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A STUDY OF OBSIDIAN SOURCE USAGE IN THE CENTRAL ANDES OF ARGENTINA AND CHILE*

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We present the results of XRF analysis for 428 obsidian samples from archaeological sites in the Argentinian province of Mendoza and from central Chile. The archaeological samples come from different environments and have dates that range from 9000 to 300 BP. The results indicate that all known sources were utilized; however, the beginnings and the intensities of their exploitation were variable. On the contrary, strong differences appear, especially between the Cordilleran and the non-Cordillera sources. We suggest that this pattern is mainly related to differences in the accessibility, quality and abundance of the obsidian in the sources.

KEYWORDS: OBSIDIAN SOURCING, XRF, SOUTHERN ANDES

INTRODUCTION

Obsidian was widely utilized in the Andes during pre-Hispanic times (see, e.g., Salazar 1992; Gnecco *et al*. 1998; Burger *et al*. 2000). In Argentina and Chile, several volcanic regions contain high-quality obsidian; and its exploitation and usage began with the very early settlers during the Pleistocene–Holocene transition and continued until historic times (see, e.g., Seelenfreund *et al*. 1996; Stern *et al*. 2000; Yacobaccio *et al*. 2002; Durán *et al*. 2004; Bellot-Gurlet *et al*. 2008).

Until the mid-1990s, little was known about the procurement and distribution of obsidian in the Cuyo region (central-west Argentina) and central Chile. Laguna del Maule was the only known source (Seelenfreund *et al*. 1996). In 2002, we began a project of systematic survey of obsidian sources in the region located between the latitudes of 32°S and 37°S. Differences in the geological structure related to the angle of the tectonic subduction of the plates generate important implications in terms of the volcanic activity in the region. In this way, there is strong volcanic activity south of 32°S and, on the contrary, little volcanic activity to the north until 28°S (Simkin and Siebert 1994).

During the past 20 years, a number of research projects have generated questions related to the exploitation, circulation and use of raw materials in the region (Lagiglia 1997; Durán 2000;

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Neme 2002; Durán *et al*. 2004; Gil 2006). In this paper, we generate a view about the differential use of the obsidian sources and how it could be related to the human use of the landscape.

The first stage of the project involved the location and chemical characterization of five obsidian sources by means of neutron activation analysis (Durán *et al*. 2004) and X-ray fluorescence (De Francesco *et al*. 2006). We compared data from these sources to 70 artefacts from archaeological sites in southern Mendoza and central Chile, which resulted in a first reconstruction of spatial and temporal patterns of use of this raw material.

Here, we present the results of XRF analysis for 428 obsidian samples from 68 archaeological sites of central-west Argentina and central Chile (Fig. 1), with chronologies that extend from the Early Holocene to the European contact. These results gave us more detailed knowledge of the chemical characterization of archaeological obsidians, and the number of both known and unknown sources has increased. A majority of the samples were obtained in excavations, but we have also included some samples from surface collections and a few from museum collections (Schobinger 1976). The archaeological sites come from all types of environments that existed in the region, and include a wide variety of functional activities (specific activities, multiple activities, workshops etc.) and site types (rock-shelters, caves and open-air sites). Analysis took place at the Geoarchaeology Laboratory of the Universidad Nacional de Cuyo.

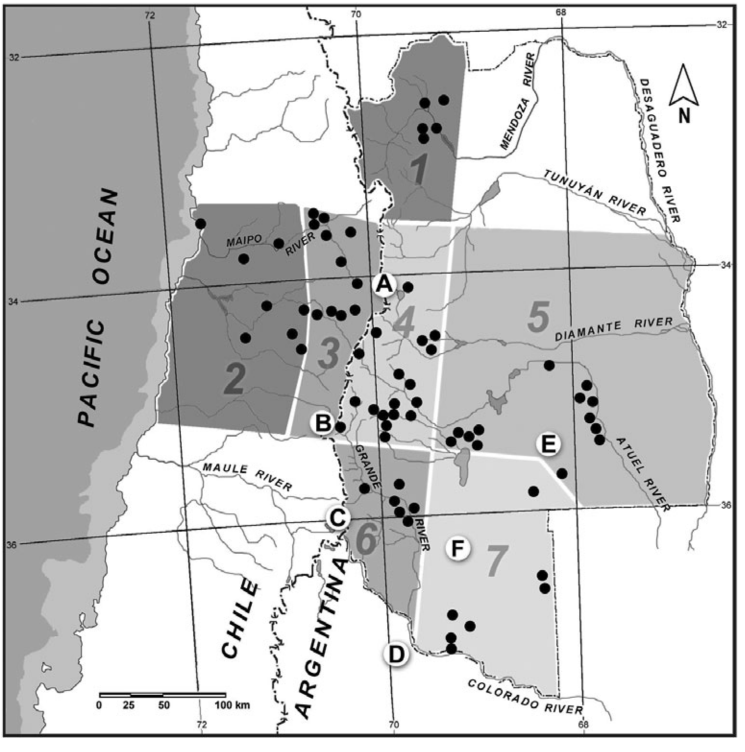

Figure 1 *A map of the study area, with sectors, sources and archaeological sites in Argentina and Chile. Sector 1, Northern Argentinian Cordillera; sector 2, Central Chilean extra-Cordillera; sector 3, Central Chilean Cordillera; sector 4, Central Argentinian Cordillera; sector 5, Central Argentinian extra-Cordillera; sector 6, Southern Argentinian Cordillera; sector 7, Southern Argentina extra-Cordillera. Source A, Laguna del Diamante; source B, Las Cargas; source C, Laguna del Maule; source D, Cerro Huenul; source E, El Peceño, source F, Payún Matrú.*

ENVIRONMENT AND SOURCES IN THE SOUTH-WEST OF SOUTH AMERICA

The research region is located between 32°S and 37°S, and 67°W and 72°W. This large territory extends from the coast of the Pacific Ocean on the west to the Mendoza plains on the east. The region is divided by the Andean mountains, which have an average width of 150 km and heights ranging up to 6900 m a.s.l. The eastern plains are not completely flat. In the south, they include several volcanoes reaching heights up to 3810 m a.s.l. From a west-to-east perspective, the environments located to the west of the Andes are more humid than those in the east and the vegetation is more abundant. The slopes to the east of the Andes are arid to semi-arid. The rivers that drain to the Pacific are shorter, but carry a greater volume of water than those that drain into the Atlantic.

On both slopes of the Andes, the altitude causes significant differences in the distribution of precipitation and in the local environments. But these differences are much more relevant in Chile, where the altitude descends from 6000 to 500 m a.s.l. in less than 70 km. As one moves upwards, rainfall increases and temperature decreases. The Andes belong to the Andean phyto-geographical province. The highlands include two vegetation provinces: the Altoandina Province, between 2200 and 4500 m a.s.l.; and the Puneña Province, developed from the north to approximately 32°S (Cabrera 1976; Roig *et al*. 2000). The central and oriental plains have developed the Monte phyto-geographical province (Roig 1972). Due to the harsh climatic conditions in the high environments, the number of archaeological sites is scant and their chronology is from the Late Holocene (Durán *et al*. 2006).

The Central Chilean Valley, between the Aconcagua and Cachapoal rivers, has a Mediterranean climate, with 350 mm winter rainfall below 500 m a.s.l. Advancing on the slopes of the Cordillera de la Costa and the Andes, rainfall increases, and the development of the arboreal stratum is more outstanding and more varied (Madrid 1977).

Numerous volcanoes, some still active, are located in the centre and southern parts of the region. Volcanic activities decrease to the north of 34°S, where volcanism diminishes its activity, but it continues to the south in Patagonia. Extra-Andean volcanism (*volcanismo de retroarco*) is very abundant in the south of Mendoza, an extension of several thousand square kilometres of volcanoes that were active during the Holocene in the Payunia region. Some of these volcanoes rise to heights of more than 3500 m a.s.l. The distribution of volcanoes and silicic lavas conditions the presence and absence of obsidian sources throughout the region.

REGIONAL ARCHAEOLOGICAL CONTEXTS

The region was settled during the Pleistocene–Holocene transition by hunter–gatherer societies from both sides of the Andes (Lagiglia 1968, 2002; Kaltwasser 1982; Kaltwasser *et al*. 1983; Hidalgo *et al*. 2000; García and Labarca 2001; Cornejo and Saavedra 2003; García 2004). The settlement process continued, with some local interruptions, during the Middle and Late Holocene (Cortegoso 2004a,b; Gil *et al*. 2005), up to the complete occupation of most environments around 1500 BP (Lagiglia 1997; Durán 2000; Gil 2002; Neme 2007).

Since the fourth millennium BP, the archaeological record indicates that important economic changes took place on a regional scale, followed by divergent trajectories for northern and southern Mendoza and central Chile. In central Chile and in the north of Mendoza, the development of farming societies was accompanied by the emergence of small villages and the structuring of wider social and exchange networks (Sanhueza and Falabella 2000; Bárcena 2001; Chiavazza and Cortegoso 2004). On the other hand, in the high Andes as well as in the lower regions of Mendoza, south of the river Diamante, the hunter–gatherer economies continued until the arrival of the Spanish in the region (Lagiglia 1977; García *et al*. 1999; Cornejo and Sanhueza 2003; Gil 2003; Dieguez *et al*. 2004; Durán *et al*. 2006; Gil and Neme 2006). These lifestyle changes may imply variation in human mobility as well as in different patterns of the circulation of goods (Neme and Gil 2008).

Along the western slope of the Andes, there were important differences between Cordilleran and coastal-inland human societies. In recent years, Chilean archaeologists have characterized the Late Holocene human societies who lived in the Andean Cordillera as hunter–gatherers, and the lower valley and coastal populations as farming and more complex societies (Falabella and Stehberg 1989; Cornejo and Sanhueza 2003). This generated different needs in terms of the circulation of goods, territoriality and resource acquisition.

Much of the archaeological research pays attention to the changes in raw material use. In this sense, the archaeological record of the sites shows an increase in the use of obsidian through time. In many areas, obsidian became the most important material found at archaeological sites (Durán 2000; Neme 2002, 2007).

MATERIALS AND METHODS

For this study, non-destructive elemental analysis of obsidian artefacts was conducted using an *ElvaX* desktop energy-dispersive X-ray fluorescence (ED-XRF) spectrometer. The instrument consists of an X-ray generator, an X-ray detector and a multi-channel analyser (MCA). The detector is a solid state Si-pin-diode with an area of 30 mm^2 and a resolution of 180 eV at 5.9 keV (at a count rate of 1000 counts per second). The *ElvaX* uses thermo-electric cooling instead of liquid nitrogen to cool the solid state detector. The output signal of the detector is formed by a time-variant time-processor with a pile-up rejector, a baseline restorer and automatic adaptation of the shaping time to the input count rate. The MCA consists of a fast shaping amplifier (FSA) and a 4096-channel spectrometric analogue-to-digital converter (ADC), built as a successive approximation ADC with channels, a 32-bit per channel buffer RAM, 'sliding scale' linearization of differential non-linearity and a dead time correction circuit. The X-ray tube has a tungsten anode with a 140 μm Be window.

The analysis was conducted at 35 kV with a tube current of 45 μA and an operating time of 400 s. Concentrations were calculated in parts per million, using the *ElvaX Regression* program, based on the quadratic regression model from a series of obsidian reference samples previously characterized by XRF and neutron activation analysis (INAA). The analysis permits quantification of the following 11 elements: potassium (K), titanium (Ti), manganese (Mn), iron (Fe), zinc (Zn), gallium (Ga), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr) and niobium (Nb). The equipment projects individual spectra on the computer screen, thus allowing visual comparisons with previous samples from sources and artefacts to perform a preliminary source identification.

The semi-portable XRF equipment provides a precise, fast and inexpensive approach to this vast obsidian collection, including the analysis of complete tools (projectile points) without having to transport them outside of Argentina. Very few samples could not be assigned with certainty to any of the sources, and these were taken to the University of Missouri Research Reactor (MURR) for analysis by INAA. To identify the obsidian sources, we utilized the MURR INAA database and we added to the analysis 20 additional samples.

Description and analysis of the sources

A total of six sources were located, the first three in the Cordillera region: (a) Laguna del Diamante (with two subsources—Arroyo las Numeradas and Arroyo Paramillos; see Fig. 2); (b) Las Cargas (Fig. 3); and (c) Laguna del Maule (with three subsources—Laguna del Maule, Arroyo El Pehuenche and Laguna Negra; see Fig. 4); and the remaining three sources are located in the oriental plains (Cerro Peceño, Payún Matrú and Cerro Huenul; see Fig. 2 and Table 1).

The obsidian sources have differences in accessibility, mainly due to the topography and seasonality. The latter is more important for the sources located in the Andes, because the winter precipitation limits access to the sources and covers them with deep layers of snow. From the Chilean archaeological sites (western slope) the seasonal problem is greater, because during most of the year the human populations were also almost unable to access the low-elevation extra-Cordilleran sources because of the difficulties in crossing the Andes, as can be seen in the absence of obsidian from the extra-Andean sources at all Chilean sites.

The great amount of obsidian knapping activity on the surface, and the selection of these materials in all sources except for Payún Matrú, suggest that Laguna del Diamante, Laguna del Maule – Laguna Negra – Arroyo El Pehuenche, El Peceño, Cerro Huenul and Las Cargas were also quarries.

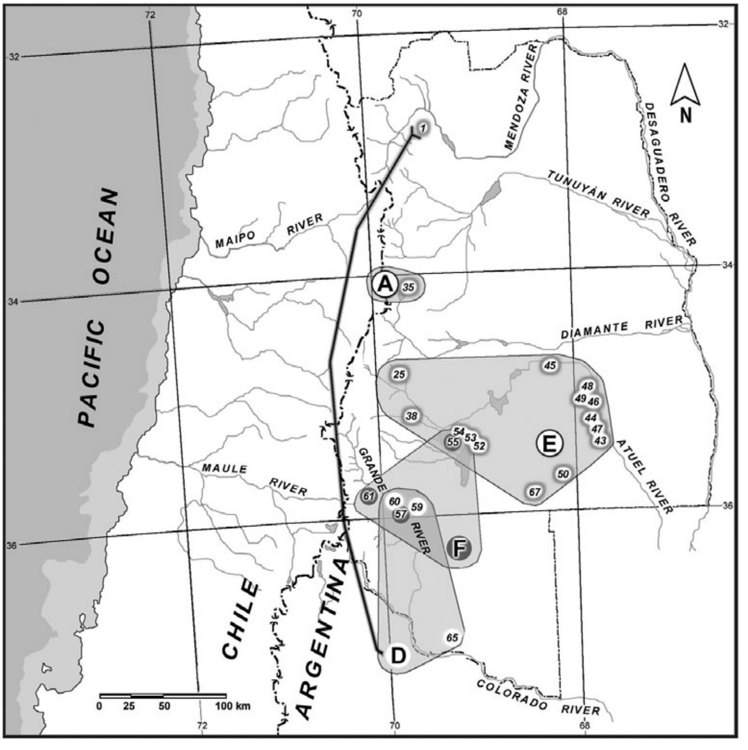

Figure 2 *The Laguna del Diamante, El Peceño, Cerro Huenul and Payún Matrú sources, and their distributions at archaeological sites.*

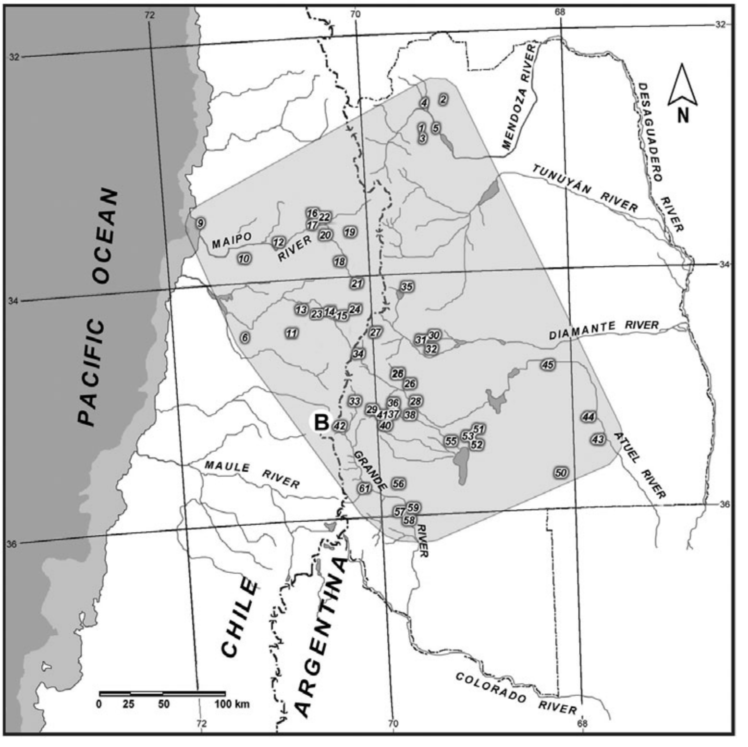

Figure 3 *The Las Cargas source and its distribution at archaeological sites.*

The Andean sources

Las Cargas is a complex source located on the border between Argentina and Chile, at 2350 m a.s.l. (Fig. 1). The total surveyed area of the primary source is around 8 km^2, but according to some information from the local inhabitants, the distribution of the obsidian in the area could be greater. The obsidian appears to be associated with volcanic tuff, with glass inclusions and blocks that can reach 0.5 m^2. There are different secondary subsources in the surrounding area, mainly related to moraines and mountain creeks (Table 2). This source has high-quality obsidian, and the obsidian is readily accessible and visible at the site. Both the primary and the secondary source show signs of knapping activities.

The Laguna del Maule area is a vast volcanic complex located in the High Cordillera, between Argentina and Chile, at altitudes around 2400 m a.s.l. In this area, we can identify three main sectors: Laguna del Maule (Chile), Laguna Negra (Argentina) and Arroyo El Pehuenche (Argentina). The Laguna del Maule complex covers a broad extension, and contains excellent flaking quality and large-sized obsidian blocks—some over a cubic metre in size (Seelenfreund *et al.* 1996). Laguna Negra has obsidian with similar quality and size characteristics. As opposed to the former, the nodules of Arroyo El Pehuenche obsidian are smaller (3–5 cm in diameter), suggesting that they were water-transported from higher altitudes. Upstream of the El Pehuenche ravine there is a great abundance of obsidian, that could come from different nearby sources. Laguna del Maule – Laguna Negra – Arroyo El Pehuenche is the largest obsidian source in the studied region, covering an extension of approximately 900 km^2.

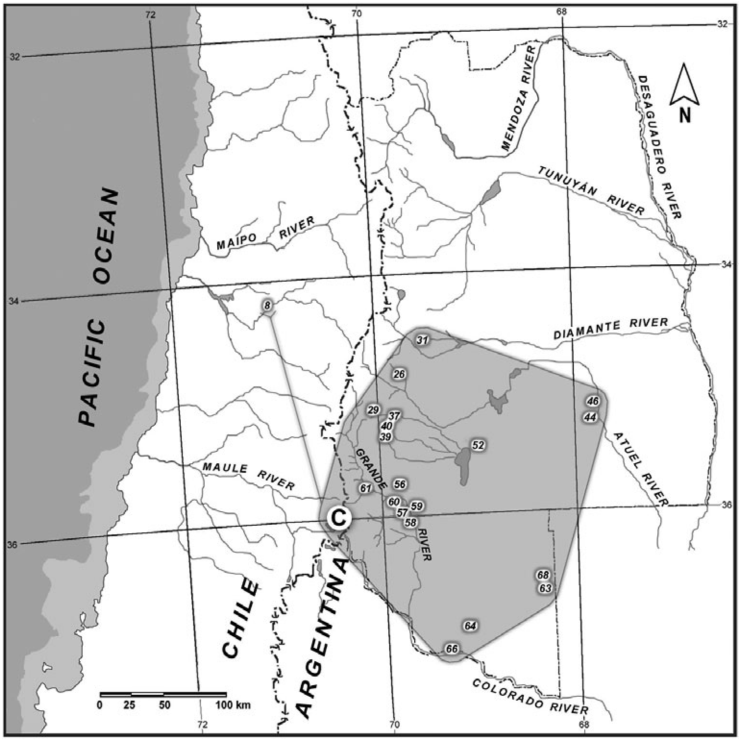

Figure 4 *The Laguna del Maule source and its distribution at archaeological sites.*

Laguna del Diamante is located at 3200 m a.s.l., in the upper valley of the Diamante river on the Argentina/Chile border (Durán *et al*. 2004; De Francesco *et al*. 2006). The area where the obsidians come from is a large volcanic caldera. The region had intense volcanic activity during the Pleistocene, and is rich in ignimbrites. Obsidian nodules, not larger than 10 cm, are widely distributed, and are found in the northeastern areas on high slopes above 3800 m a.s.l., along the ravines that drain to the lagoon and on the lake shores. The quality of the obsidian is good, but there is no great abundance. The nodules are scattered over the landscape, and even when there are some large blocks these present high natural fragmentation.

Extra-Andean (non-Cordilleran) sources

The El Peceño source is located at around 1450 m a.s.l., on the northwestern flank of the El Nevado volcano, in the eastern region of Mendoza (Durán *et al*. 2004). Raw materials are dispersed over a radius of ~1000 m around the cone. The nodules vary from large (30 cm in diameter) to very small (2 cm). The raw material availability is good, both in terms of quality and quantity, and this source is available all year round.

The Cerro Huenul source is located at 900 m a.s.l., on a plateau on the right margin of the Colorado river (Seelenfreund *et al*. 1996; Durán *et al*. 2004). Access is easy all year round, and the obsidian is of high quality. The raw material is found in vast metheorized ignimbrite

Table 1 *Element concentrations and standard deviations for obsidian compositional groups in the Mendoza region measured by NAA and XRF**

	Cerro Huenul	*El Peceno-1*	*El Peceno-2*	*Las Cargas*	*Laguna del Diamante*
NAA data	(*n* = 16)	(*n* = 28)	(*n* = 4)	(*n* = 35)	(*n* = 19)
Na (%)	3.20 ± 0.06	3.34 ± 0.08	3.11 ± 0.10	3.25 ± 0.07	3.08 ± 0.07
Al (%)	7.08 ± 0.32	7.69 ± 0.33	7.39 ± 0.24	7.73 ± 0.27	6.94 ± 0.33
Cl	356 ± 64	394 ± 54	303 ± 75	674 ± 115	511 ± 50
K (%)	3.23 ± 0.20	3.77 ± 0.19	3.97 ± 0.19	2.80 ± 0.17	3.63 ± 0.16
Sc	1.61 ± 0.03	0.28 ± 0.02	0.24 ± 0.02	2.84 ± 0.05	1.74 ± 0.06
Mn	675 ± 15	880 ± 19	793 ± 26	585 ± 18	496 ± 21
Fe	5114 ± 117	5837 ± 194	4754 ± 82	8979 ± 159	4827 ± 373
Co	0.24 ± 0.01	0.16 ± 0.05	0.16 ± 0.03	0.80 ± 0.03	0.12 ± 0.03
Zn	27.7 ± 2.2	49.0 ± 5.1	51.5 ± 2.3	36.4 ± 2.5	35.6 ± 1.5
Rb	104 ± 2	218 ± 4	238 ± 5	112 ± 2	148 ± 2
Sr	131 ± 19	364 ± 49	339 ± 45	217 ± 16	70 ± 9
Zr	95 ± 8	191 ± 11	143 ± 9	141 ± 9	109 ± 12
Sb	0.15 ± 0.01	0.49 ± 0.03	0.70 ± 0.11	0.76 ± 0.03	0.17 ± 0.01
Cs	4.24 ± 0.08	17.69 ± 0.34	20.79 ± 0.29	6.20 ± 0.10	4.42 ± 0.05
Ba	682 ± 18	1127 ± 20	866 ± 14	578 ± 18	739 ± 18
La	16.9 ± 0.4	18.4 ± 0.9	7.8 ± 0.1	28.3 ± 0.6	14.7 ± 2.2
Ce	32.8 ± 0.9	34.2 ± 1.6	15.7 ± 0.2	53.8 ± 1.0	30.7 ± 3.8
Nd	10.7 ± 1.3	11.8 ± 1.1	6.4 ± 0.5	19.1 ± 2.1	11.9 ± 1.5
Sm	2.34 ± 0.10	2.48 ± 0.10	1.62 ± 0.07	3.53 ± 0.12	2.94 ± 0.16
Eu	0.39 ± 0.01	0.47 ± 0.02	0.23 ± 0.01	0.62 ± 0.01	0.41 ± 0.02
Tb	0.32 ± 0.01	0.23 ± 0.01	0.11 ± 0.01	0.40 ± 0.02	0.39 ± 0.02
Dy	1.63 ± 0.21	1.09 ± 0.24	0.62 ± 0.10	2.32 ± 0.29	2.42 ± 0.26
Yb	1.39 ± 0.05	1.18 ± 0.05	0.80 ± 0.05	1.63 ± 0.09	1.33 ± 0.05
Lu	0.25 ± 0.03	0.26 ± 0.07	0.20 ± 0.07	0.29 ± 0.03	0.27 ± 0.03
Hf	2.44 ± 0.06	4.09 ± 0.19	2.92 ± 0.09	3.72 ± 0.09	2.77 ± 0.17
Ta	1.22 ± 0.03	1.46 ± 0.02	1.29 ± 0.02	0.71 ± 0.01	1.09 ± 0.02
Th	9.18 ± 0.19	11.4 ± 0.3	9.37 ± 0.08	13.5 ± 0.2	10.6 ± 0.7
U	4.15 ± 0.28	8.15 ± 0.45	9.60 ± 0.20	3.52 ± 0.32	5.52 ± 0.17
XRF data	(*n* = 8)	(*n* = 29)	(*n* = 13)	(*n* = 180)	(*n* = 20)
K (%)	3.35 ± 0.07	3.07 ± 0.27	3.09 ± 0.20	3.19 ± 0.10	3.62 ± 0.09
Ti	766 ± 129	1720 ± 131	1308 ± 192	997 ± 113	613 ± 126
Mn	502 ± 44	661 ± 46	567 ± 83	344 ± 80	361 ± 46
Fe	5302 ± 412	6092 ± 401	5138 ± 310	9839 ± 713	4903 ± 414
Zn	29 ± 5	40 ± 9	40 ± 7	33 ± 7	38 ± 4
Ga	14 ± 1	14 ± 1	14 ± 1	15 ± 1	15 ± 1
Rb	104 ± 4	226 ± 8	245 ± 7	120 ± 7	151 ± 4
Sr	102 ± 5	376 ± 20	379 ± 76	206 ± 15	71 ± 3
Y	15 ± 2	18 ± 2	16 ± 1	18 ± 2	18 ± 2
Zr	71 ± 3	148 ± 17	103 ± 13	129 ± 9	74 ± 5
Nb	13 ± 1	22 ± 2	20 ± 1	8 ± 2	14 ± 2

*Concentrations are listed in parts per million for each element unless otherwise indicated.

outcrops, cut in parts by several ravines. Water has dispersed the obsidian over several square kilometres. The nodules are of medium to small size, not larger than 10 cm in diameter. It is quite abundant: in less than an hour, a person can collect 50 kg of obsidian suitable for knapping (Durán *et al*. 2004).

Table 1—*continued*

	Laguna del Maule-1	*Laguna del Maule-2*	*Laguna del Maule-3*	*Payún Matrú*	*Unknown-A*
NAA data	($n = 45$)	($n = 4$)	($n = 5$)	($n = 8$)	($n = 2$)
Na (%)	3.58 ± 0.05	3.18 ± 0.03	2.93 ± 0.04	3.23 ± 0.07	3.34 ± 0.05
Al (%)	7.53 ± 0.28	6.78 ± 0.70	6.47 ± 0.42	6.95 ± 0.32	7.40 ± 0.07
Cl	775 ± 159	689 ± 52	603 ± 35	703 ± 129	551 ± 11
K (%)	3.46 ± 0.14	3.87 ± 0.18	3.95 ± 0.22	3.70 ± 0.19	3.32 ± 0.11
Sc	2.32 ± 0.07	2.37 ± 0.02	2.01 ± 0.05	2.30 ± 0.04	1.77 ± 0.03
Mn	590 ± 13	500 ± 6	448 ± 5	494 ± 16	479 ± 1
Fe	7488 ± 472	6036 ± 167	6520 ± 289	6270 ± 238	9033 ± 201
Co	0.22 ± 0.13	0.20 ± 0.04	0.44 ± 0.05	0.24 ± 0.03	0.70 ± 0.02
Zn	47.0 ± 6.0	33.6 ± 0.5	28.0 ± 1.2	35.4 ± 4.6	37.7 ± 3.9
Rb	157 ± 3	178 ± 1	186 ± 3	172 ± 3	144 ± 1
Sr	116 ± 33	114 ± 98	68 ± 13	81 ± 14	193 ± 25
Zr	202 ± 17	169 ± 7	172 ± 18	168 ± 6	276 ± 12
Sb	0.29 ± 0.02	0.34 ± 0.01	0.46 ± 0.05	0.33 ± 0.02	0.60 ± 0.07
Cs	4.55 ± 0.11	5.72 ± 0.04	8.11 ± 0.16	5.56 ± 0.09	7.04 ± 0.08
Ba	703 ± 17	652 ± 11	643 ± 13	657 ± 11	660 ± 8
La	33.3 ± 0.7	31.7 ± 0.2	33.1 ± 0.4	31.1 ± 0.6	23.7 ± 0.4
Ce	65.5 ± 2.1	60.2 ± 0.3	61.0 ± 1.3	59.3 ± 1.1	45.1 ± 0.8
Nd	23.6 ± 1.7	20.4 ± 1.3	20.3 ± 0.7	19.6 ± 1.8	15.9 ± 1.0
Sm	4.50 ± 0.12	3.86 ± 0.04	3.83 ± 0.06	3.85 ± 0.08	2.92 ± 0.03
Eu	0.74 ± 0.03	0.54 ± 0.01	0.44 ± 0.01	0.54 ± 0.01	0.53 ± 0.01
Tb	0.51 ± 0.02	0.43 ± 0.02	0.42 ± 0.01	0.42 ± 0.01	0.31 ± 0.02
Dy	2.78 ± 0.37	2.62 ± 0.29	2.86 ± 0.12	2.38 ± 0.25	1.95 ± 0.07
Yb	2.03 ± 0.05	1.83 ± 0.07	2.01 ± 0.08	1.81 ± 0.04	1.41 ± 0.04
Lu	0.36 ± 0.03	0.43 ± 0.04	0.39 ± 0.05	0.33 ± 0.04	0.33 ± 0.01
Hf	5.16 ± 0.29	4.16 ± 0.05	4.21 ± 0.28	4.26 ± 0.15	5.10 ± 0.07
Ta	0.98 ± 0.12	1.04 ± 0.01	1.04 ± 0.01	1.02 ± 0.01	0.65 ± 0.05
Th	19.9 ± 0.5	22.9 ± 0.2	24.4 ± 0.5	22.3 ± 0.5	16.8 ± 0.2
U	5.35 ± 0.48	6.09 ± 0.15	6.31 ± 0.16	5.95 ± 0.30	4.47 ± 0.05
XRF data	($n = 142$)	($n = 15$)	($n = 19$)	($n = 6$)	($n = 8$)
K (%)	3.55 ± 0.19	3.70 ± 0.11	3.49 ± 0.04	3.59 ± 0.25	3.39 ± 0.28
Ti	1095 ± 148	769 ± 28	730 ± 119	914 ± 83	1477 ± 130
Mn	339 ± 52	249 ± 61	260 ± 47	302 ± 46	477 ± 59
Fe	7177 ± 809	5656 ± 247	6122 ± 400	6852 ± 404	9439 ± 731
Zn	43 ± 11	30 ± 2	43 ± 7	42 ± 11	82 ± 8
Ga	15 ± 1	15 ± 1	14 ± 1	15 ± 1	11 ± 2
Rb	165 ± 11	173 ± 2	159 ± 4	178 ± 16	151 ± 8
Sr	109 ± 21	79 ± 9	65 ± 25	93 ± 12	227 ± 20
Y	24 ± 4	23 ± 1	14 ± 2	21 ± 2	20 ± 2
Zr	179 ± 26	131 ± 5	109 ± 28	146 ± 18	258 ± 46
Nb	12 ± 2	12 ± 1	7 ± 1	11 ± 1	12 ± 2

All the raw material sources were surveyed by the authors; their chemical characterization was carried out using INAA and has been presented in previous papers (Durán *et al.* 2004). This analysis shows important differences that allow us to discriminate between the compositions of the sources as shown in the bivariate plot (Fig. 5). The sources also show important differences in terms of size, complexity, obsidian quality and availability, as listed in Table 2.

Table 2 *The Andean obsidian sources*

Source		*Area*	*Localization*	*Altitude (m a.s.l.)*	*Accessibility*			
					From Argentina		*From Chile*	
					Summer	*Winter*	*Summer*	*Winter*
Laguna del Diamante	Arroyo las Numeradas	Central Argentinian Cordillera	34°07′34″/69°40′38″	3340	Accessible	Inaccessible	Accessible	Inaccessible
	Arroyo Paramillos		34°10′43″/69°39′40″					
Las Cargas		Central Argentinian Cordillera	35°12′01.8″/70°19′23.5″	2350	Accessible	Inaccessible	Accessible	Inaccessible
El Peceño		Central Argentina (extra-Cordilleran)	35°17′51″/68°38′16″	1550	Accessible	Accessible	Accessible	Inaccessible
Laguna del Maule	Laguna Negra	Southern Argentinian Cordillera	36°12′25″/70°24′28″	2090	Accessible	Inaccessible	Accessible	Inaccessible
	Arroyo El Pehuenche		35°58′52″/70°23′35″	2500				
	Laguna del Maule		35°59′57″/70°25′35″	2275				
Payún Matrú (Volcano)		Southern Argentina (extra-Cordilleran)	36°22′42″/69°11′38″	2850	Accessible	Accessible	Accessible	Inaccessible
Cerro Huenul		Southern Argentina (extra-Cordilleran)	35°51′34″/69°51′51″	1050	Accessible	Accessible	Accessible	Inaccessible

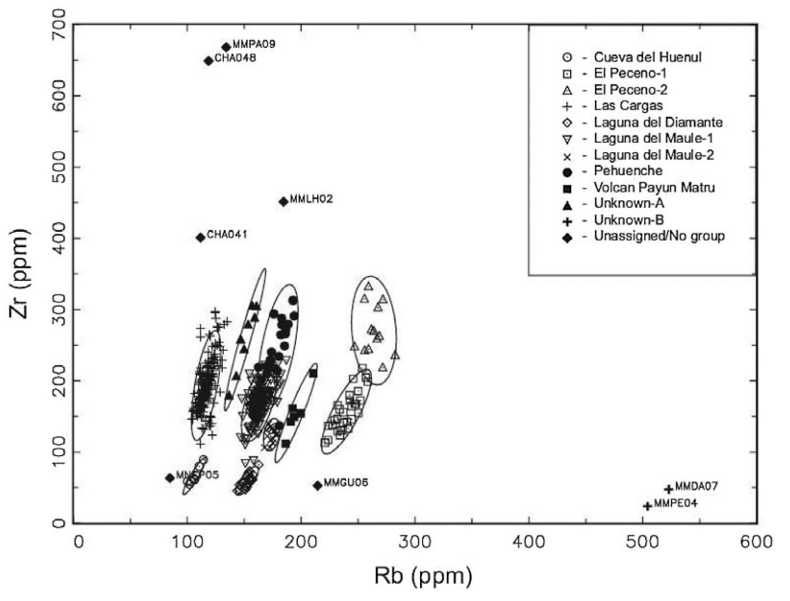

Figure 5 *A bivariate plot of the obsidian sources.*

Obsidian artefact characterization Obsidian artefacts were characterized using both INAA and XRF, as shown in Table 1. For this paper, we analysed a total of 428 obsidian samples from 68 archaeological sites located in different environmental areas of the region (see Table 3). Of these, 412 artefacts were assigned to the six main sources and their subsources. From the remaining 16 unassigned artefacts, we identified eight that formed a compositional group of an unknown source ('Unknown-A') and two that belonged to the compositional group 'Unknown-B', while the remaining six samples could not be grouped ('Unassigned group') (Table 4). To obtain additional information, 10 of the unassigned artefacts were submitted to INAA at the Missouri University Research Reactor (MURR).

We grouped the archaeological sites into seven areas (Fig. 1):

(1) The Northern Cordillera (including the upper basin of the Tunuyán and Mendoza rivers in Argentina).

(2) The western Andean slopes (including the basins of the Maipo and Cachapoal rivers in their lower valleys, and including the Pacific coast)—this area does not have an obsidian source.

(3) The Central Chilean Cordillera (including the upper Cachapoal and Maipo river basins). This area has not been systematically surveyed yet, but unpublished information suggests the existence of obsidian in the region.

(4) The Central Argentinian Cordillera (including the upper Atuel and Diamante river basins). The sources located here are Las Cargas and Laguna del Diamante.

(5) The central eastern plains (this region includes the eastern plains, between the Atuel and Diamante rivers, and the Llancanelo basin). The El Peceño source is found here.

(6) The Southern Cordillera (including the Río Grande basin). The Maule sources are in this area.

(7) The southern eastern plains. The Payún Matrú and Cerro Huenul sources are found here. It includes the area of the Barrancas–Colorado river and the Payunia volcanic region.

Table 3 *The extra-Andean obsidian sources*

Number	*Site*	*Chronology*	*Number of samples and source*
Northern Argentinian Cordillera			
1	La Manga	Late Holocene	2 (1-CH, 1-LC)
2	Agua de la Cueva	Early Holocene	1 (1-LC)
3	El Piedrón	Middle Holocene	4 (3-LC, 1-U)
4	Usina Sur	Late Holocene	14 (14-LC)
5	Río Blanco 1	Late Holocene	1 (1-LC)
Central Argentinian Cordillera			
25	Arroyo Malo 1	Late Holocene	4 (3-LC, 1-EP)
26	Arroyo Malo 3	Early to late Holocene	11 (10-LC, 1-LM)
27	El Indígeno	Late Holocene	3 (1-LC, 2-UA)
28	La Herradura	Late Holocene	3 (2-LC, 1-U)
29	Arroyo el Desecho	Middle Holocene	12 (11-LC, 1-LM)
30	Los Potrerillos	Late Holocene	4 (4-LC)
31	El Mallín	Early Holocene	2 (1-LC, 1-LM)
32	Gruta Carrizalito	Late Holocene	2 (2-LC)
33	Valle Hermoso 1	Late Holocene	4 (4-LC)
34	Los Peuquenes	Late Holocene	5 (4-LC, 1-UB)
35	Laguna del Diamante 4	Late Holocene	36 (18-LD, 18-LC)
36	Cueva Palulo	Late Holocene?	3 (3-LC)
37	Arroyo Panchino	Late Holocene	3 (2-LC, 1-LM)
38	Ojo de Agua	Late Holocene	4 (3-LC, 1-EP)
39	Cerro Mesa	Late Holocene	1 (1-LM)
40	Los Ranchitos	?	3 (1-LM, 2-LC)
41	Mallín largo	?	1 (1-LC)
42	Volcán Peteroa	Late Holocene	16 (16-LC)
Central Argentina extra-Cordillera			
43	Rincón del Indio	Late Holocene	6 (4-EP, 2-LC)
44	La Guevarina	Late Holocene	6 (1-EP, 3-LM, 1-LC, 1-U)
45	Rincón del Atuel 1	Late Holocene	6 (5-EP, 1-LC)
46	Marginal del Atuel 4	Late Holocene	7 (1-LM, 6-EP)
47	La Olla	Late Holocene	3 (EP)
48	El Bosquecillo	Late Holocene	7 (6-EP, 1-UB)
49	Los Marlitos	Late Holocene	2 (2-EP)
50	Cupertino	Late Holocene	2 (1-EP,1-LC)
51	Llancanelo 22	Late Holocene	1 (1-LC)
52	Llancanelo T 18	Late Holocene	8 (2-EP, 1-LM, 5-LC)
53	Llancanelo T 9	Late Holocene	5 (4-EP, 1-LC)
54	Llancanelo T1	Late Holocene	2 (2-EP)
55	Llancanelo 21	Late Holocene	2 (1-LC, 1-PM)
Central Chile extra-Cordillera			
6	Cuchipuy	Late Pleist-Holocene	14 (11-LC, 2-U, 1-UA)
7	Pueblo Hundido	Late Holocene	1 (1-UA)
8	Chuchunco	Late Holocene	1 (1-LM)
9	Arevalo 2	Late Holocene	6 (6-LC)
10	Popeta	Late Holocene	1 (1-LC)
11	Chamico	Late Holocene	1 (1-LC)
12	Lonquén	?	1 (1-LC)
13	El Encanto	Late Holocene	1 (1-LC)

Table 3 *(Continued)*

Number	*Site*	*Chronology*	*Number of samples and source*
Central Chile Cordillera			
14	Caracoles Alero	Late Holocene	2 (1-LC, 1-UA)
15	Caracoles Abierto	Late Holocene	1 (1-LC)
16	El Manzano 1	Late Holocene	4 (4-LC)
17	El Manzano 3	Middle Holocene	3 (3-LC)
18	Los Queltehues	Late Holocene	8 (8-LC)
19	Las Morrenas 1	Middle to Late Holocene	3 (3-LC)
20	Condominio 1	Middle to Late	1 (1-LC)
21	Holoceno	Middle Holocene	2 (2-LC)
22	La Batea 1	Late Holocene	3 (3-LC)
23	Alero Cipreces	Middle Holocene	1 (1-LC)
24	Caserón 2	Late Holocene	1 (1-LC)
Southern Argentinian Cordillera			
56	Caverna de las Brujas	Middle to late Holocene	12 (1-LC, 11-LM)
57	Cueva de Luna	Late Holocene	25 (22-LM, 1-LC, 1-PM, 1-UA)
58	Gruta El Manzano	Early to Middle Holocene	14 (11-LM, 3-LC)
59	Alero Puesto Carrasco	Late Holocene	62 (3-CH, 55-LM, 4-LC)
60	Cañada de Cachi	Late Holocene	47 (2-CH, 42-LM, 2-PM, 1-UA)
61	El Gancho	Late Holocene	4 (1-LM, 1-LC, 2-PM)
Southern Argentina extra-Cordillera			
62	Alpa Este	?	1 (1-U)
63	La Peligrosa 2	Late Holocene	2 (1-LM, 1-UA)
64	Jaguel Avelino	Late Holocene	2 (2-LM)
65	Puesto la Totora	?	2 (2-CH)
66	Ojo de agua la Totora	?	1 (1-LM)
67	Puesto Ortubia	Late Holocene	4 (4-EP)
68	Cueva Delerma	Middle Holocene	1 (1-LM)

RESULTS: GENERAL PATTERNS IN OBSIDIAN PROCUREMENT AND DISTRIBUTION

Our results indicate differential patterns of procurement and use of obsidian through space and time. In some cases these patterns were expected, according to the distance between sources and archaeological sites, while in other cases the patterns differ from the expected tendencies. Variables such as quality, abundance, natural and cultural accessibility, among others, must influence the distribution of the raw material on the landscape. When observing Table 4, we see that at a general level, the Cordilleran sources were used most often. They have wider spatial and temporal distribution than the eastern, non-Cordilleran, sources. Among the Cordilleran sources, Las Cargas has the widest distribution in Cuyo and central Chile. Las Cargas is also the source that links to sites with the oldest dates on both sides of the Andes (8900 BP in Arroyo Malo 3, and 220–240 cm Archaic levels in Cuchipuy) and it appears in the greatest number of archaeological sites. The Maule complex (Laguna Negra – Maule – Pehuenche) follows Las Cargas in spatial and temporal range.

On the contrary, the non-Cordilleran sources (Peceño, Payún Matrú and Cerro Huenul), even though they were easy to access all year round, have the smallest geographical distribution (El

Table 4 *Obsidian artefact characterization*

	Northern Argentinian Cordillera		*Central Argentinian Cordillera*		*Central Argentinian extra-Cordillera*		*Central Chilean Cordillera*		*Central Chilean extra-Cordillera*		*Southern Argentinian Cordillera*		*Southern Argentinian extra-Cordillera*		*Total*
Sources	*%*	*Total*	*%*	*Total*	*%*	*Total*	*%*	*Total*	*%*	*Total*	*%*	*Total*	*%*	*Total*	
Laguna del Diamante			17.8	18											18
Las Cargas	90.9	20	70.3	71	39.7	29	96.5	28	80.7	21	6.1	10			179
Laguna del Maule			5.9	6	6.8	5			3.8	1	86.5	142	38.4	5	159
El Peceño			1.9	2	49.3	36							30.7	4	42
Cerro Huenul	4.5	1									3	5	15.3	2	8
Payún Matrú					1.3	1					3	5			6
Unassigned	4.5	1	0.9	1	1.3	1			7.6	2			7.6	1	6
Unknown-A			1.9	2			3.5	1	7.6	2	1.2	2	7.6	1	8
Unknown-B				1		1									2
Total	100	22	100	101	100	73	100	29	100	26	100	164	100	13	428

Peceño) and are present at the fewest number of archaeological sites (Payún Matrú and Cerro Huenul). Even though it is present at numerous sites ($n = 10$), the El Peceño obsidian is rarely found at sites located more than 60 km from the source. Arroyo Malo 1 and Ojo de Agua, around 100 km from the source, are the only exceptions. We can also add that this source has only been exploited since 1500 BP. The presence of El Peceño obsidian declines in the eastern areas when we move to the south.

The Payún Matrú and Cerro Huenul sources in the non-Andean regions and Laguna del Diamante in the Cordillera region were the least utilized sources. The latter seems to have been used only at sites near the quarry itself.

In general, we notice that obsidian circulation at the regional macro-level is negatively correlated with geographical distance to each source, although this is not always the case. It is necessary to consider that we have analysed a relatively small number of samples per site, which makes it difficult to interpret these percentages.

According to this pattern of a higher frequency of use at sites closer to the source, the El Peceño source has its main distribution area in the Argentinian south and central extra-Cordillera, particularly in the low and middle Atuel basin. The Laguna del Maule obsidian was mainly distributed in the Southern Argentinian Cordillera, and Las Cargas obsidian is primarily found in the Central and Northern Argentinian and Chilean Cordillera and the Chilean extra-Cordillera (Table 4).

One of the most interesting patterns of obsidian distribution is that of the Cerro Huenul source. Even though this type of obsidian is one of the least common in Cuyo, Cerro Huenul obsidian reached very long distances to the north, east and north-east, much farther than any of the other obsidian sources that we analysed. Cerro Huenul samples match those from a site in northern Mendoza, some 450 km away, those from the Intihuasi cave some 600 km to the north-east (San Luis) (Laguens *et al.* 2007) and in southern La Pampa, 300 km to the south-east (Giesso *et al.* 2008).

Cañada de Cachi and Cueva de Luna (in the Southern Argentinian Cordillera) are two sites with obsidian from the greatest number of sources (four in each). These sites are located in the Río Grande basin, which is the area that has the greatest diversity of obsidian sources, but this is due partly to the fact that the Río Grande sites have the largest samples. Nevertheless, Las Cargas is still the most popular source in the basin. In the Payunia volcanic region sites, only southern and unassigned sources are present.

Along the western slopes of the Andes (present-day Chilean territory), we note a very homogeneous pattern, with an over-representation of the Las Cargas source with 96.5% ($n = 28$) in the Cordillera and 80.7% ($n = 21$) in the extra-Cordillera and coastal sites. Surprisingly, the extra-Cordillera area in Chilean territory is the greatest distance from the sources, but it has more sources represented (five) than the Chilean Cordillera territory (two) with nearly the same number of samples. These differences could explain the higher circulation of obsidian from different sources. While the hunter–gatherers were acquiring the obsidian directly from the sources, the farming groups with more complex trade networks were taking raw material from further away and from more diverse places.

The present research has not explored the ratios of obsidian versus all other raw materials and their changes through time. At this point it is difficult to assert in detail tendencies in increasing or decreasing obsidian procurement at different sites, except for the Cordilleran sites of the Atuel Valley, where there was an overall increase in the percentage of obsidian over all other lithic raw materials during the Holocene (Neme 2007).

DEBATES REGARDING THE USE OF SOURCES

Non-Cordilleran sources

A series of questions emerges from the observed patterns that were unexpected. One of these patterns is related to the low utilization of non-Cordilleran sources. Why did the prehistoric populations use El Peceño, Huenul and Payún Matrú obsidian in such small numbers? The El Peceño source is very easy to access from its surrounding area, it is reachable all year round and it has obsidian of excellent quality. The explanation that we can suggest here is that Payunia was settled until recent times, not before 2000 BP (Gil 2002, 2006), which can be related to more recent knowledge of the El Peceño source.

We can also argue that territoriality could have influenced the circulation of materials from this source. However, this explanation is very unlikely, as it is difficult to believe that territorial boundaries remain fixed over millennia. Another element is the quantity and quality of local obsidian. Even though El Peceño obsidian is of high quality, its outcrops are very small and unevenly distributed, and the vitreous form is present only as small nodules.

No samples from the Chilean archaeological sites come from these extra-Cordilleran sources located on the eastern slopes. In this case, it is not only the distance that is playing a role in their absence. We must take into account the presence of the Andean Cordillera, which acts as a geographical barrier (in the sense of Veth 1991), such that access from Chile is limited in terms of seasonality, because the Cordillera could not be crossed all year round.

Cerro Huenul presents conditions similar to El Peceño. It is a place of easy, year-round access and the obsidian is of high quality, and it is present in larger quantities than at El Peceño. Nevertheless, it was only found as artefacts on four sites in the region, and with a very low frequency. The earliest use of Cerro Huenul obsidian can be traced to the Late Holocene, at Cañada de Cachi (3200–2200 BP), and it arrived in northern Mendoza (at the La Manga site) around 1100 BP. Its good quality could explain its wide spatial distribution, with a radius of more than 600 km, reaching to the northeast (the central Argentinian hills) and to the east, into the Dry Pampas, during the Late Holocene.

We might argue that its limited distribution was a matter of territories and/or accessibility to the quarry from the north, because the Colorado river could have been a difficult barrier to cross. In this sense, Cerro Huenul could have been more widely used by the inhabitants of the southern areas (the province of Neuquén). We also have to consider that there are smaller sources, with easier access, close to Cerro Huenul, and it is probable that some of the unknown sources could be from this region, making it a potentially rich obsidian macro-source for southern Mendoza/Payunia.

Payún Matrú is the last example of a non-Cordilleran source. As with the other two cases (El Peceño and Cerro Huenul), this source is poorly represented in the region, including those areas that are closer to them, such as the eastern Payunia. A problem is that not all potential outcrops have been located. One of the reasons why Payún Matrú obsidian is so rarely found is that most of it is of substandard quality. It is very likely that the lack of water in surrounding areas made visits to this region difficult for the prehistoric inhabitants. If we also consider that Payunia was populated very late, and/or as Borrero (2002) suggests, it was only exploited from its margins, then access to the source could have been very occasional and sporadic, diminishing the frequency of its use. The analysed samples suggest a late use for the Payún Matrú source, with dates that correspond to the last half of the Late Holocene and that coincide with the settlement models for the region (Gil 2006). An exception to this is the presence of Payún Matrú obsidian in a 7200 BP context of Gruta del Manzano (Río Grande basin, southern Mendoza).

The Cordilleran sources

Las Cargas and El Maule were the most heavily utilized sources in the study area, both on the eastern and western slopes. The large sizes of the obsidian outcrops, and the diversity, accessibility and high quality of the obsidian, caused these sources to be the most widely utilized both in time and space. Even though we do not have a detailed map of Las Cargas, both El Maule and Las Cargas are enormous, reaching in the case of El Maule a radius of approximately 20 km, with multiple outcrops at different altitudes, and with rivers and streams that move the nodules many kilometres downstream.

Of these two sources, Las Cargas seems to have been the most important for the Cuyo – the central Chile region (41.8%). It is the most frequently represented source at sites in the Central Argentinian Cordillera (70.3%) and the Northern Argentinian Cordillera (90.0%). On the other hand, even when Las Cargas represents only 6.1% of the obsidian sample of the Southern Cordillera sites, it is present at 80% of this region's sites, which is an area where Maule obsidian is predominant. Las Cargas obsidian also has a higher presence than Maule obsidian to the east of the Cordillera (33.7% versus 11.6%) and Las Cargas is practically the only type of obsidian in Chilean sites, even though Laguna del Diamante is closer to most archaeological sites there. All of this confirms the importance of Las Cargas obsidian in the area of study.

In the case of El Maule, it represents the 37.1% of the total sample. El Maule is the most commonly represented source in the Southern Argentinian Cordillera (86.5%), but only 5% of the obsidian samples in the Central Argentinian Cordillera (the area of predominance of Las Cargas), and only 10% of the sites have Maule obsidian in this region.

On the contrary, obsidian from Laguna del Diamante has one of the most unusual patterns. Exploitation of obsidian from the source was limited to sites located in the vicinity of the quarry (similar results in Durán *et al*. 2006). It is difficult to explain the limited use of this source as a consequence of access problems, because it could not have been more difficult to exploit than El Maule or Las Cargas. It is possible that the lack of obsidian circulation from Laguna del Diamante could have been related to the very small size of the nodules available there. A similar case was observed by Shackley (2005, 2009) in relation to the Topaz Basin source in Arizona. Obsidian from Topaz was only present in the nearest sites and is underrepresented with respect to other sources such as Government Mountain, located further away. Shackley argues that the small size of the nodules, and probably the differential access to the source due to territoriality, routes and/or social relations, are potential reasons for such an unexpected pattern.

Laguna del Diamante is the northernmost source, and even so, the Las Cargas obsidian was utilized more frequently in this region. The higher proportions of debris to finished tools (Durán *et al*. 2006) suggest that it was used expediently, reinforcing the local use of this resource. Another explanation about the low intensity of use could be related to late discovery of the source—and the high altitude—*c*. 2000 years BP (Durán *et al*. 2006; Neme and Gil 2008). Surprisingly, obsidian from the Laguna del Diamante source has a very restricted range. This source is not represented at sites from the western and eastern slopes of the Andes, located in the closer valleys of the area. The only two sites with obsidian from this source are located in close proximity to the source (<5 km). On the contrary, obsidian from Las Cargas is the only source present in the Maipo Valley, which happens to be the closest valley to the Laguna del Diamante source on the western slope.

Unknown sources

A particular case is represented by a source that we call the Unknown source A: its distribution pattern ranges from the Cachapoal river in the western side, to the upper Atuel Valley in the Argentinian Cordillera, to the Río Grande, to the central and eastern plains. The wide distribution of the Unknown source A suggests that this source might be located in the Cordilleran region—as no obsidian from eastern sources was found in the High Cordillera, nor in Chile—and if we compare its distribution with that of Las Cargas and Laguna del Maule, its presence is suggested to be closer to Las Cargas than Laguna del Maule.

There are unassigned sources with one or two artefacts each, particularly in the southern areas, but at this point it is difficult to establish where these sources might be located.

CONCLUSIONS

This research has greatly expanded our knowledge of how the pre-Columbian populations of the southern Andes (32–37°S) utilized obsidian. An important sample of archaeological sites from a wide diversity of natural environments is represented in this research, allowing us to discuss obsidian distribution across a wide spatial and temporal range.

The results indicate that obsidian from the Cordilleran sources, except for Laguna del Diamante, had the widest spatial and temporal dispersal. Among these, Las Cargas, located in the vicinity of the Planchón–Peteroa volcanic complex, was the most frequently utilized, ranging from the Early Holocene (9000–8000 BP) until the Spanish Conquest. Laguna del Diamante obsidian was only found at sites located less than 5 km from the source. In the area to the east of the Andes, the El Peceño quarry, located in the north of the Payunia volcanic region, has the widest dispersal even though it was only used after 1500 BP. This late use for a lower elevation source is in agreement with the chronology of the exchange systems in the region (Neme and Gil 2005), where the diversity and quantity of goods increase in number at all archaeological sites after 2000 BP.

On the other hand, the obsidian sources at Payún Matrú and Cerro Huenul, both outside of the Cordillera, were also exploited in small amounts. Obsidian from the latter reached the largest extension, from the north of Mendoza to northeastern San Luis and southern La Pampa.

Regarding chronology, the Las Cargas and Laguna del Maule sources were the first exploited throughout the region. Their high quality and abundance could be the main reasons for their selection.

Our results allow us to discuss not only the aspects of preferred directionality in the circulation of materials, but also issues of differential use of space in the region and how this use changed with time. These tendencies have allowed us to analyse previous results in a new light and to integrate the archaeological record of both slopes of the Andes. The valuable results obtained here will motivate us to continue to explore in detail the chemical and spatial characterization of the sources, expand the number of samples to be analysed in all archaeological sites, and explore and locate sources that remain unknown.

Finally, the use of X-ray analysis has demonstrated its utility in our region not only by allowing us to accurately discriminate the raw material sources, but also because it is convenient as a rapid, non-destructive and inexpensive method.

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