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‘To and fro’ the southern Andean highlands (Argentina and Chile): Archaeometric insights on geographic vectors of mobility

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A B S T R A C T

The Andes mountain range is one key physiographic feature of South America with the potential to have acted as a barrier and corridor for human societies. The goal of this paper is to assess from where and how were the highlands utilized during the last 2000 years, which is a key period witnessing the development of productive economies and changes in the organization of mobility. We develop a regional case study focused on the highland wetland Laguna del Diamante (3300 masl), which is a highly productive ecosystem only accessible during summer. This case is based on a multidisciplinary approach combining: a) geochemical characterization of obsidian sources located in the highlands and artifacts; b) isotopic approach to ranges of paleomobility of individuals by means of $^{87}Sr/^{86}Sr$; and c) stylistic study of ceramic assemblages.

The two main obsidian types from the highlands have restricted and decaying spatial distribution, suggesting that these archaeological distributions track part of human circuits of mobility instead of indirect transport acquisition. Their archaeological distribution is heavily skewed towards the western Andean slope. We present strontium isotope values for four teeth and bone samples from two individuals recovered in the area, which are interpreted in reference to a preliminary baseline of biologically available strontium. We infer that these individuals had ranges of paleomobility systematically connecting the western slope with the highlands. The analysis of the ceramic assemblages shows that most of the diagnostic sherds can be assigned to styles that have distributional cores in the Central Valley of Chile up until the time of Inca presence, while only a minimum portion of the sample can be assigned to distributional cores on the eastern slope. By integrating the patterns in the transport of obsidian and ceramic artifacts and the paleomobility of individuals, we find support for the existence of dominant access to the highlands from the western Andean slope. A GIS-based analysis of the seasonality of precipitation shows that the western slope presents more pronounced and drier summer months, providing a context that contributes to explain these patterns. These results contradict previous interpretations suggesting that the archaeological record from the highlands is more directly tied to human groups inhabiting the eastern lowlands during most of the year. Beyond the geographic debate, this issue has an impact on the subsistence organization of the incoming groups, on the socio-economic role of the highlands, and on the demographic contexts leading to trajectories of economic intensification in both Andean slopes. This research contributes to build a framework for comparative research on human use of highland environments.

1. Introduction and goals

The Andes mountain range is one of the key physiographic features of South America, extending 7500 km along the western margin of the continent, from 10° N in Colombia to 53° S in Tierra del Fuego Island (Clapperton, 1993). In this paper we focus in a segment of the southern Andes (Argentina and Chile, 34°S), with mean altitudes above 3000 masl. At this latitude, the Andes constitute a topographic wall

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to atmospheric circulation, establishing contrasting patterns in the amount of precipitation and the structure of phytogeographical communities on both slopes (Garreaud et al., 2009). From the perspective of human biogeography, the high altitudes combined with macro-regional climate patterns (Garreaud et al., 2009) allow access to the Andean highlands basically during the summer season, whether for intermountain mobility, hunting and/or herding activities in highly productive summer ecosystems, lithic provisioning, flow of information, and exchange of material goods. This formidable geologic structure has the potential to have variably acted as a barrier and corridor for human societies through time.

The patterns of human use of the Andes have been a central topic in the archaeology of western South America for decades (Aldenderfer, 1998; Capriles et al., 2016; Durán et al., 2006; Lagiglia, 1997; Murra, 1972; Neme, 2016; Rademaker et al., 2014). In this context, the general goal of this paper is to *assess from where and how were the highlands utilized during the last 2000 years*, which is a key period witnessing the development of productive economies, the introduction of ceramic technology, and significant changes in the organization of mobility (Gil et al., 2015; Sanhueza and Falabella, 2010).

While the highlands may have been likely accessed and occupied from different areas in both slopes, dominant geographic vectors of access may emerge under specific conditions. Considering the existence of striking biogeographic and socio-demographic differences between both Andean slopes, the issue of the spatial source(s) of human groups occupying the highlands becomes significant. In this context, we will assess the existence of dominant geographic vectors of access to the highlands (Cortegoso et al., 2016). We develop a regional case focused on the Laguna del Diamante area, which is a wetland located at 3300 masl with a key position in intermountain mobility paths (Mendoza Province, Argentina, Fig. 1). We articulate three lines of research: a) Geochemical characterization of obsidian sources and artifacts focusing on two chemical types identified in Laguna del Diamante (Durán et al., 2012); b) Isotopic approach to ranges of paleomobility of individuals recovered at the only mortuary site (LD-S13) recorded in this highland locality; and c) Stylistic composition of ceramic assemblages and their likely place of provenience. Each of these archaeological proxies sheds light on different levels of the complex social webs of trans-Andean interaction. If utilized in combination, these proxies provide a robust strategy of wide methodological value.

2. Environmental setting and archaeological background

2.1. Environmental setting

The macro-region of study extends from the Pacific coast in Chile to the central western Argentinean lowlands, including a segment of the Andes mountain range of Argentina and Chile (34°S) with mean altitudes above 3000 masl and a width of ca. 150 km. The interaction of the westerly storm-tracks with the Andes results in an orographic rain-shadow effect that produces a strong west-east decrease in precipitation (Garreaud et al., 2009). Rainfall decreases with altitude on both sides of the Andes and vegetation distribution follows this gradient (Abraham et al., 2009; Muñoz-Schick et al., 2000).

The highlands are characterized by large amounts of precipitation occurring mostly in winter and by the presence of localized wetlands with high quality summer pastures that attract wild camelids and bird communities seasonally. This is the case of the Laguna del Diamante (Fig. 2), which forms a part of an annual migratory round of modern guanaco (*Lama guanicoe*) populations (Puig et al., 2011). Very dry summer seasons characterize the Pacific-dominated western slope, while summer precipitation is largely confined to the eastern flanks of the Andes, produced by moisture of Atlantic source (Hoke et al., 2013). While there is marked interannual variability in the snowpack in the highlands (Masiokas et al., 2012), the nivometric records for Laguna del Diamante indicate a mean winter cover of 453 mm for the period 1956–2014 (Pronóstico de Escurrimientos, 2015).

2.2. Archaeological background

The region witnessed a number of key historical processes beginning with the initial human colonization during the Pleistocene-Holocene

Fig. 1. Laguna del Diamante study area (obsidian sources shown).

Fig. 2. Environmental setting of Laguna del Diamante wetland (Maipo volcano is visible on the back).

transition (García, 2003), mid-Holocene occupational troughs (Méndez et al., 2015; Neme and Gil, 2008), the southern dispersion of productive economies during the late Holocene (Gil et al., 2015; Sanhueza and Falabella, 2010), and the presence of the Inca empire just before the time of the Hispanic colonization (Cornejo, 2014; Marsh et al., 2017). During the last 2000 years, at this latitude the Andes presented a complex mosaic of societies that displayed diverse socio-economic strategies combining to different extents hunting and gathering, small scale agriculture of maize (*Zea mays*), quinoa (*Chenopodium* spp.), beans (*Phaseolus vulgaris*), and squash (*Cucurbita* spp.) (Lagiglia, 2001; Planella et al., 2011). This is particularly evident when comparing the archaeological record from the two slopes, which differ not only in terms of climate, but also in key physiographic properties including amount of available space and terrain ruggedness.

On a local scale, human use of the Laguna del Diamante wetlands since the early Holocene is demonstrated by the presence of obsidian assigned to the Arroyo Paramillos type in sites from lower-altitude settings in both slopes (Cortegoso et al., 2012; Neme et al., 2011). Despite this record, the evidence recovered in the highlands of Laguna del Diamante shows a visible archaeological signature beginning only at 2100 years BP (Durán et al., 2006), at a time when there is a marked increase in the number of archaeological sites across the Andes, as well as a regional pulse in the use of obsidian types from the highlands (Cortegoso et al., 2016). Remarkable technological changes are recorded slightly before this time, including the use of bow and arrow and the introduction of ceramic technology (Sanhueza et al., 2003). The record from Laguna del Diamante shows a homogeneous composition of faunal assemblages pertaining to the last 2000 years, relying on the hunting of locally available guanacos and birds (Durán et al., 2006). A striking aspect of the record from the highlands is the presence of small stone enclosures associated with ceramics and grinding tools (Durán et al., 2006). The investment of energy and the diachronic tempo of formation of these sites would imply planned seasonal occupation of the highlands, probably organized logistically (Durán et al., 2006). Several sites recorded for the last 2000 years display architectural investment, in some cases involving the diachronic construction of tens of small habitation structures, such as in the impressive records of El Indígeno and Risco de los Indios sites in the upper basin of the Diamante River in the eastern slope of the Andes (Lagiglia, 1997; Neme, 2007; Neme et al., 2016), or those from the upper Maipo basin, in the western slope (Cornejo and Sanhueza, 2003, 2011).

This late Holocene record from the Andean highlands of Mendoza and Central Chile has triggered a number of issues that continue to be discussed. Considering that the settings above 3000 masl present a deep snow cover during winter (Capitanelli, 1972; Pronóstico de Escurrimientos, 2015), they would not be appropriate to sustain year round occupation. In this context, a first issue has been related to the *geographical source*(*s*) *of the human groups occupying them through time* (i.e., their winter residence places). This issue, in turn, influences on other aspects of this process: the economic strategies that these incoming groups deployed year round and the long-term demographic trends that set the context for the systematic or 'effective occupation' (sensu Borrero, 1994–1995) of the highlands.

Lagiglia (1997) and Neme (2007) have suggested that the groups that occupied the highlands seasonally had a hunter-gatherer organization and inhabited the eastern lowlands during the winter. Regarding the long-term trends, Neme (2007) has suggested that these occupations occur only during the late Holocene in association with a process of demographic growth and economic intensification taking place in the eastern lowlands (though see Neme, 2016, for a more flexible view on this issue). Cornejo and Sanhueza (2003, 2011) have suggested that hunter-gatherers from the western intermountain valleys occupied the highlands. Their argument implies that the societies inhabiting the western lowlands of Central Chile during the Early Ceramic Period, so called Bato and Llolleo, which were characterized by mixed economies including horticulture and produced ceramics on a domestic scale (Falabella and Sanhueza, 2005–2006; Falabella and Stehberg, 1989; Planella et al., 2011; Sanhueza and Falabella, 2009, 2010), did not occupy the highlands on a regular basis.

3. Methods

3.1. Obsidian geochemistry and archaeological distributions

Three different x-ray fluorescence (XRF) spectrometers were used to perform the non-destructive measurements of archaeological artifacts: two energy-dispersive XRF (Elva-X table top and Bruker III-V portable from the University of Missouri Research Reactor), and a wavelength-dispersive XRF (Philips PW 1480 from the University of Calabria). This equipment allows characterizing artifacts ≥ 1 cm. The data for the archaeological sites was compared with the results of source characterization performed with traditional XRF (De Francesco et al., 2006; Durán et al., 2012) and with previous results obtained with Neutron Activation Analysis (NAA) (Giesso et al., 2011). The two laboratories involved calibrated the results. Technical aspects regarding the discrimination of the sources and chemical types have been the focus of previous papers (Cortegoso et al., 2014; Giesso et al., 2011).

For the analysis of the spatial distribution of obsidian artifacts we use density analysis. The concentration of artifacts is calculated and represented as spatial clusters using the Kernel Density Estimation (KDE) method (Wheatley and Gillings, 2002). The maps show distributional cores of different sizes according to the density of materials and a color spectrum of spatial densities for the sources compared. Data were classified through an equivalent-intervals method that quantifies artifacts per km^2 in a 905.000-km^2 area.

3.2. Bioarchaeology and stable isotopes

The burial site LD-S13 contained only mandible remains plus one rib. Oral health was analyzed by macroscopic observation recording the presence of caries, abscess, and ante mortem dental loss utilizing standard methods (Buikstra and Ubelaker, 1994; Hillson, 2005). Dental wear was analyzed following Smith (1984) for anterior teeth and Scott (1979) for posterior teeth (see also Hillson, 2005; Ortner, 2003).

The samples for isotopic analysis were processed at the Archaeological Chemistry Laboratory in the School of Human Evolution and Social Change, Arizona State University. Strontium isotope sample preparation and analysis were performed at the W.M. Keck Foundation Laboratory for Environmental Biogeochemistry at Arizona State University. The strontium was separated from the sample matrix using EiChrom SrSpec resin based on published methodologies (Knudson and Price, 2007). The enamel samples were analyzed with the Neptune multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS). Sample concentrations were analyzed by a Thermo Scientific iCAP Qc quadrupole ICPMS with a 100 µl per minute nebulizer and a Peltier cooler.

Archaeological hydroxyapatite carbonate ($\delta^{18}O_{carbonate,}$ $\delta^{13}C_{carbonate}$) samples that were prepared at ASU were then analyzed at the Colorado Plateau Stable Isotope Laboratory at Northern Arizona University following Koch et al. (1997). Samples were analyzed using a Delta V Advantage isotope ratio mass spectrometer equipped with a Gas Bench II. International standards NBS-18 and NBS-19 were used to create the calibration curve. Oxygen and carbon isotope ratios ($\delta^{18}O_{carbonate,}$ $\delta^{13}C_{carbonate}$) are reported relative to the V-PDB carbonate standard and are expressed in per mil (‰).

3.3. Ceramic analysis

A total of 15 archaeological sites have been studied for Laguna del Diamante, most of which correspond to simple stone enclosures (Fig. 3). In this paper we present the analysis of the Laguna del Diamante site 4 (LD-S4, 3290 masl), which is selected because it provides the largest ceramic assemblage from surface and stratigraphy (N = 193) and the longest temporal sequence that encompasses the full ceramic period. The site LD-S4 consists of a stone enclosure that was fully excavated (context in Durán et al., 2006). The site was excavated in artificial levels of 5 cm, reaching a maximum depth of 60 cm. Three radiocarbon dates and contextual and stratigraphic information allow building a temporal sequence of site formation based on three archaeological components encompassing the last 1000 calendar years (Durán et al., 2006).

We focus on the identification of the local and non-local styles on the basis of diagnostic surface decoration choices and technical decisions that have been thoroughly characterized on both Andean slopes (Cornejo and Sanhueza, 2011; Frigolé, 2017; Lagiglia, 1997; Sanhueza and Falabella, 2009).

4. Results

4.1. Obsidian geochemistry and archaeological distributions

Laguna del Diamante and Arroyo Paramillos are the two northernmost obsidian chemical types known for the macro-region of study –34°/37°S– (De Francesco et al., 2006; Durán et al., 2004, 2012). These sources are located within a large volcanic caldera at ca. 3200 masl (Fig. 1), and are thus accessible accessible only during the summer season. The nodules assigned to the Laguna del Diamante chemical type appear scattered within the caldera with the highest concentrations recorded for Las Numeradas Creek (Fig. 3). There is a decrease in the size of nodules from the rim of the caldera (up to 40 cm) towards the low-lying lakeshores (∼2 cm). The Arroyo Paramillos chemical type has only been recorded in the field as small nodules of ∼2 cm. Although several surveys were conducted to locate the main location of this source, it has not been located yet. Chemical characterization and differentiation of this chemical type was largely conducted by means of XRF analysis of artifacts recovered around Laguna del Diamante (Cortegoso et al., 2014). Recently, we recorded the presence of obsidian nodules of ∼3 cm along the major axis in the upper Maipo River basin, immediately southwards from San José Volcano, which are assigned to a third chemical type currently known as Nieves Negras (Cornejo et al., 2017). This alternative source is located some 40 km from Laguna del Diamante (Fig. 1).

Next, we characterize the archaeological distributions of these obsidian types in the study area by means of the Kernel Density Analysis (KDA). The sample from Laguna del Diamante represents ca. 50% of the obsidian assemblage from the four studied sites (LDS2, LDS4, LDS13, and Las Numeradas). For the Maipo basin, on the other hand, the sampling is at a preliminary stage.

The total of artifacts from the macro-region that have been assigned to these types is 472 (Cortegoso et al., 2016; Durán et al., 2012; Giesso et al., 2016). The Arroyo Paramillos type is the most represented (N = 299). Of this set, 46% of the artifacts are located within Laguna del Diamante area itself, providing circumstantial evidence that the main area of availability could be located nearby the lagoon. A secondary focus of distribution is recorded along the upper basin of the Maipo River in the western slope of the Andes, also reaching low altitude-settings (40% of the artifacts recorded for 18 archaeological sites). Interestingly, while human presence has only been recorded for the last ca. 2100 years in Laguna del Diamante, the archaeological findings from the western slope span the Holocene (Cortegoso et al., 2016; Durán et al., 2012; Giesso et al., 2011). On the other hand, only six samples of Arroyo Paramillos obsidian have been recorded from the eastern slope and lowlands, basically along the Diamante River basin, plus some isolated findings from other contexts at greater distances (Fig. 4).

A total number of 159 artifacts represent the Laguna del Diamante chemical type. This type has a very restricted spatial distribution, since 151 come from the lagoon basin itself, while another eight were recorded in nearby sites in the western Andean slope (Fig. 4). Five of these artifacts come from the sites in the upper Maipo River basin between 1500 and 2200 masl (Las Cortaderas 2, Las Morrenas 1, and Los Queltehues). Considering that some of these sites are characterized by difficult access, reduced space available for human occupation, and low density of materials, they are interpreted as ephemeral occupations by groups spending most of their time at lower altitudes in the western Chilean valleys (Peralta and Salas, 2004).

Only 14 artifacts have been assigned to the Nieves Negras type: 11 of them come from three sites in Laguna del Diamante, one of which is a large core recovered in a cache within a circular stone enclosure; three samples come from sites in the Upper Maipo River basin, between 1500 and 3500 masl (Los Queltehues and Las Perdidas sites).

4.2. Bioarchaeology, biologically available strontium and stable isotopes

In 2013 we excavated a 1 × 1 m quadrat in LD13 site, a small shelter below two large erratic boulders where we recovered the partial remains of two adult individuals (Figs. 3 and 5). Only two mandibles and a small rib fragment represent these two individuals. The absence of most of the anatomical elements could be due to their relocation within the site by natural processes, though a larger excavation is

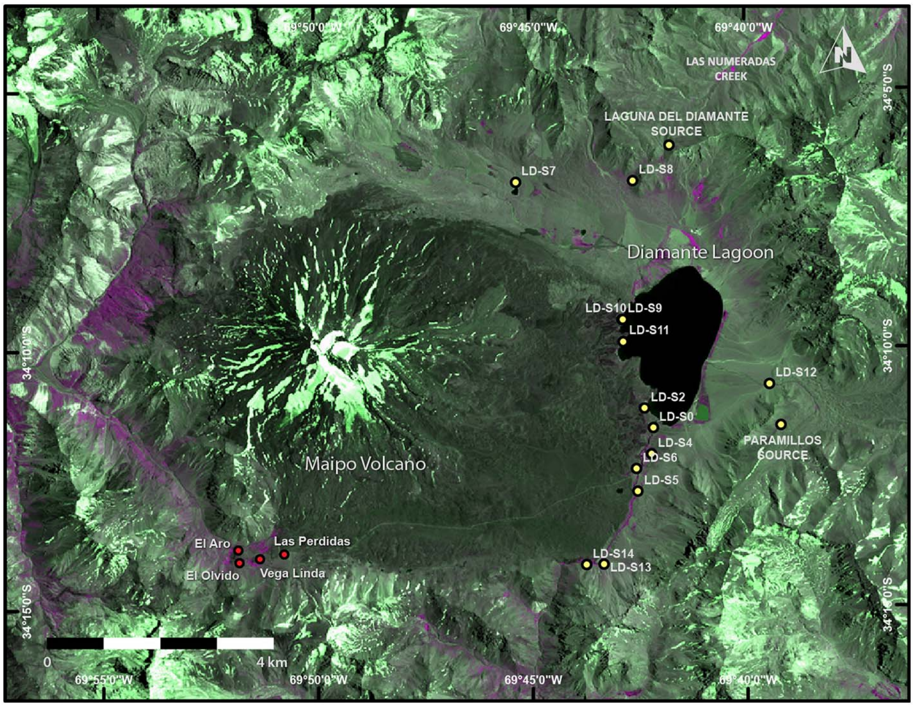

Fig. 3. Archaeological sites and obsidian sources studied for Laguna del Diamante. Reference: yellow dots are located in Argentina and red dots in Chile. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

needed to confirm this. Individual 2 was directly dated producing a ^{14}C age of 1561 ± 44 (AA-103146, calibrated range: 1520–1310 cal years BP). Based on an immediate contextual association of the individuals in the same pit and stratigraphic layer, we consider that this date would also be valid for individual 1.

Individual 1 is an adult (35–49 years) of undetermined sex represented by a poorly preserved mandible with eight dental elements. Five dental elements were lost ante-mortem, showing different degrees of reabsorption. Tooth wear could be measured in six elements of this individual, showing severe wear in three anterior teeth (6–8°, sensu Smith [1984]), two of which have a 25% of the pulpar cavity exposed. The molars show moderate wear corresponding to 26–31° (sensu Scott,

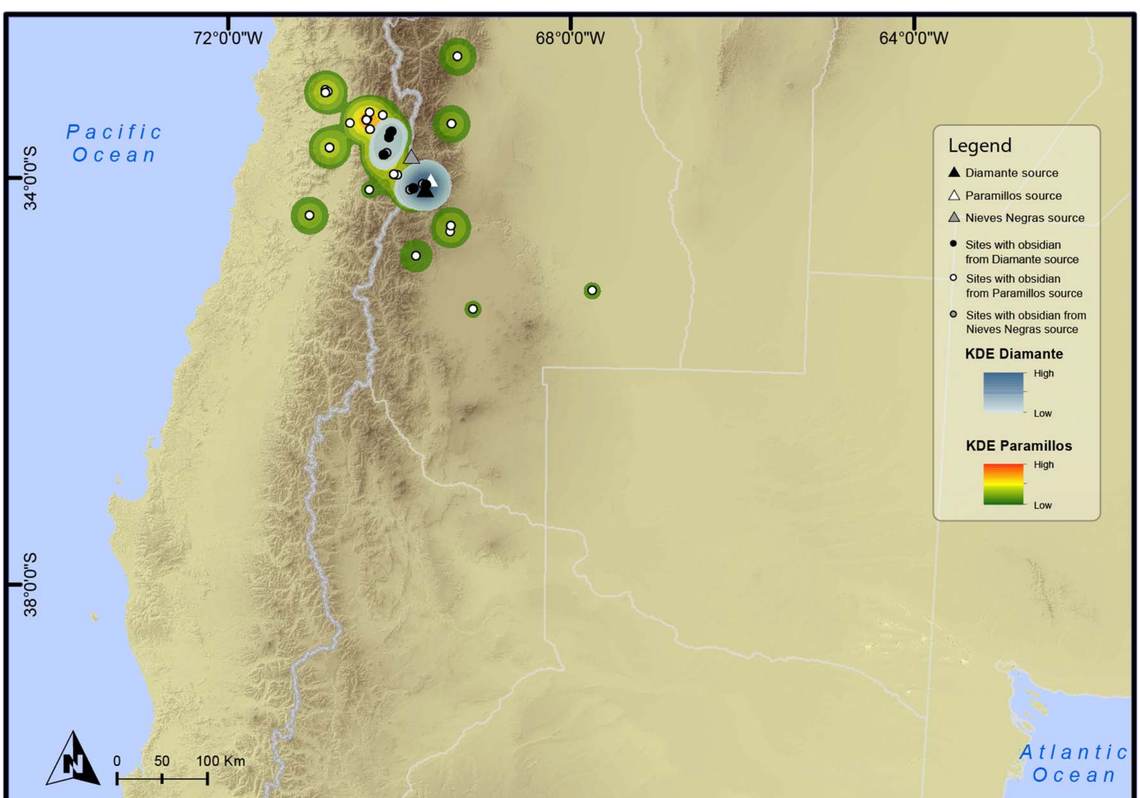

Fig. 4. Kernel density analysis of the spatial distribution of the obsidian types Arroyo Paramillos, Laguna del Diamante, and Nieves Negras.

Fig. 5. LD-S13 archaeological site.

1979). Two caries were recorded in both the left and right M1. Individual 2 is also an adult (35–49 years) of undetermined sex. It is represented by a mandible with 12 dental elements with no evidence of ante-mortem dental loss. Due to post-mortem enamel breakage, tooth wear could only be measured in seven teeth. The anterior teeth show weak-moderate wear (2–4), as do the posterior teeth (12–17°). Two caries were recorded. Comparatively, individual 1 shows higher tooth wear and ante-mortem dental loss, which could be related to the severe wear manifested in the pulpar exposure.

We present stable isotope analyses on the apatite fraction of tooth and maxilla samples from the two individuals, including $^{87}Sr/^{86}Sr$, $\delta^{18}O_{carbonate(V\text{-}PDB)}$, and $\delta^{13}C_{carbonate(V\text{-}PDB)}$ (Table 1). The two first isotopic proxies allow tracking place of residence (Knudson and Torres-Rouff, 2014; Pellegrini et al., 2016), while $\delta^{13}C$ informs on the isotopic composition of the total diet –proteins, lipids, and carbohydrates (Ambrose and Norr, 1993).

The $^{87}Sr/^{86}Sr$ values are interpreted on the basis of a geological framework that has been already presented (Barberena et al., 2017), which defines the main geological units of relevance for the study of human paleomobility: eastern lowlands (Quaternary sediments, < 1000 masl), eastern valleys (Permian-Triassic igneous rocks, 1000–3000 masl), Andean highlands, where Laguna del Diamante is located (Cretaceous sedimentary rocks, 3000–6000 masl), and western valleys (Cretaceous and Miocene volcaniclastic rocks, 2500–800 masl) (Fig. 6). Information for seven rodent samples from different localities across the Andes was also presented, as well as data already available for soil samples from the eastern lowlands (Di Paola-Naranjo et al., 2011) and human samples from intermountain valleys in El Mauro, Chile (Gómez and Pacheco, 2016). The result for one rodent sample from Laguna del Diamante provides a first assessment of the locally bioavailable strontium (Price et al., 2002), showing a value that is considerably higher than those from the Chilean valleys. This is compatible with the Jurassic-Cretaceous age of the bedrock dominant in the area. It is necessary to assess the incidence of the Pliocene-Quaternary volcanic rocks that outcrop locally (Sruoga et al., 2005) in bioavailable strontium values.

The four human samples from Laguna del Diamante site 13, corresponding to bone and teeth from the two individuals recovered, have similar $^{87}Sr/^{86}Sr$ values compared to each other, though they are depleted when compared to the local rodent sample (Fig. 6). Considering that these individuals would have spent the winter seasons in lower altitude-settings, the strontium values can be interpreted as showing an average of the signal from the highlands and the western intermountain valleys in Chile. The high values recorded for rodent samples in the eastern intermountain valleys and lowlands, widely separated from the values for human remains in Laguna del Diamante, suggest that these individuals did not spent significant amounts of time in the eastern Andean slope during their juvenile and adult lives.

The $\delta^{13}C_{carb\ (VPDB)}$ values for the four human samples, which provide an average value of total diet, indicate a diet largely based on the consumption of C_3 resources, with the exception of the PM2 sample from individual 2, which indicates a significant consumption of C_4 foods, very likely maize (see Gil et al., 2014). Interestingly, this individual would have had an isotopically enriched diet as a child (2–7 years) as indicated by a $\delta^{13}C_{carb\ (VPDB)}$ value of − 7.8‰, which shifted to a C_3-based diet during adulthood. This is consistent with wider tendencies presented by Gil et al. (2011, 1402) for the macro-region of Mendoza Province.

4.3. Ceramic assemblages: stylistic affiliation and spatial analysis

The ceramic assemblage from LD-S4 is composed of 193 sherds and

Table 1
Isotope results for a rodent sample and human remains from LD13 site.

Sample	Taxon	Element (+)	Sex	Age	Lab code	Ca/P	U/Ca	$^{87}Sr/^{86}Sr$	$\delta^{18}O_{carb}$ (VPDB)	$\delta^{18}Odw$ (VPDB)	$\delta^{13}C_{carb}$ (VPDB)
LD. Gendarmería	Rodentia (modern)	Bones	–	–	ACL-5426	NA	2.88E–07	0.70655	–	–	–
LD-S13 Individual 1	*Homo sapiens*	LC (0.3–7 years)	N D	35–49	ACL-5432	1.8	3.43E–08	0.70497	− 7.1	− 10.3	− 11.0
LD-S13 Individual 1	*Homo sapiens*	Maxilla	N D	35–49	ACL-5433	1.8	3.73E–08	0.70545	− 8.7	− 12.4	− 13.4
LD-S13 Individual 2	*Homo sapiens*	PM2 (2–7 years)	N D	35–49	ACL-5434	1.8	1.65E–08	0.70556	− 6.4	− 9.4	− 7.8
LD-S13 Individual 2	*Homo sapiens*	Maxilla	N D	35–49	ACL-5435	1.8	6.79E–08	0.70554	− 9.3	− 13.2	− 11.4

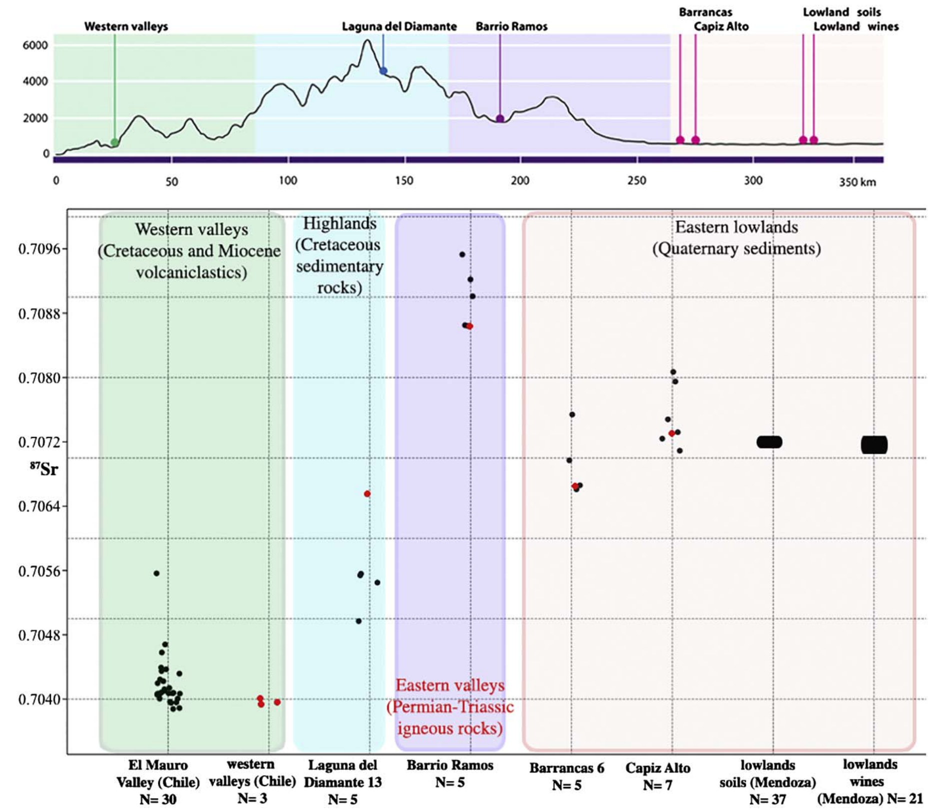

Fig. 6. ^{87}Sr/^{86}Sr values for fauna, human remains, soil, and wine samples. *References*: red dots indicate rodent samples; soil and wine samples are depicted as a range (source: Di Paola-Naranjo et al., 2011); values for the El Mauro Valley, Chile, from Gómez and Pacheco (2016). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2
Results of the ceramic analysis for LD-S4 site.

Surface treatment -decoration	Ceramic type -period	Main archaeological distribution	Component I				Component II			Component III					Total
			Level												
			S	1	2	3	4	5	6	7	8	9	10	11	
Red painting - black on red painting	Inka	Western slope	2	1	1	5	5	5	2	–	–	–	–	–	21
Red painting	Late Intermediate Period (Aconcagua)- Inka	Western slope	9	–	–	3	2	1	1	–	–	–	–	–	16
Burnished - incised	Early Ceramic Period - Llolleo	Western slope	4	–	1	1	2	–	2	7	18	8	3	1	47
Polished	Early Ceramic Period - El Molle	Western slope	–	–	–	1	1	–	–	–	–	2	2	–	6
Smoothed - incised	Middle Period	Eastern slope	–	1	–	–	1	–	–	–	–	–	–	–	2
Burnished	–	–	15	5	5	2	1	1	4	2	3	2	3	–	43
Smoothed	–	–	5	9	8	7	1	2	1	2	6	12	5		58
Total			35	16	15	19	13	9	10	11	27	24	13	1	193

shows a high degree of fragmentation, since 52% (N = 101) of the sample could not be attributed to known types. Accordingly, the following results are based on the remaining 48% (N = 92) that was assigned to known archaeological types (Table 2; Fig. 7). On the basis of the macro-regional structure of the ceramic record, these types can be respectively associated with either the western or eastern Andean slopes.

Of the 92 sherds assigned to known typologies, 90 (98%) correspond to types from central Chile and, to a lesser extent, the Norte Chico Chilean region. Only two sherds were clearly attributed to a type with a predominant archaeological representation in the eastern lowlands.

The sherds from the earliest assemblages, assigned to archaeological component III (levels 7 through 11), are mostly classified as 'Llolleo' (N = 37). Some polished types characteristic of the Norte Chico in Chile (El Molle) were also recovered in very low frequencies in this component, as well as in components II and I (Table 2). El Molle ceramics are characterized by polished and burnished surfaces, thin sections, and complex forms (Niemeyer et al., 1989). These could have been obtained by extra-regional exchange (Cornejo and Sanhueza, 2011; Frigolé et al., 2014).

The assemblages from the late components II and I are widely dominated by types with a core distribution in the western Andean slope, including the Early Ceramic-Llolleo and Inca-Aconcagua affiliated types (Table 2, Fig. 7). The Inca-Aconcagua types from Central Chile present different decorative patterns (Durán and Planella, 1989; Falabella, 1997; Sánchez and Massone, 1995). In LD-S4 we have recorded the variant with red external surface, as well as the internal brush in red and black on red-decorated ceramics, which is characteristic of Inca ceramics (Fig. 7). It is considered that these surface

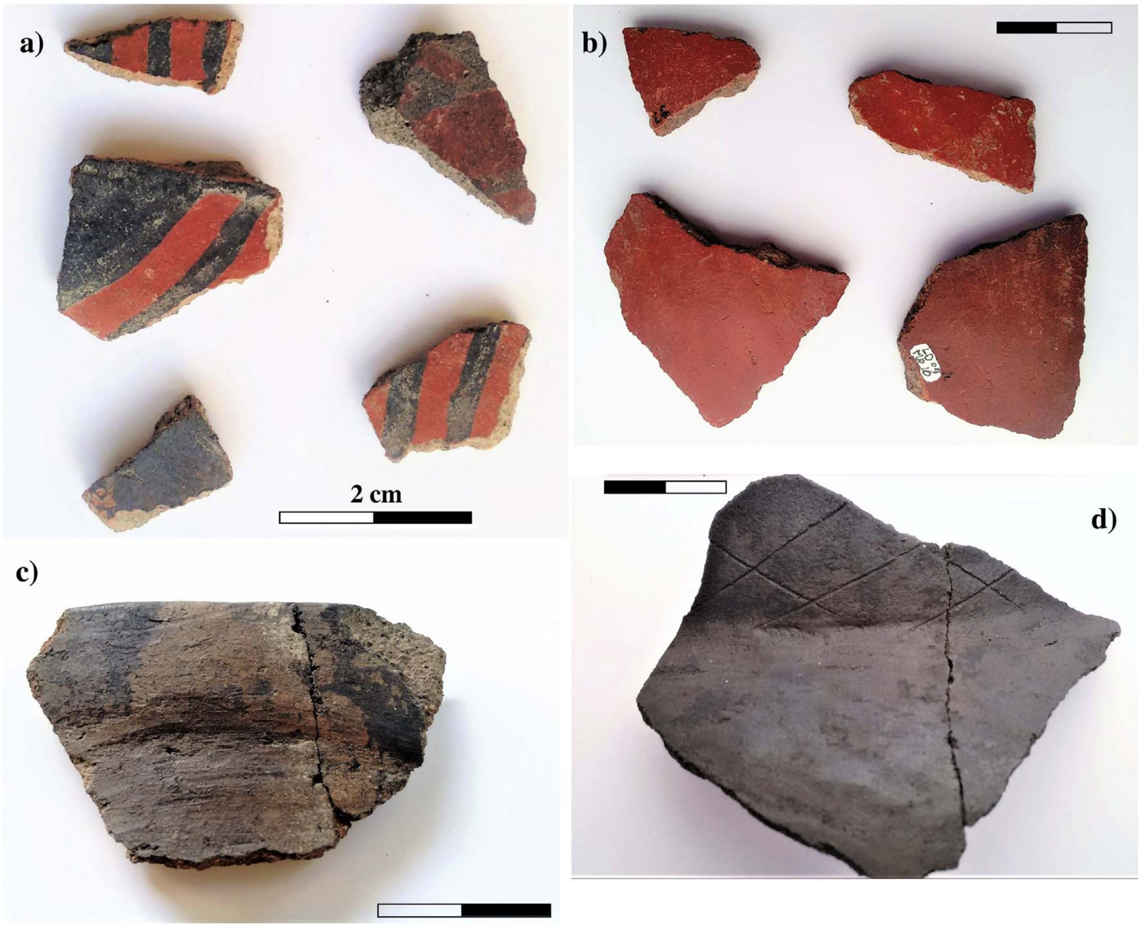

Fig. 7. Examples of the main ceramic types in the study area. References: a) Inca-Aconcagua black on red painting; b) Inca-Aconcagua red painting; c) Early Ceramic Period-Llolleo; d) Early Ceramic Period-Llolleo, burnished - incised. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

treatments were introduced in the Norte Chico and Central Valley of Chile during Inca times (Dávila Contreras, 2015; Pavlovic et al., 2001; Troncoso et al., 2004).

The Llolleo type is similar to that classified as the local style 'Overo' in the highlands of the eastern Andean slope (Lagiglia, 1997; see also Neme et al., 2016). Nevertheless, it is important to highlight that neither the external attributes nor fabric groups allow unambiguously distinguishing the so-called 'Overo' and 'Llolleo' types, sharing the surface treatments –smoothed, polished, and incised–, reinforced rims, and paste patterns (Sanhueza, 2004). In fact, analyses of the fabric groups in LD-S4 confirm the presence of the 'Llolleo' type (Cornejo and Sanhueza, 2011). The spatial distribution of Overo is restricted to an area of the highlands of southern Mendoza Province (Lagiglia, 1997; Neme et al., 2016), while Llolleo is widely represented in Central Chile from the highlands to the Pacific coast, presenting the highest densities in the lowland basins of the Maipo, Rancagua, and Cachapoal rivers (Sanhueza and Falabella, 2009).

5. Discussion: integrating biogeographic and archaeometric proxies

In the first place, we have synthesized the results of a long-term project on the geochemical characterization of obsidian sources and archaeological assemblages. The analysis focused on the highland sources in the region: Arroyo Paramillos, Laguna del Diamante, and Nieves Negras. Interestingly, when compared to other sources such as Las Cargas (Salgán et al., 2015), the cases treated here have spatially restricted and monotonically decaying distributions (Cortegoso et al., 2016). This substantiates the inference that these archaeological distributions track human circuits of mobility or home ranges, instead of alternative means of acquisition and transport of obsidian, such as exchange (Kelly, 2011). The kernel density analysis of the artifacts characterized by XRF reveals spatial distributions with a main core on the Laguna del Diamante area and heavily skewed towards the western valleys and lowlands with the Maipo River basin acting as a main geographic corridor (Fig. 4). On this basis, it can be suggested that the distribution of the artifacts assigned to the types available in Laguna del Diamante is asymmetrical between the two slopes of the Andes. While the chronological range of the sites containing these obsidian types in the western valleys of Chile spans most of the Holocene, the chronological record in Laguna del Diamante locality is restricted to the last 2100 years. The temporal structure of the archaeological record from the highlands may signal the establishment of recurrent seasonal movements to the seasonally productive patches within the highlands in the context of increasing 'territorial fidelity' (sensu Borrero, 2012; see also Neme and Gil, 2008). The evidence of recurrent occupations and architectural investment, which can be visualized as a form of built landscape (Martínez and Mackie, 2003), are the material expression of this behavior.

We have presented isotopic results for the site LD-S13 (1520–1310 cal years BP, see Fig. 5), which is the only human burial recorded in Laguna del Diamante. Strontium isotopes have the potential to shed light on the geographical source of individuals buried in the highlands. The results for teeth and bone samples of the two individuals represented have been interpreted in reference to a preliminary framework of biologically available strontium in the region (Barberena et al., 2017). These four isotopic samples represent windows to the life histories of these individuals (Knudson et al., 2012). The data are consistent with mobility circuits averaging the Andean highlands and the western valleys and lowlands, ruling out the possibility that these individuals spent significant amounts of time in the eastern lowlands (Fig. 6). The tooth sample from individual 2 has a $\delta^{13}C_{carb\ (VPDB)}$ value of $-7.8‰$, which indicates a significant amount of C_4 foods in its diet between, broadly, 2–7 years of age. While the paleodietary meaning of enriched ^{13}C values is currently being debated (Bernal et al., 2016; Llano and Ugan, 2014), it seems likely that maize contributed to this enriched value. The inference that this individual buried in the highlands during his old age would have consumed significant amounts of maize during childhood, so as to be recorded in the isotopic signal, opens a number of interesting scenarios regarding the economic organization of the groups occupying the highlands and dietary changes occurring along the life-histories of individuals, particularly if considering that this pattern of dietary change has been recorded more widely (Gil et al., 2011).

Finally, the ceramic analysis for the site LD-S4 shows that only the minimally represented smoothed-incised ceramic-type can be confidently associated with distributional cores in the eastern lowlands. The three archaeological components defined for this site reveal continuity in the representation of ceramic types with distributional cores in the western valleys and lowlands of Chile, specifically the Early Ceramic Period-Llolleo and Inca types (Fig. 7). As discussed in Section 4.3, the Llolleo ceramics have a distributional core in the Central Valley of Chile, likely in association to domestic production by horticultural societies (Falabella and Stehberg, 1989; Sanhueza and Falabella, 2009). Whether by direct access by these horticultural groups or by exchange with hunter-gatherer groups (Cornejo and Sanhueza, 2011), the dominant presence of these ceramic types in Laguna del Diamante would indicate a systematic connection with the western side of the Andes. The monotonic decay of obsidian abundance may be an argument in favor of a direct access to the highlands. The high proportion of Inca-affiliated sherds in the component I of LD-S4, on the other hand, can be related to the presence of large Inca sites in the western Andean slope (Cornejo, 2008, 2014), a situation that is not documented for the eastern valleys and lowlands.

Seasonality is the key issue to assess human use of the Andean highlands. We now turn to biogeographical information to situate human decisions of mobility and contextualize the archaeological patterns. In Fig. 8 we present a GIS modeling of the coefficient of seasonality from *WorldClim* (http://www.worldclim.org/bioclim), which suggests that the two Andean slopes have different degrees of seasonality in precipitations. The highest values in this index, identified in red, indicate the most heterogeneous precipitation throughout the year. This pattern is produced by the high summer aridity that is characteristic of the western Andean slope, which is subject to a Pacific-regime of winter precipitation (Garreaud et al., 2009; Hoke et al., 2013). This leads to the fundamental observation that the western slope presents the most demanding ecological conditions during the time-window when the highlands are available for human use. In the specific case of Laguna del Diamante wetland, the local availability of high-quality pastures would have attracted migrating populations of birds and wild camelids, such as recorded for modern populations (Puig et al., 2011).

6. Conclusions: geographic vectors of human access to the Andes

We have presented the results of a multidisciplinary project targeting the issue of geographic vectors of human access to the Andean highlands during the last 2000 years. While these lands were certainly accessed and occupied from diverse demographic nodes located in lower-altitude settings, we suggest that the combination of the spatial analysis of obsidian artifacts, ceramic types, and the range of paleomobility reconstructed for two individuals recovered from the highlands indicate the existence of dominant geographic vectors of access connecting this wetland with the western valleys and lowlands of Chile. The biogeographic analysis presented frames this inference, since the higher seasonality of precipitation would impose stronger summer constraints for human societies inhabiting those areas. This research contradicts previous interpretations suggesting that the archaeological record from the highlands is more directly tied to human groups inhabiting the eastern lowlands during most of the year (Neme, 2007; Neme et al., 2016). While not a part of the discussion developed here, the issue of geographical vectors is related to the subsistence organization of the groups accessing the Andes and, hence, on their socio-economic role of the highlands. One issue for future research stemming from this paper revolves around the ecological and demographic context leading to trajectories of economic intensification in both Andean slopes. From a theoretical (Foley, 2004; Nettle, 1998) and empirical perspective, we consider that the restricted amount of space available in the western slope due to the presence of topographic constraints versus the wider and less-rugged properties of the eastern

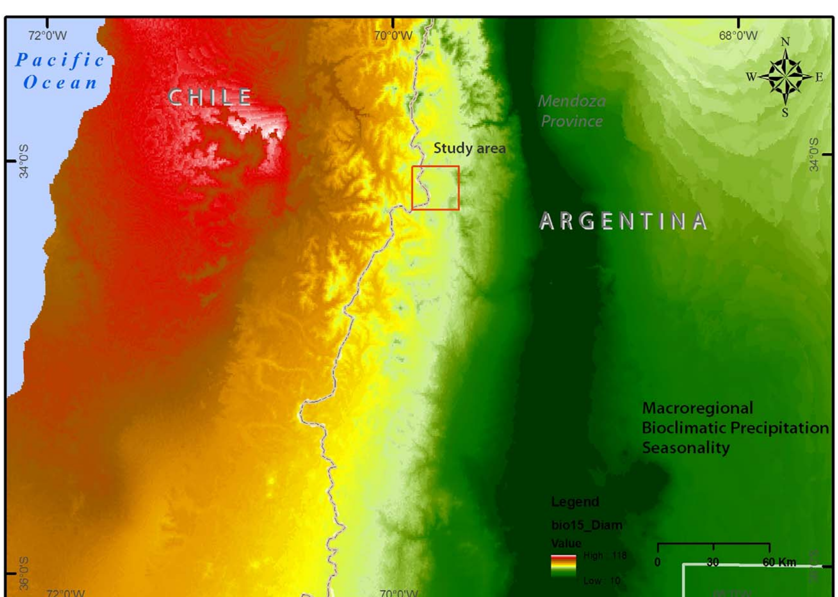

Fig. 8. GIS modeling of the *WorldClim* coefficient of seasonality in precipitations.

lowlands (Clapperton, 1993), point to the western valleys as the region where more intense experiences with economic intensification are most likely to occur during the late Holocene. In Binford's (2001) terms, these settings may have reached conditions of demographic packing earlier.

This research is relevant beyond the local scale of analysis. The combination of a biogeographic frame of reference with proxies informing on the transport of artifacts and the movement of individuals have the potential to reveal diverse facets of the complex webs of human spatial organization between highlands and their surrounding lowlands (Aldenderfer, 2011; Borrero, 2004; Capriles et al., 2016; Mitchell, 2009; Rademaker et al., 2012; Stewart et al., 2016). This contributes to build a framework for comparative research on human use of highland environments.

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