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Palynological evidence of the geoecological belts dynamics from Eastern Cordillera of NW Argentina (23° S) during the Pre-Last Glacial Maximum

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ABSTRACT. This paper presents the first palynological record for the dynamics of geoecological belts of the Eastern Cordillera in northwestern Argentina prior to the Last Glacial Maximum (LGM). The study was carried out on a 5-m deep sedimentary core raised at Laguna Blanca (23°09'S, 65°12'W; 4,256 m a.s.l.), province of Jujuy. The geochronology was based on three ^{14}C dating by AMS method. Results show the sensitive response of the geoecological belts to temperature and effective moisture variations from *ca.* 29,000 to *ca.* 25,000 cal. years BP. The High Andean belt probably suffered an altitudinal descent forced by intense cold climate conditions *ca.* 29,000 cal. years BP, and may have reached a comparable distribution to the present one on 26,300 cal. years BP, favored by a milder climate. The Puna belt did not suffer great changes, since it remained with low representation in the pollen spectrum. High percentages of tree species from the Yungas *ca.* 29,000 cal. years BP are probably a response to the intensification of anabatic winds ascending the slope of the Sub-Andean Range towards the Eastern Cordillera. These results represent an important contribution to the paleoenvironmental discussion of the Late Pleistocene for the northwestern Argentina, where the available information on vegetation history is scarce.

Keywords: Eastern Cordillera, Geoecological belts, Laguna Blanca, Jujuy, Pre Last Glacial Maximum, Pollen.

RESUMEN. Evidencias palinológicas de la dinámica de los pisos geoecológicos de la cordillera oriental del noroeste Argentino (23° S) durante el Pre Último Máximo Glacial. Se presentan las primeras evidencias palinológicas sobre la dinámica de los pisos geoecológicos de la cordillera oriental del Noroeste argentino durante los milenios previo al Último Máximo Glacial (LGM). El estudio se realizó sobre un testigo sedimentario de 5 m de profundidad extraído en Laguna Blanca (23°09'S, 65°12'W; 4.256 m s.n.m.), provincia de Jujuy. La geocronología se basó en tres dataciones ^{14}C por método AMS. Los resultados muestran variaciones de temperatura y humedad efectiva para el período *ca.* 29,000 a *ca.* 25,000 cal. años AP, a las cuales los pisos geoecológicos respondieron de forma sensible. El piso Altoandino, probablemente sufrió un descenso altitudinal forzado por condiciones climáticas de frío intenso *ca.* 29,000 cal. años AP, y habría alcanzado una distribución comparable a la actual a partir de 26,300 cal. años AP, favorecido por un clima menos frío y seco que el período anterior. El piso Puneño no sufrió grandes modificaciones, ya que mantiene una baja representación en el espectro polínico. El aporte en altos porcentajes de especies arbóreas de Yungas *ca*. 29,000 cal. años AP posiblemente sea una respuesta a la intensificación de los vientos anabáticos que ascienden por el faldeo de las sierras subandinas hacia la cordillera oriental. Estos resultados contribuyen a la discusión paleoambiental del Pleistoceno Superior del Noroeste argentino, donde la información disponible sobre la historia de la vegetación es escasa.

Palabras clave: Cordillera oriental, Pisos geoecológicos, Laguna Blanca, Jujuy, Pre Último Máximo Glacial, Polen.

1. Introduction

The high mountain sectors of the Central Andes (16°-30° S) are key regions for studying the paleoenvironmental evolution during the Quaternary. Their sensitivity to subtle effective moisture (precipitation minus evaporation) and temperature variations cause changes inducing vertical migration of vegetation associations along the slopes (Colinvaux *et al*., 1997; Grosjean *et al*., 2001; Paduano *et al*., 2003; Gosling *et al*., 2008). Thus, paleoenvironmental records offer an excellent opportunity to study changes in Andean vegetation, and their relationship with past climate change (Colinvaux *et al*., 1997; Chepstow-Lusty *et al*., 2005; Williams *et al*., 2011).

Late Pleistocene paleoclimatic records from tropical and subtropical areas of the Central Andes (*e.g.,* Clark *et al*., 2009; Zech *et al*., 2009) are restricted to very few sites, and their interpretations are controversial. In the Bolivian Altiplano, the Late Pleistocene climate reconstructions has been discussed in several studies which suggest that the transition to the Last Glacial Maximum (LGM, 26,000-21,000 cal. years BP /22,000-18,000 years BP) was a cold and wet period with regional variations of moisture availability. These variations have been attributed to changes in atmospheric circulation, greater solar insolation and precessional forcings (Garreaud *et al*., 2003; Fritz *et al*., 2004; Placzek *et al*., 2006; Gosling *et al*., 2008). Mean precipitations 30% higher (Blodgett *et al*., 1997) and temperatures 5 and 8 °C less than present values were suggested (Thompson *et al*., 1998; Argollo and Mourguiart, 2000; Imhof *et al*., 2006). During this cooling period, lake and paleolake responses in the main Altiplano basin have been reconstructed. For example, Lake Titicaca water level increased under the prevalence of cold conditions and the Puna Brava vegetation descended *ca.* 21,500 cal. years BP (Baker *et al*., 2001; Paduano *et al*., 2003; Tapia *et al*., 2003) while in the Uyuni salt lake the Sajsi cycle (between 24,000 and 20,500 cal. years BP) was contemporary to the LGM (Placzek *et al*., 2006; Blard *et al*., 2011).

Other studies in the Atacama region showed the development of a perennial lake between 26,700 and 16,500 cal. years BP (Bobst *et al*., 2001). Higher than present moisture conditions were possibly due to the increase of convective precipitations during austral summer (Ammann *et al*., 2001). Instead, pollen and sedimentary records show an increase of aridity in central Atacama Desert (22° to 24°) between 35,000 and 22,000 cal. years BP (Betancourt, 2000; Grosjean *et al*., 2001).

The knowledge of Late Pleistocene paleoenvironment in the Eastern Cordillera of NW Argentina is based on different geomorphological, sedimentological, among others archives, showing relevant environmental changes. The Sierra de Santa Victoria landscape evolved under the influence of a glacial climate, with a temperature decrease similar to those recorded in the Bolivian Altiplano and relative precipitation increase (Kull *et al*., 2003). Zipprich *et al*. (2000) find no glacial evidences for this period, but observe a periglacial belt expansion 700 m below its present limit, caused by the temperature decrease. Several authors suggest the development of paleolakes in Sierra de Santa Victoria and Laguna Guayatayoc as a consequence of glacier melting and precipitation increase between 20,000 and 17,000 cal. years BP (Zech *et al*., 2009; López Steinmetz and Galli, 2015) and in Laguna de los Pozuelos, McGlue *et al*. (2013) identified a lithostratigraphic unit which characterize a predominantly palustrine environment between 37,000 and 23,000 cal. years BP.

Knowledge of the Late Pleistocene vegetation history in NW Argentina is scarce. The most relevant data are recorded at Late Glacial period, characterized as wetter and colder than today and by soil formation on both flanks of the Andes (Veit, 1996; Zipprich *et al*., 2000). Palynological record in Tres Lagunas (Sierra de Santa Victoria) showed that the Yungas Forest expansion occurred on the slopes of the Eastern flank of the Andes at *ca.*18,250 cal. years BP (15,000 years BP), favored by a precipitation increase due to greater influence of the trade winds (Schäbitz *et al.*, 2001).

In this paper we examine the dynamics of the geoecological belts of the Eastern Cordillera and discuss their regional biogeographic implications, analyzing sediment cores collected at Laguna Blanca site.

1.1. Study Area

The study area is located in the northeastern sector of the Argentinean Puna, Province of Jujuy (Fig. 1a y b). It extends from the northern sector of Serranías de Zenta to Serranías de Aparzo to the south, where Laguna Blanca is situated (23º09' S, 65º12' W; 4,256 m a.s.l.).

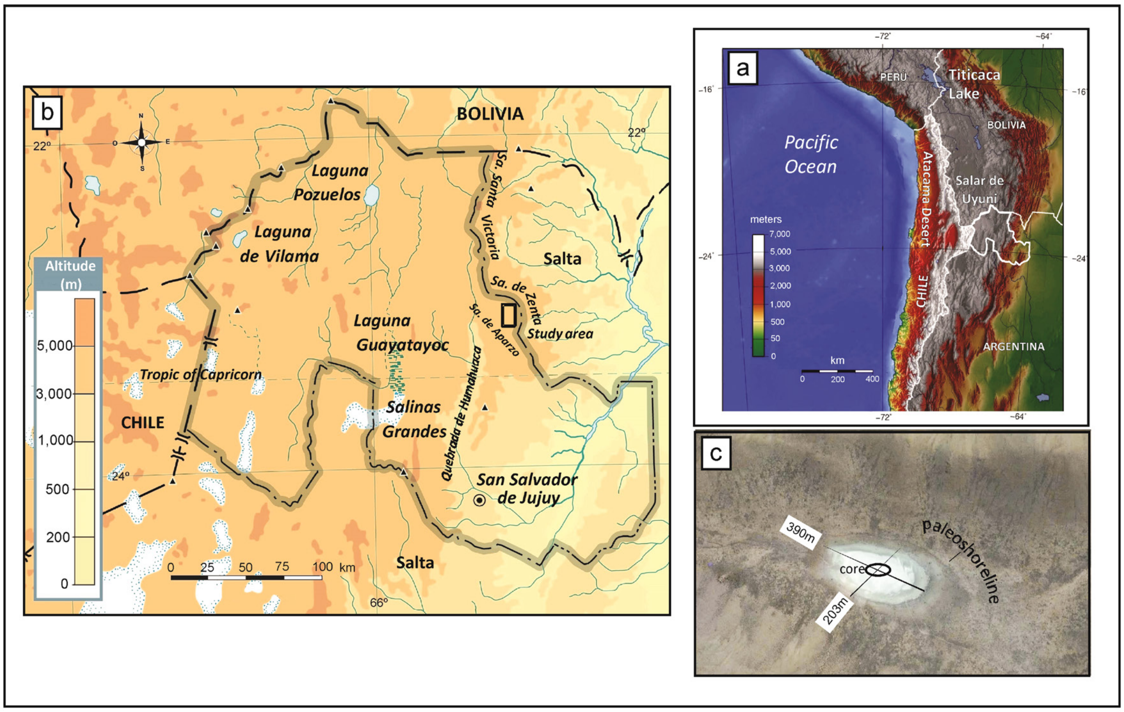

FIG. 1. **a**. Location of Jujuy province in South America; **b**. Map of Jujuy Province showing the location of study area; **c**. Laguna Blanca's basin. Map of Jujuy Province was extracted and modified of http://www.mapoteca.educ.ar (last visit 10-03-2016).

1.1.1. Geomorphologic setting

Laguna Blanca occupies a surface of 3.6 ha within an endorheic basin of 230 ha, with a paleoshoreline located at 3.5 m above the bottom of the lake (Fig. 1c). The, dominant landform surrounding the basin above 4,000 m a.s.l. corresponds to smooth, slightly rounded shapes, derived from periglacial processes. Geomorphological features are represented by plain slopes and rock glaciers with scarce recent hydric erosion.

Currently in Sierra de Zenta there are many active rock glaciers and their distribution is associated to glacial morphology modeled during the Late Pleistocene (Martini *et al*., 2013). There are also evidences of ancient glaciations represented by cirques and moraines related to several Pleistocene and Holocene glacier advances occurred along the Eastern Cordillera (Zipprich *et al*., 2000; Kull *et al*., 2003; Martini *et al*., 2013). The remains of those glaciations in the surroundings of the study area has probably been removed by the effect of more recent periglacial activity.

Below 4,000 m a.s.l., the slopes show the effects of active erosive dynamics associated to the baseline descent affecting retrogressively from the main collecting valleys towards the slopes (Abraham de Vázquez *et al*., 2000). The secondary valleys present silicoclastic deposit accumulations with different granulometry and the development of Holocene peatlands (Schittek, 2014).

1.1.2. Climate and Vegetation

Monsoon circulation, transport humidity to the study area through the trade winds originating in the Atlantic Ocean (Garreaud *et al*., 2009; Bräuning, 2009). Valley winds, which are more frequent during the warm season (December-March), play an important role advecting humidity upslope toward the Puna. In winter, intense and dry W-NW downslope winds dominate in the area (Prohaska, 1961; Tchlinguirian and Pereira, 2001).

The water deficit is one of the most noteworthy environmental limitations. Annual precipitation range from 300 to 400 mm, 80% concentrated on the summer season (Buitrago, 2000; Bianchi *et al*., 2005). Its origin is similar to that described for the Bolivian Altiplano, where the convective precipitation is controlled by atmospheric humidity advected by regional circulation within the atmospheric boundary layer (Garreaud *et al*., 2003).

Mean temperatures at Serranías de Aparzo and Zenta reach 10 and 4 ºC during January and July respectively. The daily thermal amplitude is typical of the high mountain regions, with relatively high temperatures during day hours which abruptly descend during the night to below 0 ºC (Braun Wilke *et al*., 2013).

The altitude (3,880-4,200 m a.s.l.) and topography determine an environmental complex between the Puna and High Andean phytogeographic provinces (Cabrera, 1976). Plant communities are characterized by bushy steppes, grasslands and peatlands. General composition of the Puna vegetation comprises *Baccharis boliviensis* (Wedd.) Cabrera bushy steppe with *Fabiana densa* J. Rémy and the widely distributed *Tetraglochin cristatum* (Britton) Rothm steppe co-dominated by xerophytic bushes such as *Adesmia* sp. and Cactaceae. These communities develop in arid conditions, where the mean annual precipitation ranges from 150 to 250 mm. Other typical communities are *Parastrephia quadrangularis* (Meyen) Cabrera scrubs associated with wetlands and isolated *Polylepis tomentella* Wedd woods (Ruthsatz and Movia, 1975). Above 4,200 m a.s.l., where the mean annual precipitation exceeds 300 mm, the high Andean vegetation communities are characterized by *Festuca orthophylla* Pilg grasslands accompanied by perennial herbs and *Frankenia triandra* J. Rémy cushions associated with rocky grounds. Scattered *Festuca* spp. clumps with *Nassauvia axilaris* (Lag. ex Lindl.) D. Don bushes and Puna bushes are also present (Schittek, 2014). The upper timberline of the Yungas is located at 2700 m a.s.l., more than 20 km to the east of Laguna Blanca. The dominant trees of the mountain forest are: *Alnus acuminata* Kunth., *Podocarpus parlatorei* Pilg., *Sambucus nigra* L., *Juglans autralis* Griseb., *Polylepis australis* Bitter., among others.

2. Materials and Methods

Surface soil samples were collected with the multiple subsampling technique (Adam and Mehringer, 1975), covering the altitudinal vegetation gradient from the Puna to the High Andean belt (Table 1). These samples were used to construct a modern analogue (Fig. 2) for interpreting the fossil pollen record (Markgraf *et al*., 1981; Lupo, 1998).

A 5 m sediment core (TLB-1) was raised from the center of Laguna Blanca during the winter season in August 2008, when the lake was dry. Sediment cores were collected using a modified split-spoon sampler attached to a percussion drilling system. PVC liners (1 m long, 4 cm diameter) allowed successive core sections to be collected from the open borehole. Individual core sections were sealed in the field. Coarse granulometry prevented further recovery beyond 5 m depth. Sediments were described through texture analysis and the strata color was determined with the Munsell Soil Colour Chart (1994). Twenty four samples were extracted at irregular intervals for pollen analysis. Three additional samples were taken for radiocarbon dating by the Accelerator Mass Spectrometry (AMS) at the Centro di Datazione e Diagnostica, Dipartamento di Ingegneria dell'Innovazione (CEDAD) of Università del Salento, Italy. All radiocarbon ages were calibrated using the CALPAL online program (www.calpal.de (last visit 03-05-2015)) and the CalPal2007_HULU calibration curve (Weninger *et al*., 2013). An age-depth model was constructed by linear interpolation method (Fig. 3).

Pollen samples were processed following the standard techniques for Quaternary sediments (Erdtman, 1960; Gray, 1965; Faegri and Iversen, 1989). Processing included determining of sample volume by volumetric displacement method and the addition of two *Lycopodium clavatum* tablets (x=12450) per sample to calculate pollen concentration (grains/ml) (Bennett and Willis, 2001). Pollen counts were performed with a Zeiss ICS KF2 optic microscope at 400x magnification. A minimum of 200 pollen grains per sample were counted. Pollen types were determined with the pollen reference collection of the Laboratorio de Palinología, of the Universidad Nacional de Jujuy (PAL-JUA) and pollen atlases (Heusser, 1971; Markgraf and D'Antoni, 1978).

Data are presented in percentage pollen diagrams of surface soil and fossil samples. Plotting and zonation are based on a Cluster Analysis carried out with Tilia 2.0.2 software (Grimm, 2004). In order to interpret the surface pollen diagram, several criteria were adopted: **1.** Janssen's criterion was adopted to recognize local and regional pollen deposition (Janssen, 1973). **2.** Characteristic pollen types for each geoecological belt were grouped based on Cabrera's (1976) phytogeographic classification (Yungas, Puna and High Andean). **3.** The remaining pollen types

TABLE 1. DISTRIBUTION OF SOIL SURFACE SAMPLES.

Sample	Elevation (m a.s.l.)	Latitude (S)	Longitude (W)	Dominant species
M1	4,220	23°9'14.98"	65°11'2.62"	*Stipa* sp., *Baccharis incarum*, *Frankenia triandra*, *Nassauvia axilaris*
M2	4,170	23°8'53.23"	65°11'34.82"	*Tetraglochin cristatum*, *Stipa* sp. *Baccharis incarum*, *Chersodoma argentina*
M3	4,117	23°8'27.82"	65°12'21.16"	*Stipa* sp. *Parastrephia cuadrangularis*, *Tetraglochin cristatum*
M4	3,887	23°5'38.70"	65°11'23.09"	*Baccharis boliviensis, Fabiana densa*
M5	4,017	23°3'1.25"	65°12'49.28"	*Stipa* sp., *Tetraglochin cristatum*, *Baccharis incarum*, *Nassauvia axilaris*
M6	4,069	23°2'34.66"	65°13'21.61"	*Tetraglochin cristatum*, *Stipa* sp. *Baccharis incarum*, *Astragalus garbancillo*
M7	4,138	23°2'23.10"	65°13'54.82"	*Stipa* sp., *Parastrephia cuadrangularis*
M8	4,112	23°1'57.88"	65°14'13.42"	*Stipa* sp., *Parastrephia cuadrangularis*, *Maihueniopsis boliviana*
M9	4,166	23°1'54.59"	65°14'31.74"	*Festuca orthophylla Parastrephia cuadrangularis*, *Tetraglochin cristatum*
M10	4,263	23°1'52.18"	65°14'44.21"	*Festuca orthophylla Parastrephia cuadrangularis Frankenia triandra*
M11	4,274	23°9'57.39"	65°11'30.55"	*Festuca orthophylla, Stipa* sp. *Parastrephia cuadrangularis*, *Ephedra rupestris*
M12	4,260	23°9'27.28"	65°11'52.82"	*Festuca orthophylla*
M13	4,256	23°9'24.10"	65°12'6.25"	*Festuca orthophylla*
M14	4,110	23°8'24.59"	65°12'18.16"	*Stipa* sp. *Parastrephia cuadrangularis*
M15	4,005	23°7'43.87"	65°12'11.69"	*Stipa* sp. *Parastrephia cuadrangularis, Teraglochin cristatum*
M16	4,161	23°1'42.08"	65°14'59.74"	*Stipa* sp. *Parastrephia cuadrangularis, Adesmia horrida*

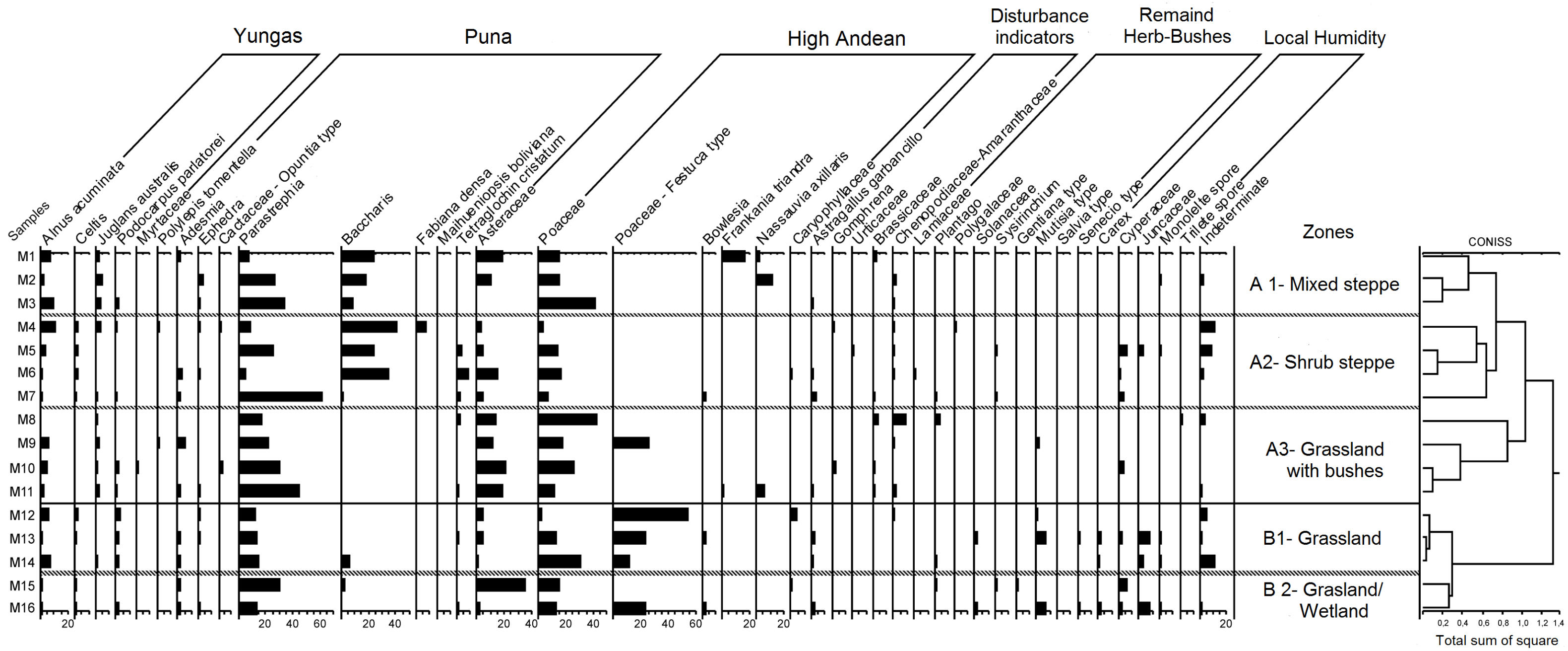

FIG. 2. Pollen diagram of soil surface samples.

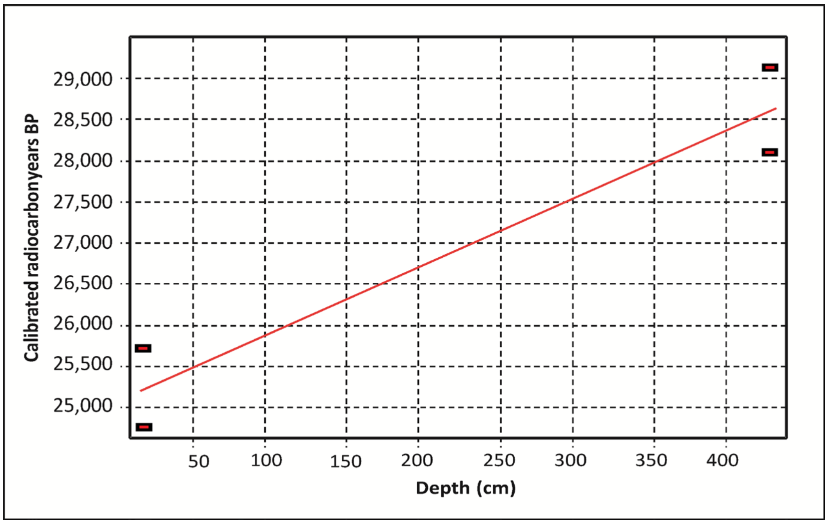

FIG. 3. Age-depth model for Laguna Blanca sediment core.

were grouped in four categories in accordance to their ecological characteristics: remaining herbs-bushes, disturbance indicators, local humidity and aquatic vegetation.

3. Results

3.1. Surface pollen from altitudinal gradient

Statistical analysis of 16 surface pollen samples allowed the recognition of two zones (A and B), mainly represented by local contribution with extralocal pollen from the Yungas Mountain Forest, such as *Alnus acuminata*, *Juglans australis*, *Podocarpus parlatorei, Celtis* and Myrtaceae, which range from 2 to 16.7% (Fig. 2).

Zone A. Reflects the vegetation corresponding to the Puna steppe/High Andean transition including three subzones.

Subzone A1. Including samples from the mixed steppe. It is remarkable the pollen content of Puna bushes such as *Baccharis* (24.3%) and *Parastrephia* (33.8%), together with *Ephedra*, Cactaceae-*Opuntia* type and high Andean elements such as *Nassauvia axillaris*, *Frankenia triandra* and high percentages of Poaceae (40.5%).

Subzone A2. Represents the Puna vegetation. The dominant contribution comprises *Baccharis* (41.2%) and *Parastrephia* (60.6%). Other typical elements such as *Fabiana densa* (6.8%) and *Tetraglochin cristatum* (7.7%) are also present. Poaceae are scarcely represented (13.6%).

Subzone A3. Represents the High Andean grassland with bushes, where Poaceae (42.3%) and *Parastrephia* (44.5%) are dominant. Typical Puna bushes such as *Ephedra*, *Tetraglochin cristatum*, *Adesmia*, Cactaceae-*Opuntia* type, and high Andean elements such as *Nassauvia axillaris* and *Frankenia triandra* are also present in low percentages (<7%). Asteraceae and disturbance indicators such as Chenopodiaceae-Amaranthaceae, and Brassicaceae are noticeable with maximum values higher than 10%.

Zone B. Represents the High Andean grassland with two subzones.

Subzone B1. Noteworthy is the dominance of Poaceae- *Festuca* type (54.6%), also with other Poaceae. There are also high percentages of Caryophyllaceae and *Bowlesia* Puna bushes including *Parastrephia* (12.2%).

Subzone B2. Comprises the grassland with wetland vegetation such as Cyperceae and Juncaceae. There are also high percentages of Asteraceae and *Parastrephia* as main Puna elements.

3.2. Analysis of TLB-1 core

3.2.1. Sedimentology and chronology

Three distinct units were recognized in the 5 m sedimentary sequence:

The lower one (unit III), comprises 39 cm of fine gravel and sand that changes into a 254 cm thick layer (unit II), of finely laminated massive olive, olive-brown, and light gray clays, with interspersing fine sand and levels with oxidation signs. The upper 254 cm (unit I) show an increase of fine gravel and clays.

According to the AMS ^{14}C dating (Table 2), the lake developed from *ca.* 29,000 to *ca.* 25,000 cal. years BP. Sample LTL4415A shows an age reversal with $\delta^{13}C$ value of -42.4±0.3 which represents a noticeable lack of analytical precision (Scott *et al.*, 2007). Given the possibility that this sample present a reservoir effect typical of aquatic systems (Geyh *et al*., 1998), it was excluded from the analysis.

3.2.2. Fossil pollen record

Twenty four fossil samples were analyzed with sample 254-255cm resulting sterile. The fossil sequence was divided into two main zones which retrieve an interpolated cutting age of 26,300 cal. years BP (Fig. 4).

Zone I. It comprises two subzones:

Subzone I-1. Prior to 28,643 cal. years BP. Pollen content is dominated by Cyperaceae (87%) and trilete spores (28%). The regional vegetation shows a steep decrease of High Andean elements from 42% to 6%. A large contribution (33.3%) of allochthonous pollen from the Yungas Mountain Forest (*Alnus acuminata*, *Podocarpus parlatorei* and *Celtis*) is evident in this zone. Fossil pollen concentration shows the lowest values of the entire record (4,700 and 7,800 grains/ml).

Subzone I-2. From 28,643 to 26,300 cal. years BP. The pollen spectrum comprises aquatic vegetation represented by *Myriophyllum*, *Isoëtes* and Hidrocharitaceae type, together with marshy vegetation such as Rubiaceae and Boraginaceae. Among the local humidity elements, the psilate monolete type reaches a maximum (78.5%), while the high Andean vegetation shows a slight increase. *Juglans australis*, is also recorded with a peak reaching 42.6%. Fossil pollen concentration values are higher than *subzone I-1* varying from 10,200 to *ca.* 42,300 grains/ml.

Zone II. From 26,300 to 25,123 cal. years BP. The pollen record shows a sharp increase of Poaceae to a maximum of 56.9% with the appearance of herbaceous elements such as Polygalaceae and Brassicaceae. Aquatic vegetation declines and there are oscillations of the local humidity indicators. Fossil pollen concentration increases *ca.* 50,000 and then decrease up to 22,200 grains/ml.

4. Discussion

4.1. Paleoenvironmental interpretation

The sediments and fossil pollen records from Laguna Blanca allow inferring environmental changes in the Eastern Cordillera of NW Argentina several millennia preceding the LGM. Figure 5 shows the modeled landscape evolution for the studied period.

Before 28,600 cal. years BP (Fig. 4, zone I-1) very low pollen concentration could be linked to low pollen production, scarce vegetation cover and/or poor preservation. During this period high percentages of Cyperaceae and trilete spores are recorded. Ferns spores are frequently abundant in Quaternary deposits but their interpretation is not straight forward. In some lacustrine records trilete spores have been associated to warm and wet conditions (*e.g., Selaginella*, Tang *et al*., 2013). Others suggest that their increase is due to local production by early colonizers and are usually better preserved in dry sediments (*e.g., Pteridium*, Williams *et al*., 2011), but also can be related to typical

TABLE 2. RADIOCARBON DATING FROM TLB-1 CORE.

Sediment depth (cm)	Material	Method	^{14}C years BP	$\delta^{13}C$‰	Calibrate age (cal. yr BP)	Lab No.
19	Organic sediments	AMS ^{14}C	20,975±200	-27.3±0.3	25,123±425	LTL4416A
335	Organic sediments	AMS ^{14}C	30,000±300	-42.4±0.3	34,237±240	LTL4415A
436	Organic sediments	AMS ^{14}C	23,683±300	-29.4±0.6	28,643±468	LTL4414A

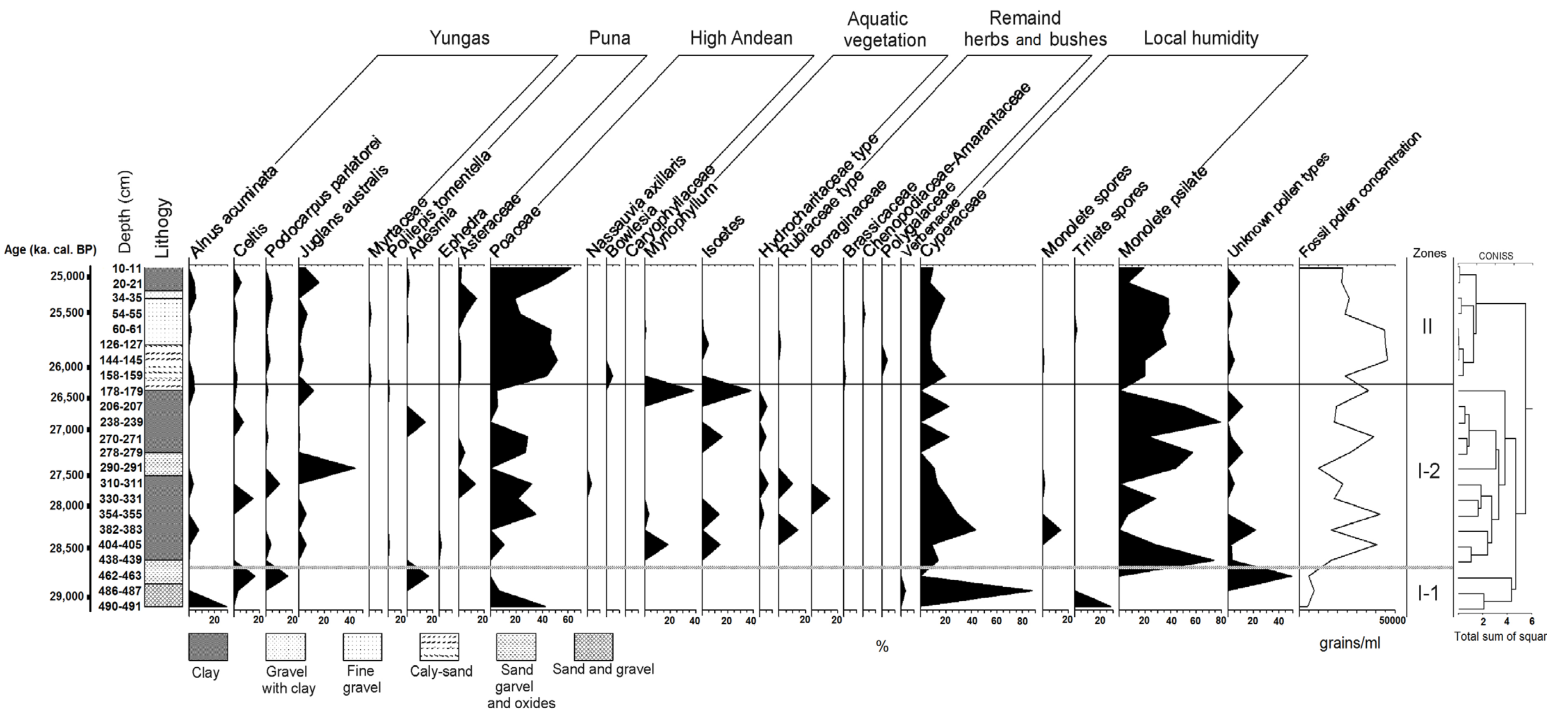

FIG. 4. Fossil pollen diagram of TLB-1 core.

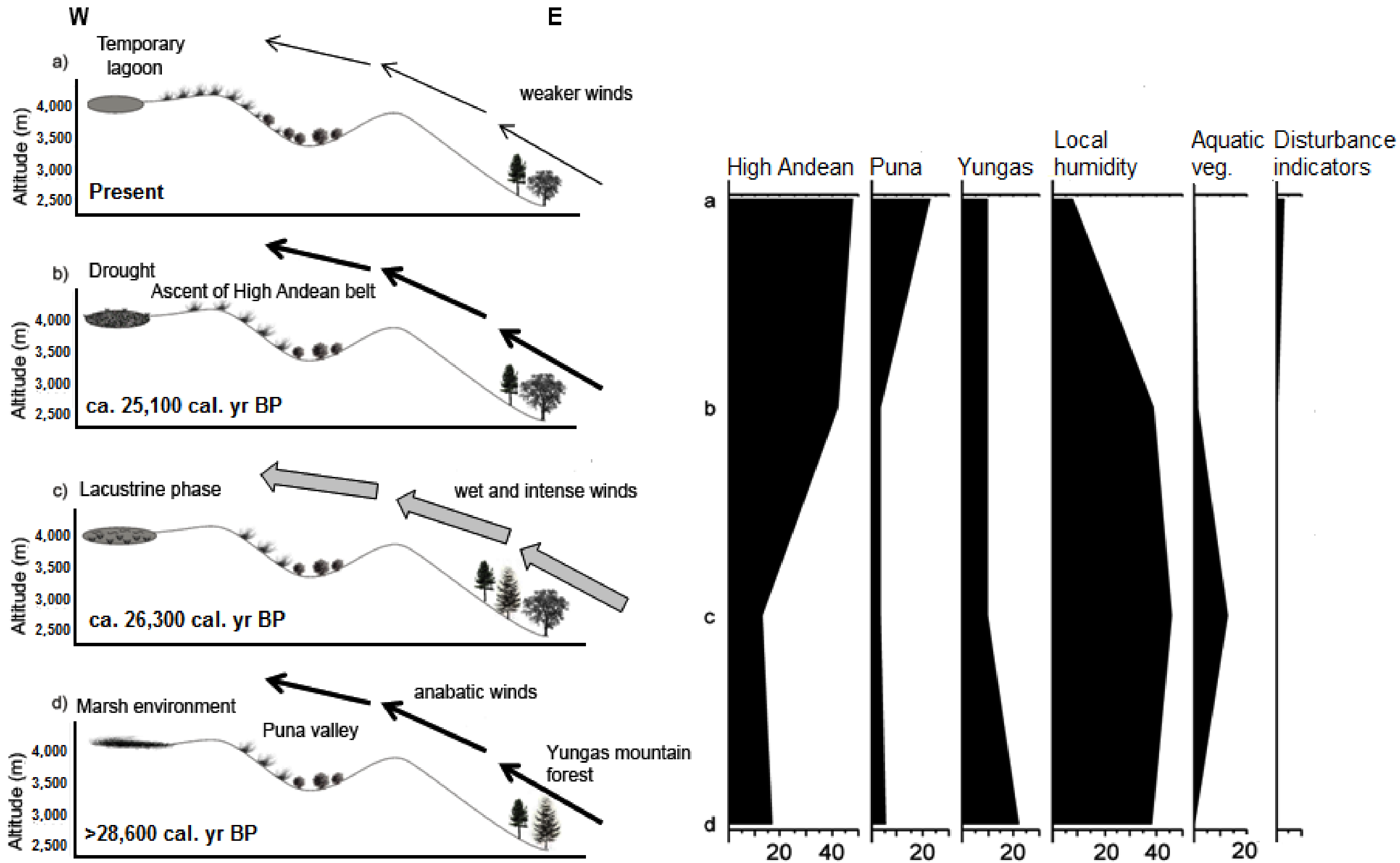

FIG. 5. Inferred vegetation change during the Pre-LGM at Laguna Blanca.

pioneer species of height swamps (*e.g., Marsilea*, de la Sota, 1977). Based on these evidences, trilete spores itself are not concluding, but its association with Cyperaceae and the abundant iron oxide nodes in the sediment let us to infer a marshy environment with greater evaporation for the period.

Poaceae exhibits a steep reduction from 40 to 6%. As the High Andean grassland reach Poaceae percentages higher than 50%, we interpret that this vegetation belt was less developed than today or may be related to downslope migration forced by intensely cold and dry climate (Fig. 5d). This response has been suggested for other regions of the tropical Andes under similar conditions (Paduano *et al*., 2003; Schittek, 2014). This interpretation is also supported by Laguna de los Pozuelos record with the gradual decrease of effective precipitation, reduction of the lake surface and subsequent formation of a marshy environment from 37,000 to 23,000 cal. years BP (McGlue *et al*., 2013).

Remarkably, high pollen percentages of *Alnus*, *Podocarpus* and *Celis* are detected in this phase which is not detected in the remaining sequence within the core. Some authors considered that the presence of these elements in fossil records are due to Eastern wind transport (Markgraf, 1981; Lupo, 1998; Torres *et al*., 2011; Cruz, 2012), while others suggested that during the Late Glacial in Sierra de Santa Victoria, the high percentages of tree pollen correspond to an upslope ascent of the Yungas Mountain Forest (Schäbitz *et al*., 2001). *Alnus acuminata* forest dynamics indicate that the main factor favoring the forest expansion on the slopes of southern exposure is temperature increase, while the precipitation increase is secondary (Grau, 1985; Aráoz, 2009). Moreover, Quiroga *et al*. (2012) suggested that in spite of being considered a cold tolerant species, *Podocarpus parlatorei* forest were located further east during the LGM than its present position, and could even be extended to sectors of the Chaco region. Therefore, the interpretation by Schäbitz *et al.* (2001) is not consistent.

On the other hand, in the context of the atmospheric circulation described for the region (Prohaska, 1961; Garreaud *et al*., 2003), it is possible that the upslope air currents represent a relevant factor to understand the presence of the Yungas tree pollen in the record. Hence we propose that the high percentages of arboreal pollen found in the fossil record of the study area should be explained by upslope pollen transport favored by anabatic winds that ascend over the slope of the Eastern Cordillera rather than migration of the forest belt.

Between 28,600 and 26,300 cal. years BP (Fig. 4, zone I-2) fossil pollen concentration increase, although High Andean vegetation shows little variation suggesting that this geoecological belt remained scarcely developed. The presence of aquatic and riparian vegetation components with low percentages of *Isoëtes* show an increase of marshy vegetation that indicate the development of a shallow lake (<4 m depth) with freezing periods (Navarro and Maldonado, 2002; Paduano *et al*., 2003; Bush *et al*., 2005). On the other hand, the sedimentary record shows predominance of clay interspersed with organic matter and coarse sand corresponding to a lake expansion with water level variation that could be linked with the paleoshore found in the basin (see Fig. 1c). During this period the paleolake could reach approximately 50 ha (Fig. 5c). The lake extension could only be supported by a higher water budget with precipitation levels 30% higher than present (Blodgett *et al*., 1997). This period was milder and more humid than the previous one. The increase of humidity could be related to greater ocean-continent thermal contrast that enhances the monsoon circulation (Fritz *et al*., 2004; Bräuning, 2009). The presence of the paleolake in Laguna Blanca indicates that there was a humid pulse in the region 2,000-3,000 years before the Sajsi high lake in Salar de Uyuni (Placzek *et al*., 2006; Blard *et al*., 2011) and a perennial lake of the Atacama salt lake (Bobst *et al*., 2001). This asynchrony may be attributed to differences of the hydrologic budget of each region.

From 26,300 to 25,100 cal. years BP (Fig. 4, zone II), the fossil pollen concentration reached the highest values indicating higher pollen input and vegetation cover that decreases toward the upper section of the record also with coarse sediments indicating greater slope activity. A sharp increase of Poaceae reflects an expansion of the High Andean belt (Fig. 5b), that is comparable to the present position (Fig. 5a). The decrease of aquatic vegetation together with oscillations of local humidity elements would indicate a moderate temperature increase and reduction of the effective moisture turning the paleolake into a freshwater marsh environment. This change of water regime is in agreement with Laguna de Pozuelos record where the presence of a perennial saline lake shows the end of the paleolake from *ca.* 26,000 to19,000 cal. year BP (McGlue *et al.*, 2013). The drier climate could have changed the Laguna Blanca lake into a playa lake system. Playa lake systems are typical of arid regions and are characterized by the reduced thickness of accumulated sediment, the presence of numerous sedimentary hiati, the complexity of evaporite deposition and early diagenetic processes (Valero Garcés *et al.*, 2000). In this context, the scarce representation or even complete absence of the Late Glacial and Holocene sedimentary record could be explained by local geomorphological inactivity or by recent eolian deflation. Similarly at Laguna de Pozuelos (McGlue *et al.*, 2013) and Laguna Guayatayoc (López Steinmetz and Galli, 2015), there is also a noticeable reduction of the record during the last 20,000 cal. years BP while Sierra de Santa Victoria and Zenta have better records for the Pleistocene-Holocene transition (Schäbitz *et al.*, 2001; Zech *et al.*, 2009). Mechanisms regulating sedimentation and preservation of the stratigraphic record of highland lakes have not been elucidated. They shall be the subject of subsequent studies to enable understanding the recent evolution of the Late Quaternary deposits and climate history.

5. Conclusions

The paleoenvironmental record of Laguna Blanca provides the first insight to the dynamics of the geoecological belts of the Eastern Cordillera in NW Argentina during the millennia prior to LGM.

The High Andean belt would have occupied lower positions at *ca.* 29,000 cal. years BP, that subsequently reached a position comparable to the present one at 26,300 cal. years BP. Noteworthy is the presence of high pollen percentages of tree species from the Yungas (*Alnus*, *Podocarpus* and *Celtis*) at *ca.* 29,000 cal. years BP, as a response to the intensification of local atmospheric circulation that may have produced higher upslope pollen transport.

From 28,600 to 26,300 cal. years BP there are evidences of a regional phase of greater water availability that favored the development of a paleolake with high water levels.

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