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Paleoenvironments and human occupation in the El Bolsón Valley of northwest Argentina (province of Catamarca, dept. of Belén)

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ABSTRACT

Using an interdisciplinary perspective that integrates archaeological, geomorphological, and palynological data, this work analyzes the relationship between environmental changes and cultural landscapes in the El Bolsón Valley in the province of Catamarca, Argentina. The palynological and sedimentological studies took place using a sediment core extracted from a seasonal lake, while the geomorphological studies made use of stratified fluvial deposits. The palynological sequence indicates that wetter conditions existed at 6400 cal BP, but that this wetness decreased to create the current more arid conditions along with increases in anthropogenic disturbance. There is also evidence for intense processes of sediment accumulation and erosion, including changes in the uses of space by human populations as recorded for the last 2000 years in fine deposits from the valley floor. The present work also makes an effort to insert this local history into its broader context, in order to contribute to existing knowledge regarding late Holocene changes at the regional level.

1. Introduction

In northwest Argentina and the Andean region, paleoenvironmental studies have been shown to be an effective tool for understanding the context in which cultural evolution took place (e.g., Markgraf, 1985; Baied and Wheeler, 1993; Grosjean and Nuñez, 1994; Kulemeyer and Lupo, 1998; Lupo, 1998; Schäbitz et al., 2001; Grosjean et al., 2005; Kulemeyer, 2005; Olivera et al., 2004, 2006; Kulemeyer et al., 2013; Ratto et al., 2013). It has also been proposed that such studies should be carried out by integrating multiple proxies and that various scales of analysis, contexts, and potential difficulties need to be taken into account in order to understand the relationships between people and their paleoenvironments in South America (Flantua et al., 2015). In northwest Argentina, existing paleoenvironmental studies have focused primarily on the more southern and northern Puna regions, or more occasionally on the low valleys and circumpuna sector (Lupo and Echenique, 2001; Oxman, 2015; Lupo et al., 2016; Peña Monné and Sampietro Vattuone, 2016; Schittek et al., 2016). This research has led to a certain degree of consensus regarding the climatic conditions existing during the Early and Middle Holocene, with oscillations between wetter and drier periods until conditions eventually became similar to the current ones, which offered locations and resources suitable for exploitation by human populations (Olivera et al., 2004, 2006; Grana and Morales, 2005; Yacobaccio and Morales, 2005, 2011; Grana, 2012; Yacobaccio et al., 2013). There is also general agreement on the existence of differentiated local processes, for example the presence of some wetter areas (Grosjean and Nuñez, 1994; Nuñez et al., 2010) that depended upon aspects including the particular characteristics of their topographical, tectonic, geological, and potentially micro-climatic contexts, and that these factors must be analyzed in a comprehensive way along with the archaeological contexts. This broad agreement has now led to the relevance of producing case studies that are able to reveal local particularities in relation to regional trends, especially in areas that have previously been largely overlooked in relation to research of this type. This is the case in the El Bolsón Valley, a space of transition between the valley and Puna environments in the province of Catamarca (Fig. 1). The transitional nature of this environment implies the existence of multiple microenvironments, which makes this location

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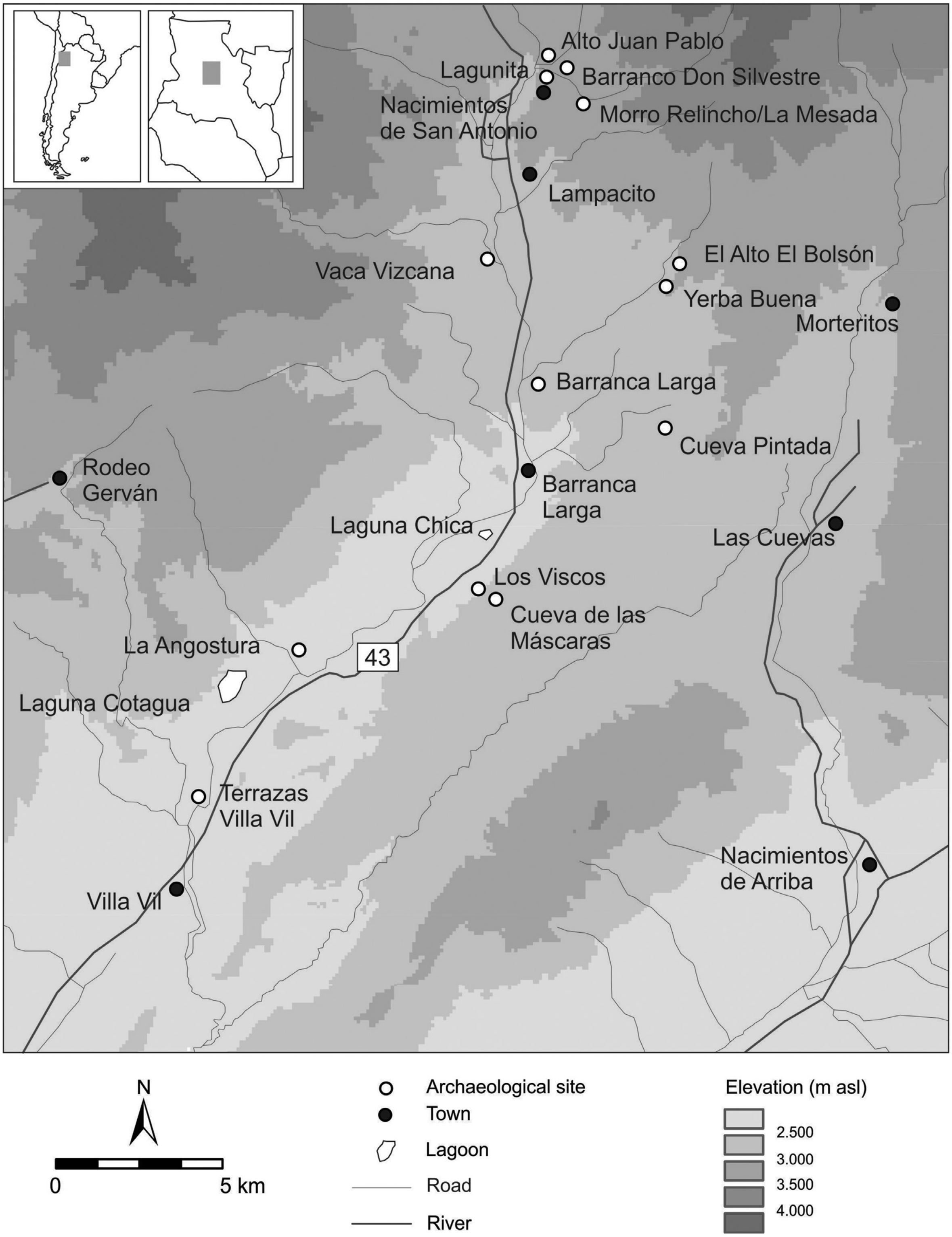

Fig. 1. "El Bolsón" Valley and mentioned sites location.

appropriate for pursuing an understanding, at multiple scales of observation, of the relationships between environmental and cultural processes as these have taken place since the Early Holocene.

Archaeological research in our study area has primarily focused on agricultural production from pre-Hispanic times until the present, and this has provided an interesting panoramic view of the history of formation of the local cultural landscapes. However, there is little information existing about human occupations during the Early Holocene. Certain discoveries, such as the appearance of a fishtail projectile point in the Yerba Buena canyon (Korstanje, 2005) or the presence of lanceolate points in some of the side valleys, which are assigned to technological types common during the Middle Holocene, indicate early occupation of the area (Quesada et al., 2013). Human settlement then becomes more visible beginning in the Formative Period (ca. 1000 BCE to 1000 CE), when sites located in the northern sector of the valley such as La Mesada, Morro Relincho, El Alto El

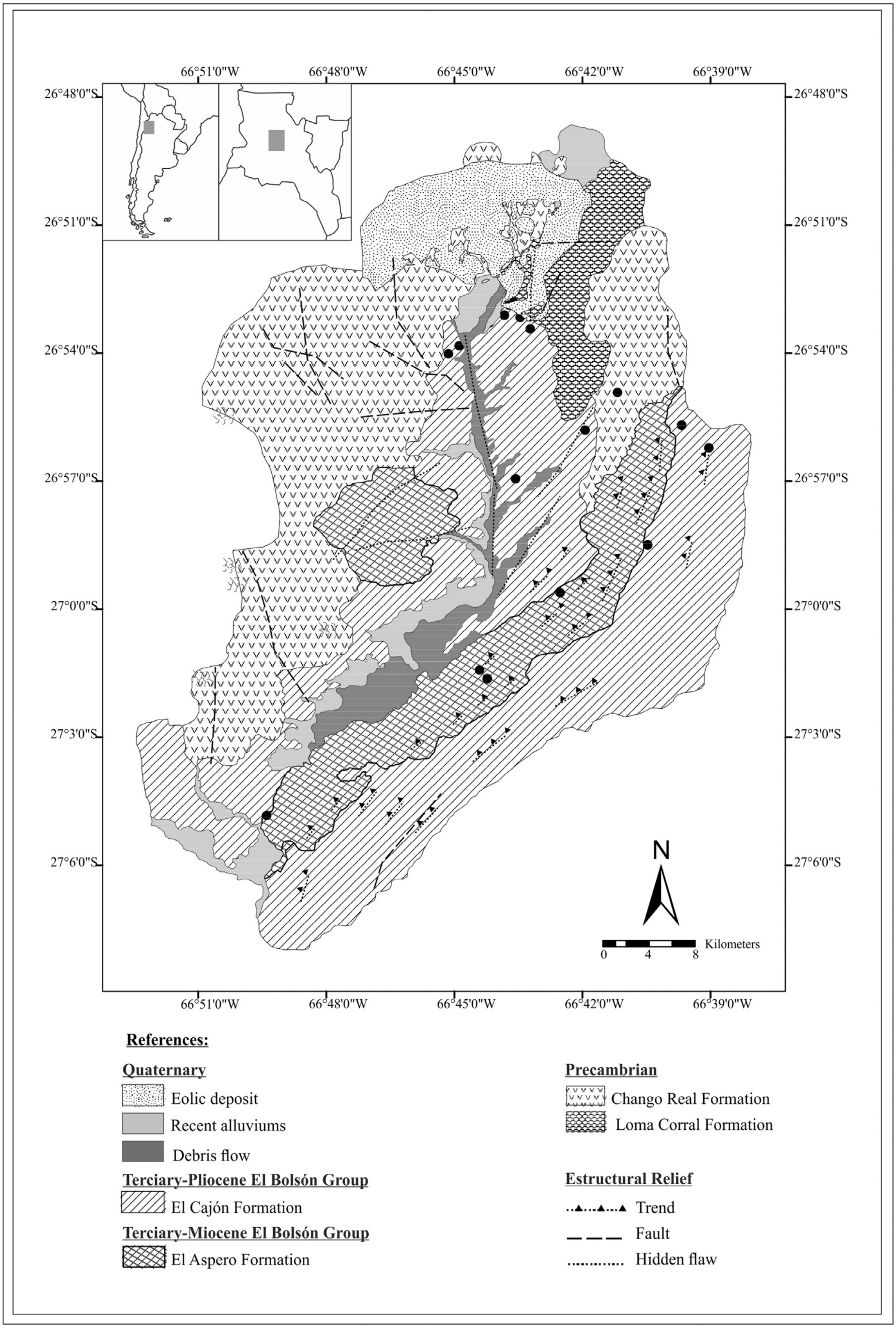

Fig. 2. Study area geology.

Bolsón, and Yerba Buena provide evidence of village-type settlements linked to agricultural production spaces. Other sites with Formative components are located in caves and rockshelters in the central sector of the valley, such as Cueva Pintada and Alero Los Viscos (Korstanje, 2005). During the Regional Development Period, (ca. 1000 to 1470 CE), some agricultural villages continued to be occupied (Quesada and Maloberti, 2015; Quiroga and Korstanje, 2007). Up until now, no information has been recorded regarding the Inka period (ca. 1470 to 1530 CE), while the Early Colonial period (16th–17th c.) is just barely represented by the Hispanic-Indigenous component at Los Viscos rockshelter. In spite of this relatively mature development of archaeological research, the environmental conditions in which these and other social phenomena recognized by archaeologists took place are still little-known, and therefore, the links between human populations and these conditions remain poorly understood. The first Holocene paleoenvironmental records in El Bolsón were obtained by Fauque and Tchilinguirian (2002), who studied seven large landslides that had blocked the course of the El Bolsón River, forming alluvial plains later cut through by fluvial erosion. Using this approach, the authors dated charcoal associated with indigenous ceramics recovered from stratigraphic layers in the fluvial terraces at Villa Vil to 1300 cal BP. Based upon the date they obtained along with calculations regarding the deposition rates for sediments overlying the dated material and subsequent erosion that formed the terraces, they estimated a minimum age of 3000 years and a maximum of 25,000 years for these seven landslides. Also, Madozzo Jaen (2009) has reconstructed the environments and climate for the last 2000 years based upon an analysis of micro-mammal remains recovered from a rockshelter located in the central sector of the valley (Cueva de las Máscaras). That sequence demonstrates that conditions similar to the current ones prevailed during this time period, with two sub-periods also being differentiated: a wetter one between 1000 and 550 BP and a drier one between 550 and 250 BP. Although both of the cited studies made significant contributions to our knowledge of the local environmental dynamics, they were not able to resolve at least two problematic situations: first, the chronological context of the environmental changes continued to have low resolution, and second, these changes do not articulate well with the concurrent cultural developments.

More recently, with the aim of providing new knowledge regarding the questions briefly summarized in the previous paragraphs, a variety of research focal points were added and integrated in order to create a first reconstruction of the past environments and climate within the context of the formation of archaeological landscapes. These included: a) sequences of Holocene terraces; b) geological and geomorphological mapping, with special emphasis on recent morphodynamics; and c) sedimentological and palynological analyses using a sediment core extracted from the Laguna Cotagua seasonal lake (Cruz, 2012; Kulemeyer et al., 2013). In the present work our intention has been to generate an integrated vision that takes both cultural history and environmental history into account, by using a multi-proxy approach oriented towards achieving the following objectives: 1) to generate new paleoenvironmental information at the local scale; 2) to fine-tune the chronological framework for the processes of environmental change; and 3) to link archaeological knowledge regarding societal processes at the end of the Holocene with these environmental dynamics.

2. The El Bolsón Valley in northwest Argentina

The El Bolsón Valley is located in northwest Argentina at an intermediate position between the more well-defined Puna and Low Valley environments, and it has altitudes ranging between 4500 masl in the Chango Real hills to the north and 2200 masl at the locality of Villa Vil in the South. This altitude gradient translates into the presence of a variety of microenvironments, distributed throughout a narrow valley that is 28 km in length, and in which the present study area is located. This valley has a general north-south orientation and follows the course of the river of the same name. Each of these microenvironments has well-defined characteristics in terms of climate, geology, geomorphology, and vegetation. Geological-structural research has also characterized this valley as asymmetrical. Within this context, the history of human occupation as briefly described above took place, and this was a critical factor in formation of the current landscape. Here we will first describe the environmental characteristics of the El Bolsón Valley, then provide an outline of its history of landscape formation, as understood from the multi-proxy perspective described.

Based upon Turner (1973), it can be confirmed that the relevant geological characteristics show an area that is made up of a low number of formations, but with a significant presence for each of these (Fig. 2). The bedrock is made up of Precambrian metamorphic stone (schists, slates, and phyllites) assigned to the Loma Corral Formation with outcroppings in the north and west, while the Chango Real Formation, present in the east and north of the El Bolsón basin, is a complex made up of metamorphized sediments with abundant igneous penetrations. These formations are overlaid by a series of Cenezoic sediments known as the El Bolsón Group, with outcroppings on the valley floor. These sediments include clastic materials, from clays and silts to conglomerates, with frequent intercalation of volcanic elements in the middle section and, to a lesser degree, in the northern part of the area where psammitic rock is predominant. The Quaternary is represented by transported materials arranged in stratified terraces, which occupy a strip of varying widths along the margins of the El Bolsón River. These same locations possess the recent alluvium that corresponds to Holocene deposits, which are generally sandy and found along the margins of the river and as modern alluvial fans, which will be discussed in more detail further below.

The El Bolsón hydrographic basin is enclosed on its east side by a structural escarpment that is cut through by various narrow, relatively short watercourses running parallel with each other. To the south there are highly eroded neogenic sediments forming a badlands-type landscape (Kulemeyer et al., 2013). The floor of the valley contains transported deposits that form alluvial terraces and fans assigned to the Holocene. There are also dunes, primarily in the northern part of the valley, that show evidence of a northwest-to-southeast advance. In this sector, soil formation and development are limited by the aridity of the climate, which makes these soils primarily sandy, saline, and poor in organic matter, with outcroppings of rock and larger stones being frequent (Kulemeyer et al., 2013).

The transition from the Puna to the valleys positions our study area as an ecotone, which contains the phytogeographical provinces of Monte, Pre-Puna, and Puna (Cabrera, 1976; Morlans, 1995). Cruz (2012) has performed botanical surveys and vegetation census and mapping, as well as a study of present-day pollen rain along an altitude gradient running from 3200 to 2200 m asl. That work included samples taken from the sites of El Alto El Bolsón, Los Nacimientos de San Antonio, Laguna Chica, and Laguna Cotagua, with some of these locations also possessing archaeological sites that had been the subject of previous studies (Korstanje, 2005, 2007).

Fig. 3 shows how the vegetation represented in each of the cited provinces can depend upon the altitude gradient in the valley in each sector (Cruz, 2012). According to the cited work, from 3180 m asl, where the La Mesada archaeological site is located, until approximately 2900–3000 m asl, the vegetation is predominantly represented by Puna grasslands. Puna shrubland steppes then appear beginning at the location of the modern town of Los Nacimientos de San Antonio at 2950 m asl. The Pre-Puna zone is found between 2400 and 2900 m asl, occupying the foothills of the mountainous ranges, while the Monte province reaches its minimum altitudes in the area of 2200 m asl in the locality of Villa Vil (Cruz, 2012).

The climate in the zone was defined as temperate Sierras y Bolsones (Argentine Monte), and there are marked contrasts in terms of temperature and rainfall between the summer and winter periods (Irurzun, 1978). In Andalgalá, the location of the meteorological station closest

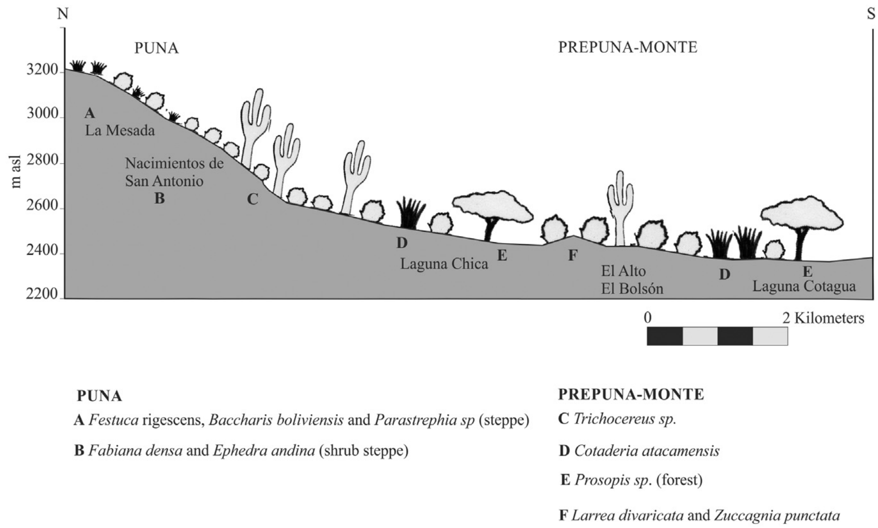

Fig. 3. "El Bolsón Valley" Vegetation types (Modified from Cruz, 2012).

to our study area[1] (approximately 80 km away), the dominant winds are from the northeast and north. The average annual temperature is 18 °C, with the average annual maximums being 26–27 °C and with minimums from 10 to 12 °C. The daytime temperature range is considerable, around 15 °C, and the area receives one of the highest sunshine durations in the entire country, with 65% effective sunshine hours. Average precipitation levels are calculated at around 200 mm/year for the valleys and basins in general, with this rainfall concentrated during the summer months. In the higher areas of the mountains more condensation occurs and rainfall can reach 450 mm/year, and local records from rainfall gauges also indicate that the highest zones receive the most moisture (Korstanje, 2005).

3. Research methods

Since our study area represents a meeting point between two large geological-structural areas with different characteristics, it was necessary to study the specific environmental characteristics of the valley. Two scales of analysis were taken into account: one regional, covering the El Bolsón Valley in a comprehensive manner because of its position as an ecotone between the Puna and Low Valley environments, and a second more local scale, with an effort to characterize the environmental conditions in particular regions of the valley.

3.1. Geomorphology and geoarchaeology

The geological descriptions from the area produced by Turner (1973) and mentioned above, along with satellite images (Google Earth, 2013), were used as the basis for an on-the-ground survey of the geomorphology described, and were also used to select potential work areas in various sectors of the valley (in the present article we consider the central and southern sectors). Intensive, systematic geoarchaeological survey was also carried out in each sector in order to identify the particular morpho-chronological and archaeological developments in the area. Special attention was given to analysis and detailed recording of geoforms and erosion-deposition events assigned to the Holocene. Transects following the margins of the El Bolsón River were defined in order to carry out this survey work in the area. The fluvial terraces along the base of the valley were walked, where deposits of Holocene sediments were found to be present.

In the present work we present the records from the fluvial terraces near the village of Villa Vil, which is located 8 km to the south of Laguna Cotagua, where 7 sedimentary profiles were studied and sampled. These were given the names of Villa Vil Profile 001 to 009 (referred to hereinafter as VVP001 to VVP009), and were selected because they showed a continuous series of sedimentary deposits without evidence of erosive disturbances, and also because they possessed stratigraphic levels with archaeological materials (except VVP005). In all cases the structures and textures of the sediments were described, along with the evidence for stratified archaeological deposits. Observations were also recorded regarding lateral variations in the sedimentary deposits, in order to support correlations made among the various profiles. In 4 of these profiles, sediment samples were taken every 10 cm from surface to base in order to perform analysis of textures and organic matter as well as radiocarbon dating and pollen studies: VVP001 (5.62 m of exposed profile), VVP002 (6.65 m of exposed profile), VVP004 (1.59 m of exposed profile), and VVP005 (2.85 m of exposed profile). For 4 other profiles with lithological characteristics identical to those of the profiles mentioned above (VVP006, VVP007, VVP008, and VVP009), levels with cultural remains were also recorded, with the materials present including fragments of ceramics, lithics, and bones, sometimes associated with carbonized remains or evidence of stone structures. Radiocarbon dating was used to date these cultural levels and the materials recovered were analyzed based upon stylistic, taphonomic, and chronological criteria.

To perform the texture analysis for the sediments, 17 samples were taken from profile VVP001, making use of the sedimentary units recognized during the survey and without exceeding intervals of 45 cm. The sediments were wet screened for the sand fraction and the pipette method was used for silt and clay, according to the United States Department of Agriculture (USDA) classifications.

3.2. Paleoecology

A sediment core extracted from Laguna Cotagua in 2010 was used for the paleoecological study. This is a seasonal body of water 0.4 km^2 in area, located in the central sector of the valley near the western edge of the foothills. The lake is delimited on three sides by sandy slopes marked by erosion processes, with small areas of active landslides (Korstanje, 2005). A 9-meter core was extracted from the center of this lake in 1-meter sections with the assistance of a two-speed Wacker percussion hammer. Descriptions were made of the sedimentary structures observed from this Laguna Cotagua core (hereinafter, the LCC) and the textures were characterized by feel. Wet screening and pipetting according to DIN 19683 were also used to analyze the textures of selected samples. Later, 3 samples taken from various steps were dated, and Tilia 2.0.41 software was used to create an age-depth model,

[1] Since 2015 a Meteorological Station has been installed in the El Bolsón Valley itself at Barranca Larga, but there is still insufficient data to be used at this scale.

with the interpolated dates used to calculate the sedimentation rate between the dated intervals, and with the uppermost point of the sequences taken to represent the year the sediments were collected (2010). There were also 44 samples taken from the LCC for pollen analysis. Out of these, 41 were found to have preserved remains, and these results were added to those from 3 samples previously analyzed by Cruz (2012). Analysis of modern pollen rain (Cruz, 2012) was used to assist with interpretation of the fossil assemblages. Based upon all of these results, ecological criteria were used to select variables in the pollen groupings during cluster analysis and to thereby allow the fossil sequence from LCC to be interpreted. The statistical analysis made it possible to differentiate the taxa and pollen associations representative of the local, regional, and extra-regional vegetation. In the modern samples from the valley there were 29 pollen types identified, and these associations were also used for analysis of the fossil sequence from the LCC.

The paleopalynological analysis was performed following standard techniques for Quaternary sediments (Faegri and Iversen, 1975; Gray, 1965) and using a single protocol: determination of sample volume; addition of two *Lycopodium* spore tablets to introduce a foreign marker; treatment with KOH; removal of sand using HF; filtration; acetolysis per Erdtman (1960); multiple rinses with distilled water, and slide mounting with glycerin.

A minimum of 300 pollen grains per sample were counted under a light microscope. Systematic determination of the pollen types took place using comparison with a pollen reference library (Palinoteca Jujuy Argentina, or PAL JUA) compiled specifically for the region by Cruz (2012), along with the existing bibliographic literature (Faegri and Iversen, 1975; Heusser, 1971; Markgraf and D'Antoni, 1978). The ecological criteria used to select variables for fossil pollen groupings were established following Cruz (2012).

3.3. Chronologies

Details regarding all of the radiocarbon dates discussed in the present work are found in Table 1. Five sediment samples were radiocarbon dated using accelerator mass spectrometry (AMS) and seven using liquid scintillation counting (LSC). The resulting dates were calibrated using OxCal 4.2.3 software (Bronk Ramsey and Lee, 2013) along with the SHCal13 calibration curve (Hogg et al., 2013).

4. Results

4.1. Sedimentology and stratigraphy for the various deposits

Our study of cleaned geoarchaeological profiles along the margins of the El Bolsón River showed similar patterns in the central and southern areas with respect to formation of finer deposits (sands, silts, and clays) during the Holocene. In the present article we focus specifically on deposits on the valley floor, especially the sediments from the Laguna Cotagua core and the deposits from the fluvial terraces near Villa Vil.

For the VVP001 profile, texture analysis was performed for the strata that made up the exposed sequence. With 5.63 m of exposed height, this profile showed the best potential for study of the sediments, with a lack of apparent evidence for erosive events or alterations during the depositional processes. This sequence consists of a succession of finer clastic materials (sands, silts, and clays), with the percentages of these varying throughout the sequence. There are only low levels of coarse sand throughout almost the entire profile, except for between 3.35 m and 4.35 m below the surface of the terrace, where these levels reach 15–32%. A sharp increase in the values for coarse silt appears between 2.65 m and 3.25 m, were these materials represent more than 50% and coincide with the presence of archaeological materials in the profile. Between 1.65 m and 1.95 m, medium and fine sands increase again, while the values for coarse sand also increase at this level, but without becoming significant.

There are low amounts of rounded gravel intercalated among these finer deposits, primarily towards the basal part of the sequences. This gravel has eroded off of the slopes, which are made up of the very friable neogenic sediments that the terrace overlies. Some larger neogenic stones are also found in levels with archaeological materials.

In profile VVP002 there is an erosional unconformity between 1.60 m and 1.65 m below the surface of the terrace, which corresponds to an ancient river course that represents the only evidence, although localized in nature, of discontinuities in the record.

The profiles exposed at Villa Vil also show stratigraphic levels with abundant archaeological materials, uncovered by erosive action. These are ashy lenses with abundant inclusions of ceramic sherds (n = 407), and to a lesser degree, lithic (n = 32) and bone (n = 21) objects, with the bones occasionally charred. These deposits also presented abundant charcoal fragments. At VVP007 some larger stones were also recorded, in size ranges similar to those used as construction material in other more well-preserved sites in the valley. The ceramics correspond to styles characteristic of various points in time during the Formative

Table 1
Radiocarbon and calibrated ages (ShCal13, Hogg et al., 2013) for "El Bolsón" Valley, Argentina.

Method	Laboratory code	Profile, sample (depth in cm)	Material	Measured ^{14}C age BP	δ^{13}C ‰	Probability range 2σ calibrated (cal yr BP)	Median calibrated (cal yr BP)
AMS	LTL4411A	LCC-870	Organic sediment	5581 ± 40	29.6 ± 0.6	6438–6296	6400
AMS	15OS/0669	VVP1-545	Organic sediment	2470 ± 34	− 22.2	2717–2380	2550
LSC	LP- 3179	VVP6-500	Charcoal	2230 ± 80	–	2379–1996	2200
LSC	LP- 3168	VVP7-400	Organic sediment	1860 ± 100	− 24 ± 2	2044–1565	1800
LSC	LP- 3171	VVP7.1-415	Chacaol	1840 ± 90	− 24,2 ± 2	1970–1560	1800
LSC	16C/1065	VVP4-300	Charcoal	1520 ± 30	–	1523–1341	1400
AMS	AA89447	LCC-590	Organic sediment	1420 ± 38	− 24.0	1516–1188	1300
AMS	15OS/0668	VVP1-65	Organic sediment	1320 ± 30	− 24.2	3350–3064	1200
LSC	16C/1064	VVP1-325	Charcoal	1310 ± 30	–	1295–1180	1200
LSC	AA88344	VVP8-300	Charcoal	1111 ± 34	–	1172–933	1000
LSC	AA88343	VVP9-500	Charcoal	818 ± 36	–	790–678	700
AMS	AA89446	LCC16	Organic sediment	345 ± 67	− 23.3	505–300	400

period (3000 to 1000 years BP). Ceramic sherds with styles corresponding to the Regional Development period (1000 to 500 years BP) were also recovered on the surface of the terraces. The taphonomic analysis (Meléndez and Sentinelli, 2014) revealed that the assemblage of ceramic, lithic, and bone materials showed a low degree of abrasion. A few mortars (*metates*) made from heavy blocks of stone were also recorded in the bases of the river courses.

4.2. Paleoecology

The sedimentological study performed on the LCC sequence provides a first approximation of morphodynamic events in the area, particularly with the sediments from the valley floor. The lower section of this core sequence, which dates to between approximately 6400 and 1300 cal BP, shows an accumulation rate of 0.06 cm/year. After this period and until 400 years cal BP this rate increases to 0.6 cm/year, while the most recent 400 years show a reduction back to 0.09 cm/year. Although these values can only be considered as suggestive because of the small number of dates in hand, they show a 1000% increase in sedimentation rate starting around 1300 years cal BP. In any event, this increase in sedimentation rate has provided some orientation for the geoarchaeological work we will discuss next, expanding the interpretive possibilities for the study of the dynamics during occupation of the valley. Fig. 4 shows the age-depth model obtained based upon the three known dates from this core.

As can be seen in Fig. 5, the fossil pollen record for the El Bolsón Valley shows a succession of six zones throughout the entire sequence, where a fluctuation between shrubland steppes and Puna grassland steppes can be observed. Next, we provide details on the results of this analysis.

Zone I corresponds to the time period between 6400 cal BP and 4100 cal BP. The sediments are coarse sand with intercalations of medium sand and clayey silts rich in humic matter. The local indicators for wetness reach their maximum peaks here (24%), with Cyperaceae (15%), trilete spores (10%), and monoletes (9%). The local vegetation, represented by Poaceae (60%), shows the highest levels here in relation to the entire sequence, accompanied by extra-regional elements of Yungas vegetation (6%) (*Celtis*, *Junglans*, and Podocarpaceae). In this zone the Poaceae reach their highest peaks of representation, demonstrating a period of time in the local sequence with more wetness, and with contributions from Yungas-type vegetation.

Zone II represents events between 4100 and 2100 cal BP, with medium sands and clayey silts rich in humic matter being dominant. The elements most highly represented in the previous zone, (extra-regional) Yungas-type vegetation and (local) Poaceae decrease slightly, reaching maximums of 9% and 50%, respectively. Indicators of local wetness are found at about 10%, while Puna elements increase notably (40%).

Zone III. The interpolated ages position this zone between 2100 and 1000 cal BP. The sediments are an intercalation of silts, clayey silts, and medium and coarse sands. There is an increase in the sedimentation rate, coinciding with what is known for the area as the Formative Period and with the first evidence of village-type occupation in the valley. The Puna elements decrease to 10%, with disturbance indicators now being present at over 10%. The indicators of local wetness and extra-regional vegetation show fluctuations around 15% (Cyperaceae, trilete spores, and monoletes) and 10% (*Celtis, Alnus acuminata*, and *Juglans australis*).

Zone IV. This zone represents the period from 1000 to 600 cal BP, and the sediments are made up of medium-coarse sands and silts. The elements indicating local wetness fluctuate around 15%, while the Puna elements show an increase at the upper end of this zone, reaching 35%. Indicators of disturbance begin to show a further increase from here until the chronological end of the sequence, up to values of 10%, while the extra-regional Yungas-type vegetation reaches maximum values of 15%.

Zone V. This includes the period from 600 to 400 cal BP. These sediments consist almost entirely of silts. Elements of Monte (20%), Pre-Puna (20%), and Puna (35%) vegetation types increase. Indicators for local wetness decrease slightly at the upper end of this zone (to 10%), while disturbance indicators remain at the same percentages as in the previous one.

Zona VI. This zone covers the most recent 400 cal BP years represented in the sedimentary column and consists of clayey silts.

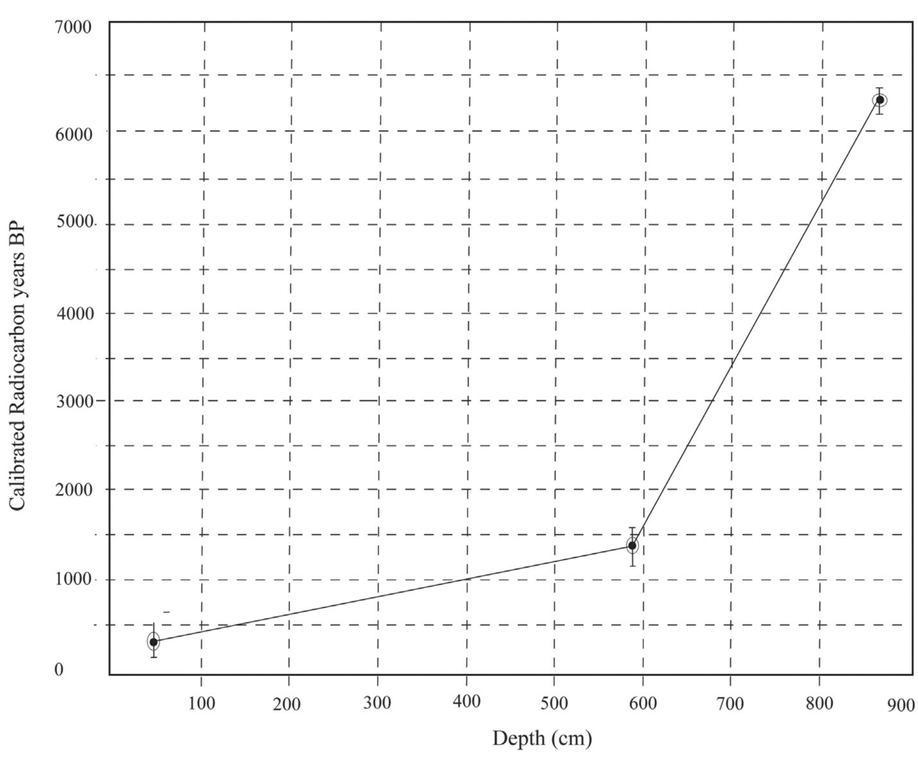

Fig. 4. Age-depth model for Cotagua Lake.

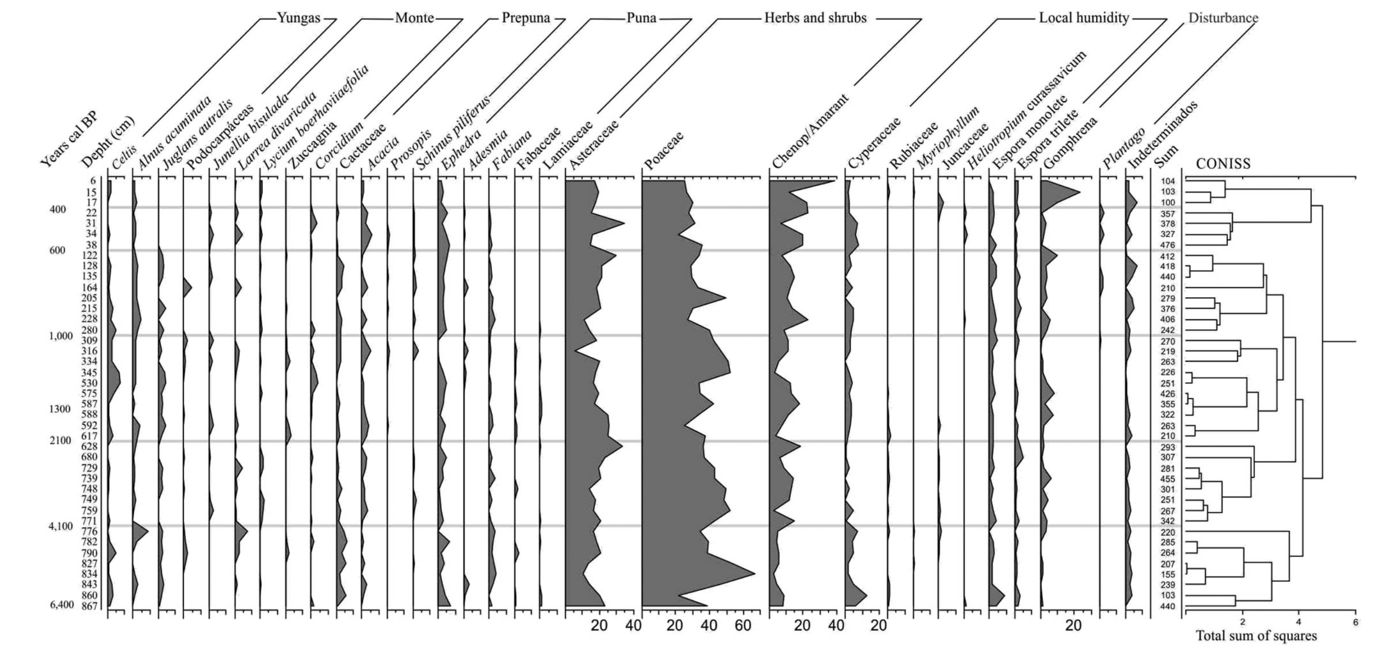

Fig. 5. Pollen spectrum for Cotagua Lake.

Elements of the local, extra-local, and regional vegetation remain constant in relation to Zone V. This period differs from the previous one by the notable increases in disturbance indicators, such as *Gomphrena* (25%), and certain pollen types such as Chenopodiaceae/Amaranthaceae (40%).

4.3. Chronology of the deposits

Nine radiocarbon dates were obtained from the fluvial terraces at Villa Vil. One dating sample was taken from profile VVP001 from sediments at a level near the base (2500 cal BP) and another was taken from near the surface of the terrace (1200 cal BP). The other seven dates correspond to six archaeological levels, which yielded the following dates, listed here as oldest first: 2200 cal BP (VVP006); 1900 cal BP and 1800 cal BP (VVP007); 1400 cal BP (VVP004); 1200 cal BP (VVP001); 1000 cal BP (VVP009); and 700 cal BP (VVP008) (Table 1). In all cases, these dates are from charcoal samples that were associated with ceramic materials with decorative and technological production styles that, although offering a lower degree of temporal resolution, coincide chronologically with the dates obtained. These new dates allow for fine-tuning of a chronological framework, since previously only a single date from an archaeological level was available, obtained by Fauque and Tchilinguirian (2002) as cited in the introduction to the present article.

Three radiocarbon dates were also obtained from the LCC, from samples of organic-rich sediment taken from levels at depths of 870, 590, and 16 cm. The ages obtained correspond to 6400, 1400 and 400 years cal BP, respectively. Table 1 summarizes the chronological information presented in the section.

5. Discussion

5.1. Geomorphological and sedimentary dynamics

Analysis of sediment textures from profile VVP001 shows an increase in coarse, medium, and fine sands, to the detriment of silts, at depths of 3.35 to 4.35 m, which in stratigraphic terms is immediately prior to the human occupation dated to 1300 years cal BP. This situation may indicate variation in the speed of the current in the El Bolsón River while the deposit was still being formed. The scarce presence of rounded stones and boulders of larger sizes, which are observed in the present-day riverbed, indicate that deposition of the sediments occurred in a relatively stable environment. The concurrent presence in levels with archaeological materials of clastics derived from neogenic outcrops in the sedimentary matrix, would indicate that their presence could be due to anthropogenic activities. The terrace sediments reflect conditions of reduced river flow in vegetated riverbeds (wetlands), with a contribution of colluvial and alluvial materials produced by slope erosion. The most recent radiocarbon date obtained from the terraces at Villa Vil (700 cal BP from VVP008) can be considered as the minimum age for the end of the accumulation phase, prior to initiation of the incision phase that has lasted until the present day.

At Laguna Cotagua, the conditions of sedimentation show a predominance of clastic materials, with an initial dominance, up until ca. 600 cal BP, of sands with characteristics similar to those in the surrounding outcrops from the El Bolsón Group, and with these sands being deposited on the valley floor as a product of erosive processes on the slopes and short-distance alluvial transport. The abrupt change in the sediment accumulation rate beginning around 1400 cal BP is not reflected in variations in the sedimentary materials, which allows us to infer an acceleration of erosive processes on the soils on the slopes, probably linked to intensification of llama herding activities.

Towards the end of the sequence, beginning around 700 cal BP, a new reduction in the accumulation rate is observed, with a predominance of silty materials, probably of aeolian origin, and a lower contribution of erosion from the slopes. In general, this time period correlates with changes in the dynamics of the El Bolsón River. In the northern part of the valley, dunes derived from the Puna areas begin to advance, with a maximum age of ca. 1000 cal BP, covering up various dry riverbeds at the headwaters of the fluvial system. This was the beginning of the incision phase mentioned above for the terraces at Villa Vil and which is also observed at various tributaries leading into the valley. It is likely that these changes took place in the context of regional aridification and anthropogenic pressure on resources.

5.2. Vegetation and ecological changes

The results of our palynological studies from Laguna Cotagua show fluctuations throughout the core sequence, but without evidence of abrupt changes in terms of the vegetation present. During the Middle

Holocene (6400 cal BP from Zone I and 2100 cal BP, the interpolated age for Zone II), there would have been a period of wetter conditions in the valley, as indicated by high values for herbaceous vegetation and contributions from Yungas-type pollens and other taxa indicating local wetness.

Between 2100 and 1000 cal BP (Zone III), the climatic conditions continue to be wetter than the present ones, since local wetness indicators remain above modern values, although an increase in Puna-type elements is also notable. Disturbance indicators also increase, indicating the beginning of a progressive rise in anthropogenic changes to the landscape. From 1000 to 600 cal BP (Zone IV) there is an increase in drier conditions as indicated by a higher presence of Puna-type elements. Disturbance indicators also increase, continuing to intensify up until the present.

The final section of the palynological sequence, dating from 600 cal BP until the present (Zones V and VI) reflects an increase in drier conditions, with a rise in Monte, Pre-Puna, and Puna elements and a decrease in contributions from Yungas-type vegetation. Disturbance indicators also increase towards the end of this period.

The local records presented here correlate with known regional trends, where there is a co-dominance of shrubland steppe and herbaceous steppe in the Dry Puna and Wet Puna. From 5000 to 2000 years cal BP, shrubland steppe and herbaceous Puna dominate and wetness increases, while the first signs of anthropogenic disturbances caused by herding also appear. At Laguna Cotagua this is seen during the interval of 6400 cal BP and (interpolated) 2100 cal BP (Zones I and II), which coincides with other research in the region such as in the Chaschuil Valley (Brunotte et al., 1988; Garleff et al., 1991), Antofagasta de la Sierra (Grana, 2012), and the Puna of Jujuy (Oxman, 2015; Oxman et al., 2016; Tchilinguirian et al., 2014). In neighboring regions of the Central Andes, vegetation changes are also observed in relation to variations in global precipitation/temperature as well as in relation to local microclimates (Liu et al., 2005; Schittek et al., 2016; Flantua et al., 2015).

5.3. Human occupations

Archaeological investigations have not yet produced contextual information about the human occupations during the earliest dates represented in the sequences analyzed here. However, a distribution of projectile points that can be typologically attributed to the Archaic period (Middle Holocene) in the middle and upper sections (high meadows) of the tributary streams in the northern sector (Quesada et al., 2013) indicate that various microenvironments in the valley were being occupied during those times. The absence of contemporaneous sites on the valley floor may therefore be explained by the geomorphological dynamics described in the present work: temporary occupations may have been buried by sediment accumulation and/or destroyed by incision. Advances in terms of reconstruction of the evolution of the local landscape are providing guidelines that can be used to develop new research programs focused on sites where the archaeological record for these periods may have been best preserved.

Between 2100 and 900 cal BP there is a period with conditions wetter than those in the present, and the first occupations from the Formative period and development of the first village-type, agro-pastoral landscapes are seen during this time (Korstanje, 2005; Maloberti, 2012). The sedimentological study from the LCC and the associated disturbance indicators show initiation of a progressive anthropological impact on the landscape. Previous work by the present research team has indicated the probability that higher availability of effective moisture in higher-altitude areas, caused by greater precipitation and lower evapotranspiration, may have been one of the factors that favored a process of intensification of human occupation during the Formative period in the northern sector of the basin (Korstanje, 2005; Kulemeyer et al., 2013). However, the geomorphological studies carried out as part of the present research have produced a new perspective on the ways in which the valley floor was occupied. In the terraces at Villa Vil there is evidence that the most low-altitude sectors in the southern part of the study area were also occupied during these earlier times, and we consider the archaeological levels from these terraces to be contexts with high integrity. The discovery of abundant charcoal fragments, which are materials with low mechanical strength, and the low degree of abrasion or taphonomic alteration seen on the ceramic, lithic, and bone materials from the assemblages recovered (Meléndez and Sentinelli, 2014) allow us to confirm that these are primary deposits rather than the results of transport and re-deposition.

Radiocarbon dates obtained from these levels associated with archaeological evidence present a view of these terraces as spaces occupied during at least six time periods over a period of around 1400 years. It must also be taken into consideration that this is a minimal set of evidence and that other occupation events may have taken place, either coinciding chronologically with the known examples or occurring at other times. Furthermore, the section of terraces under study here corresponds to a very small relic of a surface with the potential to have seen much larger dimensions of human occupation, but later destroyed by incision and along with it, the existing archaeological sites. The dating sequence therefore shows discontinuous, but repeated, occupations on top of valley floor deposits, in the degree to which these formed under relatively stable environmental conditions. Information from these profiles does not allow characterization of the spatial extent of these occupations; however, the abundant recovery of archaeological materials such as ceramics, lithics, and bones, and including evidence for stone structures and heavy grinding equipment such as stone *manos* and *metates* indicates that these occupations possessed a certain amount of permanence and intensity. It still remains unclear whether the archaeological sites recorded in the profiles at Villa Vil can be compared with contemporary village-type agro-pastoral sites recorded in the northern sector of the valley (Korstanje, 2005; Maloberti, 2012; Quesada and Korstanje, 2010; Quesada and Maloberti, 2015), where very elaborate and extensive elements of stone architecture have been recorded. This comparison is hampered by the differences in the quality of the records obtainable in these two cases.

A period of geomorphological change began after 700 cal BP, as indicated by later dates from the occupations recorded from the terraces at Villa Vil. These correspond to the end of the sediment accumulation process on the valley floor areas and the beginning of an ongoing process of incision. The discovery of ceramics characteristic of the Regional Development Period (1000 to 500 cal BP) on the surfaces of the fluvial terraces, the same surfaces occupied by present-day houses, confirms the chronology for the end and beginning of the geomorphological accumulation and incision processes, respectively. According to the pollen sequence from the LCC, this was a period of increasing dryness and growing anthropogenic impact.

Surveys conducted in the high meadows and on the valley floor shows that dunes derived from the Puna areas began to advance during this time period, and according to Gale and Haworth (2005) these could be linked to changes in land use patterns. This can be corroborated by archaeological information from this time period, when for the first time there are signs of surface occupation in all of the valley's sectors and microenvironments. In the northern sector, materials from this period were found during surveys at sites on the valley floor such as Vaca Vizcana, while continuous occupation or re-occupation in the form of agro-pastoral villages from the Formative period can be verified in the smaller subsidiary canyons (Quesada and Maloberti, 2015). In the final section of the pollen sequence, from 400 cal BP until the present, there are indications of increasingly dry conditions, and disturbance indicators also increase towards the end of this period. This is a time corresponding to the early colonial or Hispanic-Indigenous period in the regional sequence, where it is presumed that there was a significant shift in the local economic structure, from rural agro-pastoral production to extensive ranching with livestock of European origin. In this context, the El Bolsón Valley and other high valleys and

Puna oasis sites were transformed into "gateways" in the context of ranching-based production systems (Quiroga, 2003).

5.4. Scales of analysis

The various types of proxy evidence employed have made it possible to understand the origins of the processes discussed at various spatial and temporal scales of analysis. The palynological sequence from the LCC samples demonstrates a shift from a wetter period to a drier period over a timeframe covering the last 6400 years or so. However, the vegetation changes recorded during this period were not abrupt. To the contrary, the sedimentological studies from the LCC, along with the stratigraphy from the fluvial terraces, demonstrate significant changes in the geomorphological dynamics of the valley, from a period of relative stability to one of greater instability, and with an inflexion point that seems to take place around 700 BP, when incision processes began to occur. In terms of human occupation of the valley, there is evidence for a period of greater intensity, at least in relation to cultural construction on the landscape, between 2000 and cal 600 BP, which covers portions of the Formative period (ca. 3000 to 1000 BP) and Regional Development period (ca. 1000 to 500 BP). In both cases, a marked emphasis can be seen on village-type agro-pastoral development that involved all sectors of the valley. What is striking, however, is that these phenomena took place during both the period of stability and the period of geomorphological transformations, a situation that demonstrates a degree of independence between the environmental trends elucidated and cultural developments.

6. Conclusion

The objectives of the present work were: 1) to generate new paleoenvironmental information at the local scale; 2) to fine-tune the chronological framework for the processes of environmental change; and 3) to link our archaeological knowledge of cultural processes at the end of the Holocene with these environmental dynamics.

In relation to the first of these objectives, our research was focused on four types of proxy evidence: palynological, sedimentological, archaeological, and geomorphological, with all of this evidence being used in a complementary manner, although available at differing levels of resolution. While the palynological sequence from the LCC shows a gradual change in the landscape in terms of vegetation, the sedimentological evidence, such as the records from the fluvial terraces, indicates more abrupt changes, with inflexion points showing shifts between times of greater stability and periods of intensive geomorphological activity (increase in the sedimentation rate, incision of the valley floor).

In relation to the second objective, the new chronological information obtained from the various types of proxy evidence has allowed these events to be organized and interpreted at more well-defined scales of analysis, with the research on the palynological sequence from the LCC reflecting events that took place during the Middle to Late Holocene, more specifically during the most recent 6400 years or so. Furthermore, the sedimentological study from this core and from sediments on the valley floor has allowed us to better understand changes in the landscape in relation to periods of human occupation over a temporal range that covers the last 2000 years.

In relation to the third objective described, the archaeological information generated indicates that human occupation of the valley was, in general terms, relatively continuous. The geomorphological processes recorded do not seem to have acted as limiting factors for human occupation. One example of this can be seen in erosion from the slopes in the higher parts of the valley, a process that could be interpreted as environmental degradation, while at the same time it created areas on the valley floor that were advantageous in terms of human occupation. This could be recognized via the notable sequence of re-occupation of the surfaces of the fluvial deposits at Villa Vil between 2200 and 700 cal BP. In a similar way, during the Regional Development period the processes of incision that destroyed some agricultural settlement spaces from 1000 to 400 BP led to the persistence or re-occupation of agricultural landscapes of the Formative period, in the stable sector found in the middle sections of the tributary stream valleys, or else agricultural colonization of newly appearing alluvial fans on the valley floor. Furthermore, the persistence of such agricultural intensity across the span of the marked environmental transformations we have recorded indicates, on one hand, that it may not possible to directly derive cultural implications from these environmental patterns, while on the other hand suggesting the need to perform further in-depth studies on the specific ways in which populations in the El Bolsón Valley confronted such changes.

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