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DELINEATING THE DEVONIAN-MISSISSIPPIAN BOUNDARY BASED ON PALYNOLOGY AT ZUDAÑEZ IN BOLIVIA

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INTRODUCTION

The aim of this contribution is to present the first palynological assemblage recovered from deposits cropping out in the Zudañez area, as part of a major project of Devonian-Permian studies in Bolivia (Fig. 1). The lower stratigraphic deposits in this region characterized by a syncline – anticline complex, correspond to the Devonian Iquiri Formation, represented by heterolithic deposits with micaceous remains and bioturbation. Over an angular unconformity, an incognitous age-succession starts with alternated gray fangolites and diamictites embedding deformed sand bodies and probable Devonian olistoliths, followed by whitish sandstone beds with pebbly clasts and current structures and red diamictite. Over a parautochtonous contact, another section exhibits whitish sandstone and gray silt/mud and coal levels with plant fossils and interbedded green, gray and red shale/siltstone beds and whitish and red sandstones with current structures, rip-ups, bioturbation and tilloids. The palynological

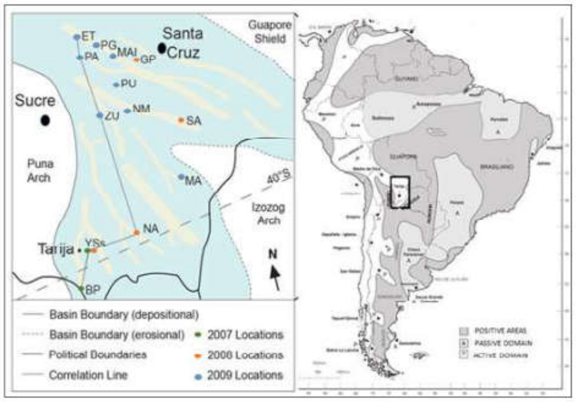

Figure 1 Carboniferous localities surveyed between 2007-2009 (left) in the Tarija-Chaco basin in Bolivia: ET- El Tunal, PG – Pampas Grandes, MAI - Mairana, GP - Ginger Paradise, PA - Pasorapa, PU – Punto Machareti, ZU - Zudañez, NM – Nuevo Mundo, SA – San Antonio de Parapeti, MA - Machareti, NA - Narvaez, YS - Yesera, BP - Balapuca (from Anderson, 2011). Map of South America basins (right, modified from Azcuy and di Pasquo, 2000).

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analysis of this succession allowed us to date and establish the stratigraphic units and to propose a correlation to palynofloral zones from South America and elsewhere.

MATERIALS AND METHODS

In the Zudañez area, two samples were obtained from the Iquiri Formation on the way to a place where we collected three more samples of the former and three more from the overlying incognitous deposits. Plant fossils were also recovered from interbedded coal levels. Two more samples were taken from a similar lateral section of the incognitous unit and its uppermost sample was the only one barren. Diamictites were sampled in another location close to the others (Figs. 2-3). A standard palynological method was performed, samples were crushed and treated with hydrochloric and after neutralization, attacked with hydrofluoric acid and finally, sieved with 10 µm and 25 µm meshes and slides mounted with glycerine jelly. Palynomorphs were analysed using a light microscope Nikon E200 and illustrated (Plate 1) with a video camera Amuscope 14 Mp. Samples were processed at the Laboratory of Palynostratigraphy and Palaeobotany, catalogued with specific acronym (CICYTTP-PI) and numbers of the collection housed at CICYTTP-CONICET-ER-UADER.

GEOLOGICAL CONTEXT

In Bolivia (Fig. 1), two main depocenters are the Madre de Dios Basin in the North extending to Peru and the Tarija-Chaco Basin (Subandean range) in the South with its extention (surface and subsurface) to northern Argentina and western Paraguay. Different stratigraphic names are given to Mississippian units in those depocenters (Fig. 2): Cumaná, Kasa and Siripaca formations and Itacua Formation respectively (di Pasquo et al., 2017 and references therein). The Cumaná diamictite beds contain faceted and striated clasts whereas in the Kasa and Siripica formations prevailed the conglomerate, sandstone, silt and shale lithologies. The Itacua Formation is difficult to differentiate from similar diamictitic units such as Cumaná (?Late Devonian-Tournaisian) and Tarija (early Pennsylvanian) formations. An early Visean age for the the Itacua Formation at Balapuca is confirmed based on a palynological study (di Pasquo, 2007), whereas a latest Devonian age given to another diamictitic deposit at Lajas (close to Santa Cruz, Fig. 1) was put on doubt by Streel et al. (2012). They argued about the chance of having reworked Devonian palynomorphs in agreement with findings documented by di Pasquo and Azcuy (1997) and di Pasquo (2003, 2007), among other records. The local unconformable and erosional character of the base of the Cumaná and Itacua formations resulted from erosional and depositional processes related to glacio-marine/ lacustrine environments (Suárez Soruco, 2000; di Pasquo et al., 2017). The change in thicknesses of Mississippian units along with their scarce record are related to the paleogeography of the basin that show a greater structural control. Two phases of uplift are defined during the Chañic Orogeny of Late Devonian to Early Mississippian and Late Mississippian times in Bolivia and northern Argentina (Tankard et al., 1995; Azcuy & di Pasquo, 2000; Suárez Soruco, 2000; Starck & del Papa, 2006). Effects of glacial/deglacial processes are recognized through much of the Mississippian and Early Pennsylvanian succession of the Tarija basin (Starck & del Papa, 2006). Therefore, thicker and widespread diamictite deposits in this region record the local advance and retreat of glaciers into the basin mostly during the Tournaisian and early Visean and Bashkirian to Kasimovian dated with palynology (e.g. Isaacson et al., 2008; di Pasquo et al., 2017).

PALYNOLOGICAL RESULTS

The five samples from the Iquiri Formation yielded diverse, abundant and well-preserved spores and scarce phytoplankton many bearing pyrite in their exines, and abundant phytoclasts mostly cuticles and tracheids. These assemblages are characterized mainly by the spores *Dibolisporites farraginis, Dibolisporites turriculatus, Samarisporites triangulatus, Grandispora pseudoreticulata, Leiotriletes balapucensis, Apiculatasporites adavalensis, Maranhites brasiliensis, Hemiruptia legaulti, Quadrisporites* spp., chitinozoans (Fig. 3), being most of them characteristic of the Givetian and Frasnian. Three assemblages were recognized from the incognitous section, in ascending order (Figs. 2-3): Assemblage 1, from the diamictitic section, is composed of indigenous spores (*Anapiculatisporites semicuspidatus, Archaeozonotriletes intrastriatus, Crassispora invicta, C. scrupulosa, Cristatisporites indignabundus, C. colliculus, Cyclogranisporites firmus, Dibolisporites microspicatus, D. disfacies, Exallospora coronata, Foveosporites appositus, Grandispora maculosa, Granulatisporites triconvexus, Knoxisporites ruhlandi, Punctatisporites lucidulus, Reticulatisporites waloweekii, Vallatisporites ciliaris, Velamisporites australiensis, Verrucosisporites morulatus, Waltzispora lanzonii*), and reworked Devonian spore and phytoplankton species (*Retispora lepidophyta, Umbellasphaeridium saharicum, Dateriocradus* sp., *Maranhites*). Assemblage 2 is characterized by some of the underlying species and the appearance of *Anapiculatisporites concinnus, Apiculatasporites caperatus, Indotriradites dolianitii, Reticulatisporites magnidictyus, Tricidarisporites phippsae, Waltzispora polita*, and tetrads of *Verrucosisporites* and *Punctatisporites*. Assemblage 3 is less diverse bearing mostly species of the underlying assemblages, the first record of *Vallatisporites agadesensis*, and most abundant spore species of *Punctatisporites* and *Calamospora* and, in a lesser amount, *Verrucosisporites* and *Cristatisporites*. Devonian reworked species are scarce in the latter two assemblages. Plate 1

CONCLUSIONS: AGE AND CORRELATION

Most of the mentioned species in Assemblage 1 (Fig. 3) are chronostratigraphically significant for the Tournaisian and Visean. *Archaeozonotriletes intrastriatus* and *Exallospora coronata* are known in the Visean of Australia, but not previously recorded in South America (Playford & Melo, 2012; Playford, 2015 and references therein). In Assemblage 2, the appearance of *Anapiculatisporites concinnus, Apiculatasporites caperatus, Indotriradites dolianitii, Reticulatisporites magnidictyus, Tricidarisporites phippsae, Waltzispora polita*, confirm a late Visean age based on the correlation to the Mag Zone Melo & Loboziak and correlative palynofloras of Gondwana, and elsewhere (Fig. 4).

Therefore, the palynological analysis of this succession allowed us to corroborate the presence of late Givetian-early Frasnian deposits of the Iquiri Formation, and to attribute the diamictites to the lower member of the Itacua Formation akin to the late Tournaisian-early Visean (A1), whereas its upper member to the late Visean to early Serpukhovian bearing A2 and A3 and plant material. The reworking of late Devonian species into the Itacua Formation confirms active tectonic processes of Late Devonian and Mississippian as well as the influence of glacial events recognized especially in other South America basins during the Carboniferous (see di Pasquo et al., 2017).

Plate 1. Selected indigenous (1-9) and reworked (10-12) species in Itacua Formation (CICYTTP-PI acronym not included, only number of slide, England Finder, size). In 1: *Cristatisporites colliculus* 45-7 Y22(65 µm). In 2: *Anapiculatisporites semicuspidatus* 45-7 W50-1(48 µm). In 3: *Grandispora maculosa* 45-6 V41(44 µm). In 4: *Reticulatisporites waloweekii* 71-7 J46(52 µm). In 5: *Tricidarisporites phippsae* 47-6 X48-2(50 µm). In 6: *Exallospora coronata* 42-1 E41(52 µm). In 7: *Archaeozonotriletes intrastriatus* 41-3 Z41-2(55 µm). In 8: *Verrucosisporites quassigobbeti* 47-2 Q38(75 µm). In 9: *Reticulatisporites magnidictyus* 47-3 Y58(100 µm). In 10: *Retispora lepidophyta* 45-5 T41-4(75 µm). In 11: *Umbellasphaeridium saharicum* 41-4 Q27-1(110 µm). In 12: *Dateriocradus* sp. 42-3 V46-2(40 µm).

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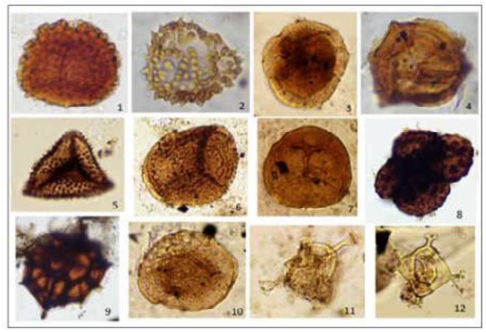

Figure 2 Chronostratigraphic scheme for Bolivia and northern Argentina across the Peru-Bolivia Master Basin.

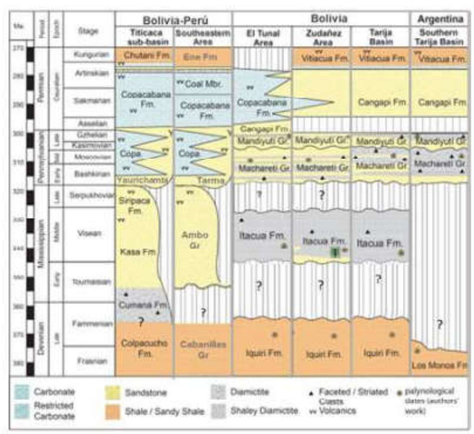

Figure 3 Stratigraphic distribution of selected species at Zudañez (left).

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GEOCHRONOLOGY			REGION	W Europe	N America	E Europe	Australia	Brazil	Argentina	Peru	Bolivia		
PERIOD	EPOCH	STAGE	W Europe subdivisions	A	B	C	D	E	F	G	H	I	Zudañez
CARBONIFEROUS	MISSISSIPPIAN	SERP.	Arnsbergian	TK	P. elegans		No data		R. magnidictyus-V. quassigobbettii (MQ Zone)	Mag Zone	R. magnidictyus Verrucosisporites sp. 85	No data	No data
			Pendleian	nitudus-carnosus	SM								Assemb. 3
		VISÉAN	Brigantian	vetustus-fracta	AT		G. maculosa					Mag Zone (Ass. 3)	Mag Zone (Ass. 2)
			Asbian	nigra-marginatus	stephanophorus			R. magnidictyus (Mag Zone)					
			Holkerian	TC									
			Arundian	TS	pusilla-columbaris	D. variabilis D. intermedius K. literatus C. appendices L. pusilla-M. cutta C. multiplicabilis	A. largus		Cordylosporites-Verrucosisporites	?	? "Itacua palynoflora"	Assemb. 2 (Lycospora)	No data
				pusilla									
			Chadian										
		TOURNAISIAN	Ivorian	claviger-macra	decorus-claviger	VG exiguus	G. spiculifera			No data	?	Assemb. 1 (R. waloweekii)	Assemb. 1 (A. largus-R. waloweekii)
				pretiosus-clavata	pretiosus	uncatus		S. pretiosus-C.decorus					
					vallatus								
			Hastarian	balteatus-polyptycha	?	P. monotuberculatus		S. balteatus-N. loganii		?		No data	No data
				hibernicus-distinctus	rotatus-explanatus	G. upensis A. septialia		R. arcuatus-W. lanzonii			C. marciae		
				verrucosus-incohatus		T. malevkensis							

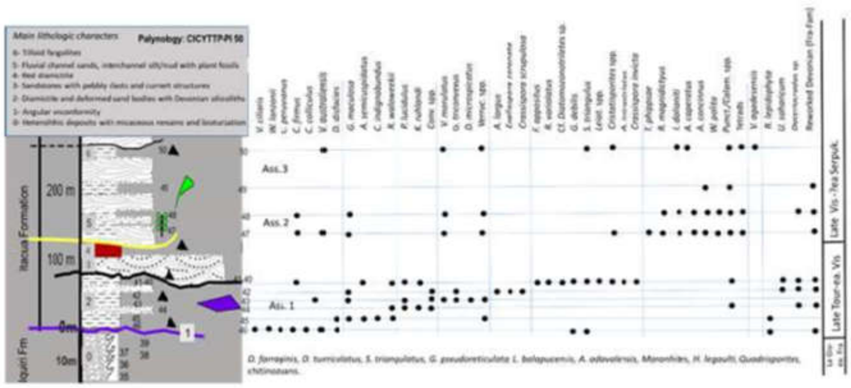

Figure 4 Biostratigraphic correlation of the assemblages recorded in Zudañez (see references A-H in di Pasquo and Iannuzzi, 2014). Abreviations: (W Europe) TS – K. triradiatus-K. stephanophorus, TC – P. tessellatus-S. camptyloptera, TK – S. triangulus-R. knoxi; (E Europe) VG – M. variomarginata-V. genuinus, (N America) SM – G. spinosa-I. magnificus, AT – S. acadiensis-K. triradiatus (right).

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