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UPDATE AND IMPORTANCE OF THE CARBONIFEROUS AND PERMIAN PALAEONTOLOGICAL RECORDS OF THE TARIJA BASIN

M. di Pasquo

CONICET-UBA, Facultad de Ciencias Exactas y Naturales, Departamento de Geología, Pabellón 2,
Ciudad Universitaria, 1428 Buenos Aires, Argentina.
medipa@gl.fcen.uba.ar

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INTRODUCTION

The Tarija Basin embraces the northern of Argentina, south of Bolivia and west of Paraguay. Upper Palaeozoic deposits crop mainly out in Argentina and southernmost of Bolivia in the Subandean Range and, to a lesser extent in the eastern part of the Cordillera Oriental and they extend in the subsurface until the Chaco-Salteña Plain (Fig. 1; Azcuy and di Pasquo, 2000; Starck and del Papa, 2006). More recent palaeontological information and its importance is summarised as follows.

EARLY CARBONIFEROUS

The Lower Carboniferous in the north of Argentina and the south of Bolivia is scarcely represented in outcrops and still very little studied. It is attributed to the Saipurú Formation in the central region of Bolivia, or Itacua in the South zone (see Súarez Soruco, 2000) and only little palynological information has been published from this deposits (see Limachi *et al*., 1996). Recently, di Pasquo (2005, 2007a, b) published new palynological data collected from pellites intercalated with diamictites at Balapuca (Fig. 1). This section of around 30 meters thick appears unconformable over the Los Monos (Middle Devonian) and below the Tupambi (Upper Carboniferous) formations. The assemblage is composed of around 40 indigenous species (e.g., *Anapiculatisporites hystricosus* Playford, *Apiculiretusispora semisenta* (Playford) Massa, Coquel, Loboziak & Taugordeau-Lantz, *Colatisporites decorus* (Bharadwaj & Venkatachala) Williams in Neves *et al*., *Convolutispora insulosa* Playford, *Convolutispora varicosa* Butterworth & Williams, *Raistrickia intonsa* (Playford) Playford & Satterthwait, *Dibolisporites microspicatus* Playford, *Cristatisporites peruvianus* Azcuy & di Pasquo, *Schopfites claviger* Sullivan *emend*. Higgs, Clayton & Keegan). Another group of palynomorphs (spores, acritarchs, prasinophytes, criptospores, megaspores and chitinozoans) is interpreted as reworked from the Devonian rocks based on their stratigraphic range. The stratigraphic range of selected indigenous species allow to date the assemblage to the early Viséan and the same age is given to the Itacua Formation at this locality (Fig. 2). Till now, this unit is correlated with the Malimán Formation

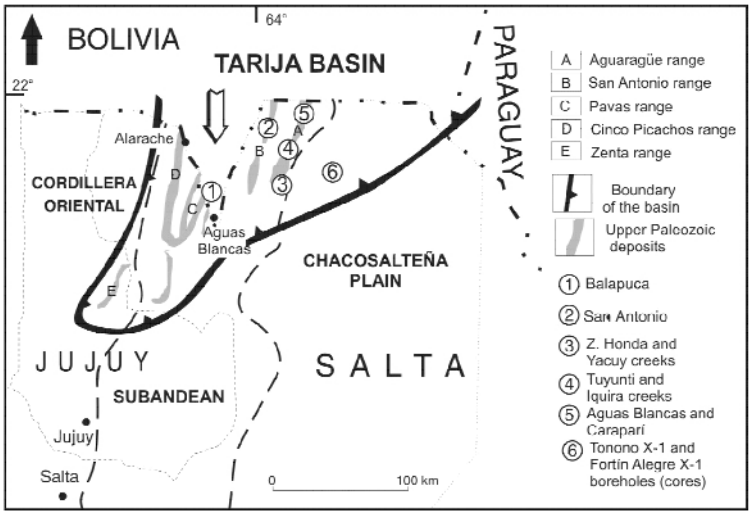

Figure 1. Geological provinces and areal distribution of the Upper Palaeozoic deposits in the Tarija Basin is shown. The numbers point out the localities with palynological and palaeontological studies (modified from di Pasquo, 2003).

from the Argentinean Precordillera (Amenábar *et al*., 2006; di Pasquo, 2007 a), and the *Endoculeospora* (*Anapiculatisporites*) *larga* Zone from Australia (e.g. Playford, 1991) based on several common diagnostic species. The absence of *Cordylosporites magnidictyus* (Playford & Helby) Melo & Loboziak, diagnostic species from the late Viséan in Brazil, Peru and Australia (see di Pasquo, 2007 b) supports this age as well. This indigenous assemblage suggests the development of a shrubby paleoflora related to humid palaeoenvironments composed of Pteridophytes (e.g., *Verrucosisporites, Convolutispora*), Lycophytes (e.g., *Cristatisporites, Densosporites*), Sphenophytes (e.g., *Calamospora*) and Pteridosperms (e.g., *Cyclogranisporites*). Nevertheless, any plant fossils have been recorded from Itacua and Saipurú formations yet. On the other hand, most of the reworked species are recognized in the assemblages from the underlying Los Monos Formation in the same outcrop [e.g., *Geminospora lemurata* Balme *emend.* Playford, *Grandispora pseudoreticulata* (Menéndez & Pöthe de Baldis) Ottone]. Thus, a hiatus is registered between both units spanning the late Frasnian to the Tournaisian. Based on the absence of diagnostic species such as *Retispora lepydophyta* (Kedo) Playford from the latest Famennian, a non-depositional period is interpreted as part of the hiatus at Balapuca (di Pasquo, 2007a, b).

LATE CARBONIFEROUS

The Macharetí and Mandiyutí Groups that are present in the Subandean region of northern Argentina and southern Bolivia (Fig. 1; Starck and del Papa, 2006), have yielded abundant and diverse microfloras from outcrop and subsurface sections at many localities. The appearance of lots of monosaccate pollen grains supports a Late Carboniferous age (excepted for the Itacua Formation, see above; di Pasquo, 2003). Di Pasquo (2002, 2003) defined a palyno-zonation composed of five first appearance biozones grouped in the *Kraeuselisporites volkheimerii-Circumplicatipollis plicatus* (VP) Superzone based on the stratigraphic

range of selected key species (VP). From base to top the Biozones are named *Crassispora kosankei-Cystoptychus azcuyi* (KA), *Raistrickia radiosa–Apiculatasporites spinulistratus* (RS), *Dictyotriletes bireticulatus–Cristatisporites chacoparanensis* (BC), *Converrucosisporites micronodosus–Reticulatisporites reticulatus* (MR) and *Marsupipollenites triradiatus–Lundbladispora braziliensis* (TB) (Fig. 2). Numerous long-ranged forms present in the VP Superzone support the interpretation of a continuous sedimentation between the Macharetí and Mandiyutí Groups with possible "short" discontinuities related to episodes of erosion or non-deposition in or between the rock units. The absence of species of genera such as *Vittatina* and *Pakhapites* registered exclusively in Permian microfloras, reinforce the late Carboniferous age for the superzone (di Pasquo, 2003).

The megafloral composition based on the botanical affinities of the palynomorphs (e.g., Balme, 1995) present in the VP Superzone, would be composed of a stable group of genera (and species) of plants through the time and a gradual and subordinated incorporation of new palynotaxa is verified (e.g., *Schopfipollenites*, *Equisetosporites*, *Marsupipollenites*, *Crassispora*, *Limitisporites*), which suggests the appearance of new plants although probably most of them would have been associated to the palaeoenvironments of stable species (di Pasquo and Azcuy, 1999). Part of the stable set would have been represented by monosaccate pollen grains that suggest the constant presence of Cordaitalean and Coniferalean forests, also recognized in other regions from Gondwana and Euramerica, and among the spores, the cingulizonate species of genera like *Cristatisporites, Kraeuselisporites* and *Lundbladispora*, would indicate the development of a herbaceous vegetation of hygrophilous lycophytes around lakes, lagoons and marshes, whereas others related to the Pteridophytes (e.g., *Raistrickia, Verrucosisporites, Reticulatispories, Convolutispora*) would represent better drained regions on plains or underbrush or slopes areas relatively humid and shady. The Sphenophytes (*Calamospora*), would have inhabited in the margins of rivers and lakes. On the other hand, the Chlorophycean such as *Botryococcus, Brazilea, Quadrisporites, Tetraporina* confirm the existence of fresh water palaeoenvironments. It is noticed that *Schopfipollenites*, related to the Medullosacea group recognized in the Palaeoequatorial microfloras, suggest that this plant group could be present in South America, but plant fossils have not been found yet (di Pasquo, 2002). From the analysis of sedimentological, palynofacial and microfloral changes in the Yaguacuá Member (San Telmo Formation) at Caraparí River (northern Argentina, see Figs 1, 2), di Pasquo and Azcuy (1999) recognized a gradual replacement of tempered and humid conditions by other semi-arid and more oxidizing ones in this region. The appearance of *Equisetosporites* and *Marsupipollenites* (of xerophytic affinities) in the TB Biozone supports this interpretation. Besides, it is reinforced due to the presence of red color rocks from the upper section of this member that resulted barren of palynomorphs. This palaeoclimatical change would be probably representing the Carboniferous - Permian transitional boundary in the Tarija Basin, also consistent with other C-P transitional boundaries in other Argentine basins (e.g., Paganzo, Uspallata-Iglesia, San Rafael, Chacoparaná) and it is supported by their palaeolatitudinal position around 35º-40º S (e.g., Conti and Rapalini, in Azcuy and di Pasquo, 2000; Starck and del Papa, 2006).

Recently, di Pasquo (2004) presented an advance on the finding of plant remains of lycophytes and platispermic seeds (and palynomorphs) from the Tarija Formation at the Aguas Blancas creek (Figs 1, 2). This is the first palaeobotanical information obtained from this unit in the Tarija Basin and supports a late Carboniferous age based until now in palynology (correlative to the BC Palynozone, see Fig. 2). Another palaeontological data not yet published is the stratigraphic relocation of the level with *Mourlonia balapucense* Rocha Campos *et al*. (1977) coming from the San Telmo Formation at Balapuca. This monospecific level contains abundant molds and rest of shells of diverse sizes, not fragmented, in the reddish layers of the middle part of the San Telmo Formation (Chimeo Member). In the mentioned palynostratigraphical

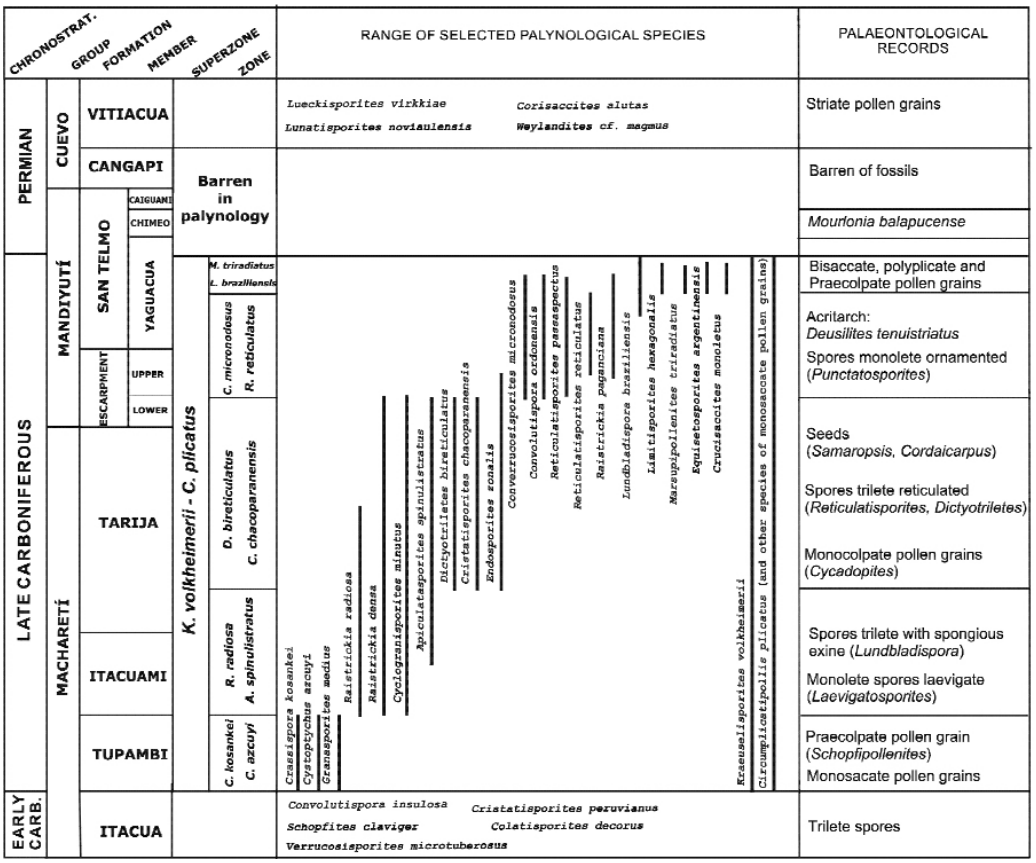

Figure 2. Stratigraphy, biostratigraphy and the main palaeontological events are summarised for the Carboniferous and Permian in the Tarija Basin (modified from di Pasquo, 2003).

scheme this level is located above the BT Biozone (see Fig. 2; di Pasquo, 2003). Instead, the lack of palynological data from the Taiguati Formation in the Parapetí river area (center of Bolivia), where the *Levipustula* fauna was registered and studied by Rocha Campos *et al.* (1977), prevents to establish its more precise correlation within this zonation (di Pasquo, 2003). Finally, it is highlighted that reworked palynomorphs of Devonian and Early Carboniferous age are frequently found in the microfloras of the Macharetí and Mandiyutí Groups. The stratigraphical analysis of the identified species has contributed among other things, in the characterization of the Devonian - Carboniferous boundary in the Tarija Basin (di Pasquo and Azcuy, 1997; di Pasquo, 2003).

PERMIAN

The Cuevo Group (Figs 1, 2) is present from the northern part of Argentina towards the south of Bolivia (e.g., Azcuy and di Pasquo, 2000). The lower and medium part of Vitiacua Formation has yielded palyno-

logical data (Sempere *et al*., 1992) and fossil fish (Beltán *et al*., 1987), that allowed to attribute it to the Medium to Late Permian and to restrict the Cangapi Formation to the Lower Permian. Besides, the presence of the fossil fish confirms a marine palaeoenvironment for the medium part of the unit, whereas the black shales in their lower part, carrying of a microflora would represent marginal settings. This microflora is dominated by striate pollen grains of genera *Lueckisporites*, *Lunatisporites*, *Protohaploxypinus*, *Striatoabieites*, that would represent xerophytic floras mainly related to the Pteridospermaphyta (Glossopteridales). Other genera (*Alisporites*, *Vitreisporites*, *Corisaccites*, *Weylandites*, Cycadopites) could correspond to groups of Coniferophyta (Cordaitales and Coniferales) and Cycadophyta (e.g., Balme, 1995). This association shares species with other microfloras of Bolivia, Peru, Argentina and Brazil with which can be correlated (see Azcuy *et al*., 2007). Till now the Cuevo Group has not provided fossils in Argentina.

CONCLUSIONS

The palaeontological information published from Carboniferous and Permian deposits present in the north of Argentina and the south of Bolivia (Tarija Basin) is updated and its stratigraphical and palaeoenvironmental importance, summarised. Recent palynological data obtained from diamictites of the Itacua Formation unconformably lying under the Tupambi Formation at Balapuca (southernmost of Bolivia), have allowed attributing this unit to the Lower Carboniferous (early Viséan). Several sections (surface and subsurface) of the Macharetí and Mandiyutí Groups (Upper Carboniferous) in N Argentina and S Bolivia have been correlated based on palynological information. The Tarija Formation at Aguas Blancas creek (north of Argentina) has yielded megafloras for the first time and palynomorphs that sustain a Late Carboniferous age and are correlated to the BC Palynozone. The Vitiacua Formation is dated as Medium to Late Permian based on palaeontological previous information. Thus, on such palaeontological records are supported the correlation of Macharetí, Mandiyutí and Cuevo Groups with coeval units of South America (see Azcuy *et al*., 2007).

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