



## Archaeometric contributions to agropastoral production research in Aguada society (Ambato Valley, Catamarca)

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### ABSTRACT

This work shows the results of a series of recently conducted archaeometric studies (camelid skeletal remains nitrogen, carbon and strontium isotopes analysis, and silicophytoliths and starches analysis to sediment recovered from cultivation terraces), to study how the economy in Ambato Valley, Catamarca, Argentina was organized from 6th to 11th A.D. For this time period and region under study, we propose the existence of an intensive integrated agro-pastoral production model, limited to a small geographic area.

Thus, through cultivated plant species identification, knowledge about camelid origins and herds management, coupled with possible manure use as fertilizer to increase agricultural production, we will have new elements to analyze the proposed model feasibility. The results obtained from isotopic studies in the valley allow us to suggest the presence of locally raised camelids, as well as camelids from outside the valley. In addition, two distinct forms of herd management, and a low use of manure as fertilizer were identified. Additionally, microfossil studies results made it possible to record crop farming that had not been already identified in the area. Although these new data allow us to maintain the validity of the previously postulated integrated agropastoral system to the valley, it is certain that it also leads us to reconsider and/or to reflect on some of its operational aspects.

### 1. Introduction

A central theme in Argentinian northwestern valleys and bolsos archaeology is the role played by plants and animals in the different livelihood strategies as implemented by regional prehispanic societies. The structuring and interaction of these productions far from being homogeneous, were characterized by variations over time and area (Albeck, 1993; Belotti López de Medina, 2013; D'Altroy et al., 2000; Izeta, 2007; Korstanje et al., 2015; Madero, 2004; Mengoni Goñalons, 2008; Olivera, 2001; Puentes et al., 2007; etc.). From 2006 to the present the archaeological team from the Institute of Anthropology of Córdoba, National University of Córdoba-CONICET, has been doing research in Ambato Valley to arrive to an understanding of its agricultural and pastoral pro-

duction organization between the 6th and 11th century A.D. This period was characterized by the presence of Aguada settlements, and with them the beginning of a socially differentiated and unique context never seen up to now for the region under study (Dantas, 2010; Dantas et al., 2014a; Figueroa et al., 2010; Laguens et al., 2013).

Geographically speaking, Ambato Valley is in the province of Catamarca, Argentina, and forms part of the northwestern Sierras Pampeanas. It is delimited by the Ambato-Manchao (4050 masl) mountainous cord to the west, Sierra Graciana-Balcozna (1850 masl) to the east, Catamarca Valley to the south, and Altos de Singuil to the north. Biogeographically, this region corresponds to the Chaco Province Chaco Serrano district (Chaco domain) Neotropical Region (Cabrera, 1976) (Fig. 1).

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Fig. 1. Image of Ambato Valley, and the sites under study.

Starting from the 6th century A.D., a heterogeneous internally differentiated society, developed in this valley which was identified archaeologically as Ambato Aguada culture (González, 1998), based on the intensification of the economy, the accumulation of surpluses, a marked increase in population, diversification of social roles, craft specialization, and social and political inequalities (Laguens, 2004, 2006).

In this context, and as a result of the research conducted until 2010, we proposed, the existence of an integrated agropastoral production system which would have covered both slopes of the valley. The main function of this system would have been to provide food and raw materials to the inhabitants of core villages located at the bottom of the valley, thus contributing to the maintenance of this new way of life (Figueroa, 2013). Such new way of production for the region, consisted of a unified camelid breeding and exclusive corn cultivation (*Zea mays*) system, targeting its infrastructure (cultivation terraces, dams, corrals, etc.) to maximize space, production, and crop production rate (Figueroa, 2012; Figueroa et al., 2010; Laguens et al., 2013; among others). The key to the system would have been based in the synergy between plants and animals, where benefits to one could not be achieved independently of the other. Some advantages to be obtained from its operation are: (a) soil improvement using fallow; (b) soil erosion prevention; (c) manure use as fertilizer for cultivated land; (d) stubble and agricultural waste use as herd food; (e) camelid use to transport agricultural products into other valley sectors or other areas; (f) livestock contribution to lessen nutritional stress during meager crops; and (g) agricultural use to resolve dietary needs in the event of a decrease in herd size.

This production system was proposed on the basis of results obtained in numerous prospecting, mapping and excavation work, ethnoarchaeological research, ceramic, stone and bone analysis, and a series of archaeometric studies were carried out such as radiocarbon dating, experimental lythic work, microfossils (silicophytolith, starch, diatoms, etc.) and sediment physical-chemical studies (organic matter, calcium carbonate, phosphorus, etc.) (Figueroa, 2008, 2012), zooarchaeological remains carbon isotopes testing (Dantas, 2010; Dantas et al., 2014a; Izeta et al., 2009, 2010), among others.

However, despite all the information obtained, several questions still remain unanswered regarding how this model would have worked. Thus, we ponder: was exclusive maize farming throughout the entire valley, or only in limited sectors?, were all domestic camelids raised locally or were they raised elsewhere, and then taken to the valley?, were camelids obtained by trade or exchange?, was there a cyclical breeding and consumption arrangement in different areas, both inside and outside Ambato Valley?, are there different camelid consumption patterns in relationship to different consumers?, were there changes over time in camelids places of origin and breeding areas?

Following such line of thought, this work aims to address some of these questions and generate new data on discussing the feasibility of this model, and the general management of the economy developed in Aguada de Ambato. To achieve this purpose, the following pages present the results of new archaeometric studies (nitrogen isotopes, which are integrated to those previously obtained by this team (microfossils, carbon and strontium isotopes).

## 2. Archaeometric studies: the potential of radiogenic and stable isotopes, and microfossil analysis

Strontium is a trace element found in rocks, ground water, soil, plants and animals (Price et al., 2002). Strontium concentration and its isotope ratios vary according to local geology, i.e.: rock age and type, with the oldest rocks having the highest  $^{87}\text{Sr}/^{86}\text{Sr}$  proportions, so it is used to test the paleomobility hypothesis (Bentley, 2006; Hedman et al., 2009; Knudson et al., 2004; Price et al., 2002). Strontium is incorporated into the food chain through soil, groundwater and air. In the case of animals and humans, since strontium chemical and atomic radio behavior is similar to that of calcium, it replaces the calcium in hydroxyapatite during teeth and bones development (Bentley, 2006; Knudson et al., 2004). Also, because the difference in mass between radiogenic strontium isotopes is very small, isotopic fractionation does not occur by biological processes (Knudson et al., 2010; Price et al., 2002). As a result, strontium isotopes relations found in bones reflect the isotopic composition of the geologic region where the person or animal lived (Knudson et al., 2004). Tooth enamel is formed during the first years of life, and does not change once formed, so isotope  $^{87}\text{Sr}/^{86}\text{Sr}$

values obtained from tooth enamel reflect the geologic region that individual lived in during the enamel formation process. On the other hand, bones continuously regenerate, and thus indicate the last years of life. In this way, the different values between bones and teeth enamel strontium isotopes proportions in a same individual reflect changes in its geological environment, and therefore changes of residence (Knudson et al., 2004; Price et al., 2002; Thornton et al., 2011).

Just as radiogenic strontium testing is used to determine paleomobility, carbon and nitrogen stable isotopes testing allow us to study the paleodiet. Carbon is incorporated into the food chain through photosynthesis, through which plants incorporate the CO<sub>2</sub> present in the atmosphere (Tykot, 2006). The variability between stable carbon isotopes in plants is derived from the differences between C<sub>3</sub>, Calvin-Benson, and C<sub>4</sub>, or Hatch-Slack photosynthetic tracks. While tropical grasses, such as corn generally use photosynthetic track C<sub>4</sub>, most of the terrestrial plants use photosynthetic track C<sub>3</sub>. A third photosynthetic track: CAM or Acid Crassulaceae Metabolism characterizes succulents and cacti, which present intermediate values between C<sub>3</sub> and C<sub>4</sub> plants (Ambrose, 1993; Tykot, 2004). Bones and animal tissues isotopic composition is correlated with diet, expressing these higher values due to the assimilation process, and averaged depending on food sources from the food chain (Ambrose, 1993; Ambrose and Norr, 1993; Schoeninger, 1995). Thus, if there are variations in vegetation cover between two particular areas, it will also be registered as different values for herbivores, and for all links in the food chain (Samec, 2011).

Nitrogen isotopes are generally used to interpret trophic levels and the consumption of marine resources, but in the case of herbivorous animals,  $\delta^{15}\text{N}$  values variation is probably related to spatial differences in soils, plants and local environments, as well as anthropic factors (Samec, 2014; Szpak et al., 2012a, 2013; Towers et al., 2010). Nitrogen isotopes values in plants depend mainly on how they obtain nitrogen, i.e. through the absorption of atmospheric N<sub>2</sub> from the symbiosis with bacteria or directly from components found in the soil, such as ammonium and nitrate. These values are transmitted in a similar way along the food chain, adding c. 3–4‰ due to fractionation. The gradual increase in  $\delta^{15}\text{N}$  values marks each step in the food web, and thus provides important data on the trophic position of animals (Barbarena, 2014; Szpak et al., 2013; Tykot, 2004). The  $\delta^{15}\text{N}$  values of marine plants are approximately 4‰ higher than those of land animals. In addition, marine food links are usually longer than in terrestrial ecosystems, providing more opportunities for isotopic fractionation and trophic enrichment (Barbarena, 2014).

In camelids, for instance,  $\delta^{15}\text{N}$  values provide an important component in dietary reconstruction, since diet varies according to the local climate; thus, studies carried out in the Dry Puna in Argentina, and other parts of the planet - as in eastern and southern Africa - indicate a negative correlation between  $\delta^{15}\text{N}$  values and annual rainfall, so that in desert arid regions, salt flats and coastal soils where rainfall is below 400 mm per year, there are recorded values of more than 10‰ in herbivores (Ambrose, 1993; Killian Galvan and Samec, 2012; Samec, 2014; among others). On the other hand, cultural practices can also cause great  $^{15}\text{N}$  enrichment in plant tissues, such as the use of organic fertilizers in the soil, especially those deriving from animal waste (Choi et al., 2002; Killian Galván and Salminci, 2014; Killian Galván et al., 2015; Mizutani et al., 1991; Szpak et al., 2012a, 2012b; etc.). In some cases, fertilized plants have  $\delta^{15}\text{N}$  values 10‰ greater than plants grown in untreated soils (Choi et al., 2002; Szpak et al., 2012a, 2012b). The intensive use of compost, manure or guano as crop fertilizer could also increase  $\delta^{15}\text{N}$  values in camelids that feed

mainly on cultigens or plants that grow in fallow fields (Szpak et al., 2012a, 2012b, 2015; Thornton et al., 2011).

Regarding silicophytoliths, which is a microscopic amorphous silica mineral or calcium crystals found in certain cells or cellular interstices, within certain plant species, with the disintegration of the plant containing it, either by natural causes or other causes, phytoliths remain as micro vestiges in sediments, ashes, dentures, ceramic artifacts, lithic tools, and humans and herbivorous animals coprolites (Babot, 2004; Korstanje, 2005; Wurschmidt and Korstanje, 1999).

The size range of these microfossils varies between 5 and 200  $\mu\text{m}$  (Pearsall, 1989). Since their forms are extremely varied, over time different morphological classifications were made (Bertoldi De Pomar, 1971; Pearsall and Dinan, 1992; Twiss, 1992; etc.). Although it should be noted that they are characterized by their multiplicity (i.e. production of many forms in a taxon), and redundancy (i.e. presence of a shape in many taxa), some forms are unique and serve as diagnostic tools (Rovner, 1971; Wurschmidt and Korstanje, 1999; Zucol and Passeggi, 2008). Even in some cases it is not only possible to identify the plant originating it, but also which part it corresponds to. This feature, added to the fact that generally phytoliths do not travel long distances, as pollen for example, their use in the archaeological field has a huge potential. You can then say that archaeologists (Babot et al., 2008a, 2008b; Colobig et al., 2015; Inda and del Puerto, 2008; Korstanje, 2005; Korstanje and Cuenya, 2008; López, 2007; Musaubach, 2012; Pearsall, 2002; Pearsall et al., 2003; Piperno, 1988; Piperno and Flannery, 2001; Wurschmidt and Korstanje, 1999; Zucol and Bonomo, 2008; Zucol and Loponte, 2008; among others) frequently use silicophytoliths as: a) microfossils indicators of changes in past environmental conditions; b) tools in the study of the relationship between technology, the economy and social organization; (c) diet and past cultural practices indicators; and (d) instruments to establish the origins and dissemination of domesticated plants, and the development of agricultural systems.

In addition, starch is a complex carbohydrate in the form of white birefringent granules, with an extinction black cross observed under polarized light. Although it is deposited throughout the body of the plant, they are more common, abundant and better diagnostic tools in storage organs such as seeds, roots, tubers, rhizomes and bulbs. For taxonomic identification, some granules attributes are taken into account, such as form, size, as well as hilum and cross positions. Maize (*Zea mays*), Amaranth (*Amaranthus* spp.), quinoa (*Chenopodium quinoa*), oca (*Oxalis tuberosa*), ullucus (*Ullucus tuberosus*), canna (*Canna edulis*), and potato (*Solanum tuberosum*) can be distinguished from their starch grain identification (Babot, 2001; Korstanje and Babot, 2004).

### 3. Materials and methods

Camelid bone samples analysis of stable and radiogenic isotopes were carried out from different site types: small and large elite residential units; sites located on the bottom of the valley and on the hillside both from Aguada and earlier settlements. In addition, microfossils studies were carried out on the cultivation terraces sediment located on the eastern slope of the valley, belonging to the agricultural subsystem Los Molina. Furthermore, radiogenic strontium isotopes, and stable carbon and nitrogen isotopes tests come from animal samples from Martinez 1 (M1), Martinez 2 (M2), Martinez 3 (M3), Piedras Blancas (PB), El Altillio (EA), Los Varela Recinto 4 (LVR4) and Los Varela Recinto 11 (LVR11) sites. Sites M1, M2, M3 y PB are located in the lower sector of the valley, while EA is located in the eastern foothills, LVR4, and LVR11 on the western

slope, and Los Molina on sierra La Graciana slopes (Fig. 1). From radiocarbon dating it could be established that M1, M2, PB, LVR4 and LVR11 are sites presenting Aguada occupations, EA shows Aguada pre-occupations, and M3 both. In addition, Los Molina terraces were assigned by relative dating to Aguada.

EA is an outdoor monticular site located on a natural ground elevation which is filled with ceramic, lithic, faunal, botanical and human remains materials (Assandri, 2007) ( $1900 \pm 70$  AP, charred branches, LP474; Bonnin and Laguens, 1997). Site M1 consists of a living-unit and a mound dump, occupied by small domestic groups carrying out various craft activities there (Assandri, 1991; Heredia, 1998) ( $1770 \pm 90$  AP, charcoal, LP461; Bonnin and Laguens, 1997). M2 presents two housing sectors separated by a central courtyard, and surrounded by a perimeter wall. In this site there would have been carried out tasks related to cooking vegetables and animals, vessels, tools, raw materials and food storage, grinding and gathering of grains and liquids, as well as pottery making and decoration (Juez, 1991) ( $990 \pm 70$  AP, charcoal, LP;  $1690 \pm 80$  AP, charcoal, LP444;  $1510 \pm 70$  AP, charcoal, LP558; Bonnin and Laguens, 1997). M3 was identified as an isolated outdoor monticular site, composed of an accumulation of various archaeological materials (Assandri, 2007). Ávila and Herrero (1991) identified two moments in M3 development: the lower levels corresponding to pre-Aguada occupations (Component II,  $1700 \pm 60$  AP, charcoal, LP553; Bonnin and Laguens, 1997), and the upper levels to Aguada (Component I,  $1458 \pm 44$  AP, camelid bone, AA93889; Marconetto et al., 2014). In terms of its function, Pérez Gollán et al. (1996-1997) indicated that the site register characteristics made it difficult to establish whether it was a mound dump, a ceremonial mound, or both. This ambiguous situation led them to consider that in this site there was a mixture of the domestic with the ritualistic. On the other hand, site PB presents a mound and a housing sector, which was defined as a very large elite residence (Assandri, 2007). On the basis of radiocarbon datings its occupation period can be placed between 574 and 1225 (1 $\sigma$ ) A.D. (Marconetto et al., 2014). LVR4 is a rectangular structure with a double stone wall, inserted into a terrace cultivation system, and its function was interpreted as a corral (Dantas and Figueroa, 2009) ( $1312 \pm 43$  AP, camelid bone, AA93890). In contrast, LVR11 was a house linked to pastoral as well as to agricultural activities ( $1326 \pm 41$  AP, charcoal, AA104044;  $1304 \pm 39$ , charcoal, AA104042;  $1271 \pm 47$ , camelid bone, AA104043). Finally, the agricultural subsystem Los Molina constitutes a concentration of 12 cultivation terraces, next to or inserted to four structures (a corral, a silo, and two structures that could not be classified due to the thick surrounding vegetation).

To carry out the isotopic studies, camelid samples were selected and extracted from postcranial skeletons and teeth elements that were in a good state of conservation (i.e., which were not burned, weathered, with chemical deposits, etc.). Priority was given to those appendicular skeleton specimens that were classified within the category llama (*Lama glama*) through osteometric<sup>1</sup> analysis, subsequently other large camelid elements were included. Molars and incisors were also used for strontium analysis. In order that samples represent the entire camelid set, 28% of the individuals identified in the sites were selected for strontium analysis, and 57% and 51% for carbon and nitrogen analysis, respectively.

<sup>1</sup> Camelid remains inter-specific identification was conducted on fused bones specimens in a good state of conservation having the required measuring points (Elkin, 1996; Izeta, 2007; Kent, 1982; Yacobaccio et al., 1997/1998). The values obtained were compiled in databases and processed in a multivariate statistical analysis, following the criteria established by Izeta (2007).

The total strontium sample analyzed consisted of 20 specimens (13 PB, 2 M1, 3 M2, and 2 M3CI), inside of which 7 were teeth, and 13 were bone fragments (Table 1). All samples selected were extracted at Ambato Laboratory, from Instituto de Antropología de Córdoba (CONICET-UNC), which were then prepared and analyzed at the Laboratory for Archaeological Chemistry, School of Human Evolution and Social Change, Arizona State University (Dantas and Knudson, 2016).

The sample considered for carbon analysis reached 61 and came from camelid remains at M1 (8), M2 (5), M3 (21), PB (18), EA (7), LVR4 (1) and LVR11 (1) (Table 1). All the selected samples were extracted at the Ambato Laboratory, while  $\delta^{13}\text{C}$  was carried out at the Laboratorio de Isótopos Ambientales del Instituto de Geocronología y Geología Isotópica, UBA-CONICET (Izeta et al., 2010), at the Environmental Isotope Laboratory (Dantas et al., 2014b), and the Arizona Radiocarbon AMS Facility, University of Arizona.

In addition, the nitrogen analysis sample used consisted of 53 camelids bone remains from M1 (8), M2 (5), M3 (20), PB (14) and EA (6) (Table 1). As in the previous cases, the samples were extracted at Ambato Laboratory, while the determination of  $\delta^{15}\text{N}$  took place in the Environmental Isotope Laboratory of the Institute of Isotope Geology and Geochronology, UBA-CONICET, and in the Environmental Isotope Laboratory, University of Arizona.

It should be indicated that carbon and strontium isotopes data, already previously studied (Dantas and Knudson, 2016; Dantas et al., 2014b; Izeta et al., 2009, 2010), were merged with the new nitrogen isotope studies so that they could be reinterpreted from a global perspective.<sup>2</sup> However, it is necessary to point out that except for the PB and EA carbon isotopes analysis results, none of the others were used for the integrated agropastoral model proposal (Dantas et al., 2014a; Figueroa et al., 2010), being this the first time they are analyzed together.

From a methodological perspective, and due to the specificity of what was intended to be analyzed through strontium testing, i.e.: camelid mobility, the samples selected represent different anatomical parts (teeth vs. long bones) that allow to observe mobility. Contrarily, for carbon and nitrogen testing, which aimed at distinguishing herd diet, we prioritized the analysis of osteometrically identified bones such as llamas, or large animals.

On the other hand, in order to obtain sediment for microfossils analysis (starches, silicophytoliths, diatoms, etc.) analysis were made in three of the cultivation terraces at Los Molina subsystem (TLM EBI, TLM EAMII and TLM EY), a task for which a mechanical borehole was used. This non-invasive and minimal impact method constitutes a rapid and effective tool for obtaining subsurface deposits, from which it is possible to determine the site stratigraphy, as well as obtaining carbon samples to carry out radiocarbon dating (Lindsoug, 2013; Ponce, 2004). The instrument used was a mechanical borehole with reinforced extensions, with a cylindrical tip (20 mm  $\times$  400 mm), and a maximum length of 3 m. Once samples were removed, the material was arranged on a surface for its description (color, matrix, granulometry, natural and cultural components, among others), which was carried out on site by geologist Silvana Bertolino (National Council of Scientific and Technical Research - CONICET). At the same time, we proceeded to separate from each profile two 10 g samples at every 5 cm.

<sup>2</sup> See Dantas and Knudson (2016), Dantas et al. (2014b), and Izeta et al. (2010) for a description of the methodology employed in sample processing and analysis. Even though  $\delta^{15}\text{N}$  data are used for the first time, the same samples were processed and analyzed jointly with the carbon isotopes (Dantas et al., 2014b; Izeta et al., 2009, 2010).

**Table 1**  
Results of carbon, nitrogen and strontium isotope analysis.

Sample	Taxonomic assignment	Element	$\delta^{13}\text{C} \text{‰}$	$\delta^{15}\text{N} \text{‰}$	C/N	Lab	$^{87}\text{Sr}/^{86}\text{Sr}$	Ca/P	Lab
EA S2 N13826	Llama	Unciform	- 17.1	3.2	3.3	AIE			
EA S2 N13841	Llama	Tibia	- 15.5	4.8	3.2	AIE			
EA S2 N13844	Llama	Humerus	- 13.1	6.6	3.3	AIE			
EA S2 N10600	Llama	Radius	- 11.8	6.7	3.2	AIE			
EA S2 N16046	Llama	Metacarpus	- 12.1	5.1	3.3	AIE			
EA S2 N16040	Llama	Humerus	- 12.2	6.5	3.3	AIE			
El Altillo	Lama sp.	Metapodium	- 16.2			AIE			
PB00 RH N107.15-B	Llama	Metapodium	- 11.9	4	3.2	AIE			
PB99 TM CE N1 021	Llama	Metapodium	- 10.7	6.5	3.3	AIE			
PB96 C1 N12 C'01	Llama	Metapodium	- 10.2	4.4	3.3	AIE	0.71301	2.21	ACL
PB00 RH N106 17	Lama sp.	Tibia	- 11.0	5.3	3.2	AIE	0.71236	2.17	ACL
PB00 RH N10762-B	Llama	Metapodium	- 10.4	7	3.2	AIE	0.71207	2.22	ACL
PB96 C1N12 C'79	Llama	Humerus	- 12.0	4	3.3	AIE			
PB96 C1 N11 A'00	Llama	Femur	- 11.9	5.4	3.3	AIE			
PB99 C56 N3 303	Llama	Metatarsus	- 12.7	5.2	3.2	AIE			
PB99 C56 N3 300	Lama sp.	Metapodium	- 10.3	6.2	3.2	AIE			
PB99 C15 44	Lama sp.	Femur	- 13.1	4	3.2	AIE	0.71165	2.17	ACL
PB96 C2 N22 A63	Llama	Metacarpus	- 12.7	5.1	3.3	AIE	0.71212	2.13	ACL
PB00 RH N104 41	Lama sp.	Femur	- 9.9	5.8	3.3	AIE	0.71181	2.24	ACL
PB99 C15 39	Llama	Metapodium	- 9.5	5.7	3.3	AIE	0.71204	2.20	ACL
PB99 C8 N19 h.36	Llama	Metacarpus	- 10.8	3.6	3.3	AIE			
Piedras Blancas	Lama sp.	Long bone	- 10.1			AIE			
PB Rec. H Estruct. 1	Lama sp.	Phalanx 1	- 11.2			AA			
PB Rec. F AMS	Lama sp.	Femur	- 11.5			AA			
PB Rec. G AMS	Lama sp.	Tibia	- 12.7			AA			
PB00.RA.N107.51	Lama sp.	M1					0.71309	1.97	ACL
PB99.C52.N8.302	Lama sp.	I1					0.71287	1.94	ACL
PB00.RH.N104.37	Lama sp.	I1					0.71274	1.94	ACL
PB99.C16.N6. 151-157	Lama sp.	PM3					0.71241	1.97	ACL
PB00.RH. Est 5. 22	Lama sp.	I1					0.71333	1.98	ACL
PB00.RH.N106.72-7/8	Lama sp.	I2 and I3 deciduos					0.71341	1.96	ACL
M3CI/02	Lama sp.	Femur	- 11.5	5.4	2.9	A			
M3CI/03	Lama sp.	Phalanx 2	- 15.3	5.2	2.9	A			
M3CI/04	Lama sp.	Phalanx 2	- 14.8	3.9	2.9	A			
M3CI/09	Llama	Phalanx 2	- 12.6	4.9	3	A	0.71204	2.12	ACL
M3CI/10	Llama	Phalanx 2	- 14	4.2	2.8	A	0.71206	2.17	ACL
M3CI/11	Lama sp.	Humerus	- 16.8	4.5	2.9	A			
M3CI/12	Lama sp.	Humerus	- 11.9	5.5	2.9	A			
M3CI/13	Lama sp.	Humerus	- 17.1	4.6	2.8	A			
M3CI/16	Lama sp.	Tibia	- 12	5.7	2.9	A			
M3CI/20	Lama sp.	Long bone	- 13.7	3.9	2.9	A			
M3 AMS	Llama	Femur	-13.4			AA			
M3CII/01	Lama sp.	Metacarpus	- 13	3.9	2.8	A			
M3CII/05	Llama	Phalanx 2	- 11.3	4.3	2.9	A			
M3CII/06	Lama sp.	Phalanx 2	- 11	4.7	2.9	A			
M3CII/07	Llama	Phalanx 2	- 11.1	5	2.9	A			
M3CII/08	Lama sp.	Humerus	- 11.9	5.4	3	A			
M3CII/14	Lama sp.	Metapodium	- 12.9	8.8	2.9	A			
M3CII/15	Lama sp.	Humerus	- 14.2	3.9	2.9	A			
M3CII/17	Lama sp.	Radius	- 11.3	5.2	2.9	A			
M3CII/18	Lama sp.	Tibia	- 11.2	5.2	2.9	A			
M3CII/19	Lama sp.	Radius	- 16.8	5.5	2.9	A			
MI/21	Lama sp.	Humerus	- 11.6	5.9	2.8	A			
MI/22	Lama sp.	Tibia	- 19.9	2.4	2.9	A			
MI/23	Lama sp.	Metacarpus	- 13.6	4.1	3	A			
MI/25	Lama sp.	Phalanx 1	- 16.2	5.8	3.6	A			
MI/26	Lama sp.	Metapodius	- 15.5	4.4	3.1	A			
MI/27	Lama sp.	Radius	- 14.8	4.5	2.8	A			
MI/28	Llama	Phalanx 2	- 11.8	4.5	3	A	0.71237	2.23	ACL
MI/29	Llama	Phalanx 2	- 16.4	3.8	2.9	A	0.71266	2.22	ACL
M2/24	Lama sp.	Pisciform	- 13.7	6	2.9	A			
M2/30	Llama	Phalanx 2	- 17.1	7.1	3	A	0.71236	2.24	ACL
M2/32	Lama sp.	Caudal vertebra	- 16.1	4.5	3	A	0.71164	2.38	ACL
M2/34	Lama sp.	Astragalus	- 12.5	3.5	2.8	A			
M2/35	Lama sp.	Astragalus	- 12.5	9.8	3	A			
M2.2C.200	Lama sp.	I2					0.71198	2.00	ACL
LVR4	Lama sp.	Radius	- 12.2			AA			

Table 1 (Continued)

Sample	Taxonomic assignment	Element	$\delta^{13}\text{C}$ ‰	$\delta^{15}\text{N}$ ‰	C/N	Lab	$^{87}\text{Sr}/^{86}\text{Sr}$	Ca/P	Lab
LVR11	<i>Lama</i> sp.	Long bone	- 12.8			AA			

The methodology used in the laboratory to study siliceous microremains concentration was based on the conventional methodological guidelines to rescue biominerals in clastic materials (Bonomo et al., 2012; Zucol et al., 2010b). In addition, a morphotype database was compiled in accordance with different qualification schemas and proposed descriptors, which - like their acronyms - have been treated in Zucol et al. (2010a). In this study we use the acronyms proposed by Patterer et al. (2011), and Zucol et al. (2012). As regards to starch grains concentration, the methodology proposed by Pearsall et al. (2004) and Horrocks (2005) was adapted. While, for starch grains descriptions the guidelines and quali-quantitative attributes proposed by Cortella and Pochettino (1990), Korstanje and Babot (2007), Babot et al. (2007, 2008a, 2008b), Babot (2011), and ICSN (2011) (The International Code for Starch Nomenclature) was followed. The microscopic observations were conducted in a petrographic Nikon Eclipse E 200 microscope, with built-in camera. It should be noted that all this work was carried out by specialized personnel from Laboratorio de Paleobotánica, Centro de Investigaciones Científicas y Transferencia de Tecnología a la Producción, Diamante, Entre Ríos<sup>3</sup>.

#### 4. Results

Strontium analysis values found were from  $^{87}\text{Sr}/^{86}\text{Sr} = 0.71341$  to  $^{87}\text{Sr}/^{86}\text{Sr} = 0.71164$ , averaging  $^{87}\text{Sr}/^{86}\text{Sr} = 0.71241$  (Tables 1 and 2). Fig. 2 shows the results of strontium distribution values from archaeological samples biologically available in the valley,<sup>4</sup> where all M2 and M3CI specimens are within local value range. In M1, however, one individual is above the local range, as well as 6 specimens in PB, while 7 specimens are within the local range.

In M1, M2 and both M3 components  $\delta^{13}\text{C}$  values presented a considerable variability, oscillating between  $-19.9\text{‰}$  and  $-11.0\text{‰}$ , with a standard deviation between 1.87 and 2.50 (Tables 1, 3 and Fig. 3). The data indicate that these animals would have been feeding - at various degrees - with a  $\text{C}_3$  and  $\text{C}_4$  photosynthetic pathway mixed plant diet. Similarly, although there is considerable diversity among individuals sampled, they presented an average per site varying between  $-15.0\text{‰}$  and  $-12.5\text{‰}$  (Table 3) which points to a diet similar to  $\text{C}_3$  y  $\text{C}_4$  plant percentages. These results are similar to those obtained earlier in EA, where values between  $-17.1\text{‰}$  and  $-11.8\text{‰}$  were also identified, with an average of  $-14.0\text{‰}$ , and a standard deviation of 2.0. In M1, sample M1/22 constitutes an exceptional case, presenting an extremely negative signal such as the one registered in animals inhabiting ecological areas with higher  $\text{C}_3$  plant percentages, as the Puna (Fernández and Panarello, 1999-2001; Samec, 2014).

<sup>3</sup> For more details on this study see Zucol et al. (2015).

<sup>4</sup> Biologically available strontium values were determined on the basis of local animal values, which have a minimum value of  $^{87}\text{Sr}/^{86}\text{Sr} = 0.71079$  and a maximum of  $^{87}\text{Sr}/^{86}\text{Sr} = 0.71208$ . Following Price et al. (2002), we used the mean value of the local fauna  $\pm 2$  s.d. to establish the local range, resulting in  $^{87}\text{Sr}/^{86}\text{Sr} = 0.71025-0.71249$ . As this is the first study of this isotope that is performed in the region or northwest Argentina, there are no regional strontium values with which can be compared (Dantas and Knudson, 2016).

In contrast with these sites, PB specimens show a more positive isotopic signal, since the lowest value is  $-13.1\text{‰}$ , and the highest  $-9.5\text{‰}$ , with an average of  $-11.3\text{‰}$ . In addition, the variability between individuals is much lower, as reflected by standard 1.10 deviation (Table 3). These results indicate that camelids from this site received a food supply composed of higher proportions of plants with  $\text{C}_4$  photosynthetic pathway.

The sample obtained from LVR4 presents a value of  $-12.2\text{‰}$ , while LVR11 has a value of  $-12.8\text{‰}$ , indicating consumption with the highest proportions of  $\text{C}_4$  plants, according to Tykot (2006), than a diet consisting of a mixture of 50%  $\text{C}_3$  plants and 50%  $\text{C}_4$  plants that produces a  $\delta^{13}\text{C}$  of  $\cong -14.5\text{‰}$  value.

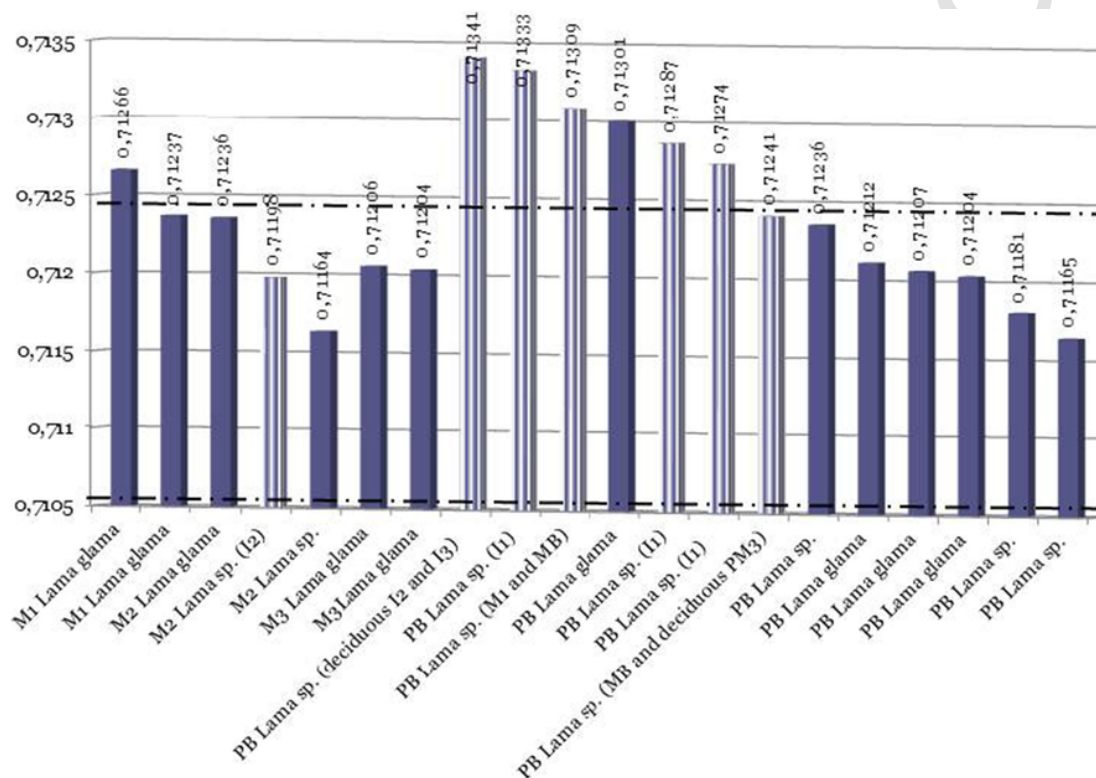
Finally, nitrogen analysis presented values ranging from  $2.4\text{‰}$  to  $9.8\text{‰}$  showing a standard deviation between 0.6 and 2.2, being M3CI the one exhibiting less standard deviation, and M2 presenting greater deviation. The average varies between  $4.4\text{‰}$  and  $6.2\text{‰}$ , close to the average value set for terrestrial mammals (i.e.  $5.7\text{‰}$ ) by Ambrose (1993), and Pate (1994). In this way, one can observe a lower variability in  $\delta^{15}\text{N}$  values than in  $\delta^{13}\text{C}$  values. Also, we could not observe noticeable variation between the different sites. Even though M2 presents a greater variability, it is generated by a single specimen with a very positive value, while the rest of the samples are not outside the range recorded in the other sites. The M1 specimen ( $2.4\text{‰}$ ) with the lowest values of all the sites is the same one that presents a  $\delta^{13}\text{C}$  extremely negative value (Tables 1, 4, and Fig. 4).

In regard to the relationship between  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ , Fig. 5 shows that the most notorious variation occurs in  $\delta^{13}\text{C}$  values, identifying only some specimens from the general groupings: the same M1 specimen we mentioned earlier, one from M3CII, and two from M2 which stand out from this grouping due to their higher positive  $\delta^{15}\text{N}$  values (specimens marked with ovals). At this time we do not find a possible explanation for the latter three, as in the case of the M2 specimens that have very different  $\delta^{13}\text{C}$  values between them ( $-12.5\text{‰}$  y  $-17.1\text{‰}$ ), and in the case of the M3IIC specimen which is the only one in this site with such high values to be able to deduce that these values are linked with any specific animal food pattern and/or particular herd handling.

As regards to merging the three types of isotopes studies, Fig. 5 shows those specimens to which strontium analysis were made. As mentioned in Section 3, because initially we had different objectives, not all specimens have the same analysis, so it will only be possible to compare some postcranial skeleton elements of individuals identified by osteometry such as llamas, coming from Aguada occupation sites. Within them, most have local strontium values, and include animals with varied  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values. Between the two samples showing non local values, M1 would represent a feeding pattern as expected of a mixed diet, but with the highest  $\text{C}_3$  plants ( $-16.4\text{‰}$ ) proportions. The second sample is a notorious PB metapodial presenting a diet type with a high proportion of  $\text{C}_4$  plants ( $-10.2\text{‰}$ ), in concordance with recorded camelids values that had controlled diets. This data generates the question whether this specimen corresponded to an individual who had controlled feeding, i.e. whether there was a herd management strategy in other places beyond Ambato Valley, or if it came from an area where natural vegetation has greater  $\text{C}_4$  plant availability.

**Table 2**  
Descriptive statistics of strontium isotopes values.

$^{87}\text{Sr}/^{86}\text{Sr}$	n	Maximum	Minimum	Mean	Median	SD
M1	2	0.71266	0.71237	0.71252	0.71252	0.00021
M2	3	0.71236	0.71164	0.71199	0.71198	0.00036
M3	2	0.71206	0.71204	0.71205	0.71205	0.00001
PB	13	0.71341	0.71165	0.71253	0.71241	0.00058
Total	20	0.71341	0.71164	0.71240	0.71236	0.00053



**Fig. 2.** Results of strontium isotopes values. Note: dotted lines represent Ambato Valley local values; grated bars represent teeth, and solid lines represent bones.

**Table 3**  
Descriptive statistics carbon isotopes values.

$\delta^{13}\text{C}$	n	Maximum	Minimum	Mean	Median	SD
EA	7	- 11.8	- 17.1	- 14.0	- 13.1	2.0
M3CII	10	- 11.0	- 16.8	- 12.5	- 11.6	1.8
M3CI	11	- 11.5	- 17.1	- 13.9	- 13.7	1.8
MI	8	- 11.6	- 19.9	- 15.0	- 15.2	2.5
M2	5	- 12.5	- 17.1	- 14.4	- 13.7	1.9
PB	18	- 9.5	- 13.1	- 11.3	- 11.1	1.1
LVR4	1	- 12.2	-	-	-	-
LVR11	1	- 12.8	-	-	-	-
Total	61	- 9.5	- 19.9	- 13.0	- 12.5	2.2

On the other hand, detailed results of microfossils studies with emphasis on the presence of phytolith and starch grains allowed us to establish composition trends that distinguish associations consisting of cultivated and wild grasses/ruderals, and thus enabling the estimation of the presence of crops that do not produce phytolith. It was possible then, to identify the presence of potatoes and corn in different levels of two of the three agricultural structures excavated in Los Molina, TLM EY and TLM EAMII (Figs. 6 and 7) (Zucol et al., 2015). However, the most interesting finding of the analysis

may be that in TL MEY, potatoes and corn were identified in the same levels. This situation perhaps was the product of the tillage of material in the soil, and this may be the reason that they coexisted at the same level. Another alternative is that in the case of maize there was both leaf and fruit contribution, as are phytoliths and starches, which could have been a deliberate contribution of plant material and leaves to enrich the soil. A last alternative could be that they were mixed when the tubers were collected (as tubers are buried, unlike maize which grows upwards). Finally, Zucol et

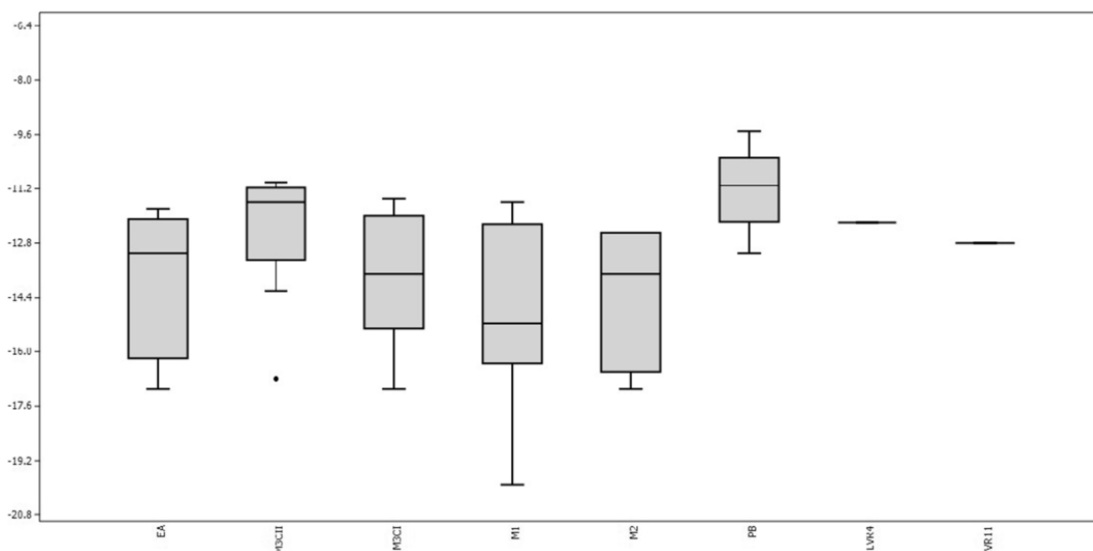


Fig. 3. Carbon isotopes values results.

Table 4  
Descriptive statistics of nitrogen isotopes values.

$\delta^{15}\text{N}$	n	Maximum	Minimum	Mean	Median	SD
EA	6	6.7	3.2	5.5	5.8	1.3
M3CII	10	8.8	3.9	5.2	5.1	1.3
M3CI	10	5.7	3.9	4.8	4.8	0.6
MI	8	5.8	2.4	4.4	4.5	1.0
M2	5	9.8	3.5	6.2	6.0	2.2
PB	14	7	3.6	5.2	5.3	1.0
Total	53	9.8	2.4	5.1	5.1	1.3

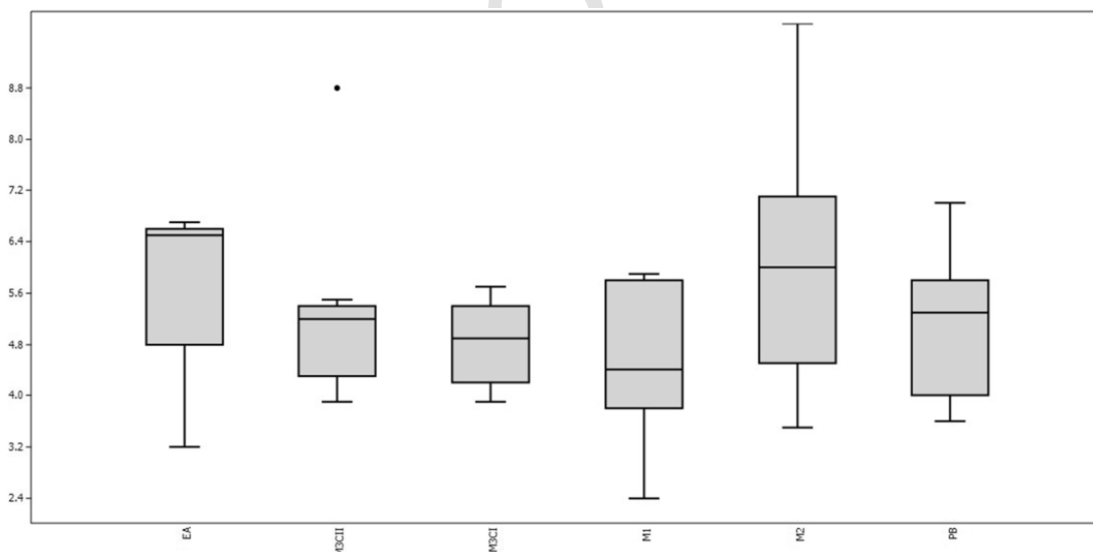


Fig. 4. Nitrogen isotopes values results.

al. (2015) could also identify some phytolith morphotypes - as in the case of somewhat oval contoured serrated edges phytoliths obtained from cystoliths and hair, among others - that have not shown a decisive abundance in the overall analysis, and could be linked with the surrounding vegetation in many cases, but in others - such as oval contour and serrated edges phytoliths - which can be linked to cucurbitaceous plants (Piperno and Stohert, 2003; Lema et al., 2008). This morphotype has been reported at one TLM EBMI

level, and in all profiles samples corresponding to TLM EAMII and TLM EY (Fig. 6).

### 5. Discussion

The recent analysis of microfossils in agricultural terraces located to the southeast of the valley, and camelid skeletal remains nitrogen isotopes generated new information that, once integrated



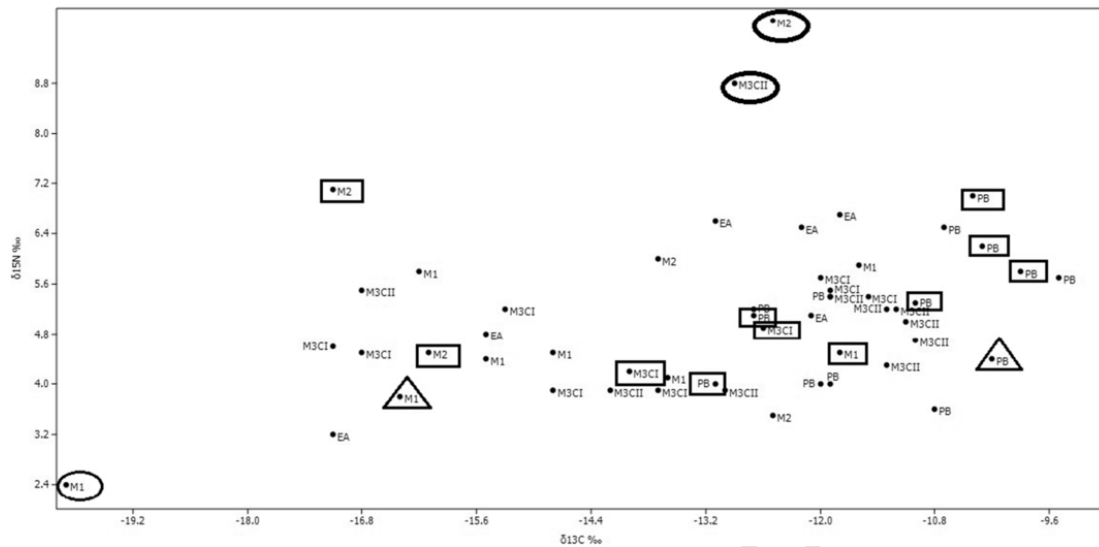


Fig. 5. Results of carbon, nitrogen and strontium isotopes values. Note: triangles represent specimens with <sup>87</sup>Sr/<sup>86</sup>Sr values from outside the valley, and squares are local specimens with <sup>87</sup>Sr/<sup>86</sup>Sr values; ovals represent specimens with exceptional δ<sup>15</sup>N y δ<sup>13</sup>C values.

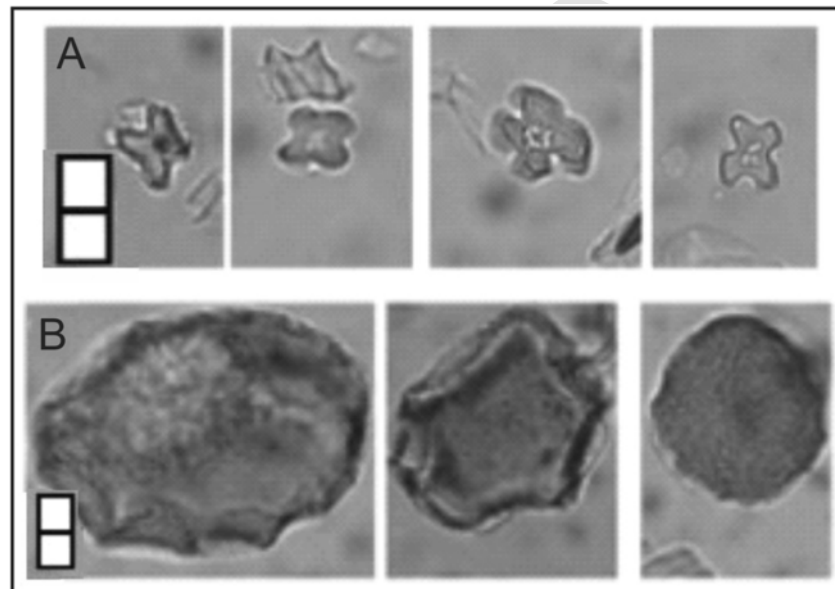


Fig. 6. Maize and cucurbitaceous silicophytoliths. Scale: 20 μm (taken from Zucol et al., 2015).

with existing data, leads us to rethink and reinterpret various aspects of the economic model previously proposed. In this regard, sediment study from three cultivation terraces from Los Molina subsystem (TLM EBMI, TLM EY and TLM EAMII) allowed us to recover not only maize phytolith, but also phytolith from cucurbitaceous plants, and starches from solanaceous species such as potato (Zucol et al., 2015), which would indicate that agricultural production in cultivation terraces would not have been focused exclusively on corn cultivation (Figueroa et al., 2015; Zucol et al., 2012), as originally proposed, but would have included a broader spectrum of plant species (Zucol et al., 2015). On this topic, it is useful to recall, that up to now, six agricultural structures have been excavated in the entire valley, and through their sediment analysis (starches, silicophytolith, etc.), it was possible to verify the exclusive presence of maize only in five of them (Figueroa et al., 2015; Zucol et al., 2012).

In addition to production context, it should be noted that through stratigraphic excavations carried out on sites EA and PB,

located in the piedmont and the valley bottom, isolated grains and sub global corn cobs were recovered - which by their shape and size - would correspond to *Microsperma* (Popcorn) specie commonly called Pearl Maize or Rosita, and *Oryzaea* (Pisingallo Maize) species. Moreover, bean remains (*Phaseolus vulgaris*) were identified (Pochettino, 2000). However, beyond their presence in the archaeological record, it should be noted that beans were not linked to production, but to a residential/ceremonial context. It can be considered that beans could have been cultivated in the valley, but also that they could have been obtained through the exchange and/or trade with other populations.

In short, while the new data from the valley southern terraces break down the initial hypothesis on the intensive and exclusive maize practice in terraces, one should not ignore the fact that the cultivated species variety recorded so far in Ambato are scarce (potato, maize, cucurbitaceae, and possibly beans). This way, in line with the productive model proposed, one may conclude - at least for the time being - that although maize planting was not ex-

clusive in the valley slopes, it was surely the plant resource of greater importance through which revolved different aspects of life: economic, political, social, religious, etc., of the ancient settlers.

Another point that emerges from new microfossil analysis is the presence of potato and corn in the same TLMEY levels, which could be linked to the reasons already pointed out. However, the most interesting alternative in this context would be that it resulted from intentionally enriching the soil for planting through the introduction of leaves and vegetable fruits. Therefore, although this hypothesis would not fully agree with the integrated agropastoral model postulated, in which soils were only fertilized with camelid manure, it allows us to maintain the idea of a productive model intended to achieve increased production through various strategies. Thus, the use of agricultural residues for fertilization, as well as artificial irrigation were possibly added to camelid manure composting (Dantas et al., 2014a; Figueroa, 2012; Laguens et al., 2013). Up to this point, no water channels linking directly to the cultivation terraces were identified, yet Zucol et al. (2012) showed evidence of irrigation indicators in increased diatoms and spongiaria spicules, the presence of non articulated phytoliths, and partial phytolith wear that could be linked to their allochthonous source.

In regards to the radiogenic strontium isotopes analysis, it was possible to identify that the majority of domestic camelids presented  $^{87}\text{Sr}/^{86}\text{Sr}$  matching available local values. This is seen especially in bones, but also in a premolar and an incisor, which would allow us to infer that the animals were raised locally. This is consistent with the implementation of a productive agropastoral strategy within Ambato Valley, where llamas spent their whole life. On the other hand, there were some specimens that are not within the local pattern (for the most part correspond to juvenile animals or adults), providing interesting information regarding the presence of domesticated animals that could have been raised in other areas, and that were brought to the valley already as adults or juveniles (Dantas and Knudson, 2016).

Regarding stable isotopes, new  $\delta^{13}\text{C}$  camelid skeletal remains analysis allowed us to identify two clearly differentiated patterns. In the first place, one identifying individuals from the PB site that fed mostly from  $\text{C}_4$  plants, primarily maize, and secondly, another pattern recorded at M1, M2, M3 and EA sites which fed on a diet consistent with local isotopic ecological values, and included a greater  $\text{C}_3$  and  $\text{C}_4$  plant diversity (Dantas et al., 2014b). This allowed us to consider the existence in the valley of two different ways of animal handling: (a) that which existed during the Aguada period - when llamas had mostly restricted mobility, and controlled feeding based on maize - as proposed under the agropastoral production model; and b) an open field grazing animal management practice, and wider mobility as it was recorded from Pre-Aguada occupation, and which continued until around 1000 A.D. (Dantas et al., 2014b).

On the one hand, Ambato nitrogen values registered are quite uniform in all analyzed samples, without indicating differences between materials from the different sites studied, between Aguada sites (PB, M1, M2, Component I of M3), and pre-Aguada (EA, Component II of M3). Furthermore, these data are close to the average proposed for terrestrial mammals and differ from those recorded in lower rainfall areas as the Puna, where Samec (2014) recorded an average value of 8.3‰ in current llamas herds located below 3900 masl. On the other hand, neither do they agree with what is expected for camelids that have eaten fertilized plants, for which an enrichment between 1.8 and 4.2‰ is expected, as compared to unfertilized plants, and the presence of individuals with values above 10‰ (Szpak et al., 2012a; Thornton et al., 2011). Regarding this last point, it should be noted that, according to Szpak et al.

(2012a), the extent to which the manure could affect  $\delta^{15}\text{N}$  plants value is linked to several factors: animal diet, the amounts of different N carrier compounds in manure, if the manure was composting, time length the manure composted, and if the composting occurred aerobically or anaerobically. To these factors may be added soil chemical composition, and crop nutrients availability (Killian Galván et al., 2015). In this way, one might think that the near absence of  $^{15}\text{N}$  enriched specimens in the samples processed in Ambato Valley, do not necessarily indicate that camelid manure was not used for crop fertilization, but that the  $\delta^{15}\text{N}$  values were not reflecting this cultural practice.

However, beyond these considerations, the similarity of the values at different sites studied is striking, especially comparing PB results with those of the other sites, in which dissimilar herd feeding and management strategies were identified. Therefore, it is more feasible to consider that the values recorded here were a reflection of the local soil chemical composition, and that in the cases of the camelids fed with cultivated plants, these plants were not fertilized with manure sufficiently to be reflected in the  $\delta^{15}\text{N}$  values.

Finally, it should be noted that the crossing of  $^{87}\text{Sr}/^{86}\text{Sr}$  values with  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  reinforce the inferences that had already been made regarding the presence during the Aguada period of locally bred camelid herds which received two types of food and/or had two different modes of management.

## 6. Conclusions

The results of archaeometric studies recently conducted in Ambato, such as silicophytolith and starch granules analysis, brought progress to former valley inhabitants on two fundamental aspects of the economy. In the first place, it was possible to identify the cultivated plant species in the Piedmont terraces, and valley slopes. In this sense, the presence of potato and cucurbitaceae are now added to the established maize registry. This information not only allowed us to investigate individual's daily life various facets but, fundamentally, it enabled us to deepen on aspects related to their diet composition. Secondly, this kind of study also enabled us to recognize the main management practices of productive space (crop rotation, irrigation, fertilization, etc.). On this last point, in the light of the information obtained, we can propose that there existed not only a soil productivity improvement method, such as the use of manure as fertilizer, but also of soil enrichment through the use of agricultural residues and artificial irrigation.

In regards to the reinterpretation of strontium and carbon isotope studies conducted some time ago, and their link with new nitrogen studies carried out in the valley, results suggest the presence not only of locally raised camelids, but also of outsider animals in these areas. Among the local herds it was possible to distinguish two different ways of handling them, linked with a specific and restricted use of the landscape, as well as with their differentiated access and distribution at the different types of sites studied. Lastly, it could be observed that apparently animals-plants integration was not as close as initially believed.

To conclude, the new data obtained allow us to still maintain the validity of the integrated agropastoral system, but it led us to reconsider and/or to reflect some of its operational aspects, which should continue to be studied in depth from sustained research in the area (surveys, excavations, materials analysis, and archaeometric studies).

Finally, it is essential to do similar research in neighboring regions to assess if the productive model proposed for Ambato is only a local case or whether, on the contrary, it had a regional scope. Thus, archaeometric studies of this type are being conducted by other research teams in neighboring regions, such as the Catamarca

Valley, Balcosna Valley, and Campo de Pucara. Only once these studies are compared we will have a regional economical perspective of the west-central Catamarca province ancient inhabitants.

#### Uncited reference

Lema et al., 2008

#### Acknowledgements

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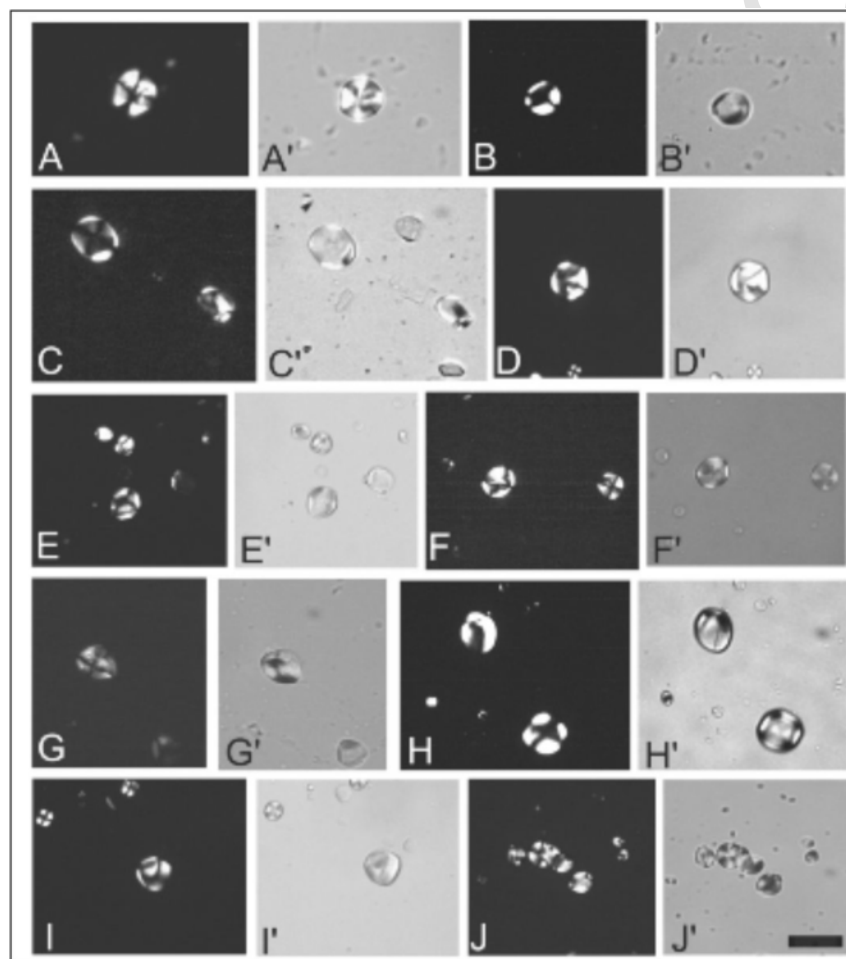


Fig. 7. Starch grains identified. Left, with polarized light; right, with normal light. Scale in J': 20  $\mu$ m. (Taken from Zucol et al., 2015.)

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