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ORIGINAL PAPER

Obsidian sources from the southern Andean highlands (Laguna del Diamante, Argentina and Chile): geochemical insights on geological complexity and human biogeography

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Abstract
New geochemical results for two obsidian types, Laguna del Diamante and Arroyo Paramillos, naturally available in the Laguna del Diamante locality, a seasonally accessible highland wetland emplaced in the current border between Argentina and Chile at 3300 masl (34°S), are presented. A total of 1219 archeological artifacts from 41 sites located on both sides of the Andes have been assigned to these sources. The artifacts were analyzed by non-destructive, energy-dispersive X-ray fluorescence (ED-XRF). Archeological distributions of these obsidian types are assessed through GIS spatial analysis. Results show a great asymmetry in the distribution of these sources toward the two Andean slopes: the Laguna de Diamante chemical type shows a fairly local use pattern, being concentrated almost entirely in Cordillera sites, but the Paramillos shows a less homogeneous distribution and tends to be more concentrated in the sites that are in the western natural corridor. Although these lands were accessed and occupied from diverse demographic nodes in lower-altitude settings, the spatial analysis of obsidian artifacts reinforces the argument of dominant geographic vectors of access connecting with the western valleys and lowlands of Chile.

Keywords Andean highlands · Diamante caldera · Obsidian geochemistry · GIS analysis · Human patterns

Introduction and goals

Obsidian was a highly valued material that was transported and exchanged by ancient societies worldwide. Owing to its homogeneous composition, it is traceable in space by means of geochemical analyses and has been broadly used globally to reconstruct the organization of technology, mobility, exchange, and trade (Cobean 2002; Dixon et al. 1968; Glascock et al. 1998; Hughes 1998; Eerkens et al. 2008, among others). In South America, there is evidence of obsidian use since the earliest stages of continental colonization, including the manufacture of fishtail projectile points (Rademaker et al. 2014; Miotti et al. 2012). In the central and southern Andes, obsidian has been used for over 10,000 years, largely but not exclusively fulfilling functional roles, because the maintenance of long-distance social ties and the inclusion in rituals have also been recorded (Burger et al. 2000; Campbell et al. 2017; Nami et al. 2015; Tripcevich and Contreras 2013).

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As part of this large-scale analytical movement, during the last two decades, we have developed a macro-regional program of obsidian source identification and characterization in the Andes of central Argentina and Chile (34°/37°S), articulating geoarcheological, geochemical, and archeological approaches (Barberena et al. 2019; Cortegoso et al. 2016; De Francesco et al. 2018; Durán et al. 2004; Giesso et al. 2011; see also Seelenfreund et al. 1996; Stern et al. 2012). These analyses involved the characterization of over 4000 artifacts by means of neutron activation analysis (NAA) and X-ray fluorescence (XRF). As a result, several primary and secondary sources have been identified encompassing from the Andean highlands to the dry regions in the Argentinean lowlands (Fig. 1). By tracking the spatial–temporal distribution of obsidian artifacts, we have been able to assess the scale(s) of past mobility and exchange and patterns and geographical vectors of seasonal access to the highlands (Cortegoso et al. 2016; De Francesco et al. 2018).

In this paper, we present new geochemical results for artifacts made on two obsidian chemical groups naturally available in the Laguna del Diamante, a seasonally accessible wetland emplaced in the highlands of the southern Andes of Mendoza Province, Argentina, at 3300 masl (34°S, Fig. 1). These chemical groups are known in the literature as Laguna del Diamante and Arroyo Paramillos, and owing to their geological and geochemical complexities, they have produced enduring debates regarding availability and patterns of transport (see Cortegoso et al. 2014, for an overview). These results are combined with those previously published and described by means of a kernel density analysis produced with GIS aiming at assessing the patterns of transport of these highland obsidians (Durán et al. 2004; Giesso et al. 2011).

Although these obsidian groups have not been widely transported owing to their medium-to-low quality compared with other sources (Cortegoso et al. 2016), they are emplaced in one of the most efficient trans-Andean routes connecting central Argentina and Chile (Cornejo and Sanhueza 2011), thus providing a key proxy of human access and settlement in the productive highland ecosystems. This analysis contributes to a wider regional issue on the organizational and geographical modes of highland–lowland articulation (Cornejo and Sanhueza 2011; Durán et al. 2018; Méndez et al. 2015; Neme et al. 2016), which converges with debates of human colonization and use of the world highlands (Rademaker et al.

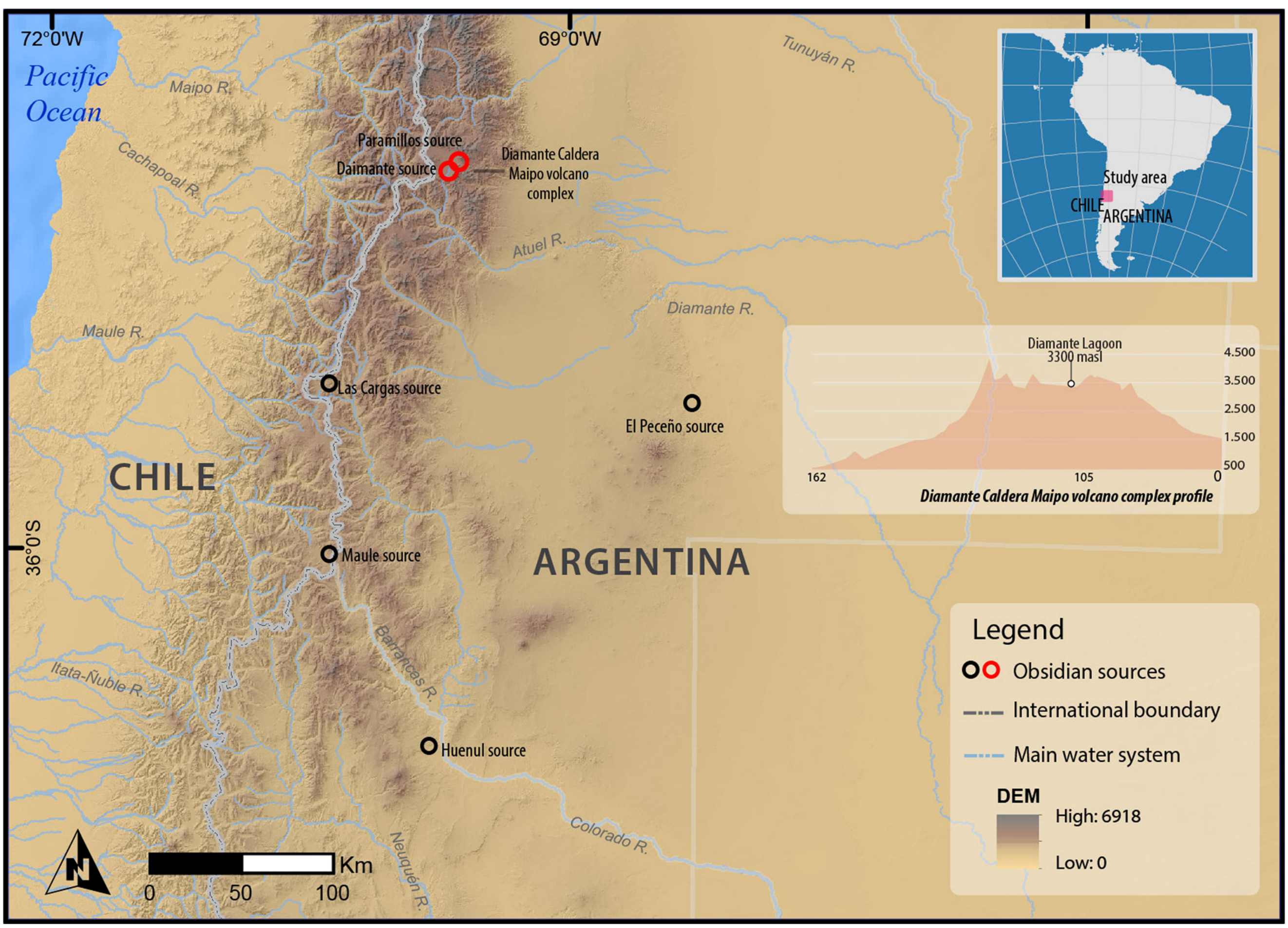

Fig. 1 Regional obsidian sources including Laguna del Diamante and Arroyo Paramillos

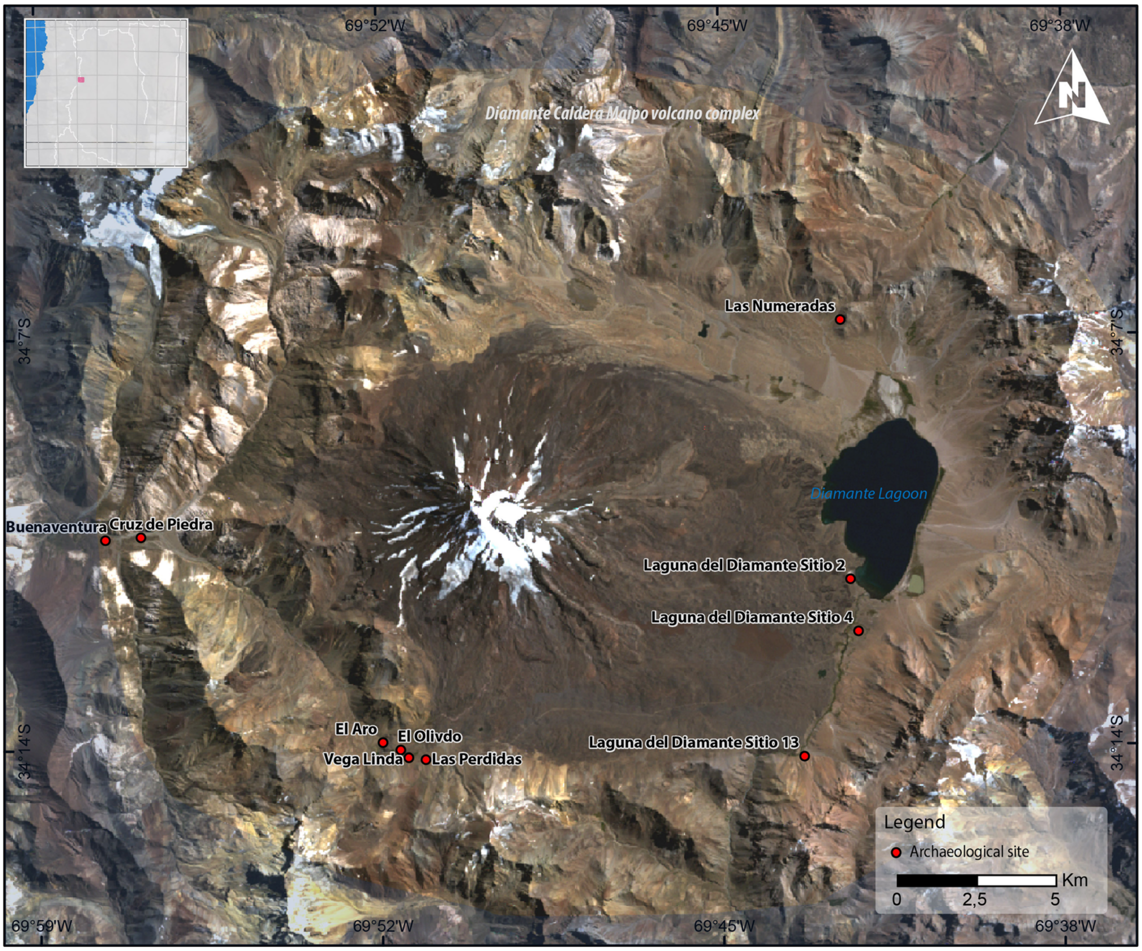

Fig. 2 Laguna del Diamante wetland and main archeological sites

2014; Capriles et al. 2016; Aldenderfer 1998; Stewart et al. 2016) (Fig. 2).

Geological and environmental setting and archeological background

The Laguna del Diamante environment

This is a highland wetland located at 3300 masl that is accessible for humans and other animal species only during the austral summer months, offering highly productive ecosystems that attract seasonally migrating birds, such as the Andean goose (piuquenes, *Chloephaga melanoptera*) and wild camelids (guanacos, *Lama guanicoe*) (Puig et al. 2011) (Fig. 3). The Laguna del Diamante is located within a volcanic old caldera of ca. 20 km diameter that includes the lake and the Maipo volcano (Fig. 2). The Diamante is a deep lake partially surrounded by a long stratigraphic sequence of lake sediments indicating past high-stands ca. 50 m above the current shoreline.

The Laguna del Diamante is fed by small streams draining from the edges of the volcanic caldera, of which the most important are the Arroyos Las Numeradas and Paramillos. On the other hand, the Diamante River drains the Laguna toward the southeast in the Argentinean lowlands, being one of the main fluvial systems in the Mendoza Province. As mentioned, the Laguna del Diamante is emplaced in the most efficient trans-Andean route connecting central Argentina and Chile, because it is at a lower altitude than alternative mountain passes, hence being available for circulation for a longer part of the year, it is wide and is characterized by a lower topographic gradient (Cornejo and Sanhueza 2011, see subsequent texts). The Maipo River basin connects the highlands with the western central Valley in Chile along 65 km (Börgel 1983).

Geological setting and local obsidian sources

The Diamante volcanic complex is located at the northern end of the South Volcanic Zone (Stern 2004). Its activity dates back to between 450/150 ky (Stern et al. 1984; Lara et al. 2008) and is marked by two main eruptive stages. Initially,

Fig. 3 Highland environment in Laguna del Diamante

the so-called "Diamante stage" occurred, which resulted in the collapse of the caldera. The collapse led to the expelling of ignimbrite deposits known as the Diamante Ashflow Tuff (450 ka), which covered a huge area of land that reached the central Valley of Chile and the eastern lowlands in Argentina (Stern et al. 1984; Harrington 1989). Afterwards, the "Maipo stage" took place with the occurrence of andesite-dacite stratocone-building lavas and pyroclastic sediments that formed a ring-fault dome and adventitious cones (100 ka) (Sruoga et al. 2005, 2012).

Two obsidian chemical groups have been recorded in geological deposits in the Laguna del Diamante locality, respectively known as the Laguna del Diamante and Arroyo Paramillos (Cortegoso et al. 2016; De Francesco et al. 2006, 2018). The Laguna del Diamante obsidian is available in the form of nodules of variable quality distributed along the high slopes around the lagoon, in the ravines converging in the lake, such as Las Numeradas stream, and in the lakeshores. There is a positive correlation between nodule size and altitude with the largest specimens, which can exceed 40 cm, available in the highlands around the lake up to 3800 masl. This obsidian often presents inclusions and devitrification leading to a non-isotropic mass that can be characterized as having medium to low knapping-quality (Cortegoso et al. 2016).

The Arroyo Paramillos chemical group partially overlaps with a non-local obsidian type at Las Cargas, located 100 km toward the southeast (Salgán et al. 2015). This led to incorrect artifact assignations and, as a consequence, misleading interpretations of artifact transport and human mobility (Giesso et al. 2011). Different analytical methods have been applied at the University of Missouri Research Reactor (MURR) (Giesso et al. 2011) and the Universitá della Calabria (De Francesco et al. 2006, 2018) in order to solve this geochemical equifinality (Cortegoso et al. 2014). We tackle this issue here on the basis of new geoarcheological and geochemical results.

The Arroyo Paramillos obsidian group has only been recorded in the field as small or medium nodules of 2 to 3 cm along the major axis; however, since we have observed the presence of artifacts larger than this size, we expect the presence of larger nodules in settings not yet located. There are also some macroscopic differences in these obsidians: the most abundant variant is opaque black and semi-translucent. The raw material is mainly of very good quality owing to its homogenous fracture and the absence of inclusions. During the recent field work, we have also noted the presence of medium-sized nodules in the matrix of ignimbrites deposited in the eastern rim of the Diamante caldera. These results were recently confirmed by INAA conducted by Glascock following the procedures outlined in Glascock et al. (1998), thus bolstering the argument of a local geological expression of the Arroyo Paramillos chemical group. However, they also indicate a complex volcanic history that requires an interdisciplinary approach.

Archeological background

Humans have occupied the mountain environments of central Chile and central-western Argentina since the late Pleistocene (Cornejo 2010; García 2003; Núñez et al. 1994). Mobile foraging was the dominant way of life for most of the Holocene, as revealed by diverse hunting weapon systems, the consumption of wild plants, such algarrobo (*Prosopis* sp.), and the hunting of the wild camelid guanaco (*Lama guanicoe*) (Cortegoso 2005; Frigolé and Gasco 2016; Llano 2015). There are indications of a major regional shift in human adaptations and practices beginning before 2000 years BP. First, domestic plants became a clear component of the material record, including maize (*Zea mays*), quinoa (*Chenopodium* spp.), beans (*Phaseolus vulgaris*), and squash (*Cucurbita* spp.) (Gambier 1988; Gil et al. 2006; Lagiglia 2001; Planella et al. 2011; Llano et al. 2017). Additionally, the presence of the domestic camelid llama (*Lama glama*) has been suggested at this time (Gasco 2013). Second, the earliest pottery appeared (Sanhueza and Falabella 2009; Marsh 2017). These processes appear to occur in the context of demographic increase (Gil et al. 2015). Interestingly, it is at this time that Laguna del Diamante is systematically seasonally occupied in order to produce a visible archeological signature (Durán et al. 2006, 2018). The Inca Empire arrived from the north at around 550 BP (Cornejo 2014). Finally, at Spanish contact, population density and social complexity were low compared with other areas of the Andes (cf. Stanish 2003).

Materials and methods

The artifacts were analyzed by non-destructive, energy-dispersive X-ray fluorescence (ED-XRF) using two different portable handheld instruments owned by MURR while on loan at the Universidad de Cuyo in Mendoza, Argentina, in two different opportunities (2014 and 2017). The source assignments involved comparisons between the compositional data for the artifacts and the MURR XRF obsidian database for sources in Argentina. As a result of this project, thousands of artifacts have been characterized by non-destructive methods. From a larger database reaching thousands of artifacts from Argentina and Chile, 1098 unpublished samples have been assigned to the sources Laguna del Diamante and Arroyo Paramillos: 271 in 2014 and 827 in 2017. The concentrations for all measured elements are provided in Supplementary Tables 1 and 2.

Importantly, from a methodological perspective and inherent to a long-term project involving analytical facilities, technical advancement has occurred in the field of analytical chemistry. Hence, comparability of the assignment results obtained through time is a fundamental issue. In the subsequent texts, we describe the technical aspects of the methods applied for the analysis of artifacts.

In 2014, ED-XRF was performed using a Bruker Tracer III-V handheld portable spectrometer. The Tracer III-V with rhodium tube was operated at 35 kV with a current of 17 microamps and a counting time of 3 min per sample. A copper–aluminum filter was used to reduce the background counts in the area of interest. The elements measured were Mn, Fe, Rb, Sr, Y, Zr, Nb, and Th. Calibration of the tracer III–V was accomplished from a suite of 40 obsidian sources (each 0.5 to 1 cm thick) from around the world with a wide range of concentrations previously determined by NAA, inductively coupled plasma-mass spectrometry (ICP-MS) and XRF (Glascock and Ferguson 2012).

In 2017, we utilized a Bruker Tracer-5i energy-dispersive XRF spectrometer. This instrument has a rhodium-based X-ray tube and thermoelectrically cooled silicon-drift detector (SDD). The X-ray tube operated at 50 kV with the current of 35 microamps. To reduce the background counts beneath the peaks for the mid-Z elements, a "green" filter (i.e., Cu 100 μm, Ti 25 μm, Al 300 μm) was placed between the tube and the sample. The X-ray beam passed through a 3 mm collimator before arriving at the sample position. Samples were analyzed for 1 min each to facilitate measurements for the following elements: K, Ca, Ti, Mn, Fe, Zn, Rb, Sr, Y, Zr, and Nb. However, for sourcing purposes, the most important elements are Rb, Sr, Y, Zr, and Nb (Shackley 2002). Calibration of tracer-5i was accomplished using the same suite of source samples mentioned previously.

In XRF analysis, the tube emits X-rays with a range of energies from low to high. Confidence ellipses drawn to represent the artifacts and sources become elongated in scatterplots of the data. Despite this difficulty, in most cases, source assignments are possible when sources are chemically distinct. One statistical approach that improves the ability to assign small artifacts to sources is to examine plots of the element ratios (e.g., Sr/Rb, Rb/Zr, Sr/Zr, Y/Zr, Nb/Zr), instead of elemental concentrations. The latter is the method we utilized here.

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 square kilometer in a 905,000 km^2 area.

Results for geological and archeological samples

The results for source samples analyzed by XRF are shown in Fig. 4 using the most sensitive element ratios (Sr/Rb versus Rb/Zr). Although the Laguna del Diamante samples are easily separated from the Arroyo Paramillos, the Las Cargas group is similar to the latter. The Sr/Rb ratio is the most reliable indicator for separating between these sources by using a factor of approximately 1.55 (Hughes 2010; Fig. 4).

In Fig. 5, we present an example illustrating the inter-source chemical variation based on results produced in 2017 for 839 samples from Mendoza province using the same ratios and including those assigned to other obsidian sources from this Andean macro-region. The plot shows the important differences in the chemical composition of the two sources from Laguna del Diamante locality. The sources observed more frequently are Laguna del Diamante ($n = 451$), Arroyo Paramillos ($n = 204$), Las Cargas ($n = 66$), and Laguna del Maule-1 ($n = 65$). In addition, Cerro Huenul ($n = 4$), El Peceño-1 ($n = 4$), Laguna del Maule-2 ($n = 5$), Unknown-A ($n = 4$), and Unknown-B ($n = 28$) were observed in minor abundance, consistently with their availability far from Laguna del Diamante. Finally, three additional artifacts remain as unassigned. A total of 1219 archeological artifacts from both Andean sides have been assigned to the groups Arroyo Paramillos ($n = 593$) and Laguna del Diamante ($n = 626$).

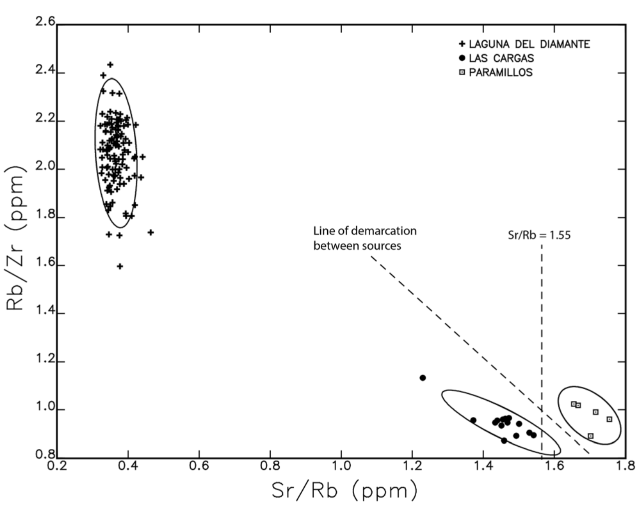

Fig. 4 Scatterplot of Sr/Rb versus Rb/Zr for geological samples by XRF

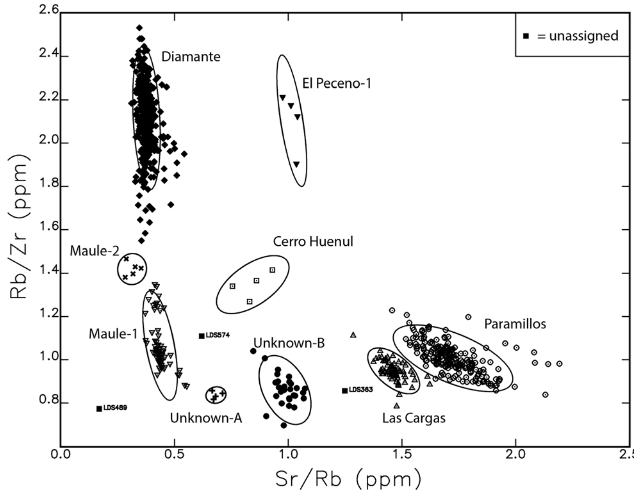

Fig. 5 Scatterplot of Sr/Rb versus Rb/Zr for obsidian artifacts from Mendoza (ellipses represent 90% confidence interval for each chemical group)

Spatial distribution of the archeological samples from Arroyo Paramillos and Laguna del Diamante

In Table 1, we present the abundance of artifacts assigned to the Laguna del Diamante and Arroyo Paramillos chemical groups by using distance intervals to the areas of confirmed availability. A total of 626 artifacts have been assigned to Laguna del Diamante source. A 96.8% of these artifacts come from archeological sites within the volcanic caldera, indicating repeated use of a locally available tool-stone. On the other hand, 32 (11.9%) artifacts coming from 27 archeological sites located in the western Andean shed (Chile) have been assigned to Laguna del Diamante and 238 (88.1%) to Arroyo Paramillos. Most of these sites are emplaced along the Maipo River basin (Table 1). Conversely, on the eastern Andean shed (Argentina), there are only 18 artifacts outside of the caldera that have been assigned to Arroyo Paramillos. These artifacts come from sites scattered across a very broad area including places, such as northern Mendoza, that do not have naturally occurring obsidian.

At the first spatial interval that corresponds with the volcanic caldera (0–21 km), we have assigned 13 samples to the Laguna del Diamante group and 27 samples to the Arroyo Paramillos group in the western area (Chile). There is an abrupt falloff in the representation of this raw material outside of the caldera, being asymmetric toward this side of the Andes. In the next spatial interval (21–40 km), which includes the cordilleran area of the upper Maipo river basin, we record 70 artifacts from Arroyo Paramillos (8%). Sites located in the next spatial interval (40–100 km) on this western Andean flank account for an even higher proportion of 21% ($n = 125$). This difference could be explained in terms of landscape topography, because the interval between 21 and 40 km includes only

Table 1 Sites and number of samples in both slopes. Diamante caldera (≤ 21) and ranges up to (≥ 100 km)

Distance to the sources	Western slope sites	Eastern slope sites	Arroyo Paramillos	Laguna del Diamante	Total
0–21 km (Diamante Caldera)		LD_S2	85	39	124
		LD_S4	174	425	599
		LD_S13	74	116	190
		Las Numeradas	5	13	18
	El Aro		1	0	1
	Las Perdidas		13	9	22
	Vega Linda		6	4	10
	El Olvido		7	0	7
21–40 km	Holoceno		34	1	35
	El Plomo		32	0	32
	Valle Blanco		1	0	1
	El Arenal		1	0	1
		Potrerillos del Diamante	2	0	2
40–100 km	Los Queltehues		53	13	66
	Caseron 2		1	0	1
	Las Cortaderas 2		4	1	5
	Las Cortaderas 3		6	1	7
	Condominio 1		5	0	5
	Las Morrenas		11	2	13
	El Manzano 1		22	1	23
	El Manzano 2		2	0	2
	El Manzano 3		17	0	17
	La Batea 1		3	0	3
	Doña Leonor		1	0	1
	Escobarino 1		1	0	1
		Gruta el Carrizalito	1	0	1
		La Herradura	2	0	2
>100 km	Cuchipuy		2	0	2
	Popeta		1	0	1
	VP-1		5	0	5
	RML. 021		1	0	1
	RML. 034		5	0	5
	RML. 037		1	0	1
	Llanos de Runge 6		2	0	2
		Llancanelo T9	1	0	1
		La Guevarina	1	0	1
		Agua de la Zorra	0	0	1
		El Piedrón	8	1	8
		Quebrada de la Manga	1	0	1
		La Manga	1	0	1

seasonally accessible environments located between 2000/3000 masl. Considering the seasonally limited access, rugged topography and reduced space available for human occupation, and the low density of the archeological record, these highland sites have been interpreted as the result of ephemeral occupations by groups spending most of their annual cycles at lower altitudes in the western Chilean valleys (Peralta and Salas 2004). Finally, sites located in the last spatial interval (≥ 100 km) in the western shed (Chile) represent 2.8% of the artifacts assigned to Arroyo Paramillos ($n = 17$).

In the case of the eastern Andean slope (Argentina), 593 artifacts from 13 archeological sites were assigned to the Laguna del Diamante group in the interval corresponding to the caldera itself (0–21 km). Only one artifact was identified outside of this local interval, actually located to ca. 200 km from the source, in the north of the Precordillera of Mendoza (Cortegoso et al. 2019). On the other hand, 338 (36.3%) artifacts were assigned to Arroyo Paramillos in the first interval within the caldera (Table 1).

Discussion

Spatial distribution of the obsidian types: a GIS approach to geographic vectors of access to the highlands

We characterized the archeological distributions of these obsidian groups by means of Kernel Density Analysis (KDA) (Herzog and Yepez 2010) and evaluated their abundances at a local scale, within the volcanic caldera, and at a regional scale encompassing both Andean slopes. The focus is to compare the spatial structure of the distributions and evaluate its implications in terms of the mechanisms of provisioning involved (Kuhn 2004), whether direct or indirect (Kelly 2011).

Arroyo Paramillos obsidian represents 48.6% of the total sample ($n = 593$). Of this set, 61.5% comes from the Laguna del Diamante area, either within the caldera or immediately outside of it, hence providing contextual evidence that the—still unrecorded—main area of availability would be located nearby the lagoon. Four sites in the western shed of the caldera (El Aro, Vega Linda, El Olvido, and Las Perdidas) have higher frequencies of Arroyo Paramillos (67.5%) than those in the eastern flank (36.3%). Although the Laguna del Diamante group has a relatively homogeneous distribution largely circumscribed to the caldera, Arroyo Paramillos has a much broader and asymmetric distribution toward the western Andean slope (Fig. 6), consistently with previous analyses suggesting the existence of dominant geographic vectors of access to Laguna del Diamante (Cortegoso et al. 2016). Considering that these high-altitude settings would be available for human occupation during the summer, the geographical homeland of the human groups occupying the highlands is an important issue to consider. From a biogeographical perspective, it is of key relevance that the western slope experiences the most pronounced aridity stress during the time when the highlands are available for occupation. Additionally, based on the restricted amount of habitational space available on the Pacific side owing to the presence of topographic constraints versus the wider and less-rugged properties of the eastern lowlands (Clapperton 1993), we have suggested that the western valleys were the area where higher economic intensification was more likely to have occurred during the late Holocene (Durán et al. 2018), because these settings may have reached conditions of demographic packing (sensu Binford 2001) in advance.

Although these lands were certainly accessed and occupied from diverse demographic nodes located in lower-altitude settings, the analysis of obsidian artifacts presented here would suggest the establishment of dominant geographic vectors of access to the highlands from the western valleys and lowlands of Chile. Laguna del Diamante and Arroyo Paramillos are the two northernmost obsidian groups known for the macro-region of study. Archeologically, their distribution is centered around the lagoon and heavily skewed toward the western slope, largely along the Maipo River basin. Interestingly, sites located in the cordilleran basin of the Diamante river in

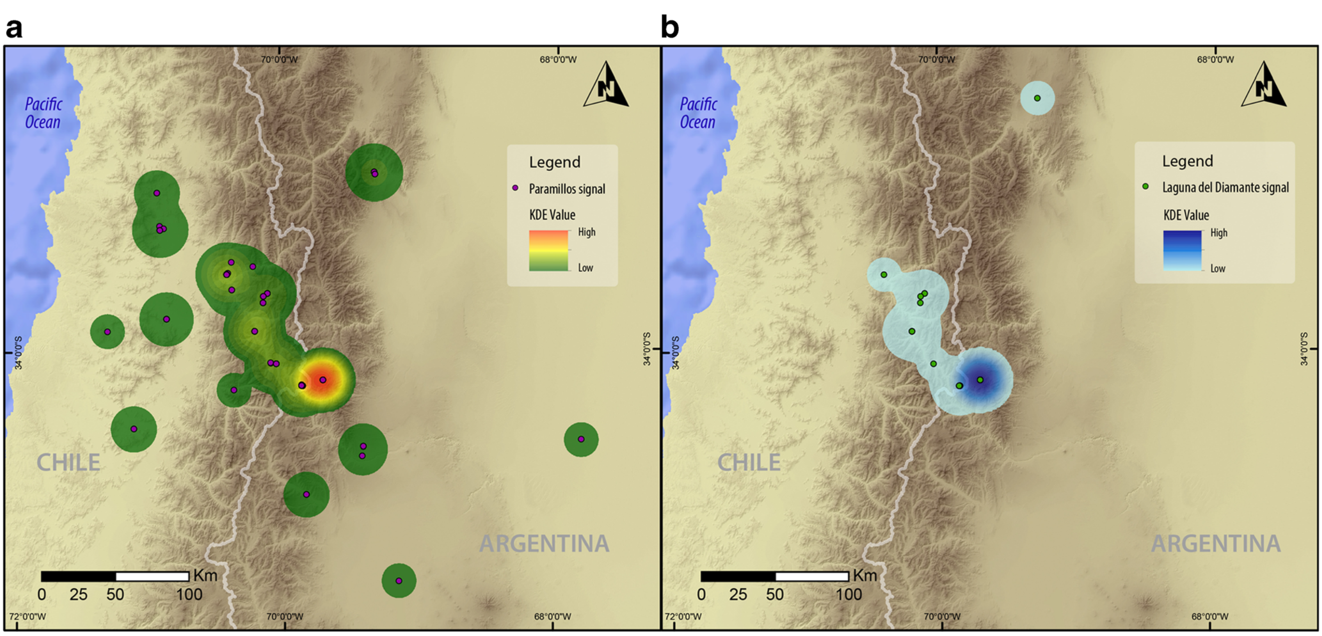

Fig. 6 Kernel density analysis of the spatial distribution of the chemical groups: (**a**) Arroyo Paramillos and (**b**) Laguna del Diamante

Argentina, southwards from the Laguna del Diamante Caldera, contain artifacts made on obsidian from sources in southern Mendoza and not from the nearby chemical signals studied here (Morgan et al. 2017).

Conclusions

The geochemical and archeological results presented show a marked asymmetry in the distribution of these sources between the two Andean slopes. Laguna de Diamante shows a fairly local pattern of use, being concentrated almost entirely in the highland sites within the volcanic caldera and slightly toward its western flank. A very low number of artifacts with the Laguna del Diamante signal have been identified in sites from the upper basin of the Maipo River in Chile. Therefore, the archeological distribution of this obsidian is restricted to the area of natural availability within the caldera. Ongoing studies will allow assessing the temporal patterns of use of this source during the 2000 years of occupation recorded for the Laguna del Diamante (Durán et al. 2006).

Arroyo Paramillos obsidian is more concentrated in the sites from the Maipo River, which is the natural corridor of access to the lake from the western slope. Sites with higher density kernels indicate areas from which groups may have had direct access to these sources. These kernel cores also reinforce the necessity to examine the geological structure of this source in greater detail. The geological availability of Arroyo Paramillos obsidian is still largely unknown and is likely available in the western Andean slope that is undersurveyed yet. This source has a strong presence in the western flank reaching contexts beyond the Maipo basin, which would have been occupied by different social groups (Cornejo 2017). This pattern suggests the Arroyo Paramillos obsidian would have circulated across different interaction networks, hence indicating an indirect access to the cordilleran sources. On the other hand, Arroyo Paramillos obsidian is discontinuously present in the eastern slope (Fig. 6), represented in isolated or scattered contexts mainly in northern Mendoza, an area devoid of obsidian sources.

Considering the spatial distribution of artifacts made on Arroyo Paramillos, its regional importance in the western slope and its discontinuous distribution in the eastern slope, embedded within networks that would have extended during several millennia (Cortegoso et al. 2019), we reconsider its previous characterization as a "minor" source (Cortegoso et al. 2016), because it would have had an important role during some periods and in certain areas. Conversely, based on the evidence presented for the obsidian Laguna del Diamante, which indicates a locally restricted use within the Diamante caldera, we confirm its role as a "minor" regional source (sensu Shackley 2009).

Finally, and adding another layer of analytical complexity but also probably a path to enhanced analytical resolution, recent and still unpublished INAA analyses suggest the existence of two subgroups of the Arroyo Paramillos obsidian that present different compositions in Sc and La, which cannot be accurately detected by XRF (Supplementary Table 3). In this context, Arroyo Paramillos 1 would be the most frequent archeologically, presenting a still undefined main area of availability, while Arroyo Paramillos 2 is confirmed as locally available within the volcanic caldera (Supplementary Table 3). We look forward to a next stage of our macro-regional program of obsidian characterization by expanding geoarcheological sampling in less studied areas, such as the western Andean shed, and a strategic combination of analytical techniques such as XRF and INAA targeting a cost-efficient and resolution-maximizing approach to disentangling the history of human use of Andean obsidian sources and highland areas.

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