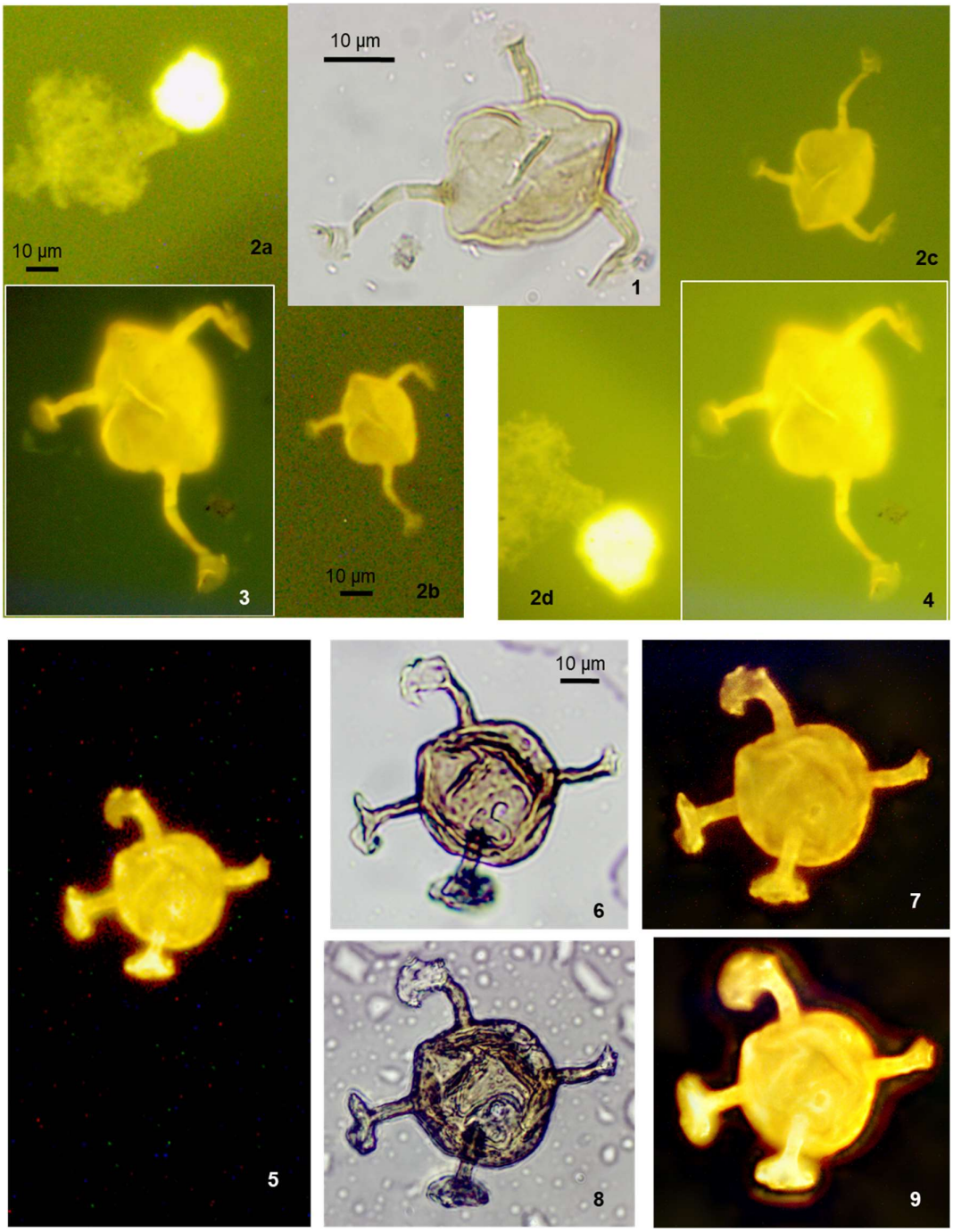


Figure 25. Inambari (MD-204C). 1-13. Palynomorphs from oxidized residue mounted with Canadian Balsam (MD204-1B-B-oxid). 1-10. Indigenous palynomorphs and phytoclasts, EF P35/0, illustrated using different magnifications and time of exposition and gain for comparison. 1. (x10, 1035 ms, 2g), 2. (x10, 2000 ms, 2g), 3. (x10, 2000 ms, 3g). 4-8. *Oedogonium* and *Botryococcus* indigenous algae (x40; 5. 465 ms, 2g; 6. 2000 ms, 1g; 7. 2000 ms, 2g; 8. 2000 ms, 3g). 9-10. *Cyatheacidites annulatus* (x100, 2000 ms, 2g). 11-13. *Ipomea*-like and poaceae pollen grains, EF P44/0. 11. (x40, 1000 ms, 2g), 13 (x100, 1000 ms, 2g). 14-15. Poaceae, specimen picked and mounted in slide with water (x100, 2000 ms, 2g).

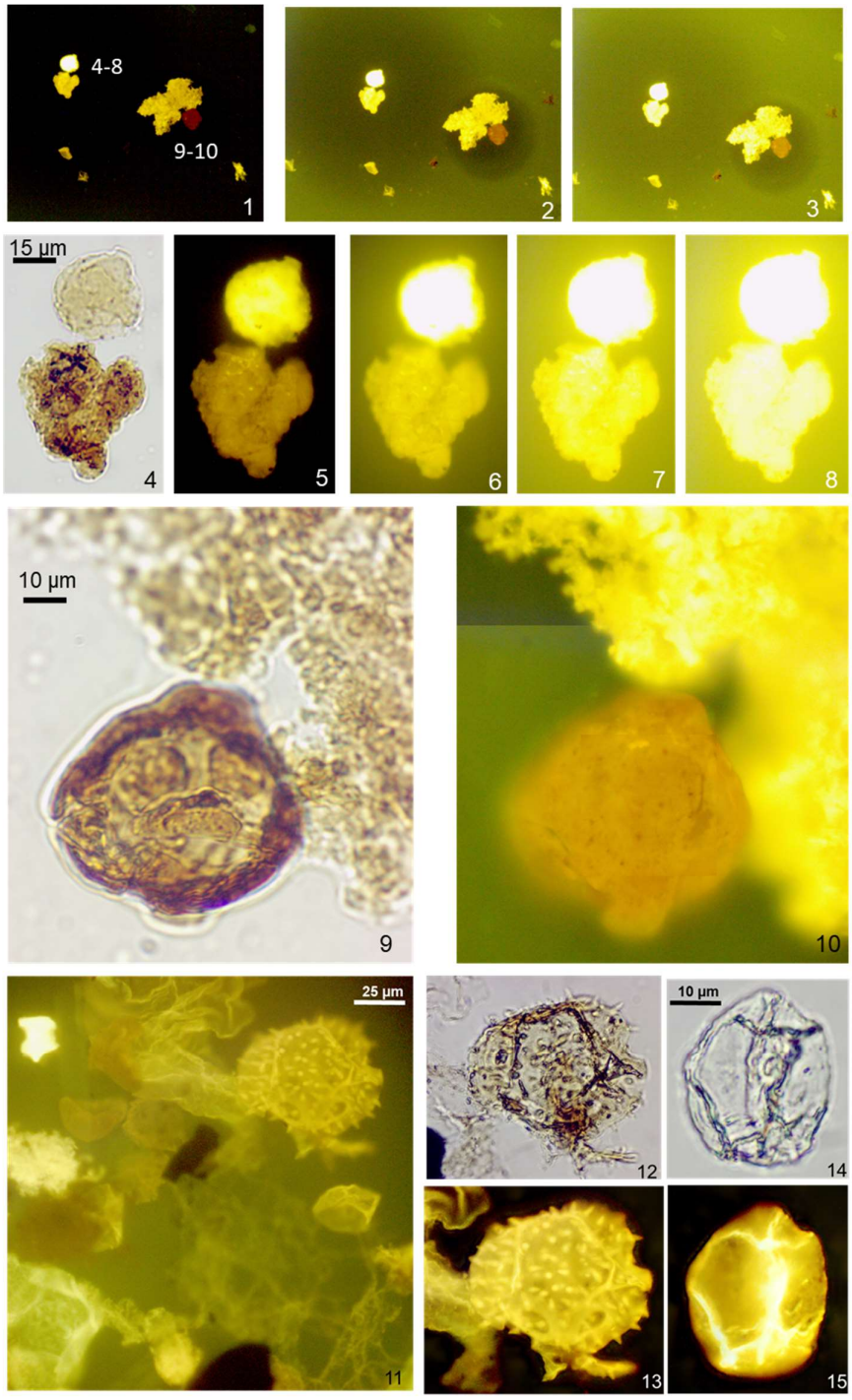


Figure 26. Paleogeographic map showing two stars corresponding to Montana and Appalachian regions from which samples were studied in this contribution.

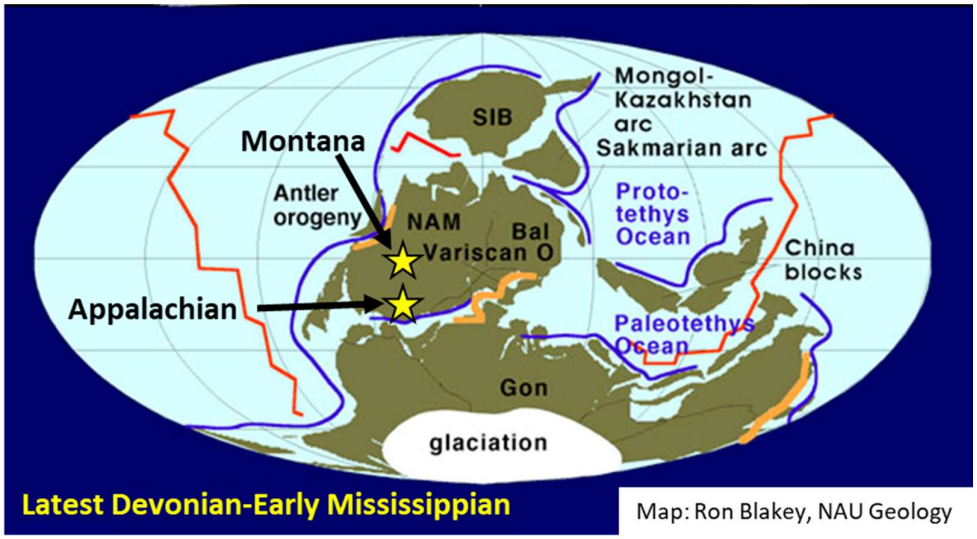


Figure 27. Logan Hollow section in Kentucky, which correspond to the stop 6 of the field trip organized during AASP meeting (Lexington 2012), where a granitic dropstone embedded in the uppermost Cleveland shale Member of the Ohio shale Formation. 1-2. Picture of the participants of the field trip taken by MdP. 3-6. Pictures of the location of the three samples collected at this locality (by MdP).

Figure 28. 1-9. Palynomorphs from non-oxidized residues of Cleveland 1 (1-5. CICYTTP-Pl 954-1-HF-glyc, slide mounted with Glycerin and paraffin; 6-9. CICYTTP-Pl 954-1-HF-Trabasil). Maximum fluorescence color is shown under 2000 mili-seconds time of exposition (ms) and 3 gain using the video camera AmScope's software. The recognition of some morphologic features of specimens exhibiting high fluorescence required changing these values. They are indicated in each illustration. 1-3. *Leiosphaeridia*, EF J55/0 (2. 40x, 2000 ms, 3 gain, 3. 477 ms, 3 gain). 4-5. *Tumulispora* cf. *rarituberculata*, EF J55/0 (x40, 2000 ms, 3 gain). 6-7. *Retispora lepidophyta*, EF G57/0 (x100, 2000 ms, 3 gain). 8-9. Phytoclasts and few acritarchs, EF W28/1 (x10, 2000 ms, 3 gain). 10-15, Bedford 1 (CICYTTP-PI 958-HF-2-glyc, slide mounted with glycerin and paraffin). 10, 12, 14, 15. *Leiosphaeridia* spp., EF L55/1 (x10, 2000 ms, 3 gain). 11, 13. *Retispora lepidophyta*, EF L55/1 (x10 and x40, 2000 ms, 3 gain).

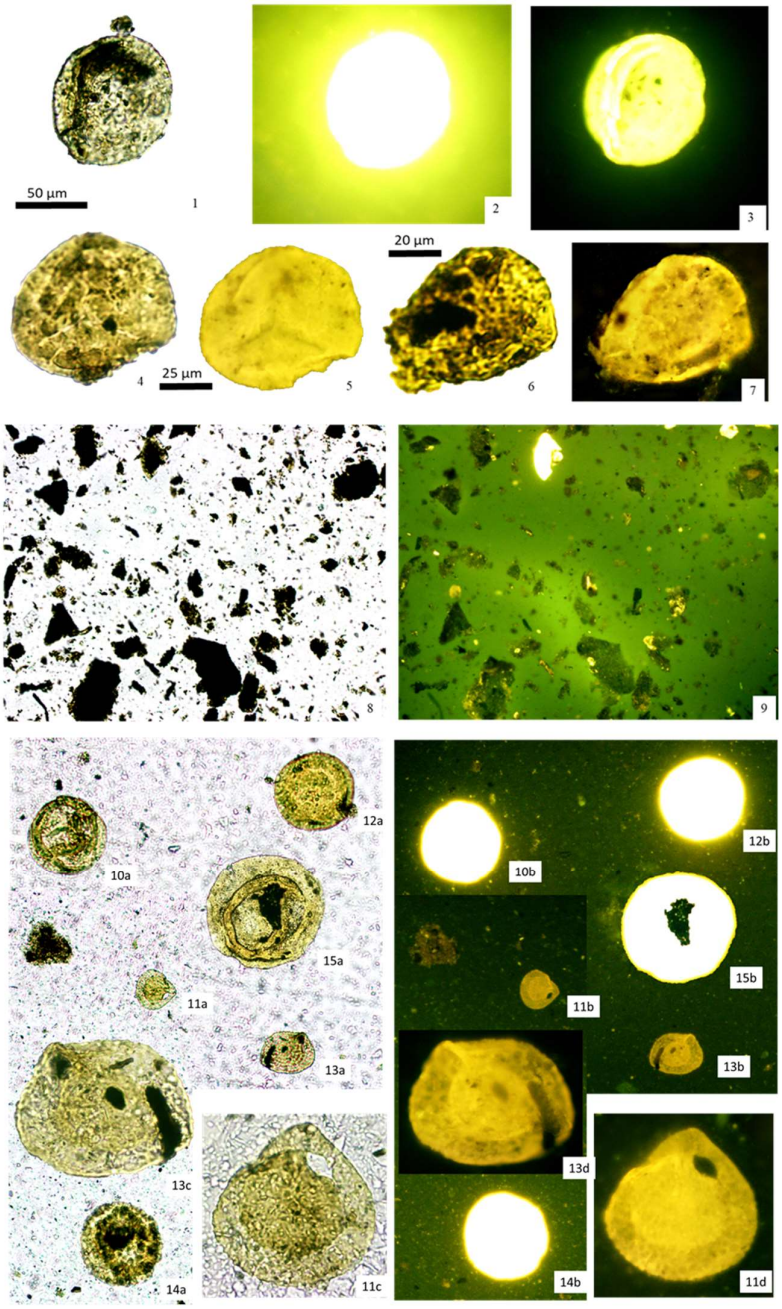


Figure 29. 1-8. Bedford 1 (CICYTTP-Pl 958-HF-2-Trabasil). 1-2. *Retispora lepidophyta*, EF V32/0 (x100, 2000 ms, 3 gain). 3. *Cymatiosphaera* sp., EF U33/2 (x100, 2000 ms, 3 gain). 4-6. *Retispora lepidophyta* (distal face), EF K40/4 (4-5 (x40), 6 (x100), 2000 ms, 3 gain). 7-8. *Retispora lepidophyta* (proximal face), EF K40/4 (x40, 2000 ms, 3 gain). 9-12. Bedford 1 (CICYTTP-Pl 958-HF2-jelly-glycerin). 9-11. *Maranhites perplexus*, EF G31/4 (x40, 10. 1062 ms, 1 gain, 11. 2000 ms, 3 gain). 12. Prasinophyte and almost indistinct *Retispora lepidophyta*, EF G31/2 (x40, 2000 ms, 3 gain).

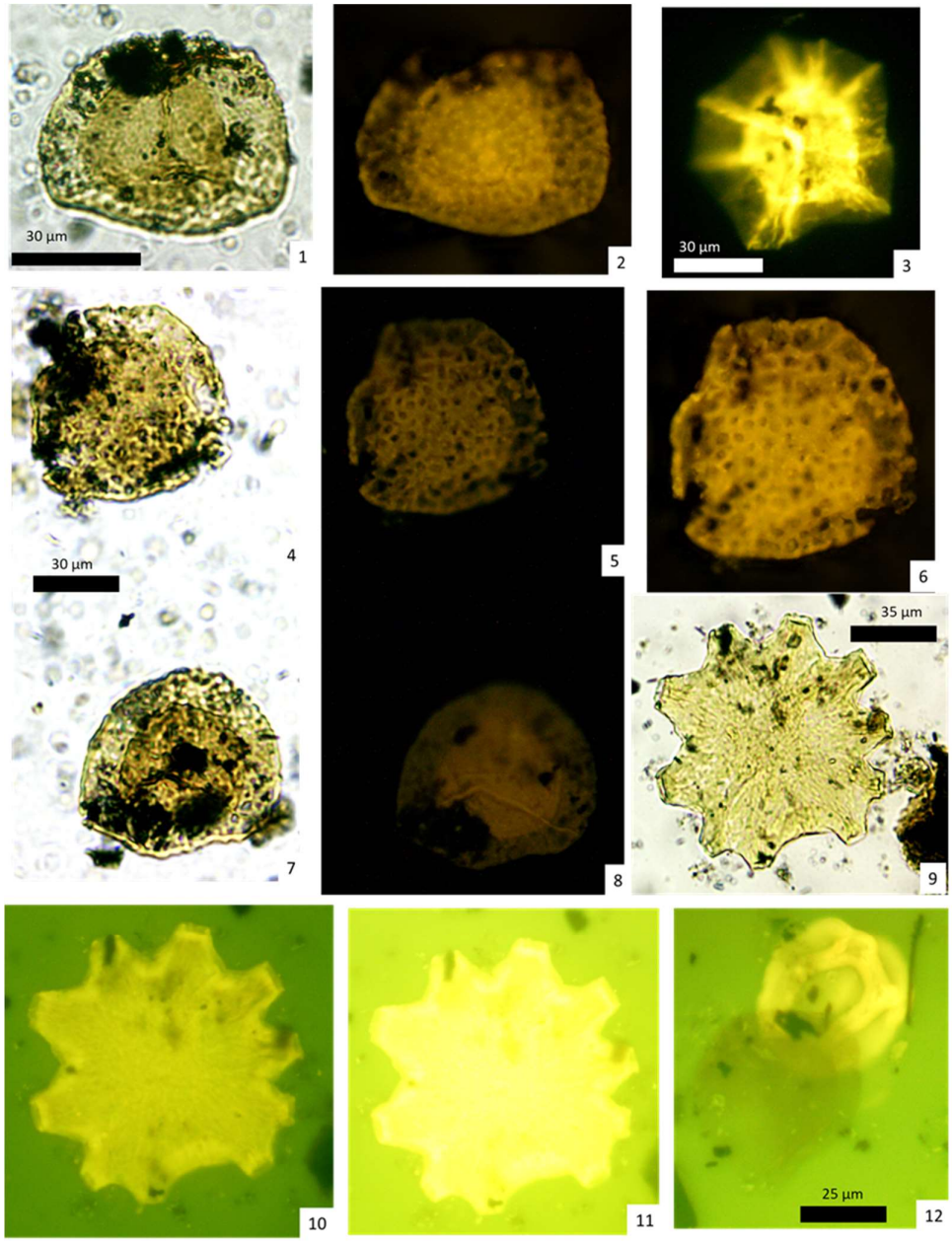


Figure 30. 1-5, 9-12. Bedford 2 (CICYTTP-Pl 959-1-HF-Trabasil). 1. *Retispora lepidophyta* (two specimens, a, and b) and *Leiosphaeridia*, EF Y23/0 (x10, 2000 ms, 1 gain). 2-3. *Retispora lepidophyta*, EF T30/1 (x100, 930 ms, 2 gain). 4-5. *Kraeuselisporites explanatus*, EF Q27/0 (x100, 930 ms, 2 gain). 9-10. *Grandispora echinata* and other spores, EF T24/0 (x40, 10. 2000 ms, 1 gain). 11. *Dactylofusa* sp. (similar to specimens illustrated in late Famennian of Sappington Formation in Montana by di Pasquo et al., 2019c), EF M25/2 (x40, 995 ms, 1 gain). 12. *Leiosphaeridia* sp., EF Y23/0 (the same in Fig. 1, x100, 211 ms, 1 gain). 6-8. *Retispora lepidophyta*, CICYTTP-Pl 959-1-HF-glycerin), EF N29/3 (x100, 7. 500 ms, 2 gain, 700 ms, 2 gain).

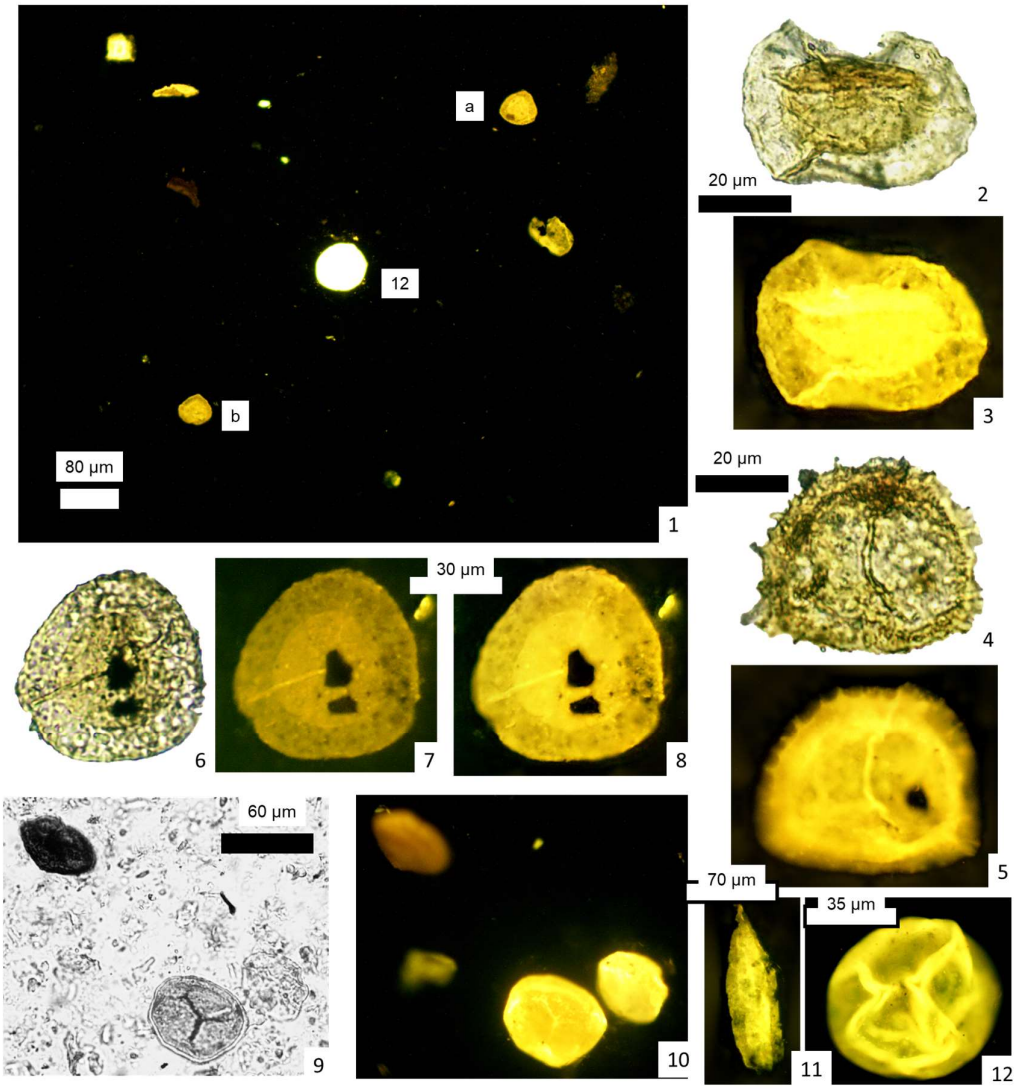


Figure 31. General palynofacies characteristics showing different preservation and thermal alteration index (TAI) of palynomorphs documented in samples of Sappington Formation in different localities (Warren et al., 2014; Rice et al., 2016; di Pasquo et al., 2017b).

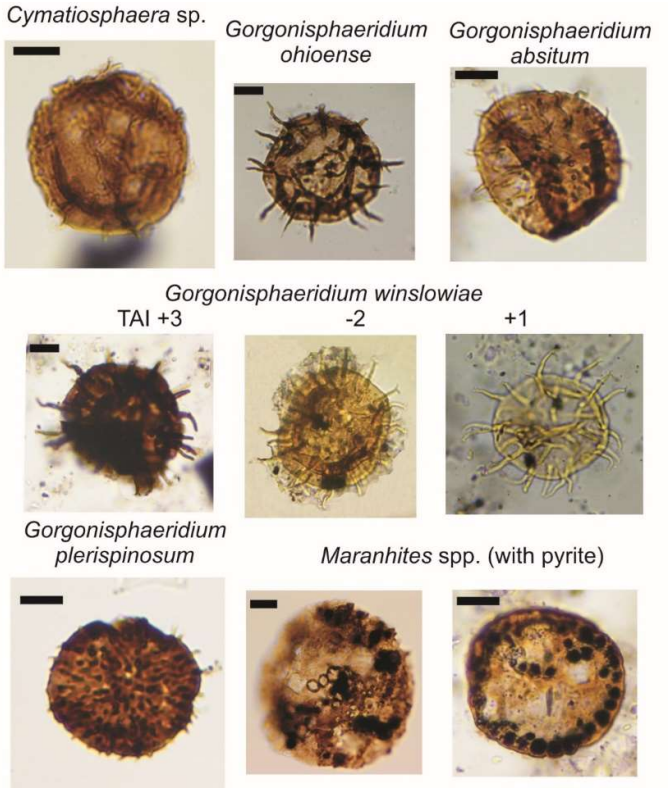
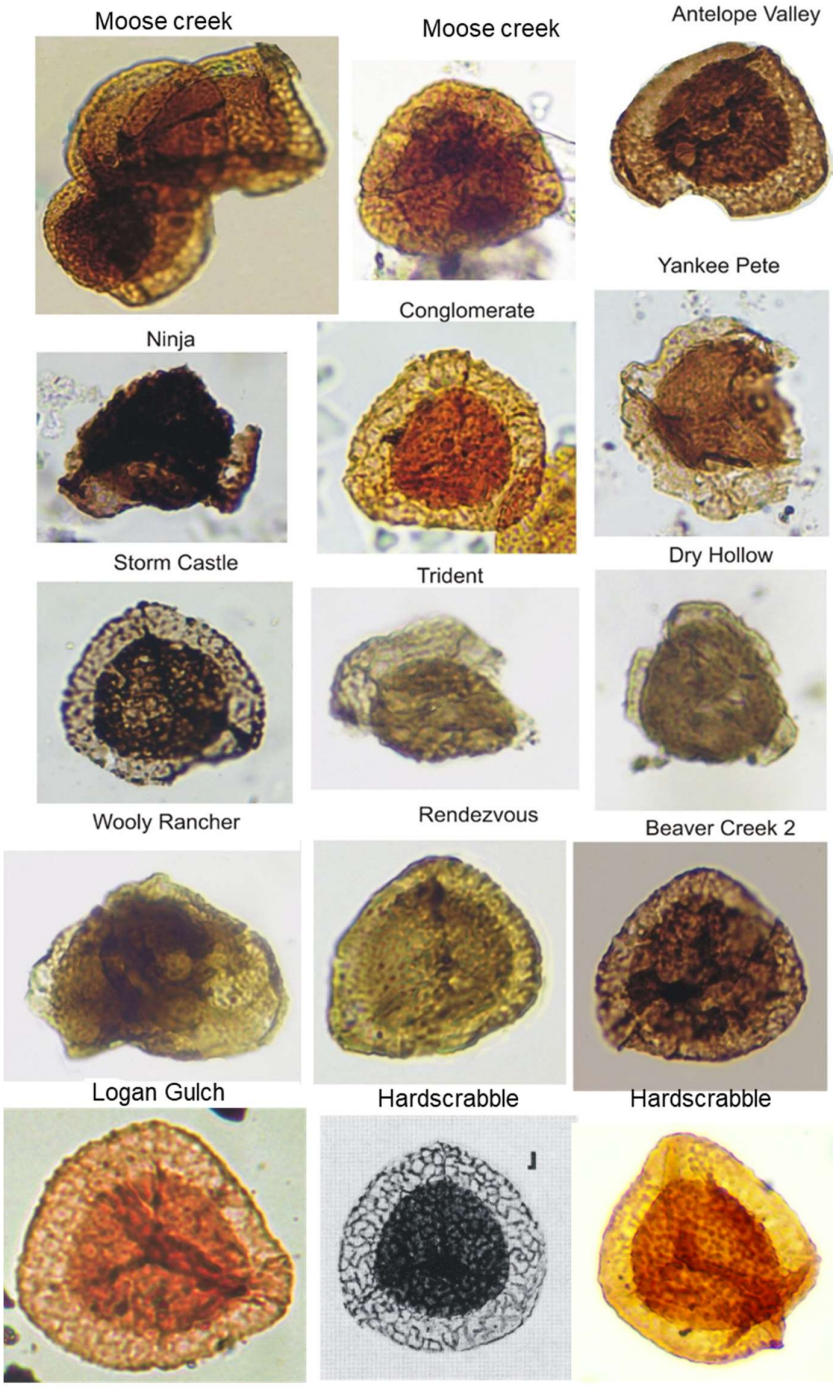


Figure 32. *Retispora lepidophyta* depicts different preservation states and different TAI values documented in samples of Sappington Formation in different localities (Warren et al., 2014; Rice et al., 2016; di Pasquo et al., 2017b; for more detailed information see appendices 4-6 and text). Specimen illustrated from Hardscrabble **(J)** was published by Sandberg et al. (1972).



Retispora lepidophyta (size range 28-65 µm in all samples)

Figure 33. Koch section. Four samples were obtained of 4 m thick shale interval (Unit 4) of Sappington Formation (Montana, USA). The star marks the sample CICYTTP-Pl 1615 taken at 30 cm below the top of this bed (Unit 4), from which most representative species of Sappington Formation are illustrated herein (see appendix 4; di Pasquo et al., 2019d).

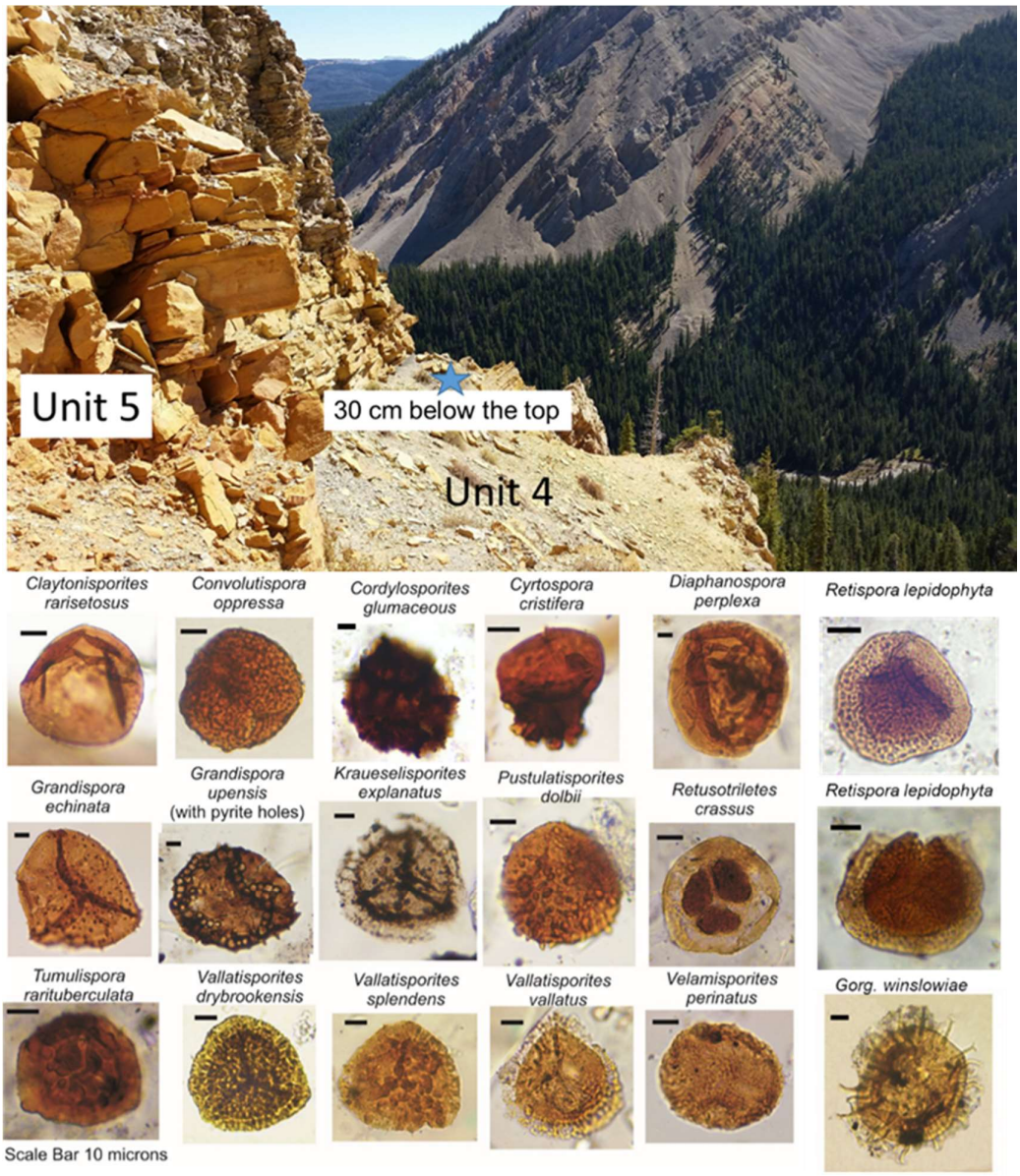


Figure 34. Palynoassemblage (CICYTTP-Pl 1615) at Koch bearing *Lagenicula devonica* (megaspore) and *Retispora lepidophyta* among other spores and phytoplankton that allowed the correlation to the Latest Famennian *Retispora lepidophyta-Verrucosisporites nitidus* LN Zone after di Pasquo et al. (2019d).

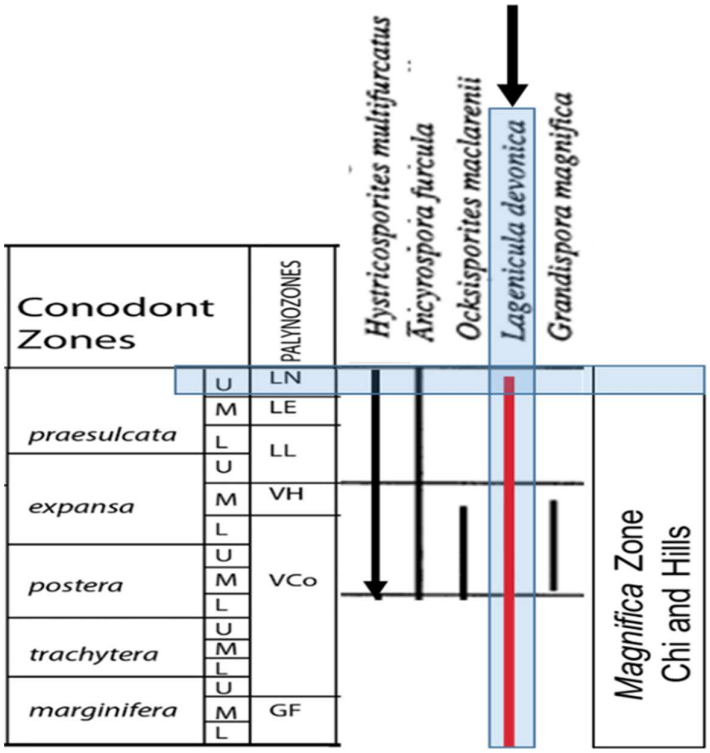


Figure 35. Selected palynomorphs illustrated with white and fluorescence lights and SEM from Logan Gulch (1-6) and Koch (7-21) sections (non-oxidized residues). 1-2. *Retispora lepidophyta*, CICYTTP-Pl 1109-HF2-norland (mounted in 2022), EF R43/2 (x100, 2000 ms, 2 gain). 3-4. *Tumulispora rarituberculata*, CICYTTP-Pl 1109-HF2-norland EF R38/0 (x40, 2000 ms, 3 gain). 5-6. *Reticulatisporites cancellatus*, CICYTTP-Pl 1110-HF2-norland EF T60/4 (x100, 2000 ms, 3 gain). 7-9, 12-14. Specimens picked and mounted in slide with water from residue (CICYTTP-Pl 1615), some illustrated with SEM. 7-9. *Retispora lepidophyta* (7-8. focus in proximal and distal face with x100 magnification; 9. 2000 ms, 3 gain; 12-14. SEM pictures of distal face). 10-11. *Hystricosporites costatus* (x40, 2000 ms, 3 gain). 17-19. *Cordylosporites glumaceus* (x40, 2000 ms, 3 gain). 15-16, 20-21. *Gorgonisphaeridium ohioense* (x40, 16. 2000 ms, 3 gain; 20. 2000 ms, 3 gain, BG38; 21. SEM image).

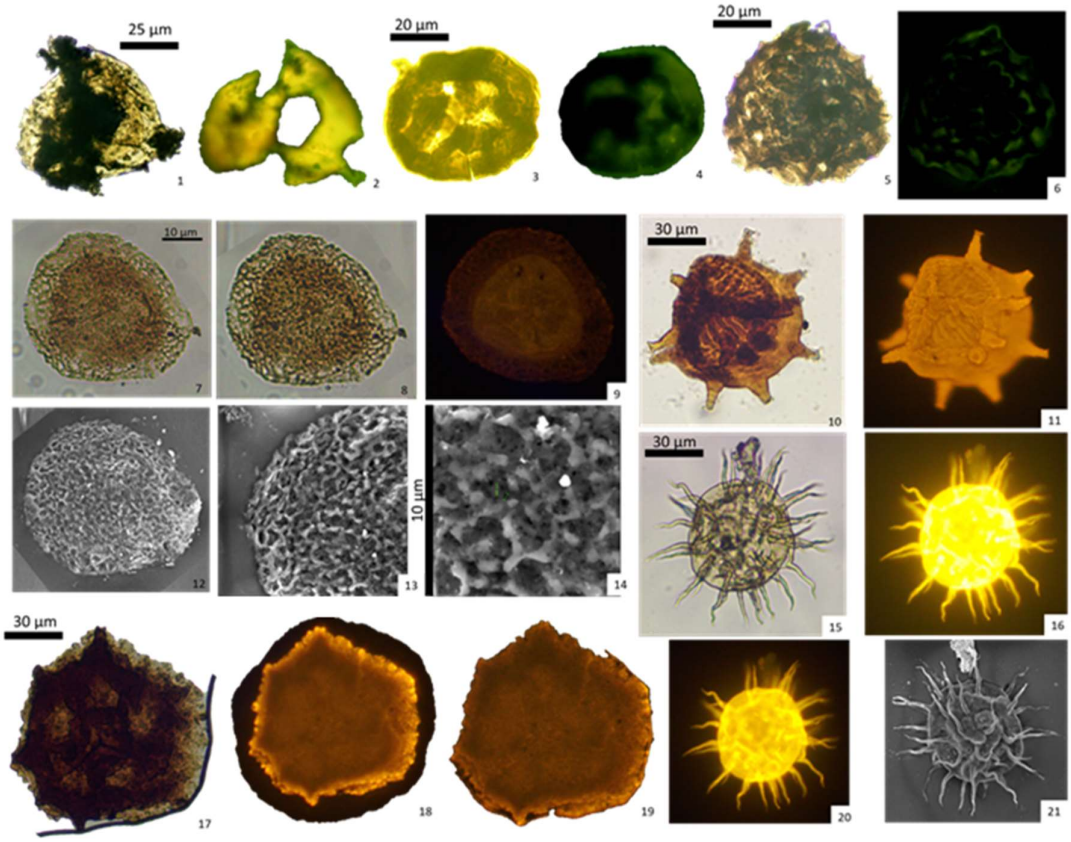
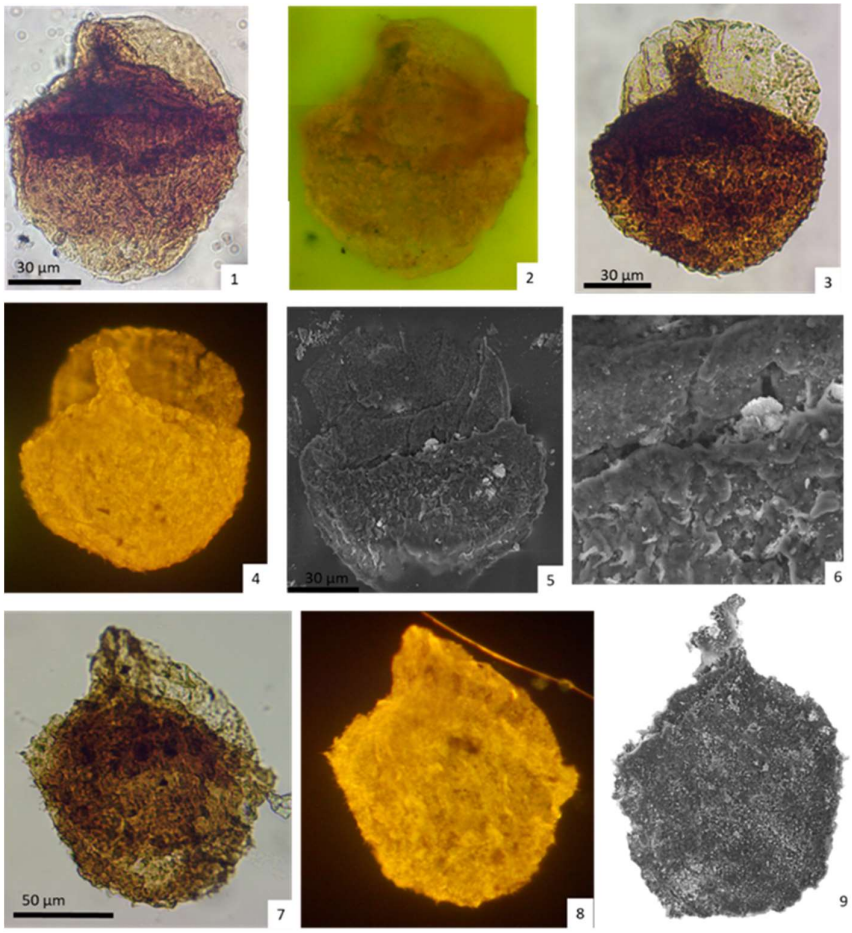
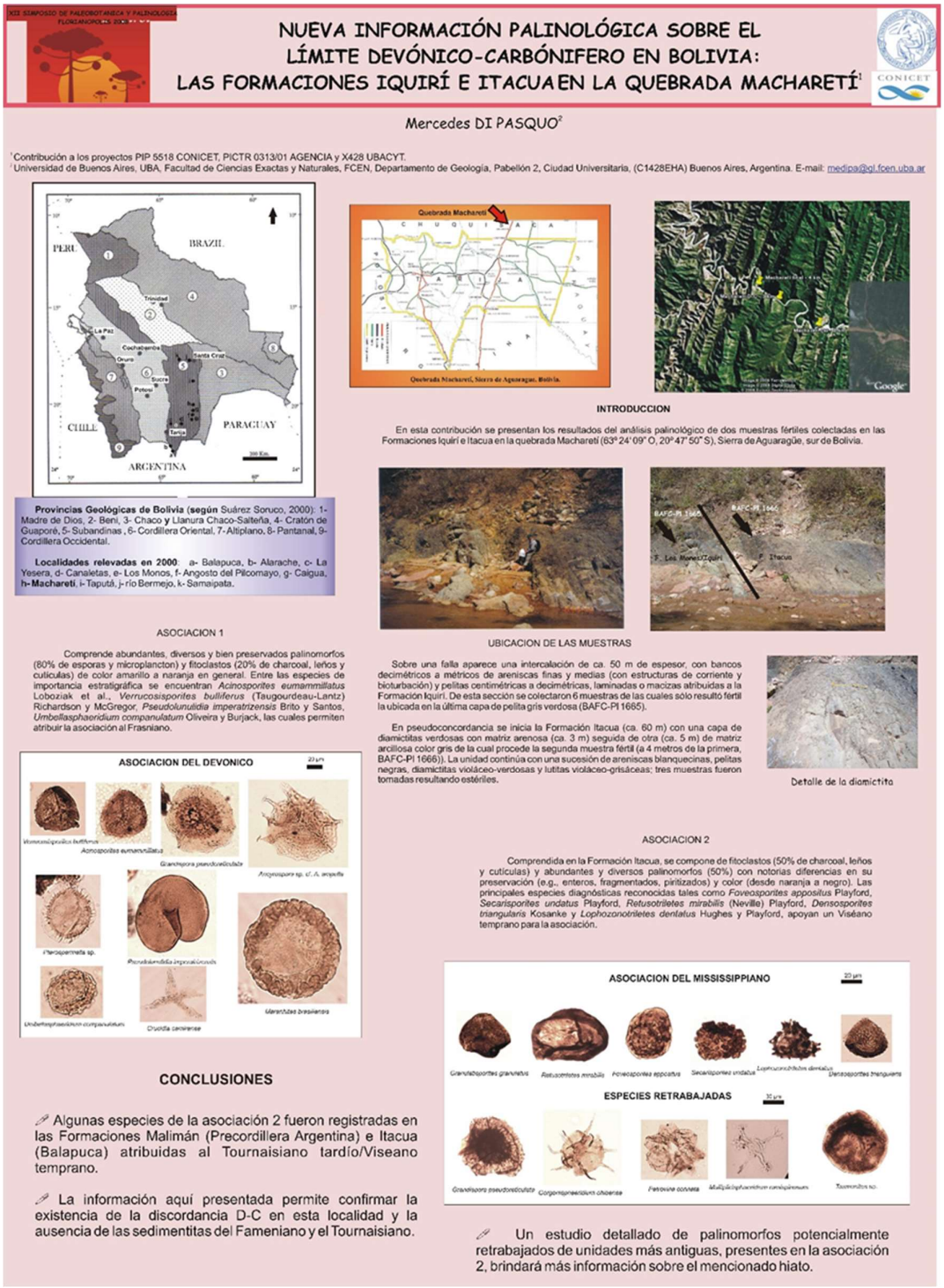


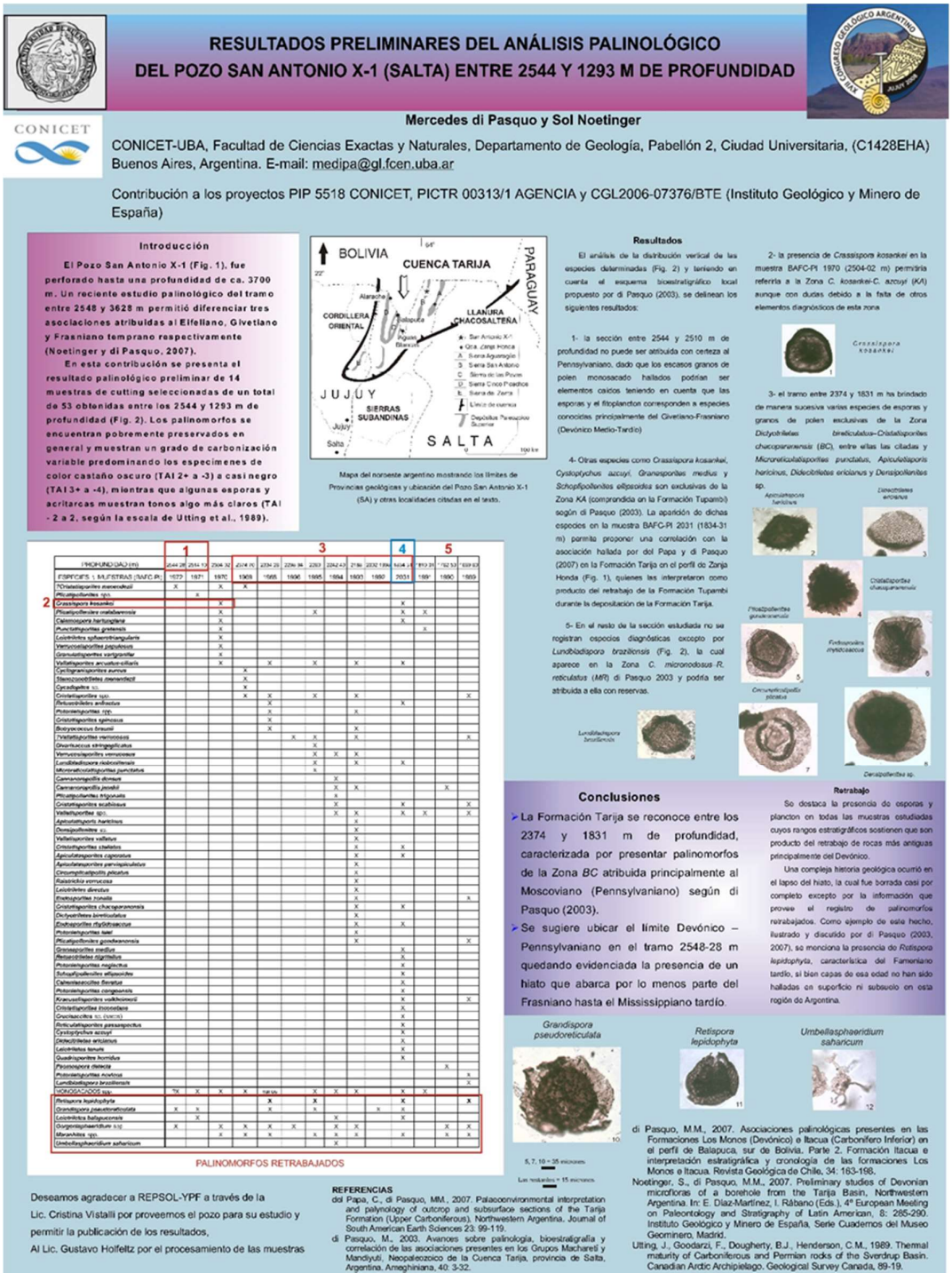
Figure 36. Koch (CICYTTP-Pl 1615). 1-9. Three megaspore specimens of *Lagenicula devonica* illustrated under white and fluorescent optic microscope and SEM. 1-2. Specimen figured in slide with jelly-glycerin (x40, 2000 ms, 3 gain). 3-9. Two specimens picked and mounted in a temporary slide with water, with yellow- orange fluorescence color (4 and 4. x40, 2000 ms, 3 gain). 5-6, 9. SEM pictures of these two specimens using low vacuum energy without metallization.



APPENDICES 1-8



Appendix 1 (di Pasquo, 2008a)



RESULTADOS PRELIMINARES DEL ANÁLISIS PALINOLÓGICO
DEL POZO SAN ANTONIO X-1 (SALTA) ENTRE 2544 Y 1293 M DE PROFUNDIDAD

Mercedes di Pasquo y Sol Noetinger

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Contribución a los proyectos PIP 5518 CONICET, PICTR 00313/1 AGENCIA y CGL2006-07376/BTE (Instituto Geológico y Minero de España)

Introducción

El Pozo San Antonio X-1 (Fig. 1), fue perforado hasta una profundidad de ca. 3700 m. Un reciente estudio palinológico del tramo entre 2548 y 3628 m permitió diferenciar tres asociaciones atribuidas al Eifeliano, Givetiano y Frasniano temprano respectivamente (Noetinger y di Pasquo, 2007).

En esta contribución se presenta el resultado palinológico preliminar de 14 muestras de cutting seleccionadas de un total de 53 obtenidas entre los 2544 y 1293 m de profundidad (Fig. 2). Los palinomorfos se encuentran pobremente preservados en general y muestran un grado de carbonización variable predominando los especimenes de color castaño oscuro (TAI 2+ a -3) a casi negro (TAI 3+ a -4), mientras que algunas esporas y acritarcas muestran tonos algo más claros (TAI - 2 a 2, según la escala de Utting et al., 1989).

Mapa del noroeste argentino mostrando los límites de Provincias geológicas y ubicación del Pozo San Antonio X-1 (SA) y otras localidades citadas en el texto.

Resultados

El análisis de la distribución vertical de las especies determinadas (Fig. 2) y teniendo en cuenta el esquema bioestratigráfico local propuesto por di Pasquo (2003), se delinean los siguientes resultados:

1- la sección entre 2544 y 2510 m de profundidad no puede ser atribuida con certeza al Pennsylvaniano, dado que los escasos granos de polen monosacado hallados podrían ser elementos caídos teniendo en cuenta que las esporas y el fitoplancton corresponden a especies conocidas principalmente del Givetiano-Frasniano (Devónico Medio-Tardío)

2- la presencia de *Crassispora kosankei* en la muestra BAFC-PI 1970 (2504-02 m) permitiría referirla a la Zona *C. kosankei-C. azcuyi* (*KA*) aunque con dudas debido a la falta de otros elementos diagnósticos de esta zona

3- el tramo entre 2374 y 1831 m ha brindado de manera sucesiva varias especies de esporas y granos de polen exclusivas de la Zona *Dictyotriletes bireticulatus–Cristatisporites chacoparanaensis* (*BC*), entre ellas las citadas y *Microreticulatisporites punctatus*, *Apiculatisporis hericinus*, *Didecitriletes ericianus* y *Densipollenites* sp.

4- Otras especies como *Crassispora kosankei*, *Cyclopychos azcuyi*, *Granasportites medius* y *Schopfipollenites ellipsoides* son exclusivas de la Zona *KA* (comprendida en la Formación Tupambi) según di Pasquo (2003). La aparición de dichas especies en la muestra BAFC-PI 2031 (1834-31 m) permite proponer una correlación con la asociación hallada por del Papa y di Pasquo (2007) en la Formación Tarija en el perfil de Zanja Honda (Fig. 1), quienes las interpretaron como producto del retrabajo de la Formación Tupambi durante la depositación de la Formación Tarija.

5- En el resto de la sección estudiada no se registran especies diagnósticas excepto por *Lundbladispora brasiliensis* (Fig. 2), la cual aparece en la Zona *C. microreticulatus-R. reticulatus* (*MR*) di Pasquo 2003 y podría ser atribuida a ella con reservas.

Conclusiones

- La Formación Tarija se reconoce entre los 2374 y 1831 m de profundidad, caracterizada por presentar palinomorfos de la Zona *BC* atribuida principalmente al Moscoviano (Pennsylvaniano) según di Pasquo (2003).
- Se sugiere ubicar el límite Devónico – Pennsylvaniano en el tramo 2548-28 m quedando evidenciada la presencia de un hiato que abarca por lo menos parte del Frasniano hasta el Mississippiano tardío.

Retrabajo

Se destaca la presencia de esporas y plancton en todas las muestras estudiadas cuyos rangos estratigráficos sostienen que son producto del retrabajo de rocas más antiguas principalmente del Devónico.

Una compleja historia geológica ocurrió en el lapso del hiato, la cual fue borrada casi por completo excepto por la información que provee el registro de palinomorfos retrabajados. Como ejemplo de esta hecho, ilustrado y discutido por di Pasquo (2003, 2007), se menciona la presencia de *Retispora lepidophyta*, característica del Fameniano tardío, si bien capaz de esa edad no han sido halladas en superficie ni subsuelo en esta región de Argentina.

Grandispora pseudoreticulata — *Retispora lepidophyta* — *Umbellasphaeridium saharicum*

5, 7, 10 = 35 micrones
Los restantes = 15 micrones

Deseamos agradecer a REPSOL-YPF a través de la Lic. Cristina Vistalli por proveernos el pozo para su estudio y permitir la publicación de los resultados,
Al Lic. Gustavo Holfeltz por el procesamiento de las muestras

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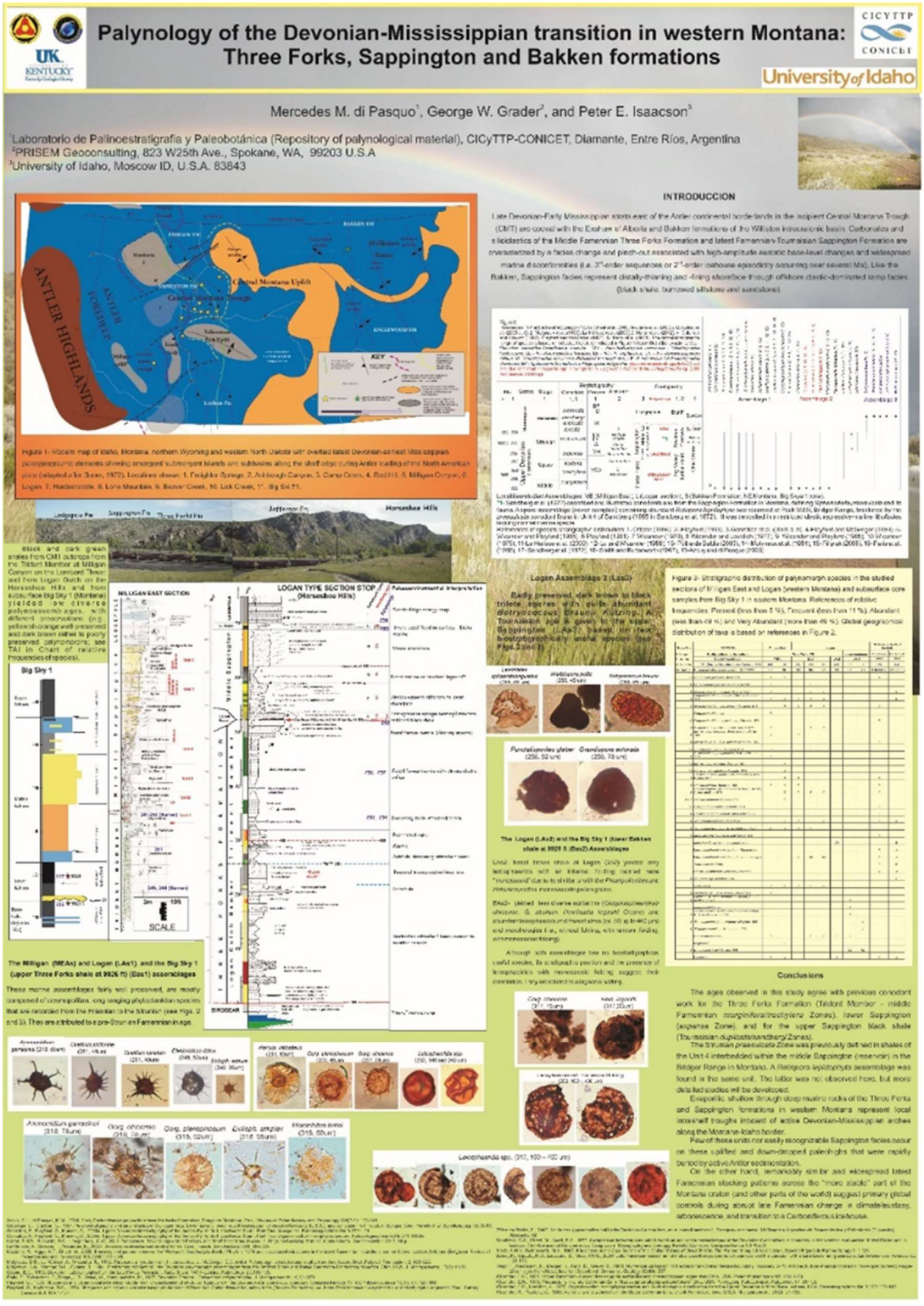
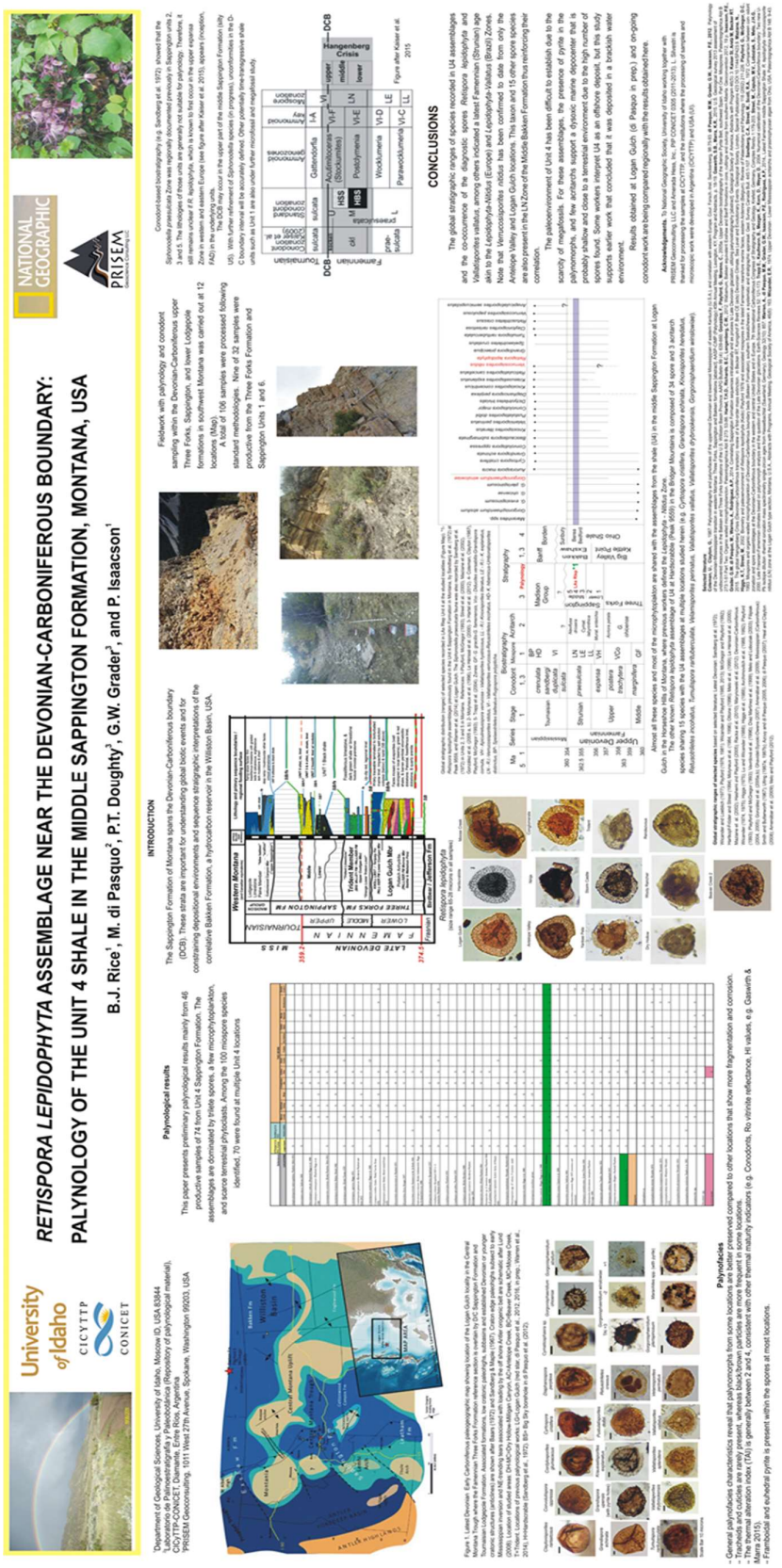
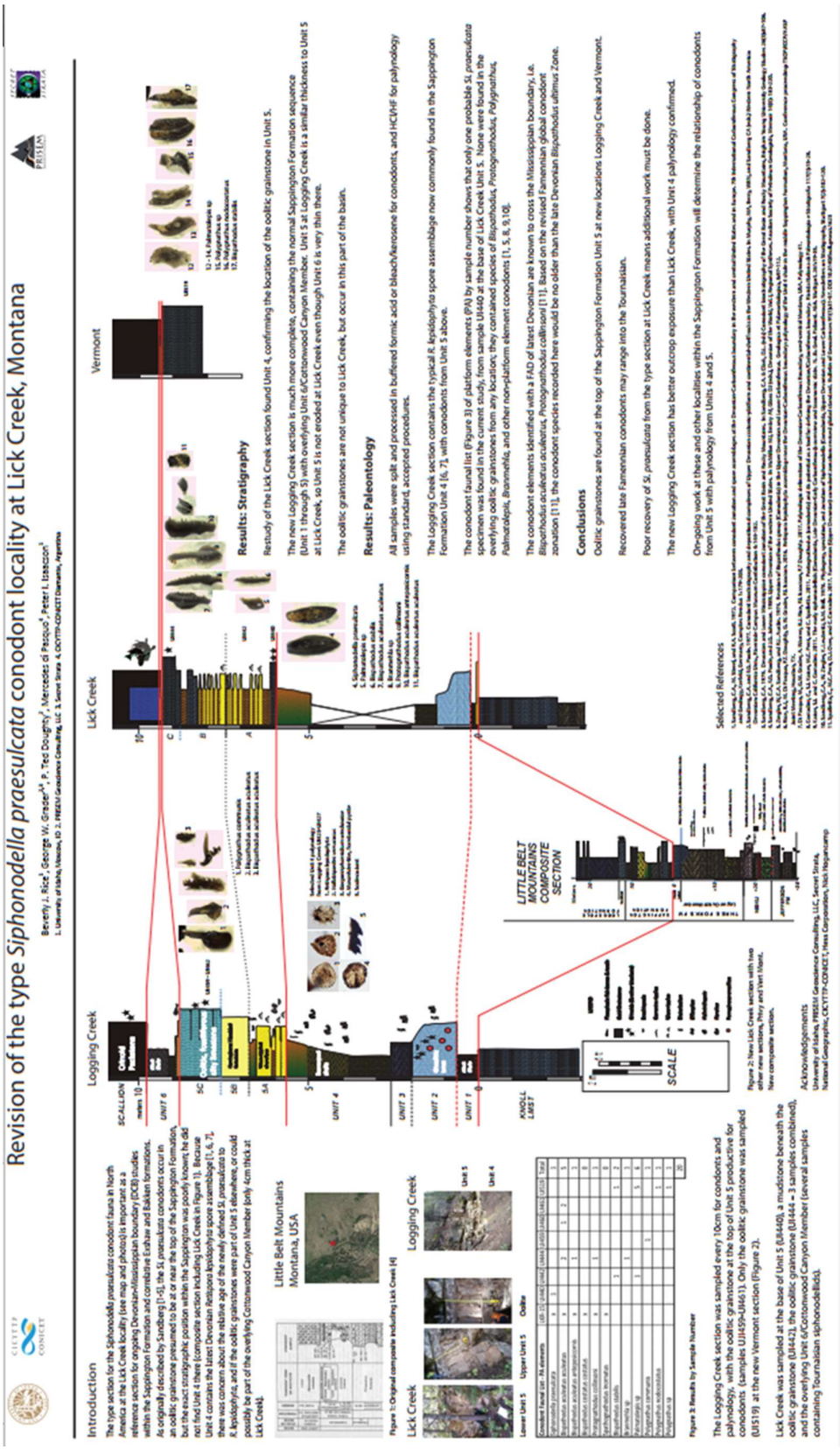
Appendix 2 (di Pasquo and Noetinger, 2008)



Appendix 3 (di Pasquo et al., 2012)

Appendix 4 (Rice et al., 2016) (next page)





Appendix 5 (Rice et al., 2017)

BIOSTRATIGRAPHY OF DEVONIAN-MISSISSIPPIAN SAPPINGTON FORMATION IN SOUTHWESTERN MONTANA, U.S.A.

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XII Congreso de la Asociación Paleontológica Argentina
23 y el 26 de noviembre del 2021

Map Code	Locality Name	Latitude	Longitude
1	Antelope Valley	45.7830	-111.8069
2	Beaver Creek East	46.8574	-111.7127
3	Bombing Range	46.3267	-111.5922
4	Devils Fence West	46.1663	-111.8539
5	Dry Hollow	45.8681	-111.7062
6	Green Mountain	46.9922	-110.9528
7	Hardscrabble	45.9047	-110.9773
8	Horseshoe Canyon West	46.0302	-111.8451
9	Lick Creek	47.1378	-111.0176
10	Logging Creek	47.0971	-111.0119
11	Moose Creek	45.3354	-111.1143
12	Snake Pit	45.9222	-111.9923

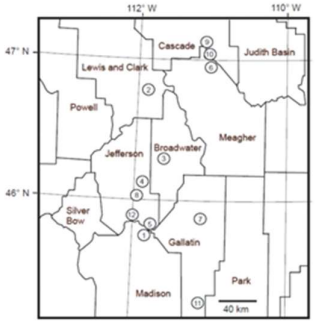


Figure 1. A. Montana State, USA. **B.** Localities that yielded Mississippian conodonts from upper Sappington Formation (see Chart for geographic coordinates)

INTRODUCTION

New conodont results from the Sappington Formation in southwestern Montana revise its age from primarily Devonian to Mississippian, and question the utility of using global species like *Siphonodella praesulcata* and *Siphonodella sulcata* and the palynomorph, *Retispora lepidophyta* for delineating the Devonian/Mississippian boundary, largely used in Europe and elsewhere (e.g. Higgs et al., 2013).

This boundary has been placed at the top of the upper Sappington Formation (Unit 5) for over 40 years based on the latest Devonian conodont *Siphonodella praesulcata* and the latest Devonian miospore *Retispora lepidophyta* found in the underlying Unit 4. An unconformable contact with the overlying Cottonwood Canyon/Lodgepole Formation is confirmed by conodonts of the Early Mississippian *crenulata* Zone with several missing zones at the contact (Sandberg et al., 1972; di Pasquo et al., 2017, 2019).

RESULTS

We present main results of a paleontologic and stratigraphic study of 33 localities studied using large sample sizes (especially for conodonts) and close sample spacing (Rice, 2021). Figure 1

Diverse miospore assemblages bearing *Retispora lepidophyta* were retrieved throughout the Sappington Formation in the lower Shale (U1), the middle shale (U4) and from rare shales occurring in the upper clastics (U5). See Plate 1

In contrast, several localities yielded Early Mississippian conodonts (see Fig. 2, Plate 2) and primary observations are:

(1) siphonodellids *Siphonodella sulcata* and *Siphonodella praesulcata* were found coexisting in U3 from Beaver Creek East and in U5 at Snake Pit, Horseshoe Canyon West and Vermont, all barren of palynomorphs. Previous studies only found *Siphonodella praesulcata* without *Siphonodella sulcata* in U3 and U5 at Lick Creek and other localities in the Basin;

(2) an Early Mississippian conodont with nodose ornamentation and rostral ridges, identified as *Siphonodella* cf. *S. hassi*, occurs with *Retispora lepidophyta* in a unique, fossiliferous lower U4 channel sandstone at Antelope Valley;

(3) an Early Mississippian conodont *Siphonodella bransoni* occurs in the middle of U5 at Horseshoe Canyon West and near the top of U5 at Devils Fence West; neither outcrop contains palynomorphs;

(4) an Early Mississippian conodont *Siphonodella cooperi* was found in oolitic grainstones within lower U5 at Moose Creek, above *Retispora lepidophyta* -bearing U4.

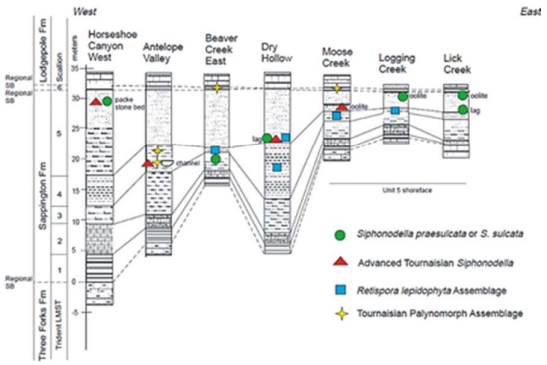


Figure 2. Siphonodellid conodont recovery by location and unit compared with palynomorphs.

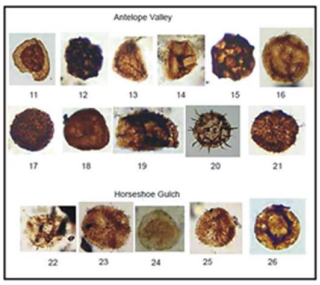


Plate 1.
Antelope Valley, locality 2, Unit 4: (11) *Retispora lepidophyta*, (12) *Cordylosporites glumaceus*, (13) *Vallatisporites vallatus*, (14) *Velamisporites perinatus*, (15) *Dictyotriletes flavus*, (16) *Dictyotidium* sp, (17) *Convolutispora fromensis*, (18) *Spelaeotriletes crustatus*, (19) *Vallatisporites drybrookensis*, (20) *Gorgonisphaeridium ohioense*, (21) *G. plerispinosum*

Horseshoe Gulch, locality 31, Unit 4: (22) *Gorgonisphaerium absitum*, (23) *G. evexispinosum*, (24) *Retispora lepidophyta*, (25) *G. plerispinosum*, (26) *Maranhites mosesi*

FINAL CONSIDERATIONS

These new data show that:

- *Siphonodella praesulcata* and *Siphonodella sulcata* coexist with Early Mississippian conodonts and further work is needed to determine if they are morphotypes of the same species, or can still be used to indicate the Devonian/Mississippian boundary as previously thought. See Figure 2

- A controversy remains as to whether or not *Retispora lepidophyta* is *in situ* everywhere in the Northern Rockies since it has now been documented in Early Mississippian strata in the Sappington, Bakken, and Banff Formations (e.g. Richards et al., 2002). Globally, it is frequently found reworked from Late Devonian deposits, triggered by global regression of glacio-eustatic origin confirmed by diamictites in South America, Africa, and eastern North America (e.g. Isaacson et al., 2008).

Considering all this information, the boundary in the Sappington Formation must be below U4 and could be as old as U3, but it would be difficult to identify without the diagnostic Tournaisian conodonts found using large sample sizes. See Composite figure

These results are consistent with previously published Early Mississippian conodonts from the top of the Middle Bakken in East-Central Alberta Alberta (Hogancamp and Rodriguez, 2020; Hogancamp and Pocknall, 2018) and current conodont zones from Spalletta et al. (2017).

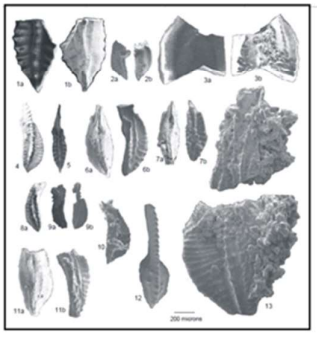
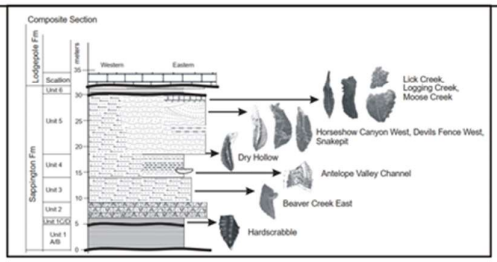


Plate 2. Unit 1C: (1) sp. a: oral view; b: aboral view, Locality 7, sample UI546. Unit 3: (2) *Siphonodella sulcata* Huddle, 1934; a: oral view; b: aboral view Locality 2, sample UI529. Unit 4: (3) *Siphonodella* cf. *Hassi* Ji, a: aboral view, b: oral view, Locality 1 - channel, sample UI435. Unit 5: (4) *Siphonodella bransoni* Ji, oral view, Locality 8, sample UI315; (5) *Siphonodella praesulcata* Morph 3 Sandberg, 1972, oral view, Locality 9, sample UI444; (6) *Siphonodella sulcata* Huddle, 1934, a: aboral view; b: oraloblique view, Locality 12, sample UI189; (7) *Siphonodella praesulcata* Sandberg, 1972, a: aboral view; b: oral view; Locality 5, sample UI190: (8) *Siphonodella sulcata* Huddle, 1934, oral view, sample UI189; (9) *Siphonodella sulcata* Huddle, 1934, a: oral view; b: aboral view, Locality 10, sample UI458; (10) *Siphonodella* xxx, oral view, Locality 4, sample UI527; (11) *Siphonodella* sp., a: aboral view; b: side view, Locality 12, sample UI189; (12) *Protognathodus collinsoni-kockeli*, a: oral view, b: lateral view, Locality 9, sample UI444; (13) *Siphonodella cooperi*, Locality 11, sample UI636.



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Appendix 6 (di Pasquo et al., 2021)

Appendix 7+8 (next page). These posters were published to celebrate the 10 years of the Laboratory of Palynostratigraphy and Paleobotany- LPP, funded by M.diP in 2010 at the CICYTTP (CONICET-ER-UADER). Her own researches carried out with colleagues from Argentina and elsewhere. She is responsible (researcher curator) for creating different collections of fossils for scientific purposes, incorporating her own materials and some collected in the framework of doctoral thesis that she supervised. Leonardo Silvestri (CPA, CONICET) is responsible for the processing of samples under her supervision at the LPP, as well as co-curator of the collections DOI: 10.13140/RG.2.2.18645.45283

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