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Geographic vectors of human mobility in the Andes (34–36° S): Comparative analysis of 'minor' obsidian sources

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ABSTRACT

We have carried out long-term comparative in a wide latitudinal range of the Andes (29°–37° south), encompassing selected areas that differ in ecology and biogeography. This latitudinal span shows diversity in subsistence modes across time and space, ranging from Andean agro-pastoralists in the north to Patagonian hunter-gatherers in the south. As part of this research, a program of geochemical and archaeological characterization of obsidian sources and distributions is being developed, attempting to assess connections between different biogeographical contexts. This work has allowed recognizing five Andean sources with different geological and topographical properties. Stemming from this macro-regional endeavor, in this paper we present a comparative analysis of the human use of two sources that, based on the intensity of human use on a macro-regional scale, can be interpreted as 'minor' sources.

This study is framed on GIS least-cost models for human circulation across rugged landscapes allowing access to the sources. We assess temporal and spatial patterns of human occupation of high-altitude Andean deserts and neighboring areas comparing two of obsidian sources: Laguna del Diamante (34° S) and Cerro Huenul (36° S). The results indicate the existence of asymmetric distributions, particularly in the case of Laguna del Diamante. This evidence is used to assess the existence of dominant geographic vectors of human access and use of the Andean highlands. On this basis, we explore the analytical potential of minor sources for the study of human biogeography and organization of technology.

1. Introduction

Long-term comparative research has been carried out in a wide latitudinal range of the Andes of Argentina (South America) extending from 29° to 37° south, including selected areas that differ in ecological, biogeographical, and archaeological levels (Cortegoso et al., 2014a). This latitudinal span shows diversity in subsistence modes across time and space, ranging from Andean agro-pastoralists in the north to Patagonian hunter-gatherers in the south, in a scenario of divergent cultural trajectories that took place since 2000 years BP. As part of this research, a program of geochemical and archaeological characterization of obsidian sources is being developed, attempting to assess connections between different biogeographical settings (Durán et al., 2012; Cortegoso et al., 2012a). This work has allowed recognizing five Andean sources with different geological and topographical properties (Durán et al., 2004; Giesso et al., 2011). More than two thousand samples have been analyzed so far, with different analytical methods and laboratories, providing a solid basis that allows pursuing comparative research questions. Building on this previous macro-regional work, in this paper we present a comparative analysis of the human use of two Andean obsidian sources that, based on the intensity of human use recorded on a macro-regional scale, can be described as 'minor' sources (sensu Shackley, 2009): Laguna del Diamante source at 34° south, located in central Mendoza Province (De Francesco et al., 2006), and Cerro Huenul at 36° south, in northern Neuquén Province of Patagonia (Durán et al., 2004; Barberena et al., 2011).

We present a synthesis of the geochemical and geological characterization of these sources, as well as an assessment of their archaeological record in space and time. On this basis, we evaluate the differential exploitation of these environments and patterns in

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the dominant geographical vectors of access and distribution of these rocks. This is a means of evaluating the scale of use of the sources, economic modes, and technological strategies of human groups occupying these territories during the Holocene.

We assess spatial and temporal patterns of use of these obsidian sources considering distance and slope in order to build least-cost models of access to the sources that can be compared across regions (Tripcevich, 2007; Rademaker et al., 2012). Finally, we discuss patterns of use, mobility and exchange that involve different societies in both slopes of the Andes throughout the Holocene. On this basis, we explore the analytical potential of minor sources for the study of human biogeography and organization of technology.

2. Regional setting and background

2.1. Regional setting

In a west–east axis, this large territory extends from the Pacific coast in Chile to the central western Argentinean plains. The region is divided by the Andes mountain range with an average width of 150 km, and heights reaching up to 6900 masl. The eastern plains include several volcanoes reaching heights up to 3810 masl. Precipitation occurs through frontal systems associated with migratory surface cyclones that tend to migrate eastward along rather narrow latitudinal bands known as storm tracks (Garreaud et al., 2008). As a consequence of the rain shadow effect produced by the forced subsidence of the surface winds over the Andes, precipitations present a strong west–east decreasing gradient. The slopes to the east of the Andes are arid to semiarid. As one moves upward, rainfall increases and temperature decreases. Vegetation distribution follows this precipitation gradient. These differences are more strike in the Chilean side, where the altitude descends from 6000 to 500 masl in less than 70 km.

Laguna del Diamante is a high-altitude enclosed wetland of the Central Andes of Mendoza with accessibility that is restricted to the austral summer months. This locality has an excellent supply of biotic and abiotic resources providing a unique paleoecological and archaeological archive (Durán et al., 2006). Cerro Huenul, on the contrary, is located in a yearlong accessible setting in the lowlands of northwestern Patagonia. According to herbivore carrying capacity, this xeric desert can be considered marginal in relation to neighbor regions (Barberena, 2013).

Fig. 1 shows the study region with the main river basins, all the obsidian sources that have been reported and characterized, and the least cost paths of access to the two sources compared in this paper.

2.2. Background: obsidian in the central Andes of Argentina and Chile

Two types of sources can be differentiated on the basis of their topographic emplacement: (1) high-altitude sources emplaced in the Andes range (more than 2500 masl) having seasonally restricted access from both slopes, including the Laguna Diamante, Laguna del Maule, and Las Cargas sources; and (2) low-altitude (less than 1500 masl) extra-Andean sources associated with extensional settings that are situated on the eastern plains and have year-long access (from Argentina) such as Cerro Huenul source in northern Patagonia.

The macro-regional obsidian archaeological record is dominated by two large high-altitude sources: Las Cargas and Laguna del Maule (Seelenfreund et al., 1996; Durán et al., 2004; Giesso et al., 2011; Cortegoso et al., 2014b). These two are primary sources with an excellent availability of raw material, though due to their high-altitude location, they can only be accessed seasonally. The two sources selected for comparison in this paper – Laguna del Diamante and Cerro Huenul – show less intensive human use, being underrepresented even in close areas in comparison to Laguna del Maule and/or Las Cargas sources (Barberena et al., 2011; Durán et al., 2012). Though these two sources are dominant in their respective regions, they can be considered as 'minor' in terms of the spatial scale and amount of obsidian transported. In Fig. 2 we

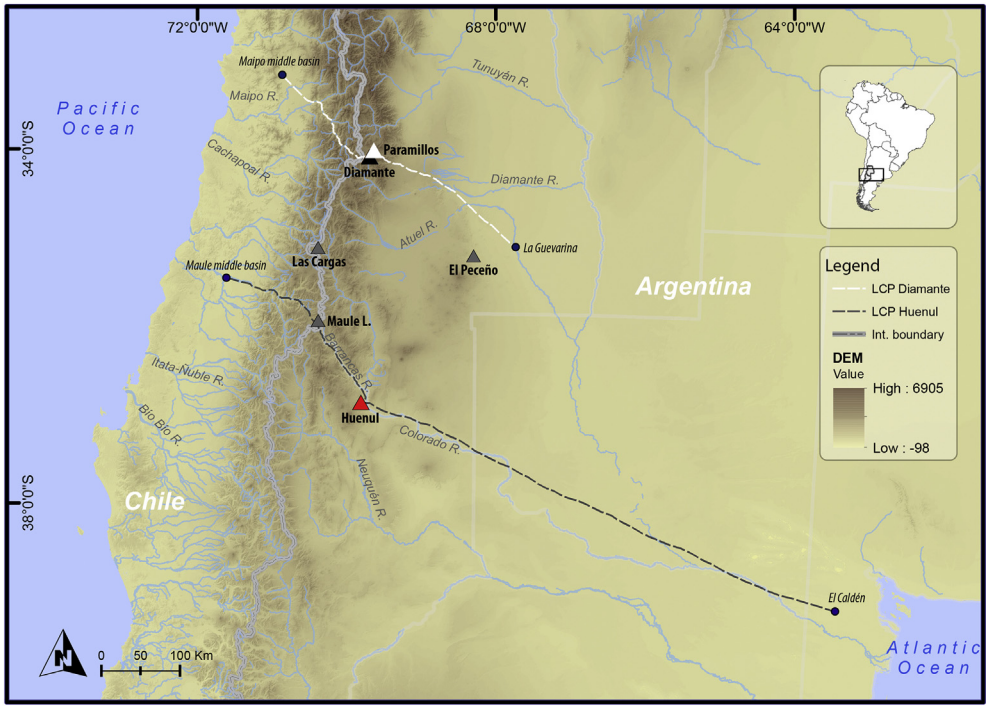

Fig. 1. Study region: obsidian sources, and least cost path of Diamante and Huenul sources.

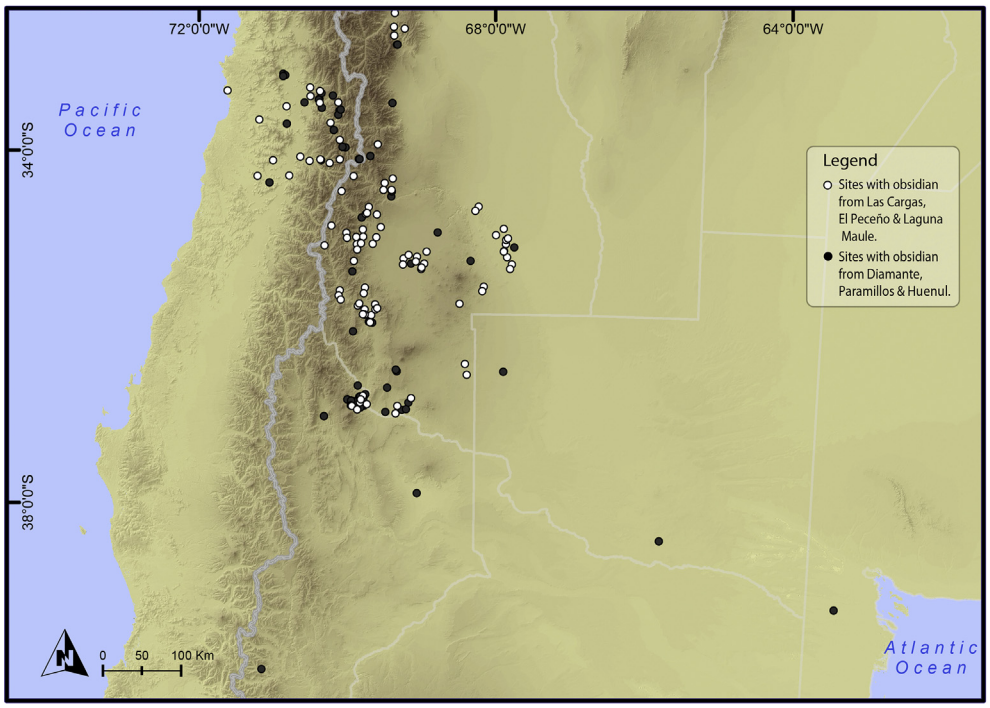

Fig. 2. Sites with obsidian from Laguna del Diamante, Arroyo Paramillo and Cerro Huenul vs. alternative sources (Laguna del Maule, Las Cargas, El Peceño).

compare the number of sites with obsidian from Laguna del Diamante and Cerro Huenul vs. the number of sites with obsidian from alternative sources (see Giesso et al., 2011).

2.2.1. Laguna del Diamante (central western Mendoza Province, 34° S)

Laguna del Diamante is the northernmost source studied, located at 3200 masl in the upper valley of the Diamante River in the Argentina-Chilean border (Fig. 1; Durán et al., 2004; De Francesco et al., 2006). The obsidians come from a large volcanic caldera with a diameter of 20 km, resulted from a cataclysmic eruption that occurred ca. 500.000 years BP (Sruoga et al., 2005). Importantly, this region is characterized by the presence of two distinctive chemical types, respectively denominated as Laguna del Diamante and Arroyo Paramillos (De Francesco et al., 2006).

The Laguna del Diamante type is available in the form of nodules distributed along the high slopes around the lake, in the ravines that drain to the lagoon, and in the lakeshores. The size of the nodules increases with altitude up to 3800 masl.

The position of the Arroyo Paramillos chemical type in the field has only been recorded as small nodules of ca. 2 cm in diameter. Although several surveys were conducted to locate the main location of the source, it has not been found yet. Chemical characterization and differentiation of this chemical type was largely conducted by means of XRF analysis of artifacts recovered around Laguna del Diamante region (Cortegoso et al., 2014b).

2.2.2. Cerro Huenul source (northern Neuquén Province, 36–37° S)

Cerro Huenul is a secondary obsidian source with a very wide and discontinuous natural distribution with a NW–SE axis of ca. 60 km (Durán et al., 2004; Barberena et al., 2011). Obsidian nodules of varying size are contained within ignimbrite deposits belonging to the Tilhué Formation, dated between 4 and 0 my BP (Groeber, 1946; Narciso et al., 2004; Folguera et al., 2008). The erosion of these pyroclastic deposits produces the accumulation of lag surface assemblages composed by different rocks including obsidian. Based on our field survey, we have recorded that only some Tilhué outcrops contain obsidian nodules (Barberena et al., 2011). This may be related to the dynamics of formation and deposition of ignimbrites (Freundt et al., 2000), and needs further field-testing.

3. Materials and methods

3.1. Materials

We have analyzed 160 archaeological samples assigned to Laguna del Diamante with its two subsources: Laguna del Diamante and Arroyo Paramillos. 82 of these samples come from 23 archaeological sites in Chile and 78 from 8 sites in Argentina (De Francesco et al., 2006; Giesso et al., 2011; Durán et al., 2012; Cortegoso et al., 2012a). On the other hand, regarding Cerro Huenul source, we have characterized 303 archaeological samples from 41 sites located in Argentina (Barberena et al., 2011, 2015a).

3.2. Geochemical analyses of sources and artifacts

Three different XRF spectrometers were used to perform the measurements of the non-destructive archaeological artifacts analysis which results are used here: 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). 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. The application of non-destructive XRF has allowed analyzing all ranges of artifact sizes including flakes of ca. 10 mm. Technical aspects regarding the discrimination of the sources and chemical types have been the focus of previous papers (Giesso et al., 2011; Cortegoso et al., 2014b).

3.3. Topography and accessibility to the sources: a least-cost perspective

Least cost path analysis (LCP) is used with GIS as a methodology suitable to model and study mobility patterns in heterogeneous landscapes (Tripcevich, 2007; Rademaker et al., 2012, 2014; Surface-Evans and White, 2012; Lucero et al., 2014). We produced an anisotropic cost/friction surface through the ArcGIS 10.1 *Path-Distance* function (Tripcevich, 2007, 2008; Contreras, 2011). Afterwards, we added isochrones equivalent to 8 h of walk (Jennings and Craig, 2001). The background map is the ASTER GDEM v2 with a resolution of about 30 m (Tachikawa et al., 2011). By means of Profile Graph changes, this software was used to produce least cost paths connecting selecting localities that include the obsidian sources. The variables considered are distance, slope gradient, time, and elevation (see also Barge and Chataigner, 2003; Tripcevich, 2007; Rademaker et al., 2012).

For the analysis of the distribution of archaeological samples of obsidian we used maps of densities. The concentration of artifacts is calculated and represented as spatial clusters using the Kernel Density Estimation (KDE) method (Baxter and Beardah, 1997; Wheatley and Gillings, 2002). The maps show a gradient of size cores and a color spectrum of spatial densities for the sources compared. Data were classified through an equivalent-intervals method that quantifies elements per km^2 in a 905.000-km^2 area.

4. Results

We begin presenting a short assessment of the properties and quality of the obsidian sources, followed by a least cost analysis of human circulation and access to the sources. The first analysis of archaeological distributions is spatial and includes all the samples analyzed. Then, to develop a temporal analysis, we organize the samples in three chronological intervals: 1) 10.000/4000 cal years BP; 2) 4000/2000 cal years BP; 3) 2000/300 cal years BP. Samples lacking chronological context are excluded from this analysis.

4.1. Raw material availability at the sources

Laguna del Diamante locality is a volcanic caldera (Sruoga et al., 2005) that contains two subsources that are easily differentiated on the basis of geochemical data. The homonymous type Laguna del Diamante is conformed by nodules widely distributed in the landscape, recorded along the ravines that fill the lagoon, in the lakeshores, and in the slopes surrounding the lagoon up to 3800 masl. The diameter of nodules decreases in size along Las Numeradas creek from 50 cm in the high areas, where the primary sources were presumably located, to 10 cm in the beaches of Laguna del Diamante. This obsidian has brittle fracture and relatively poor knapping quality.

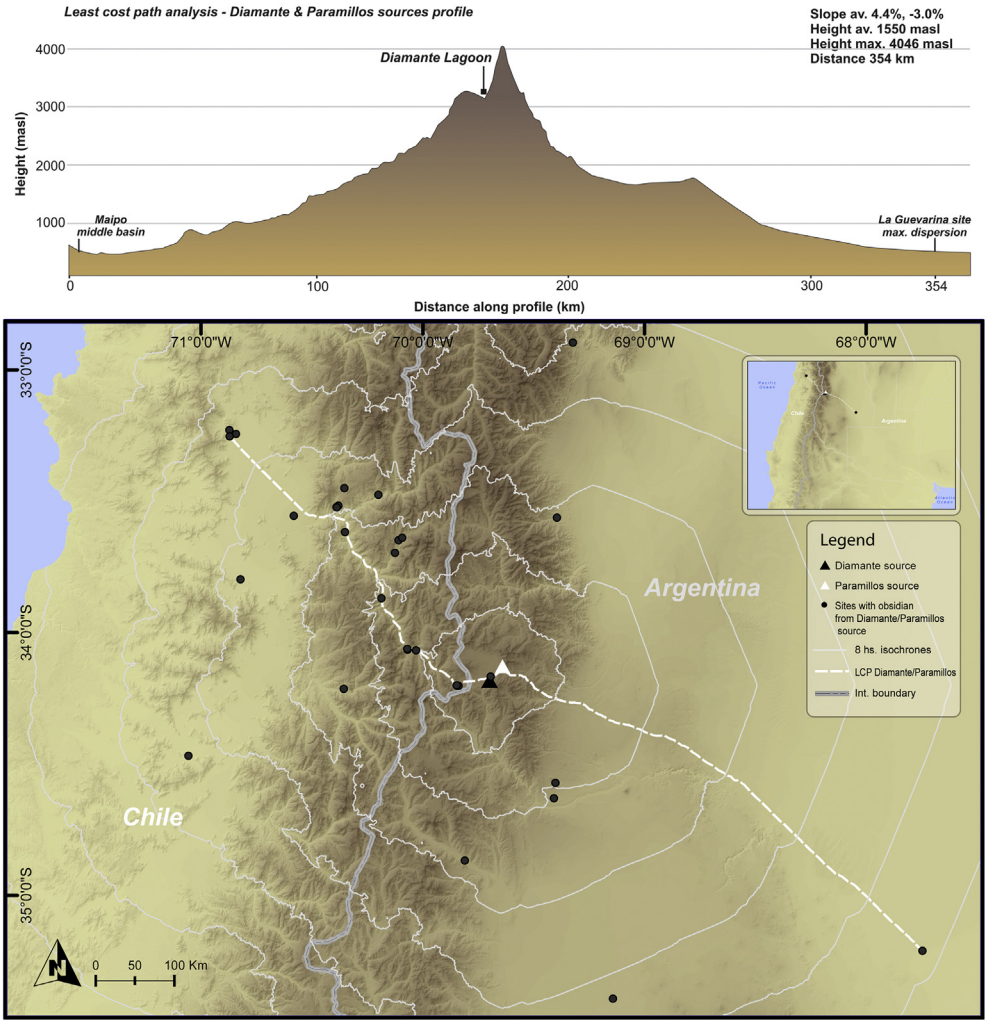

Fig. 3. Least cost path analysis, anisotropic friction surface, isochrones (8 h of walk), and archaeological sites containing obsidian from Laguna del Diamante locality.

Arroyo Paramillos is the second subsource in Laguna del Diamante locality. Chemical characterization and differentiation of this subsource was conducted by means of XRF analysis of small obsidian nodules recovered from near the Laguna del Diamante. Several surveys were conducted in the Argentinean area failed to find the main area of availability. In the near future this field sampling will be extended to the area of this locality currently located in Chile. The Arroyo Paramillos chemical type is compositionally similar to another source located 25 km to the south, known as Las Cargas (Salgán et al., 2015), producing an overlapping signal that complicated their geochemical discrimination (De Francesco et al., 2006; Giesso et al., 2011; Cortegoso et al., 2014b). Currently, these two sources can be accurately distinguished on the basis of an array of chemical elements (Cortegoso et al., 2012b, 2014b, unpublished data).

In the case of obsidian from Cerro Huenul, we have already published preliminary morphometric studies (Barberena et al., 2011). The predominant nodule volume in four transects with 40 nodules each is of 30.7 mm^3. We have recorded the concentration of large nodules in intermittent gullies with a mean nodule volume of 58 mm^3, and a maximum value of 642.6 mm^3 (up to 25 cm along the major axis). Though large nodules are clearly not the most abundant in this source, our data indicates that search guided by some basic geomorphic aspects produces suitable nodules in short amounts of time (cf. Shackley, 1992). Importantly, obsidian from Cerro Huenul is of the highest quality among all the sources from the macro-region. It does not show inclusions or internal fracture planes, minimizing the need for field-testing of the nodules in advance of transport.

Laguna del Diamante and Cerro Huenul sources are both secondary sources. When compared to Andean primary sources, such as Las Cargas and particularly Laguna del Maule (Seelenfreund et al., 1996), these sources are amply surpassed in terms of the size of blanks that can be produced. Nevertheless, information on the maximum sizes available at Laguna del Diamante and Cerro Huenul indicates sizes adequate for the production of the suite of tools represented in the archaeological record. On the other hand, Cerro Huenul ranks first in terms of quality and year-round accessibility.

4.2. Least-cost analysis of the sources

Figs. 3 and 4 present the profiles for the least-cost routes of access, an anisotropic cost/friction surface displaying isochrones equivalent to 8 h of walk, and the distribution of sites respectively containing obsidian from Laguna del Diamante and Cerro Huenul

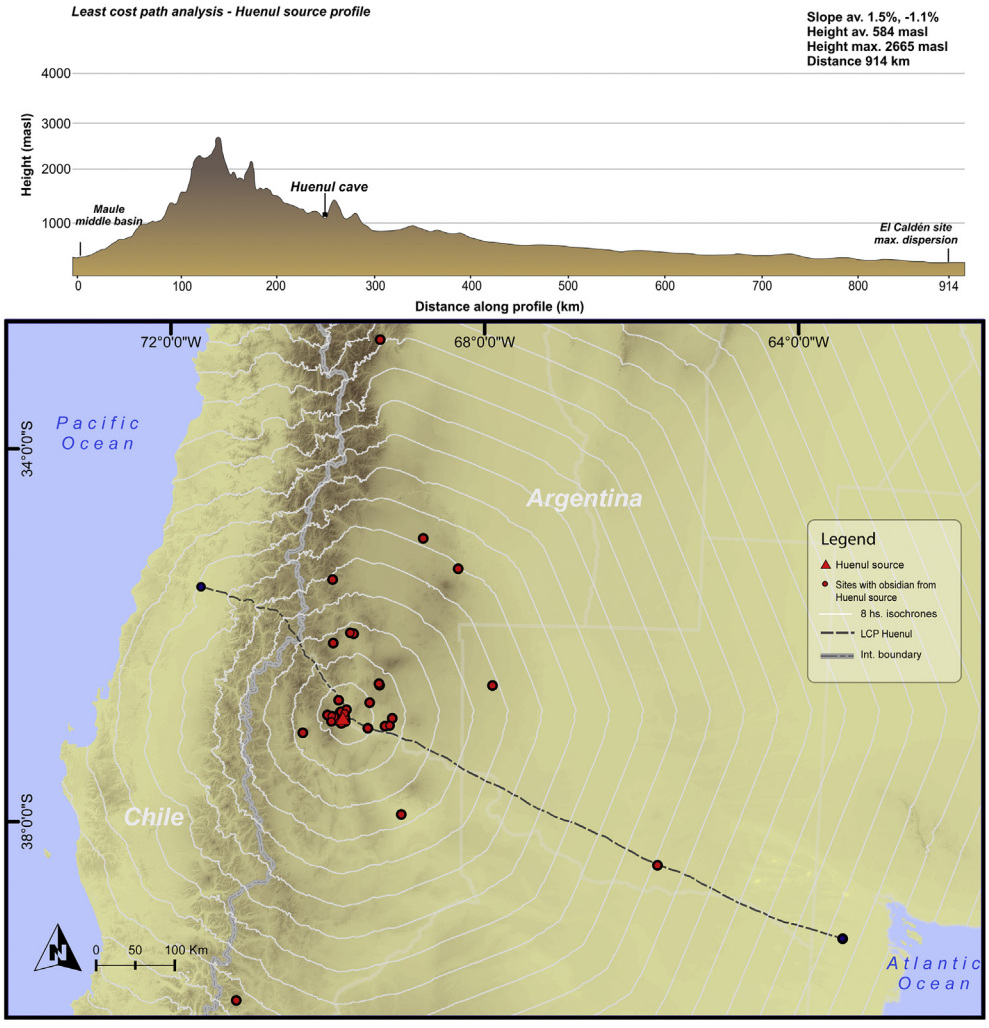

Fig. 4. Least cost path analysis, anisotropic friction surface, isochrones (8 h of walk), and archaeological sites containing obsidian from Cerro Huenul locality.

types. This analysis provides the frame to assess the costs of human travelling. On this basis, we build the comparative study of human use of these sources.

Laguna del Diamante locality (3000 masl) includes obsidian with two different chemical signatures: Arroyo Paramillos and Laguna del Diamante. Though located on the Argentinean side of the Andes, the least cost analysis shows that this obsidian source is accessed with lower costs from the Chilean lowlands to the west (Table 1, Fig. 3). This contrast in the costs of access to a high-altitude setting may have played a role in the patterns of use of this obsidian source. Interestingly, since this locality can only be accessed during summer months, the use of this source provides a glimpse on seasonal movements of mobility. The surface analysis indicates that 77% of the sites with obsidian assigned to the types Laguna del Diamante and Arroyo Paramillos are recorded in a distance below four days of walk from the source, while the remaining 23% is located in a distance equivalent to 4/6 days of walk from the source (Fig. 3).

Fig. 4 presents the case of Cerro Huenul source, located on the lowlands of Neuquén Province (900–1100 masl) and readily accessible year round. The profile and anisotropic surface indicate the maximum dispersion of artifacts made on this source, reaching the Atlantic coast at the mouth of the Colorado River. This obsidian source has low costs of access from the Atlantic side of continent, whereas access from the western side of the Andes implies circulating across mountain passes of ca. 2500 masl that are only accessible during the summer. 76% of the sites with obsidian from Cerro Huenul are localized within a distance equivalent to four days of travel from the source, while the remaining 24% is located that is equivalent to 4/17 days of walk (Fig. 4).

In comparison with the Laguna del Diamante area, Cerro Huenul source has much lower costs of access, as well as no seasonal constraints (Durán et al., 2004). On the other hand, there is an interesting contrast in the difficulties of access from both sides of the Andes: Laguna del Diamante has the least costs of access from the western side, while circulation from the east implies circulating across mountain ridges of higher average altitudes, reaching up to 4000 masl. On the other hand, Cerro Huenul is readily accessible from the eastern plains, presenting much higher costs of access from the west (Table 1).

The analysis of the spatial scale of distribution of obsidian from Cerro Huenul vs. Laguna del Diamante/Arroyo Paramillos indicates an interesting difference in the minimum number of days of journey involved in each case. 24% of the sites with Cerro Huenul obsidian are located in a distance that suggests either curation of obsidian in long distances or indirect access, beyond the scale of home ranges. This is not the case with Laguna del Diamante/Arroyo Paramillos, reaching a maximum distance that can be travelled within 6 days of walk. Though this contrast is recorded in low frequencies of artifacts/sites, it would suggest a differential insertion of these different obsidian types at a macro-regional scale of human interaction. This should be further explored in the future on the basis of an expanded database.

4.3. Spatial distribution

Fig. 5 shows a kernel density analysis (KDA) of the spatial distribution of the two subsources of Laguna del Diamante locality (Laguna del Diamante N = 47; Arroyo Paramillos = 113). The KDA relates color spectrum with density of evidence, being determined by the total number of samples corresponding to a given source in each location. In the Laguna del Diamante area, where the homonymous subsource is located, we record the maximal concentration of the artifacts of this chemical type with a main axis of distribution towards the western slope of the Andes, specifically in sites located in the upper Maipo River basin (Cortegoso et al., 2012b; Durán et al., 2012).

The Arroyo Paramillos subsource, whose primary source remains unknown, shows a main core in the upper basin of the Maipo River in the western slope of the Andes. This may be a good indication of the primary location of this raw material. On the other hand, its distribution reaches low altitudes along the Maipo basin, as well as in places located northwards (Mapocho basin) and southwards (Cachapoal basin). Towards the Argentinean lowlands in the east, Arroyo Paramillos only shows relatively significant amounts of artifacts in the upper section of the Diamante River, draining the Laguna del Diamante, with a very low presence in the highlands of northern Mendoza and two isolated samples in the southern plains.

Fig. 6 shows the falloff curve of artifacts assigned to Laguna del Diamante source, discriminating the frequencies between the western (Chile) and eastern (Argentina) sides of the Andes. As could be predicted from the KDA presented above, there is a contrast in the distribution of artifacts in both slopes of the Andes, since the distribution towards the east does not extend beyond 10 km; on the western side, the curve shows an initial drop between 5 and 10 km, signaling the highest part of the route, followed by two moderate peaks reaching 100 km from the source.

Fig. 7 shows the falloff curve of Arroyo Paramillos chemical type. Once more, there is a contrast in the distribution towards both sides of the Andes mountain range. Followed by an initial drop at ca. 10 km from the source towards both sides, associated to the rugged terrain surrounding Laguna del Diamante, most of the artifacts assigned to this source are located in the western side, with density peaks up to 100 km from the source.

This pattern is relevant considering that we have no specific information about the primary location of this source.

Fig. 8 shows the KDA of the artifacts assigned to the Cerro Huenul source. The main core of the archaeological distribution overlaps with the source itself, which is irregularly distributed in widely separated patches. Outside of the source, Cerro Huenul obsidian has a relatively discrete distribution extending in particular towards the northeast, where La Payunia volcanic field is

Table 1
Least cost analysis routes from the sources areas (Fig. 1).

From	To	Distance	Hours	Days	km/h	Elevation		Slope			
						Min	Max	Max		Average	
Diamante Source	Guevarina	193	41	5	4.7	498	4348	31.4%	−39.5%	2.9%	−4.5%
Diamante Source	Maipo	161	34	4	4.7	478	3448	37.0%	−38.4%	6.3%	−9.5%
Huenul Source	El Caldén	645	125	16	5.2	11	1560	1.5%	−2.9%	0.4%	−0.5%
Huenul Source	Maule	269	55	7	4.9	99	2787	34.8%	−42.4%	7.2%	−5.7%

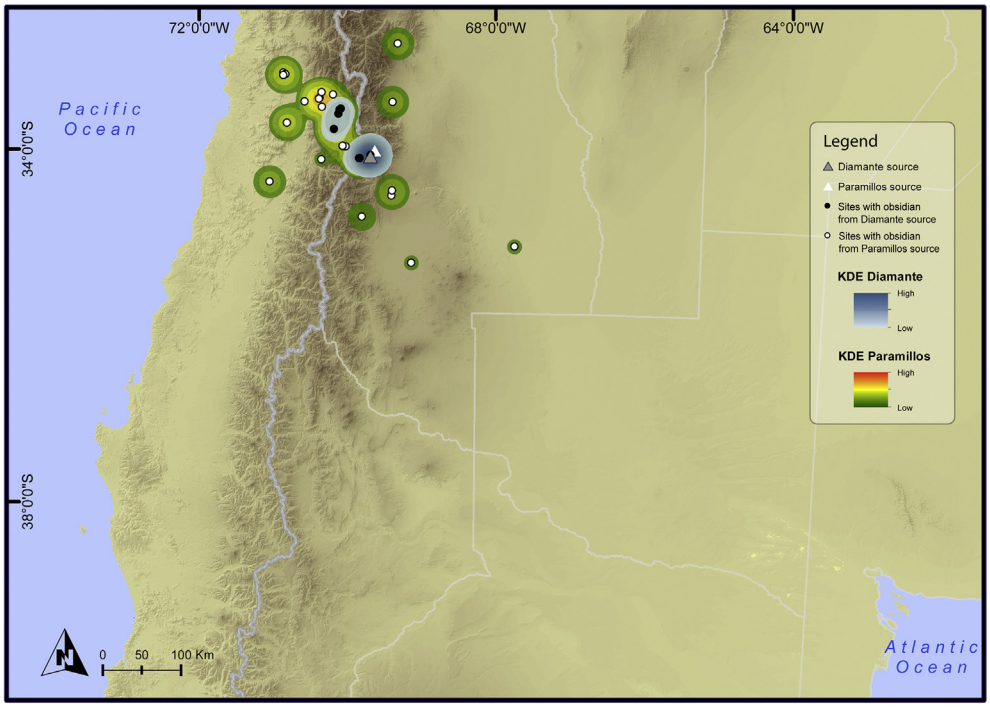

Fig. 5. Kernel density analysis of the spatial distribution of the obsidian from Laguna del Diamante and Arroyo Paramillos sources.

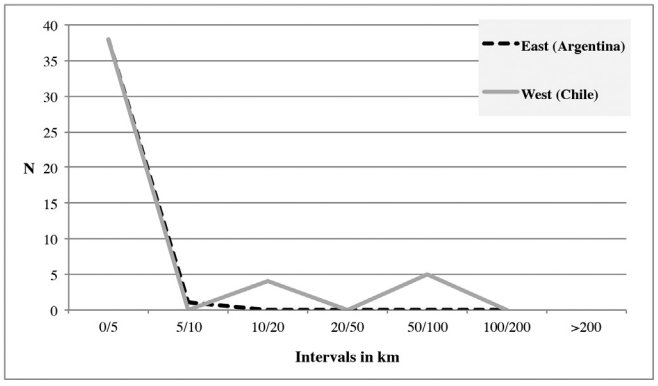

Fig. 6. Falloff curve of the frequency of artifacts assigned to Laguna del Diamante chemical type.

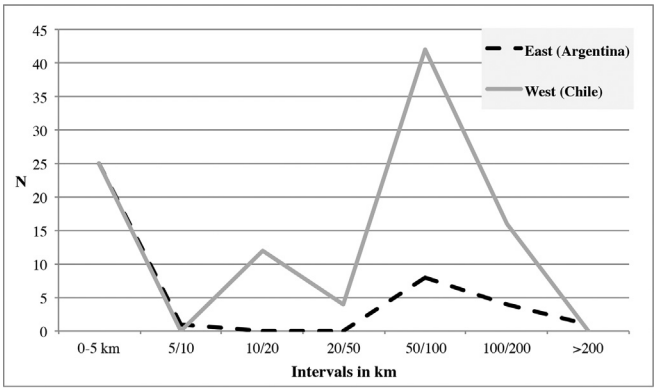

Fig. 7. Falloff curve of the frequency of artifacts assigned to Arroyo Paramillos chemical type.

located (Neme and Gil, 2008; Salgán et al., 2012). The geographical axis of this immediate distribution could be related to biases in the available geochemical sample, since very few artifacts have been characterized from contexts southwards from the source. This prevents us from conducting a falloff analysis that discriminates between the different axes of the distribution.

The falloff curve of Cerro Huenul obsidian shows a main core of distribution within 20 km from the source, sharply decreasing beyond 50 km. This is followed by an increment in the frequency of artifacts in La Payunia volcanic field, around 100 km from the source, and then scattered isolated finds in contexts located up to 500 km (Fig. 9). This spatial pattern would imply an intense use of this raw material at the source and nearby areas, with a sharp falloff in a short range, and also very exceptional transport of items far of the source.

4.4. Temporal distribution of obsidian artifacts

We only include those artifacts that can be bracketed in time, accounting for 54.7% of the total sample (Fig. 10).

The earliest chronological interval accounts for 9.4% of the total sample analyzed (N = 47, Table 2). In this early stage, in the northernmost area we only record the human use of Arroyo Paramillos obsidian in the western slope of Andes along the Maipo River (Durán et al., 2012; Cortegoso et al., 2012b), as well as a minimal presence in high altitude sites northern Mendoza during the mid-Holocene (Giesso et al., 2011). The Laguna del Diamante chemical type is not recorded during this early interval. These early records away from the source mark the first evidence of use of the source, since the archaeological record in Laguna del Diamante has an initial date of ca. 2000 years BP (Durán et al., 2006). Cerro Huenul source has a relatively intense local human use during the early Holocene, in particular at the Cueva Huenul 1 site (Barberena, 2015).

The next temporal interval accounts for a 3.4% (N = 17) of all the samples analyzed. Overall, it indicates a low intensity of exploitation of the three obsidian types compared. In the case of the Cerro

Table 2
Frequency of artifacts assigned to the obsidian sources analyzed.

Temporal interval (^{14}C years BP)	Cerro Huenul	Laguna del Diamante	Arroyo Paramillos	Total
9000–4000	36	0	11	47
4000–2000	2	3	12	17
2000–500	121	42	47	210
unknown	182	2	43	227

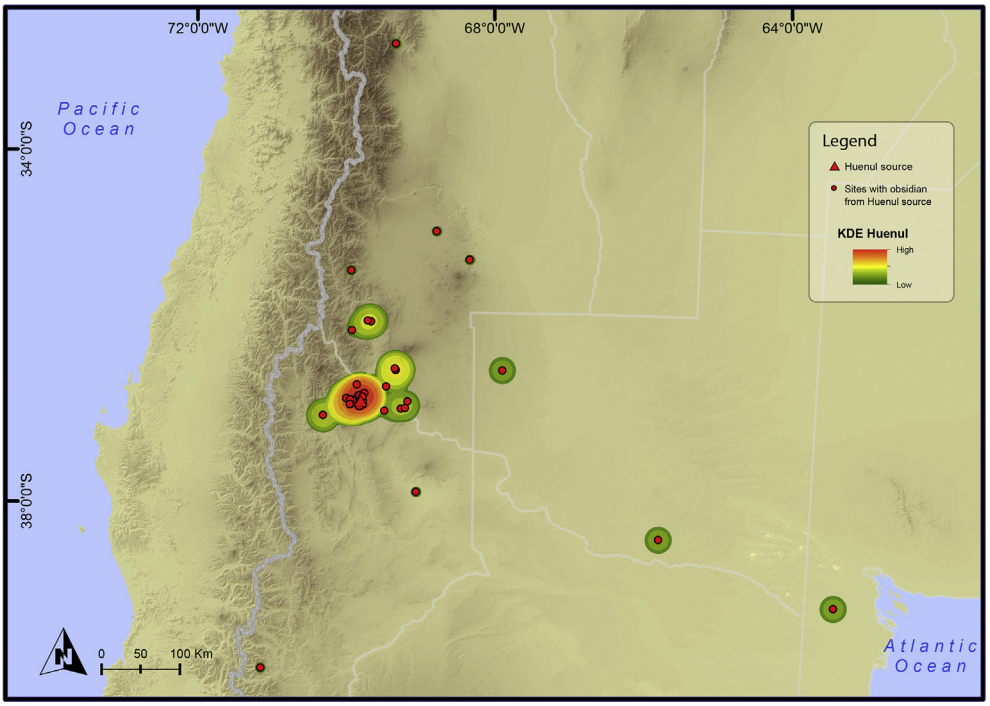

Fig. 8. Kernel density analysis of the spatial distribution of the obsidian from Cerro Huenul source.

Huenul source, only represented by two artifacts recovered away from the source, this would be due to the absence of archaeological components dated to this interval (Barberena et al., 2015b). Further excavation and dating may substantially modify this pattern.

The use of obsidian from both Diamante subsources is recorded in the western slope: Paramillos subsource appears in the upper Maipo basin (N = 2), and Laguna del Diamante subsource in the high Andes of the western slope (N = 3). These samples represent the first evidence of human use of Laguna del Diamante locality, and were recorded out of the source itself, which has an archaeological signature starting at ca. 2000 cal years BP (Durán et al., 2006). This early pattern may illustrate the consolidation of the use of height Andean environments by societies with large mobility circuits across the Andes at this latitude, with a significant knowledge of raw material availability in the area. This would suggest a 'colonization stage' within the process of human colonization (sensu Franco, 2004). This interval would represent a period before the changes in subsistence occurring in the last 2000 years, when divergent cultural trajectories are emphasized in northern vs. southern Cuyo and Patagonia.

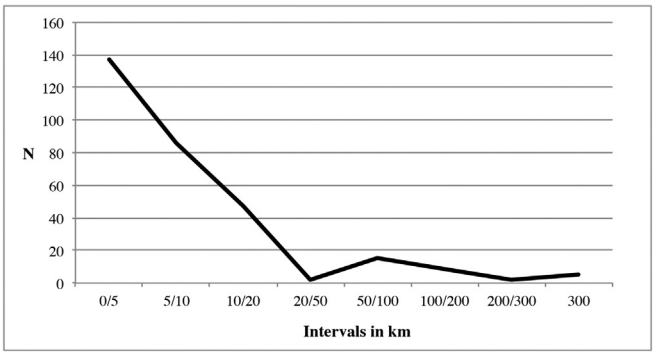

Fig. 9. Falloff curve of the frequency of artifacts assigned to Cerro Huenul source.

The last interval includes the period between 2000/300 years BP, representing 41.9% of the obsidian samples. Human use of the two chemical types from Laguna del Diamante is strongly biased towards western settings, particularly along the Maipo River in Chile. Overall, Arroyo Paramillos obsidian was used more intensively in the lagoon itself and towards the eastern lowlands in Argentina. This late Holocene record may illustrate the consolidation of transhumant patterns of use of high altitude Andean environments by societies with demographic nodes located in the lowlands. Cerro Huenul obsidian displays a strong signal at the source, as well as a significant presence in the Payunia volcanic field towards the northeast.

5. Discussion: intensity and geographic vectors of human use of the sources

5.1. Spatial scale and intensity of use of the sources

When information on the sources analyzed here is visualized in the context of the data for all the available sources in the macro-

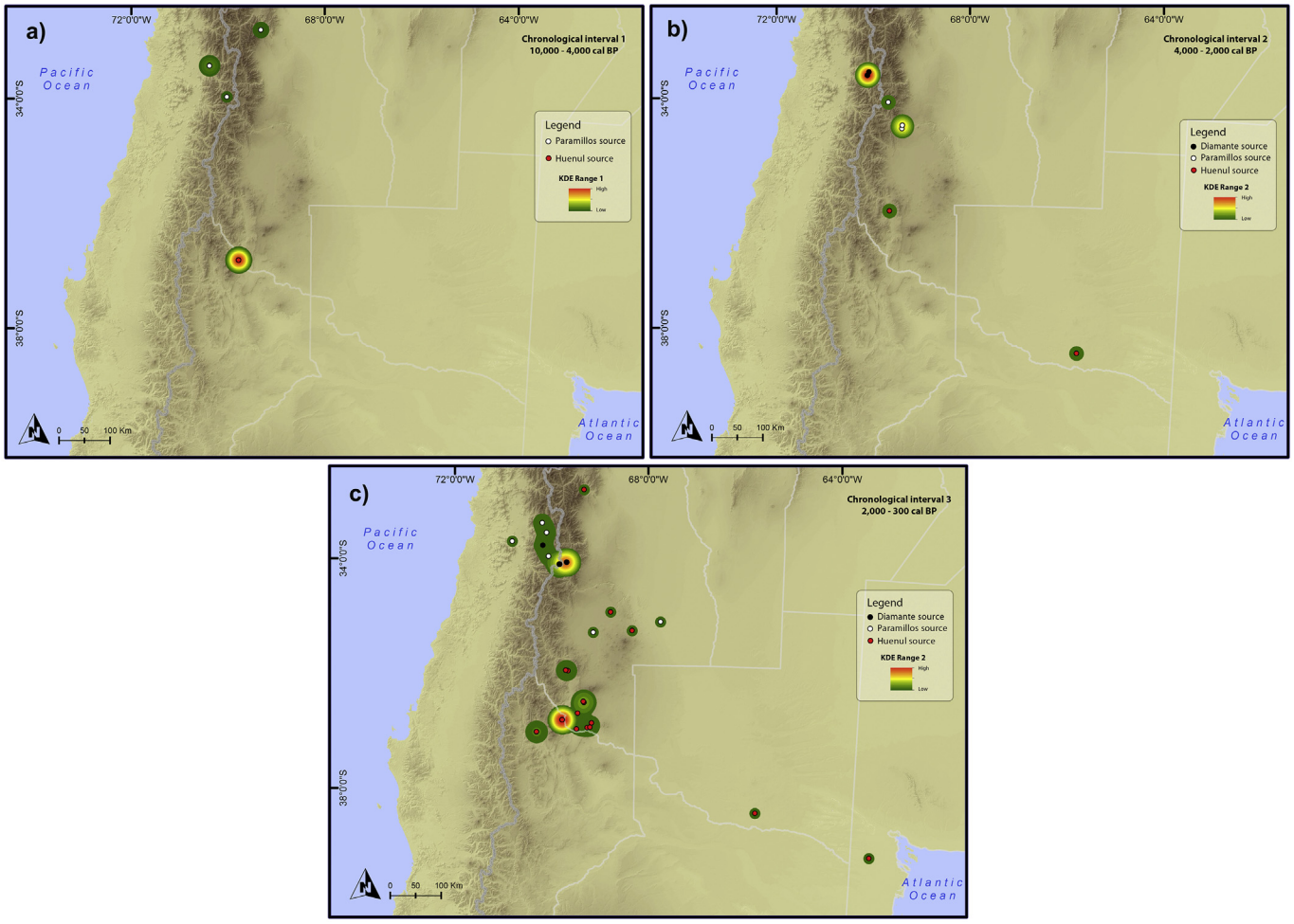

Fig. 10. Human use of the obsidian sources in the three intervals considered: a) 10.000–4.000 years BP; b) 4.000–2.000 years BP; c) 2000–300 years BP.

region (Durán et al., 2004; De Francesco et al., 2006; Giesso et al., 2011; Durán et al., 2012; Cortegoso et al., 2012a), it is evident that other sources were used much more in terms of intensity and spatial scale of transport in both watersheds of the Andes. This is the case of Las Cargas source in the northern region (34° S), compared to Laguna del Diamante, and Laguna del Maule in the southern region (36° S), compared to Cerro Huenul (Giesso et al., 2011; Durán et al., 2012; Salgán et al., 2012).

Our frame of research intends to assess the organizational decisions behind these spatial discontinuities. Following Shackley (2009), we suggest that rocks with relatively limited archaeological distributions provide an opportunity to learn on different levels of human organization of technology, mobility, and landscape use. First, it is fair to ask, to what degree are these distributions isomorphic with human home ranges?

The two obsidian types from Laguna del Diamante present different distributions. Laguna del Diamante type shows a distribution that is limited to areas immediately adjacent to the source, being distributed beyond this area in very low frequencies (Figs. 3 and 4). Arroyo Paramillos, on the other hand, has an asymmetric distribution, very limited in distance and intensity towards the east, though much more significant towards the western watershed of the Andes (Fig. 5). Therefore, despite being approximately available in the same area of supply, these two chemical types imply different explanations.

Laguna del Diamante type is underused in comparison to Arroyo Paramillos, available at the same localities, lending support to aspects of quality of the source as the explanation for its limited distribution. Arroyo Paramillos, on the other hand, reaches the lowlands along the Maipo River in a relatively systematic fashion. This could be the scale of transhumant patterns of mobility connecting the Andes with its western watershed. Clearly, other types of evidence will have to be summoned to test this hypothesis. Recent osteometric studies on assemblages from Laguna del Diamante suggest the presence of domesticated camelids (*Lama glama*) at ca. 500 year BP in the area (Gasco, 2013). The presence of societies with herding strategies opens the possibility to explore the existence of transhumant routes that usually are accompanied by reduced quantity of obsidian in disseminated sites in long distances from the source (Barge and Chataigner, 2003) like the pattern recorded in the latter period.

Cerro Huenul obsidian provides an intriguing record. Despite being the closest source and accessible year round, it constitutes only 14% of the obsidian characterized in La Payunia volcanic field, being outnumbered by Laguna del Maule source (Barberena et al., 2011; Salgán et al., 2012; Cortegoso et al., 2012b). Recent technological analysis of these assemblages indicates that the complete reduction sequence is represented, though in very low frequency in comparison to Laguna del Maule (Salgán et al., 2012). The falloff curve presented in Fig. 7 indicates a sharp drop in the intensity of transport of this raw material beyond 20–50 km from the source. We do not consider that this indicates the scale of human mobility, since other obsidian types are being transported for larger distances systematically. Cerro Huenul provides high-quality obsidian

of suitable sizes for manufacture of the lithic tools recorded at the macro-region. In this context, an alternative hypothesis can be suggested. Assuming the prevalence of a strategy of provisioning embedded in the process of conducting other activities (sensu Binford, 1979), if the region where the source is located results less attractive, we can expect an underutilization of the obsidian source not related to its intrinsic properties. We can define this as the *marginal region hypothesis* (Barberena et al., 2011), indicating that the source could be positioned far of the major interaction spheres. This could be related to dominant geographic vectors of mobility, as discussed below.

Particularly in the case of Cerro Huenul, the distribution reaches ca. 500 km from the source in very low frequencies (Fig. 10). Skipping an argument on the means of acquisition – direct vs. indirect–, for which there is no unambiguous evidence, we can substantiate that these artifacts are transported beyond the spatial scale of territories or home ranges (cf. Gamble, 1992; Borrero et al., 2011; Kelly, 2011). Interestingly, these cases occur during the late Holocene, in a context of increasing regionalization and, particularly in the north, diversified subsistence, decreased mobility, and long-distance interactions observed in the material record (Frigolé et al., 2014).

5.2. Dominant geographic vectors of access to the sources

The human use of high altitude settings only available in a seasonal basis is a key topic in the archaeology of the Andes, and other high altitude settings around the world (Bender and Wright, 1988; Aldenderfer, 1998; Barge and Chataigner, 2003; Rademaker et al., 2012). These settings, as well as any other part of a given landscape, are usually accessed and occupied from multiple adjacent regions. Nevertheless, *dominant geographic vectors* of use may emerge under specific conditions. The least cost analyses presented here provide the geographical basis for an assessment of patterns of human circulation.

In the case of Laguna del Diamante locality, our results indicate that the high altitude settings are more easily accessed from the lowlands on the western side of the Andes (Fig. 2). The geochemical results discussed for the two chemical types available at this locality indicate a human transport and discard that is spatially heterogeneous, being skewed towards the west in terms of scale and intensity of transport (Figs. 4 and 5). This is particularly evident in the temporal interval 3, covering the late Holocene (Fig. 10). We suggest that this indicates an *asymmetric human use of highland Andean settings with a dominant vector of access from the western lowlands*. This would be in agreement with the different costs of access modeled with GIS. Building on this, we suggest that biogeography conditions but does not determine actual patterns of human spatial organization. The existence of different demographic and economic conditions in the western vs. eastern Andean watersheds could provide the social basis for such an asymmetric dynamic of circulation.

Human paleodiets inferred from stable isotopes in human remains from the Chilean side of the Andes indicate the existence of diverse economic modes associated to different parts of the landscape (Sanhueza and Falabella, 2010). The area of the upper basin of the Maipo River has been proposed as ecological and cultural threshold around 3500 years BP characterized by innovations in subsistence that include the handling of botanic resources, such as Chenopodiaceae (Planella et al., 2011). Interestingly, tools made on obsidian from Arroyo Paramillos have been recorded at this site. Though not conclusive, this is consistent with some levels of demographic packing (sensu Binford, 2001). Considering also that the rugged and circumscribed character of a large part of the available space in the Pacific watershed limits the amount of productive lands, these would be the most appropriate conditions for intensification of resources and systematic annexation of the highlands (cf. Durán et al., 2006). Interestingly, this scenario provides an alternative for current arguments on intensification processes in the Atlantic watershed of the Andes (Neme and Gil, 2008; Neme et al., 2013). The correlation of the obsidian results with isotopic information on the geographic origins of human remains (Quiroga et al., 2015) and style of ceramic assemblages (Frigolé et al., 2014) will provide fertile ground for a comprehensive assessment of this hypothesis.

Cerro Huenul source provides a different case, since it is located in the lowlands. As mentioned before, our data is biased towards the east and northeast, hampering an assessment of other spatial patterns. Nevertheless, we hypothesize that this situation may hold in the face of an improved database, since the presence of Laguna del Maule source to the west of Cerro Huenul would provide a more attractive alternative. Currently available data allows suggesting that human societies from the deserts of southern Mendoza (La Payunia) favored a west-east vector of mobility, connecting with Laguna del Maule source, in detriment of movements towards the south and southeast, connecting with Cerro Huenul (Giesso et al., 2011).

6. Conclusions: what can minor obsidian sources teach us about human biogeography?

We have presented the case of two obsidian sources located in the highlands (Laguna del Diamante) and lowlands (Cerro Huenul) of central-western Argentina. This analysis has allowed us to consider three main issues in a preliminary manner: a) biogeographical context of the sources and intensity of use and transport, b) existence of dominant geographic vectors of access and exploitation, c) temporal patterns of use since the Pleistocene–Holocene transition, and possible relations to socio-economic changes.

A macro-regional perspective on the use of these sources and alternative ones indicates that these two were used and transported less intensively than Las Cargas and Laguna del Maule, respectively. In this context, the notion of 'minor sources' (Shackley, 2009) seems relevant for asking questions about human mobility and organization of technology. Why were these sources underutilized vis-à-vis the others? Considering that Las Cargas and Laguna del Maule are primary sources, the pattern of exploitation of Laguna de Diamante and Cerro Huenul may be explained in terms of their lower ranking in terms of potential blank size. On the other hand, these sources have varying costs of access, as quantitative least cost paths models show. Cerro Huenul has lower costs of access than all the alternative sources, year-round availability, and excellent nodule quality. In this context, we suggest that alternative scenarios have to be considered for certain time periods, when these regions were of little interest or inaccessible due to social or geographical boundaries.

The two chemical types from Laguna del Diamante locality are located in the Andean highlands with high, but different, costs of access from the Atlantic and Pacific watersheds. Differences in altitude and slope make access less costly from the western side of the Andes. We suggest that the geographic source(s) of the occupations is a fundamental aspect of a study attempting to explain the dynamics of human use of the Andean highlands through time. The topographically enclosed character of Laguna del Diamante may have produced a nearly exclusive exploitation pattern (Barge and Chataigner, 2003). The temporal pattern of use indicated by the successive temporal density maps likely suggests this exploitation mode. On the basis of archaeological distributions, we have suggested the existence of dominant geographic vectors of access to Laguna del Diamante from demographic nodes located on the

western watershed of the Andes. A review of the macro-regional evidence indicates that, during the late Holocene, the western areas presented geographic and socio-demographic conditions more conducive to an intensification of subsistence if compared to the eastern watershed of Southern South America.

In the case of Cerro Huenul obsidian, associated costs of access are much higher from western settings, due to the presence of the Andes as well as the Cordillera del Viento range. Interestingly, despite it is the source that is closest to La Payunia volcanic field, it is underrepresented in the obsidian assemblages. As has been suggested before (Giesso et al., 2011; Cortegoso et al., 2012a), we consider this can also be explained in terms of dominant vectors of circulation with a west–east axis.

The macro-region studied here was settled during the Pleistocene–Holocene transition by hunter-gatherer societies from both sides of the Andes (Cornejo and Saavedra, 2003; García, 2003). The settlement process continued with local interruptions during the middle and late Holocene (Cortegoso, 2005; Gil et al., 2005) until the occupation of most environments around 1500 years BP (Lagiglia, 1999; Durán, 2000; Neme and Gil, 2008). Since ca. 3000 BP, the archaeological record indicates that important economic changes took place on a regional scale, followed by divergent trajectories for areas north and south of 34° S in Argentina and Chile. In the north, farming strategies were incorporated in association with the emergence of small villages and the structuring of wider exchange networks (Sanhueza and Falabella, 1999–2000; Cortegoso, 2006). On the other hand, in the Andean highlands, as well as in the lowlands south of the Diamante River up to northern Patagonia, hunter-gather economies persisted until the arrival of the Spanish (Cornejo and Sanhueza, 2003; Durán et al., 2006; Hajduk et al., 2011).

In this paper we have presented a biogeographic and comparative approach to the study of obsidian sources located in highlands and lowlands of the Andes of Argentina and Chile. This analysis opens questions for future research at different levels, such as the technological signature of different strategies of supply and transport and the meaning of spatial discontinuities in these 'minor' obsidian sources. Our research program draws heavily on archaeometric methods, that will soon be expanded to include obsidian hydration as a tool suited to provide relative chronologies to lithic assemblages (Garvey, 2012). The results on the distributional patterns of obsidian will be combined with chemical information ($\delta^{87}Sr$, $\delta^{18}O$) on human remains in an attempt to correlate patterns in the transport of material goods with strategies of human mobility and migrations.

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