

# The Use of Hunting and Herding Spaces: Stable Isotope Analysis of Late Archaic and Early Formative Camelids in the Tulan Transect (Puna de Atacama, Chile)

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**ABSTRACT** We present the results of analysing stable carbon and nitrogen isotopes in camelid remains found at the Late Archaic site TU-52 (ca. 5000–3800 BP), the Tarajne Phase site TU-94 and the Early Formative sites TU-54, TU-85 and TU-122 (ca. 3100–2400 BP). All of the sites are located in the Puna de Atacama (Northern Chile) along the 14 km Tulan transect, between the head of Tulan ravine (ca. 3000 m.a.s.l.) and the border of the Salar de Atacama (2317 m.a.s.l.). Our aim is to understand how the space was used by hunter-gatherers and early herders from the beginning of camelid domestication to the consolidation of herding practices. Isotopic analyses were complemented with osteometric data in order to correlate changes in animal size and isotopic values with the initiation of animal husbandry. Isotopic and osteometric results show less variability of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values during the Late Archaic and Tarajne Phase, whereas variability is higher during the Early Formative. We postulate that during the latter period, there was more widespread use of hunting and herding spaces along the Tulan ravine, including areas above 3000 m.a.s.l. as result of more consolidated herding practices, while the highlands were used as a complementary space to hold livestock near ritual sites and residential settlements. Copyright © 2017 John Wiley & Sons, Ltd.

*Key words:* Atacama Desert; camelids; domestication; Early Formative; Late Archaic; stable isotopes

## Introduction

In the archaeological sequence of the Tulan transect (Northern Chile; Figure 1), Late Archaic hunting traditions (ca. 5000–3800 BP) reached a turning point with the gradual management and control of the main Andean animal resource—camelids. Studies on the domestication of camelids in this area have included different types of evidence such as osteometry, fibre analysis, pathologies, age profiles and isotopic data, among others (Cartajena *et al.*, 2007; Hesse, 1982a, 1982b; López *et al.*, 2013). Early studies by Hesse (1982a) suggesting initial domestication events during

the Late Archaic were taken up by Cartajena *et al.* (2007), who identified a greater heterogeneity in the bone measurements of TU-52 (Late Archaic), related to the initial stages of domestication. Evidence also shows that while in the Late Archaic, there was a high variability in the lower size range of large camelids (llama/guanaco) that heterogeneity decreased during the Early Formative, pointing to the disappearance of smaller animals in this group, which has been interpreted as the result of more consolidated camelid management practices (Cartajena *et al.*, 2007).

Despite these advances, few studies have examined the shift from Archaic hunter-breeder groups to Formative early herders in Tulan, in regard to socio-economic, political, territorial and even ideological aspects. It is known from the literature that this shift differs from traditional agrocentric and unilinear models. Both in the Late Archaic and the Early

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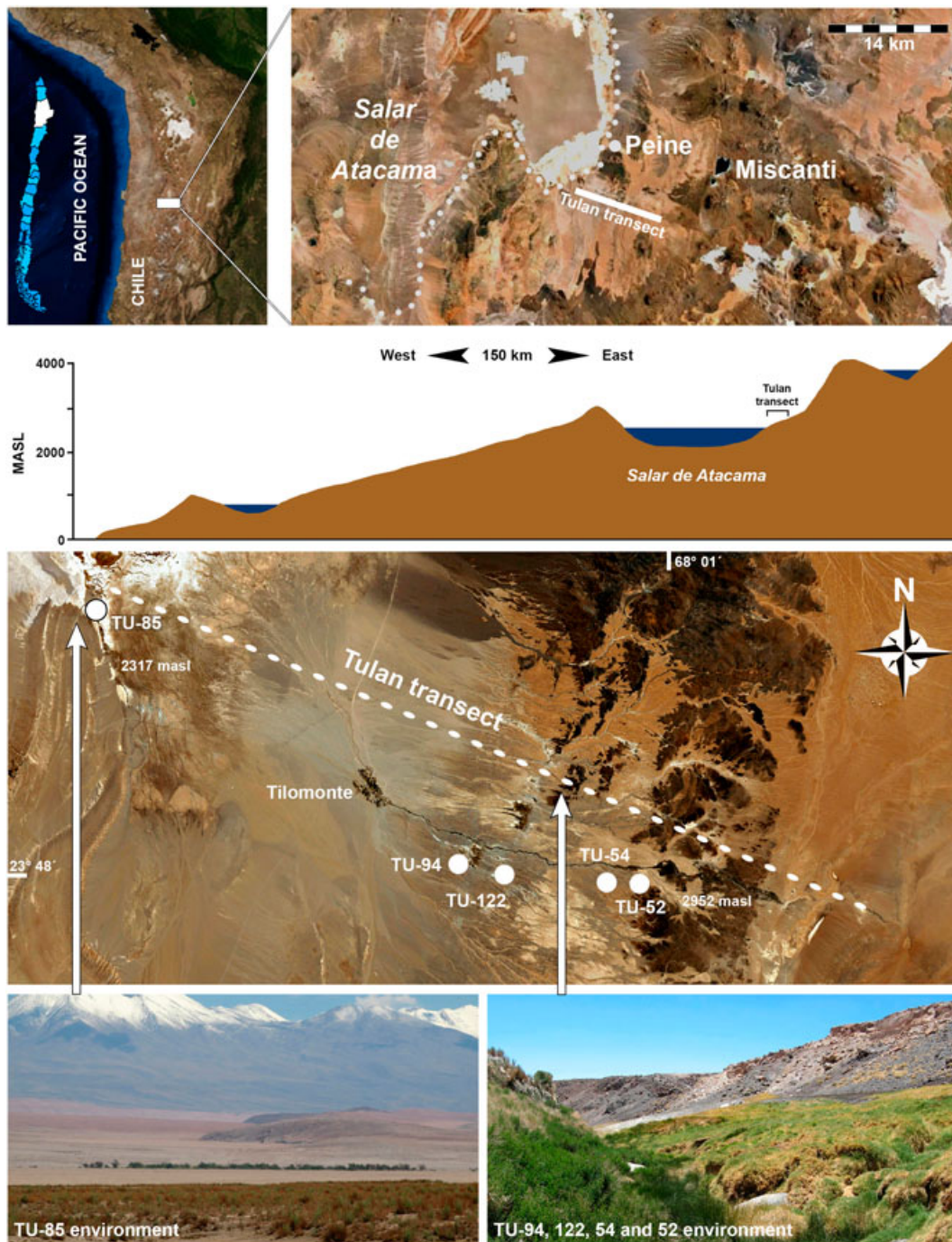


Figure 1. (From top to bottom) Location of the Tulan Transect; Transect location on an altitudinal cross section; sites studied (TU-85, TU-94, TU-122, TU-54 and TU-52) in the Transect; and environments of the sites studied. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

Formative, there were human groups practicing a way of life based on hunting and gathering and small-scale horticulture (Núñez *et al.*, 2006), but a hunter-gatherer-herder system requires its own definition (Capriles & Tripcevich, 2016). In this regard, a crucial piece of the puzzle can be found in the evolution of the Tulan transect from a traditional

hunting and gathering space to a herding space, and the way that shift was defined and negotiated by local communities during the period, from ca. 3100 to 2400 years BP. Unfortunately, the archaeological record of the area surrounding the transect is scant due to the lack of archaeological surveys of areas above 3000 m.a.s.l.

In recent years, the use of stable isotope analyses in the area at ecological, paleoenvironmental and archaeological levels (Díaz *et al.*, 2016; López *et al.*, 2013; Quade *et al.*, 2007) has identified differences in the isotopic signatures of vegetation existing at different ecological tiers, from the foothill oases (2000 m.a.s.l.) to the intermediate ravines (3000–3800 m.a.s.l.) and the high Puna (>3800 m.a.s.l.). This, in turn, has allowed a preliminary modelling of potential wild and domestic animal pastures in archaeological sites located below 3000 m.a.s.l. Within that context, this paper addresses the use of hunting and grazing spaces in the Tulan transect during the Late Archaic and Early Formative periods by analysing stable carbon and nitrogen isotopes in bones of wild and domestic camelids (Mengoni-Goñalons, 2012; Panarello & Fernández, 2002, Yacobaccio *et al.*, 2009, 2010). Interestingly, for both periods, there are transitional changes in the size of camelids associated with the process of anthropic management. Thus, we observed groups of sizes associated with wild animals (guanacos and vicuñas), and others conformed by animals in initial domestication processes with greater morphometric variability, and that for the Tarajne transitional phase and Early Formative, due to cultural selection, is conforming a new group of larger size and slightly separated from the rest. This is the reason why the present research crosses two variables: the isotope and the osteometric data, to generate a more accurate picture of possible differences between wild and domestic animals.

### Puripica-Tulan, Tarajne and Tilolacar phases

The Puripica-Tulan phase refers to local occupations of the Tulan Ravine in the Late Archaic period, as defined in the TU-52 site (2969 m.a.s.l.) dated from 4390 to 3800 BP (non-cal. dates). At this site, circular agglomerated structures built from vertical blocks arranged on the surface (Núñez *et al.*, 2006) have been identified, completely covered by stratified deposits generated by domestic activities. Through osteometric and animal fibre analyses, the remains of guanacos (*Lama guanicoe*), vicuñas (*Vicugna vicugna*) and llamas (*Lama glama*) have been identified, the first-ever record of domestic camelids in the Tulan transect (Cartajena *et al.*, 2007). In addition to this evidence, several indicators later identified as part of the Tilolacar phase (Early Formative) were observed, such as undermined wells, incised blocks, evidence of flake and copper ore bead manufacturing and micro-drills (Núñez *et al.*, 2006).

The transitional or Tarajne phase is represented only in the TU-94 site (2620 m.a.s.l.). Dating from 3400 to 3110 BP (non-cal. dates), this site is characterised by two adjacent sets of circular and subcircular structures with a total of 19 precincts, with stratified deposits that reach 70 cm deep, in which lithic remains, skeletal remains (mainly camelids), plants, shells and beads, among others, were recorded. The transitional character of TU-94 is observed in the use of conical hollow mortars, the scant presence of early ceramics of the *Los Morros* type, the predominance of lanceolate projectile points, the presence of a gold sheet and an agglomerated circular architectural pattern of the Puripica-Tulan phase (Núñez *et al.*, 2006).

Meanwhile, the Tilolacar phase characteristic of the Early Formative period is represented in TU-54 (2952 m.a.s.l.), TU-85 (2317 m.a.s.l.) and TU-122 (2680 m.a.s.l.). TU-54, located on the southern edge of the Tulan Ravine, consists of a central temple with interior niches on a megalithic foundation, covered entirely with debris to form a stratified mound (Núñez *et al.*, 2006). At the centre of the site is an oval structure with a perimeter wall built from vertical blocks and interior dividing walls. The deposits surrounding the ceremonial centre contain remains of the primary and secondary order, with hearths and dispersed ash deposits, bones, plant and lithic remains dating from 2380 to 3080 BP (non-cal. dates) (Núñez *et al.*, 2017). Three types of camelids – guanacos, vicuñas and llamas – have been identified (Cartajena *et al.*, 2007). TU-85 is located at the edge of the Salar de Atacama at 2317 m.a.s.l. and consists of a residential settlement with structures and a dense deposit in the form of a mound from which plant remains were recovered, as well as carved and grinding lithic artefacts, ceramic remains, animal fibres, coprolites and skeletal remains of vicuñas, guanacos and llamas (Núñez *et al.*, 2006). At the earliest occupational stratum, a date of 3140 BP (non-cal. date) was obtained, whereas an infant grave yielded a date of 2660 BP (non-cal. date) (Núñez *et al.*, 2006). Finally, the TU-122 site is situated on the southern edge of the ravine (2680 m.a.s.l.) and has a start date of 4120 BP (non-cal. date) and an Early Formative occupation dated from 2740 ± 40 to 2510 ± 40 BP (non-cal. dates) (Núñez *et al.*, 2006).

### Isotopic ecology of the Salar de Atacama and environs

The isotopic composition of the current vegetation in the study area and the coastal sector comes from the

transects sampled by Ehleringer *et al.* (1998), Quade *et al.* (2007) and Díaz *et al.* (2016). These values were adjusted by +1.5 per thousand (‰) considering the modern  $^{12}\text{C}$  enrichment caused by the burning of fossil fuels (Yakir, 2011). The transect performed by Ehleringer *et al.* (1998) in the *Paposo* sector (25°00'S, 70°27'W) ranges from 90 to 1010 m.a.s.l. and consists mainly of  $\text{C}_3$  cycle plants with an average value of  $-23.1$  and one indeterminate species of *Cistanthe* sp. with a value of  $-16.5$  (CAM). In this same sector, Quade *et al.* (2007), in a transect that ranges from 130 to 1460 m.a.s.l., identifies a set dominated by  $\text{C}_3$  cycle plants averaging  $-19.4$ , in addition to CAM cycle succulents, averaging  $-12.6$ , and *Atriplex mucronata* of the  $\text{C}_4$  cycle with a value of  $-13.6$ . According to Quade *et al.* (2007), towards the higher areas, the vegetation associated with the Salar de Atacama corresponds to the *Prepuna* (2500 to 3200 m.a.s.l.), *Tolar* or *Puna* (3200–4000 m.a.s.l.), Andean Steppe (4000–4500 m.a.s.l.) and the Subnival Area up to (6000 m.a.s.l.). The majority of plants distributed in these areas possess photosynthetic pathway  $\text{C}_3$ , except some of the CAM and  $\text{C}_4$  type (Quade *et al.*, 2007; Díaz *et al.*, 2016). In the *Paso Jama* transect (22°54'S, 67°57'W), the sectors sampled by Quade *et al.* (2007), ranging from 3475 to 4070 m.a.s.l., show a  $\text{C}_3$  plant domain with an average value of  $-20.4$  and a few plants with CAM and  $\text{C}_4$  cycle (*Opuntia* and *Atriplex imbricata*) with a value of  $-13.3$  and  $-12.6$ , respectively. On the other hand, in the *Socompa* transects (24°12'S, 68°32'W), ranging from 3123 to 4000 m.a.s.l., the average value of  $\text{C}_3$  plants is  $-21.4$ , along with one  $\text{C}_4$  cycle species (*Atriplex imbricata*) with a value of  $-13.7$  (Quade *et al.*, 2007).

Díaz *et al.* (2016) provided the results of six plant species sampled at 2870–4480 m.a.s.l. These species correspond to *Jarava frigida* of the  $\text{C}_3$  cycle and an average of  $-23.2$ ‰ (3870–4480 m.a.s.l.), *Parastrephia quadrangularis* of the  $\text{C}_3$  cycle with an average of

$-21.4$ ‰ (3770–4370 m.a.s.l.), *Baccharis tola*, also  $\text{C}_3$ , with an average of  $-20.4$ ‰ (3470–4072 m.a.s.l.), *Atriplex imbricata* of the  $\text{C}_4$  cycle with a value of  $-13.8$ ‰ (2870–3470 m.a.s.l.), *Maihueniopsis camachoii* of the CAM type with a value of  $-11.8$ ‰ (2670–3870 m.a.s.l.) and finally *Tiquilia atacamensis*, cycle  $\text{C}_3$ , with an average value of  $-24.7$ ‰ (2870–3270 m.a.s.l.). This same study provided values of  $\delta^{13}\text{C}$  extracted from camelid faeces, which indicate an average value of  $-23.0$  ( $n = 9$ ), with lower values between 3765 and 3972 m.a.s.l. (Díaz *et al.*, 2016).

Table 1 summarises the trends of the  $\delta^{13}\text{C}$  values for plants analysed by Ehleringer *et al.* (1998), Quade *et al.* (2007) and Díaz *et al.* (2016), according to photosynthetic cycle and altitude. Figure 2a shows the values of  $\delta^{13}\text{C}$  and its relationship to altitude. This relation expresses values that increase as soil elevation decreases from 1500 to 0 m.a.s.l. and as it increases from 2500 to 4500 m.a.s.l. The  $\text{C}_4$  cycle taxa that dominates the area are *Atriplex*, which corresponds to a genus of *Amaranthaceae* used as fodder for domestic camelids and consumed by wild camelids such as *Lama guanicoe* (Cadwallader *et al.*, 2012). It is important to note that domesticated crops with a  $\text{C}_4$  cycle such as maize are absent or scarce during the Late Archaic and Early Formative, and probably foraneous, and in general, the cultigen has a very low and almost marginal intensity (Núñez *et al.*, 2009), and as such, the use of guano as fertiliser is an unlikely scenario (Szpak *et al.*, 2012).

Regarding nitrogen values, Díaz *et al.* (2016) indicate that the soil values in areas surrounding the Salar de Atacama, from 2500 to 4500 m.a.s.l., range from 3.3‰ to 12.2‰ with an average of 8.2‰ and are dependent upon elevation values (Table 2). On the other hand, the values of  $\delta^{15}\text{N}$  in the plants range from  $-2.0$ ‰ to 8.8‰ and are inversely correlated with the elevation (Figure 2b). The values of the plants sampled in each area in the work of Díaz *et al.* (2016) are highly

Table 1.  $\delta^{13}\text{C}$  values for plants of the Atacama Desert, at altitudes ranging from 0 to 15 000 m.a.s.l. and from 2500 to 4500 m.a.s.l.

Statistics	$\text{C}_3$	$\text{C}_4$	CAM	$\text{C}_3$	$\text{C}_4$	CAM	$\text{C}_3$	$\text{C}_4$	CAM
	Total	Total	Total	0–1500 m	0–1500 m	0–1500 m	2500–4500 m	2500–4500 m	2500–4500 m
N	154	23	25	85	1	8	69	22	17
Min	-27,4	-15,5	-22,5	-27,4	-13,6	-16,9	-26,4	-15,5	-22,5
Max	-17,8	-12,4	-7,4	-18,2	-13,6	-7,4	-17,8	-12,4	-10
Sum	-3426,3	-313,8	-306,5	-1926,9	-13,6	-104,5	-1499,4	-300,2	-202,0
Mean	-22,3	-13,6	-12,3	-22,7	-13,6	-13,1	-21,8	-13,6	-11,9
Standard error	0,2	0,2	0,7	0,2	0,0	1,4	0,2	0,2	0,7
Variance	3,8	0,7	10,7	3,8	0,0	15,2	3,5	0,7	9,0
Standard Dev	2,0	0,8	3,3	1,9	0,0	3,9	1,9	0,8	3,0
Median	-22,3	-13,7	-11,4	-22,7	-13,6	-13,5	-21,4	-13,7	-11
Coefficient Variation	-8,8	-6,0	-26,7	-8,6	0,0	-29,8	-8,6	-6,1	-25,0

$\Delta^{13}\text{C}$  values adjusted by +1.5 per mil (‰). Data from Ehleringer *et al.* (1998), Quade *et al.* (2007) and Díaz *et al.* (2016).

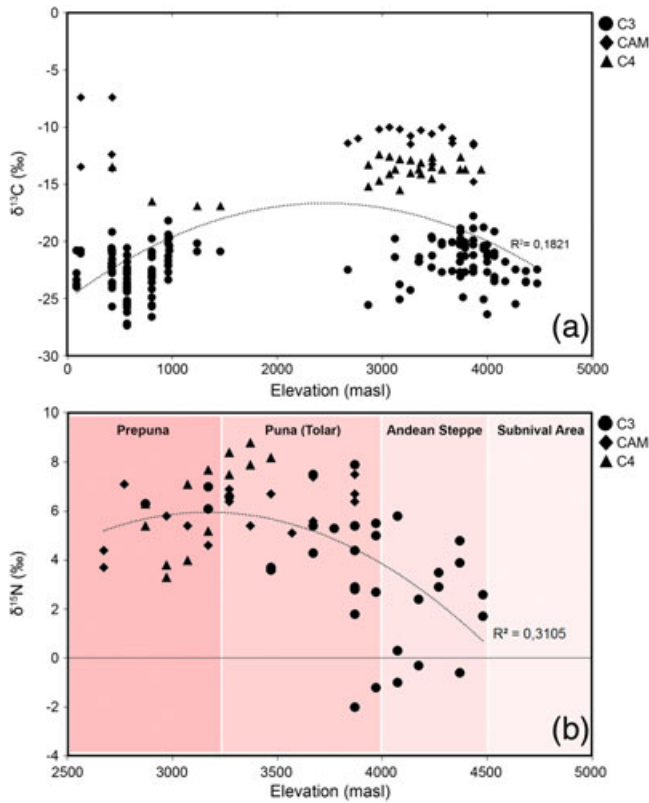


Figure 2. (a) Relation between  $\delta^{13}\text{C}$  values for plants of the Atacama Desert and the altitude of the sector up to 4500 m.a.s.l. (b) Relation between  $\delta^{15}\text{N}$  values for plants of the Atacama Desert and altitude of the sector from 2500 to 4500 m.a.s.l. A polynomial regression was fitted to describe the relationship between  $\delta^{13}\text{C}$  (plants)– $\delta^{15}\text{N}$  (plants and soils) and elevation.  $\Delta^{13}\text{C}$  values adjusted by +1.5 per mil (‰). Data from Ehleringer et al. (1998), Quade et al. (2007) and Díaz et al. (2016). [Colour figure can be viewed at wileyonlinelibrary.com]

variable due to the diversity of plants observed, with species such as *Jarava frigida* showing the lowest value of  $\delta^{15}\text{N}$  (1.3‰) and *Tiquilia atacamensis*, the highest value (6.5‰). Finally, from the same study, herbivorous faeces (rodents and camelids) were extracted that range from 2.1‰ to 8.3‰, with a direct relation to

Table 2. Statistics of the  $\delta^{15}\text{N}$  values for Atacama Desert plants found at 2500 to 4500 m.a.s.l. Data taken from Díaz et al. (2016)

Statistics	Plants 2500–4500 m
N	66
Min	–2
Max	8,8
Sum	310,7
Mean	4,7
Standard error	0,3
Variance	6,3
Standard deviation	2,5
Median	5,4
Coefficient variation	53,5

the altitudinal distribution observed for the plants and similar values between plants and herbivores sampled at medium elevations, although at the extremes of the gradient, the plants presented values that were more enriched than those of the animals (Díaz et al., 2016).

### Hypothesis and expectations

This background information generates different expectations for the pasture areas during camelid domestication and early husbandry in the Tulan transect. Today, Atacameño communities in Peine (13 km north of Tulán) lead their flocks to the highland meadows (*vegas*) from November to March and the rest of the year make use of lower-altitude pastures near the town of Peine (2400 m.a.s.l.) and Tilomonte, their main residential hubs (Núñez, 2015). It is apparent, then, that contemporary herders use pasturelands at different attitudes, including the Puna, during the year.

However, during the initial domestication and breeding stages, the herders would have favoured pasturelands near their settlements in order to better control the feeding and mobility of a small herd of animals and prevent them from crossing with wild camelids, possibly by using enclosures located on the ravine bottom (Moore, 2016). Those enclosures have not been successfully dated, but based on their building technique and proximity to the settlements, they could be assigned to Late Archaic-Early Formative. Therefore, as a working hypothesis, it is argued that the mobility associated with camelid-raising would have been more limited in the Late Archaic than in the Early Formative. This means that during the initial stages of domestication (Late Archaic-Tarajne phase), more homogeneous isotopic values associated with more restricted movements would be expected, while towards the Early Formative, the values should become more heterogeneous, representing pasturelands in the ravine as well as highland meadows (Puna), owing to the presence of more numerous herds of animals. However, considering that forage was readily available in both Tilocalar and the ravines throughout the year (González et al., 2011), the intense use of the Puna may be less likely. Finally, a fourth scenario suggests movement towards the coast, although that would have involved a limited number of animals as part of the nascent caravan trade.

### Material and methods

The isotopic analysis was performed on 38 samples, as set out in Table 3, corresponding to both the first and

Table 3. Measurements and results of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  analyses from samples taken from the sites studied.

Sample	Period	Laboratory code	Size group/taxa	Bone	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	%C	%N	C/N	BFp	Dp
TU-52/3	LA	UGAMS 24560	LGS	1st ant. phal.	-14.9	12.8	44	16	3.2	22.8	20.5
TU-52/4	LA	UGAMS 24561	<i>Vicugna vicugna</i>	1st ant. phal.	-17.7	8.9	47	17	3.2	16.4	16.1
TU-52/9	LA	UGAMS 24562	LGS	1st ant. phal.	-16.7	11.3	34	11	3.6	19.4	19.7
TU-52/12	LA	UGAMS 24563	LGS	1st ant. phal.	-16.7	11.7	41	15	3.3	21.4	19.9
TU-52/20	LA	UGAMS 24564	LGS	1st ant. phal.	-17.1	10.3	38	14	3.2	19.4	18.1
TU-94/1	LA-EF	UGAMS 24582	<i>Vicugna vicugna</i>	1st ant. phal.	-17.3	12.3	43	15	3.3	16.1	15.3
TU-94/2	LA-EF	UGAMS 24583	LGS	1st post. phal.	-13.8	12	45	16	3.2	20.5	19.4
TU-94/5	LA-EF	UGAMS 24584	LGS	2nd ant. phal.	-14.5	12.5	44	16	3.2	19.6	17
TU-94/4	LA-EF	UGAMS 24585	LGS	2nd post. phal.	-14.4	10.7	45	16	3.4	18.5	17.1
TU-54/1	EF	UGAM 24677	LGS	1st ant. phal.	-12.8	10.1	45	17	3.2	19.4	18.1
TU-54/2	EF	UGAM 24678	<i>Vicugna vicugna</i>	1st ant. phal.	-16.2	8.3	45	16	3.2	15.1	15.2
TU-54/4	EF	UGAM 24675	<i>Vicugna vicugna</i>	1st ant. phal.	-17.6	9.8	44	16	3.2	15.2	17.2
TU-54/5	EF	UGAM 24676	<i>Vicugna vicugna</i>	1st ant. phal.	-17.9	9.4	42	15	3.2	17.2	17.2
TU54/6	EF	UGAM without code	LGS	1st ant. phal.	-13.9	13.2	40	14	2.8	21.2	20.4
TU54/7	EF	UGAM without code	LGS	1st ant. phal.	-12.6	12.3	44	16	2.7	20	18.6
TU54/8	EF	UGAM 24679	LGS	1st ant. phal.	-16.8	8.9	44	16	3.2	21.4	19.9
TU-54/9	EF	UGAM without code	LGS	1st ant. phal.	-15.4	13.3	43	16	2.6	22.1	20.7
TU-54/10	EF	UGAM 24681	LGS	1st ant. phal.	-16.6	11.4	45	16	3.2	21	19.9
TU-54/12	EF	UGAM 24680	LGS	1st post. phal.	-15.5	12.4	46	17	3.2	22.2	10.1
TU-54/13	EF	UGAM 24674	<i>Vicugna vicugna</i>	1st ant. phal.	-17.6	10.4	47	16.9	3.2	17.4	17.8
TU54/14	EF	UGAM without code	LGS	1st ant. phal.	-16.4	8.6	40	14	2.9	19.2	19.7
TU54-S/N°	EF	Beta - 432371	LGS	Thoracic	-14	12.4	-	-	-	-	-
TU-85/1	EF	UGAM 24673	<i>Vicugna vicugna</i>	1st ant. phal.	-17	8	45	16	3.3	15.3	14.2
TU-85/2	EF	UGAM without code	LGS	1st ant. phal.	-14.1	11	42	15	2.9	18.9	17.5
TU-85/3	EF	UGAM 24666	LGS	1st post. phal.	-17.3	9	35	12.3	3.3	20.1	18.2
TU-85/4	EF	UGAM 24672	LGS	1st post. phal.	-15.9	8.8	43	15.5	3.3	20.1	18.4
TU-85/7	EF	UGAM without code	LGS	1st ant. phal.	-16.8	7	40	14	2.9	19.7	-
TU-85/8	EF	UGAM without code	LGS	1st ant. phal.	-13.9	10.9	42	13	3.1	22	21.4
TU-85/9	EF	UGAM 24667	LGS	1st post. phal.	-21.7	15.3	33	6.6	5.9	20	17.6
TU-85/10	EF	UGAM 24670	LGS	1st ant. phal.	-22.8	14.7	38	7.2	6.2	22.1	21.6
TU-85/11	EF	UGAM 24665	LGS	1st ant. phal.	-23.1	14.8	19	3.3	6.7	18.8	18.3
TU-85/13	EF	UGAM 24664	LGS	1st ant. phal.	-21	13.6	32	5.4	7	21.3	20
TU-85/14	EF	UGAM without code	LGS	1st ant. phal.	-16.4	9.8	33	11	2.9	21.7	21.6
TU-85/17	EF	UGAM 24669	<i>Vicugna vicugna</i>	1st ant. phal.	-17.4	10.7	44	16	3.3	16.6	15.9
TU-85/20	EF	UGAM 24671	LGS	1st post. phal.	-15.4	11.3	43	15	3.3	22.1	20.2
TU-122/1	EF	UGAM 24696	LGS	2nd post. phal.	-19.4	17.8	20	3.3	7.1	19.1	16.3
TU-122/2	EF	UGAM 24697	LGS	2nd post. phal.	-19.5	19.9	8.8	1.2	8.3	18.5	15.9
TU-122/3	EF	UGAM 24698	<i>Vicugna vicugna</i>	2nd ant. phal.	-21	20.2	3.1	0.5	8	12.6	11.5

The specimens with poor preservation of collagen are highlighted in grey. LA, Late Archaic; EF, Early Formative; BFp, Breadth of the *Facies articularis proximalis*; Dp, Depth of the proximal end; LGS, large group size.

second anterior and posterior phalanges of adult animals. These bones were selected for their potential usefulness in separating the animals into size groups and, within those groups, identifying possible metric differences between species. Isotopic analyses of bone collagen were performed at the Center for Applied Isotope Studies at the University of Georgia, except for a fragment of thoracic vertebra of a *Camelidae*, which was analysed in Beta Analytic. The values of  $\delta^{13}\text{C}$  ( $^{13}\text{C}/^{12}\text{C}$ ) are expressed in parts per thousand (‰) following the international standard Pee Dee Belemnite, with an error rating below 0.1‰, and those of  $\delta^{15}\text{N}$  ( $^{15}\text{N}/^{14}\text{N}$ ) in parts per thousand (‰) according to the international standard for atmospheric nitrogen, with an error rating below 0.2‰. The C/N ratio was measured via EA-MS. The C/N ratio was calculated to evaluate collagen preservation. To obtain that value,

the C/N ratio was compared with ranges (2.9 to 3.6) deemed acceptable in the literature (De Niro, 1985). The measurements of the analysed samples were plotted in scatter-plots and contrasted with all the isotope values obtained to date from the TU-52, TU-54 and TU-85 sites. For the phalanges, the BFp measurements (width of the proximal articular surface *sensu*; von den Driesch, 1999) and Dp (depth of the proximal epiphysis *sensu*; von den Driesch, 1999) were chosen, as they were discriminant for the separation of the samples into two size groups, one large (*Lama guanicoe* and *Lama glama*), the other small (*Vicugna vicugna* and *Vicugna pacos*), for both archaeological and modern camelid standards (Cartajena et al., 2007). In order to evaluate whether the observed differences in the size groups correlated with the isotopic differences, the first anterior phalanges were chosen. Finally, the measurements

obtained for both groups and the isotopic values of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  were compared.

## Results

Table 1 shows  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values related to the taxonomic identification of each sample. In relation to the osteometric analysis, measurements of first phalange samples were plotted to scatter-plots, considering the total number of measurements available for the Late Archaic ( $n = 53$ ) and Early Formative ( $n = 27$ ). As detailed in Figure 3a, the size groups can be easily separated, with the small size group (vicuñas) presenting less variability, especially in relation to BFp measurements, and the large size group presenting greater variability (Figure 3a). Although there are fewer samples for the Late Archaic (TU-52  $n = 5$ ), those obtained cover both size groups, as does the Early Formative sample group (TU-54  $n = 9$ , TU-85  $n = 8$ ). Unfortunately, for site TU-94, only one measurement was obtained for the first anterior phalanx, corresponding to the small size group.

In the case of the small camelid group, osteometric measurements suggest that the remains correspond to vicuñas (Cartajena, 2009). During the Late Archaic, the set of large camelids displays greater variability in measurements than the smaller set, owing to the presence of two species, one wild (*Lama guanicoe*) and one domestic (*Lama glama*), resulting from a domestication process. However, the large degree of overlap made it difficult to assign a portion of the sample to a particular species. A similar pattern is observed in the Early

Formative; however, the upper range of the large camelids displays a more homogeneous distribution (Figure 3b) (Cartajena *et al.*, 2007). This overlap between the size of wild and domestic camelids has also been observed in contemporary sites of Northwest Argentina with larger domestic animals (López, 2003), suggesting that the domestic taxa varied significantly in size during this period.

Regarding the isotopic results, among the entire sample, four specimens from TU-85, three from TU-54 and the same number from TU-122 had poor collagen preservation, so the values were not considered in the final interpretation and charts. In the case of  $\delta^{13}\text{C}$ , values for each site yield averages of  $-16.6\text{‰}$  (SD = 1.1) for TU-52,  $-15\text{‰}$  (SD = 1.6) for TU-94,  $-16.1\text{‰}$  (SD = 1.6) for TU-54 and  $-16$  (SD = 1.3) for TU-85. Lastly,  $\delta^{15}\text{N}$  values average  $11\text{‰}$  (SD = 1.5) for TU-52,  $11.9\text{‰}$  (SD = 0.8) for TU-94,  $10.8\text{‰}$  (SD = 1.8) for TU-54, and  $9.6\text{‰}$  (SD = 1.5) for TU-85 (Figures 4 and 5). In order to relate the isotopic to the osteometric values, 3D scatter diagrams were plotted for the BFp and Dp measurements of the anterior first phalanges, as well as  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values, respectively. As Figure 6a shows, the set of camelids corresponding to vicuña is grouped very homogeneously, both by size and by isotopic values for carbon-collagen, which range from  $-17.9\text{‰}$  to  $-16.2\text{‰}$ , with very little variation (CV =  $-3.1$ ) regardless of temporal and site assignment. The large-size group presents specimens with isotopic values ranging between  $-17.3\text{‰}$  and  $-12.8\text{‰}$  (CV =  $-8.7$ ). Although for the Late Archaic there are only three observations, the values are less dispersed than those

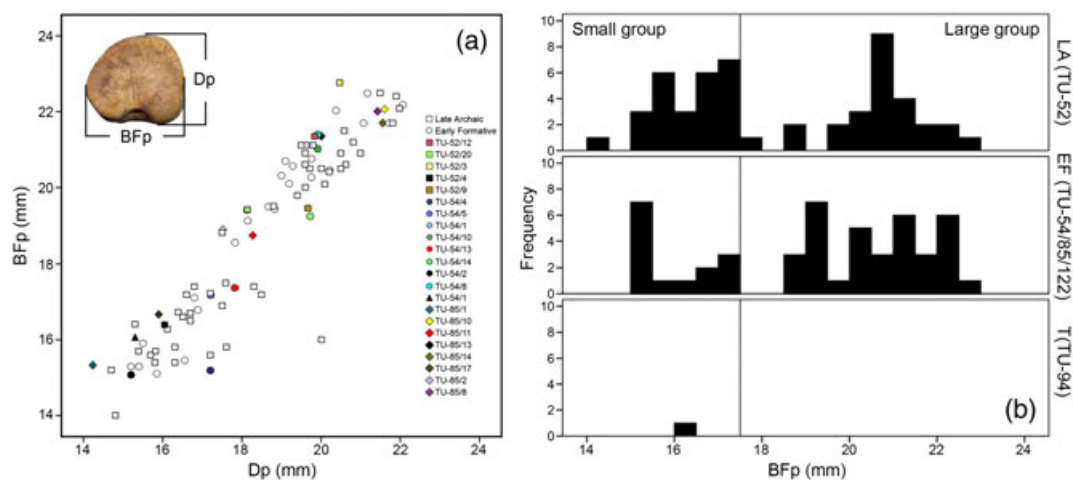


Figure 3. (a) Scatter plot of the first anterior phalanges chosen for isotopic analysis. (b) Distribution of the BFp (mm) measurements of the first anterior phalanges for small and large-sized camelid groups. LA, Late Archaic; EF, Early Formative; T, Transition; BFp, Breadth of the Facies articularis proximalis; Dp, Depth of the proximal end. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

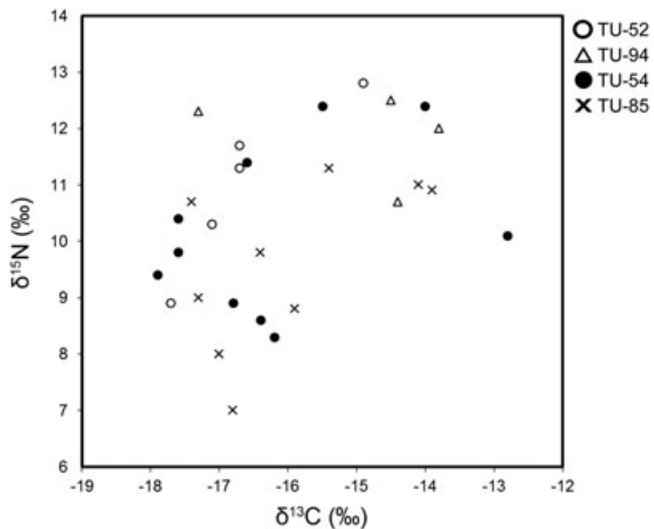


Figure 4. Relation of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from the sites studied.

observed for the Early Formative sites. In the Early Formative, specimens of the large-size group from the TU-85 site are less dispersed ( $-17.3\text{‰}$  to  $-13.9\text{‰}$ ) than those of TU-54 ( $-16.8\text{‰}$  to  $-12.8\text{‰}$ ).

In the scatter-plots of Bfp and Dp measurements of the anterior phalanges and the nitrogen isotopic values, vicuña values range between  $8.0\text{‰}$  and  $12.3\text{‰}$  ( $\text{CV} = 14.5$ ), with only one specimen from the transitional site TU-94 showing a very high value ( $12.3\text{‰}$ ; Figure 6b). Combining the metric variables and isotopic values, especially carbon, the results suggest the presence of three groups – first, vicuñas; second, Late Archaic and Early Formative large-sized camelids; and third, large-sized camelids of the Tarajne transitional phase and Early Formative.

Although the samples from the first posterior phalanx and the second anterior and posterior phalanges were not plotted, the results follow the same trend. In the case of the first posterior phalanx ( $n = 6$ ), the samples correspond only to the group of large camelids of sites TU-54, TU-85 and TU-94. The  $\delta^{13}\text{C}$  values range from  $-13.8\text{‰}$  to  $-17.3\text{‰}$ . Likewise, the  $\delta^{15}\text{N}$  values are similar to the results obtained for the anterior phalanges ( $8.8\text{‰}$  to  $12.4\text{‰}$ ). Two second phalanges in the large-sized camelid group (TU-94 site) presented the same tendency observed for the other anatomical units, with  $\delta^{13}\text{C}$  values of  $-14.4\text{‰}$  and  $-14.5\text{‰}$  and  $\delta^{15}\text{N}$  values of  $10.7\text{‰}$  and  $12.5\text{‰}$ , respectively.

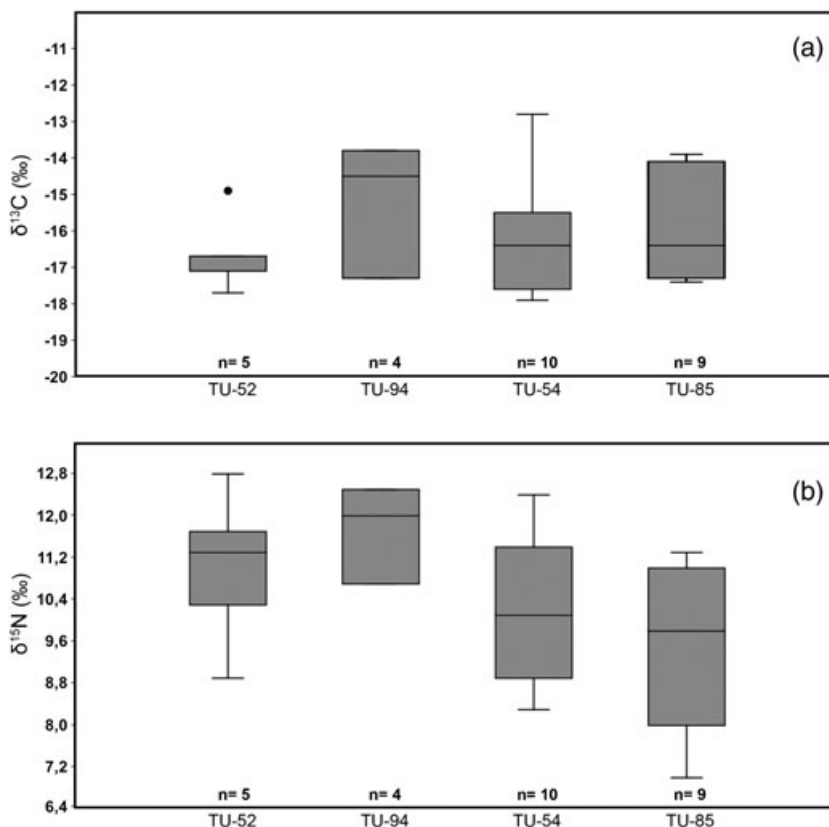


Figure 5. (a) Graphic representations of  $\delta^{13}\text{C}$  and (b)  $\delta^{15}\text{N}$  values from the sites studied.



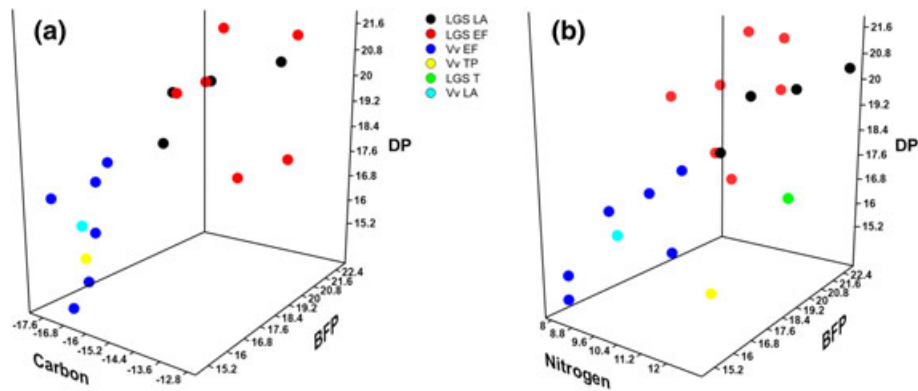


Figure 6. (a) 3D Scatter plot of BFP and Dp (mm) measurements of the anterior first phalanges and  $\delta^{13}\text{C}$  isotopic values, (b) 3D Scatter plot of BFP and Dp (mm) measurements of the anterior first phalanges and  $\delta^{15}\text{N}$  isotopic values. LGS, large group size; LA, Late Archaic; EF, Early Formative; T, Transition; BFP, Breadth of the Facies articularis proximalis; Dp, Depth of the proximal end. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

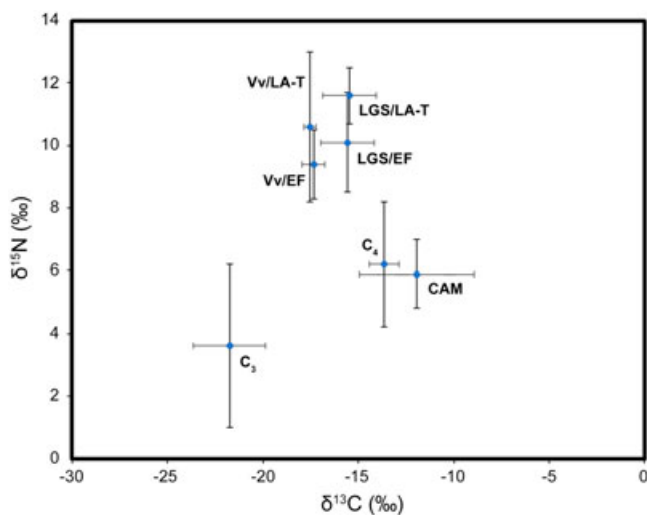


Figure 7. Scatter plot of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for plants located between 2500 and 4500 m (data taken from Díaz *et al.*, 2016) associated with the values obtained from camelid bones of the Tulan transect. LGS, large group size; Vv, *Vicugna vicugna*; LA, Late Archaic; EF, Early Formative; TP, Transition Phase. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

## Discussion and conclusions

In the case of *Vicugna vicugna* specimens, the combined osteometric analysis and isotopic values indicate less variation in this group compared with the larger sized camelids across sites and periods. In the case of  $\delta^{13}\text{C}$  values, for the Late Archaic-Tarajne phase and the Early Formative, the group of vicuñas presents similar consumption of  $\text{C}_4$  and  $\text{C}_3$  type plants and more homogeneous values. In contrast, the large-size camelid group shows greater osteometric and isotopic variability over sites and periods, with more  $\text{C}_4$  type plants in their diet, with the Early Formative values being most diverse.

As for  $\delta^{15}\text{N}$ , during the Late Archaic-Tarajne phase, the values for vicuñas are extremely variable compared with the vicuñas of the Early Formative; this may be due to the small sample size, and/or the presence of animals from different territories. In the large-size camelids group, the differences between the Late Archaic-Tarajne phase and the Early Formative are minimal, although the values for the latter period display greater variation (Figure 7). According to data published by Díaz *et al.* (2016),  $\delta^{15}\text{N}$  values of the samples from Tulán are associated with plants that grow up to 3500 m.a.s.l. In this regard, De Niro (1988) attributes high  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values among camelids from La Paloma and Chilca (Peru) to the consumption of non-terrestrial resources such as marine plants and vegetation growing along the banks of rivers and/or the shores of lagoons and saltwater lakes (see also Thornton *et al.*, 2011). These kinds of environments can be found in the Tulan Ravine and in the Miñiques and Miscanti lagoons. As for marine plants, the extremely arid desert and remote inland location would have made it extremely difficult to drive herds of animals from Tulan to coastal areas for grazing alone.

One of the difficulties we encountered in this study was differentiating domestic camelids from their wild counterparts within the large-size group, where we can only visualise trends and changes in size variability. By the same token, the correlation analysis between BFP measurements and  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  isotopic values for all first anterior phalanx yielded significant positive results, especially in the relation between size and  $\delta^{13}\text{C}$  values ( $r_s = 0.572$   $p \leq 0.004$  in the case of  $\delta^{13}\text{C}$  and  $r_s = 0.524$   $p \leq 0.010$  for  $\delta^{15}\text{N}$ ;  $n = 23$ ), that is, the larger the size, the higher the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  isotopic values. Considering the increased variability and the presence of more large-sized animals (in the upper range), which may reflect sustained breeding and selection practices

over time, this isotopic variability could be the result of animal husbandry. During the Late Archaic, flock animals were kept near settlements such as Tulán-52 in the Tulán Ravine, favouring local feeding areas in a pattern that remained stable between 5000 and 3800 BP. During the Early Formative, the consolidation of herding practices (complemented by vicuña and guanaco hunting) led to more extensive use of different pasture areas along the transect. This can be explained primarily by the greater integration and participation of individuals in pastoral practices, which led to an increase in the number of managed animals.

Although evidence from the highlands is scant, excavations at the Meñiques-1 site (4100 m.a.s.l.) indicate a Late Archaic occupation dated to  $5470 \pm 60$  BP (non-cal. date) and an undated Early Formative reoccupation (Núñez *et al.*, 2005). The location of the Formative settlements of the transect coincides with the distribution of settlements used until recently by the last remaining herders of the present-day village of Peine. These herders follow a pattern similar to that observed in other areas like the Puna of Jujuy (Argentina), where residential and temporary sites are used seasonally (Yacobaccio *et al.*, 2010). More in-depth comparisons with nearby areas should provide a better understanding about the increasingly complex use of space by early pastoral groups.

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