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Deconstructing a Complex Obsidian ‘Source-scape’: A Geoarchaeological and Geochemical Approach in Northwestern Patagonia

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This is the author manuscript accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the [Version of Record](#). Please cite this article as [doi: 10.1002/gea.21701](https://doi.org/10.1002/gea.21701).

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ABSTRACT

Northwestern Patagonia is located in a tectonically active part of the southern Andes (Argentina), which has facilitated the formation of obsidian, including pyroclastic deposits that have been affected by geomorphic processes, resulting in a complex obsidian landscape. Until now, the geomorphic relocation of obsidian in the landscape has not been a focus of systematic research, and this hampers our understanding of prehistoric human mobility. We present an updated assessment of the regional availability of different obsidian types based on results from our research program, which combines geoarchaeological survey and geochemical characterization to understand the properties and distribution of obsidian. This robust ‘source-scape’ provides a robust foundation for reconstructing patterns of lithic provisioning and discard. Our results suggest that interpretations of obsidian availability across the landscape should be more

nuanced than is typically acknowledged. Based on our improved ‘source-scape’, we discuss the patterns observed in an archaeological XRF database. When compared to the geoarchaeological reconstruction of obsidian availability, the archaeological record conforms to a distance-decay pattern. Contrary to previous interpretations, we suggest that the distribution of obsidian types is not isomorphic with human home ranges. This geoarchaeological research program provides a basis for integrating the archaeological records of different Andean regions.

Keywords: Geoarchaeology of obsidian sources; Southern Andes; Patagonia; Geochemistry; Lithic provisioning.

1 INTRODUCTION

Northwestern Patagonia is located in a tectonically active setting of the southern Andes (36°-37° S, Argentina) where obsidian has formed in arc and back-arc contexts, including extensive and spatially complex pyroclastic deposits containing obsidian nodules (Stern, 2004; Kay, Burns, Copeland, & Mancilla, 2006; Andersen, Singer, Jicha, Beard, Johnson, & Licciardi, 2017). During the late Quaternary, diverse geomorphic processes modified the spatial structure of these deposits, resulting in a highly complex macro-regional obsidian landscape. The geomorphic processes of obsidian nodule relocation across the landscape have not yet been systematically investigated, hampering archaeological interpretations of lithic procurement, transport, and discard.

Understanding primary and relocated obsidian deposits is the fundamental step to developing an analysis of raw material provisioning and conveyance (Kuhn, 2004; Smith & Harvey, 2018; Shackley, Morgan, & Pyle, 2018). We present the results of a research

program that combines geoarchaeological survey and geochemical characterization of obsidian sources from northwestern Patagonia (Argentina). Our research efforts have improved upon previous knowledge of known chemical types and identified new sources in areas about which we had no prior knowledge.

Surveys conducted during the last two decades have led to the identification of two main obsidian sources in our study area (Figure 1): Laguna del Maule and Cerro Huenul (Seelenfreund, Rees, Bird, Bailey, Bárcena, & Durán, 1996; Durán, Giesso, Glascock, Neme, Gil, Sanhueza, 2004). The geological complexity of these two sources demands an approach that carefully distinguishes between the geological and geochemical bases for the definition of a ‘source’. As Hughes (1998, 104) suggests, “Obsidian sources are defined, geochemically speaking, on the basis of chemical composition—not spatial distribution”. This is fundamental in this study area since, whether by primary obsidian formation in widespread ash-fall tuff deposits or by secondary fluvial transport of nodules, it is usually not possible to assign a given chemical type to a restricted area of availability. In addition, the Laguna del Maule source is characterized by the presence of several chemical types. In sum, the concepts of primary and secondary sources (Luedtke, 1979) do not account for the full range of variability recorded in this complex geological context. Since our knowledge of the geological distribution of chemical types is being continuously updated in the light of increasing field data—including those presented here—, we opt to utilize the chemical types as the units of analysis (Hughes, 1998; Eerkens & Rosenthal, 2004; Ericson & Glascock, 2004).

We strategically combine geochemical characterization by means of X-ray fluorescence (XRF) and neutron activation analysis (NAA), considering their respective abilities to discriminate between sources and evaluate intra-source variability (Millhauser, Rodríguez-Alegría, & Glascock, 2011; Glascock & Ferguson, 2012; Shackley et al., 2018). By generating the necessary geoarchaeological foundation (Shackley, 1992; Glascock, Braswell, & Cobean, 1998; Glascock, 2016), the ultimate goal of this research lies in reconstructing patterns of technological organization, human mobility, and social interaction in a highly heterogeneous Andean landscape, which includes yearlong potential for lowland habitation and limited seasonal availability of highlands and associated resources. In the discussion section, we present a preliminary analysis of archaeological obsidians' geochemical signatures from the Barrancas-Buta Ranquil region (Figure 1), recorded in the context of a program of systematic survey and excavation (Barberena, Romero Villanueva, Lucero, Fernández, Rughini, & Sosa, 2017).

The regional archaeological record indicates the presence of mobile societies with diets predominantly based on the consumption of *guanaco* (a wild camelid) and wild vegetal foods, such as *Prosopis* sp. (Llano & Barberena, 2013; Gordón, Perez, Hajduk, Lezcano, & Bernal, 2017). Foraging for these food resources in a highly seasonal and rugged landscape gives lithic technology a central role in the organization of mobility, tightly linked to obsidian accessibility, knapping quality, and abundance (Torrence, 2001; Kuhn, 2004).

2 MATERIALS AND METHODS

The regional landscape is a complex mosaic where tectonics, volcanism, landslides, fluvial and glacial processes have interacted to greater and lesser degree through time (González Díaz & Di Tommasso, 2011; Singer et al., 2014). In order to maximize the representativeness of samples from the diverse geological contexts where obsidian is found, we combine different survey strategies as described below.

2.1 Sampling a Fluvial Context: Laguna del Maule

Laguna del Maule is a complex source located in the Andean highlands of Chile and Argentina (2300-2000 masl) with extensive primary outcrops and distinct obsidian chemical signatures (Seelenfreund et al., 1996). This source is only accessible during the summer months. Within this obsidian complex, the Laguna del Maule 1 type is mostly black and can be banded or translucent. Its knapping quality varies between regular and very good (*sensu* Aragón & Franco, 1997), depending on the amount of banding and abundance of crystaloclasts. Based on its primary area of availability within the study region, hereafter will refer to it as ‘Laguna del Maule 1-Laguna Negra’. Laguna del Maule 2 obsidian can be black or gray with good to excellent quality. It may also contain crystaloclasts. For geological reasons discussed below, hereafter we refer to this chemical type as ‘Laguna del Maule 2-Río Barrancas’.

The archaeological distribution of Laguna del Maule obsidian types has been used as proxy evidence for seasonal access to the highlands and transport to the lowlands in circuits reaching up to 150 linear km, thereby providing a measure of the large spatial

scale of human home ranges (Giesso, Durán, Neme, Glascock, Cortegoso, Gil, & Sanhueza 2011; Salgán, Gil, & Neme, 2014).

The primary lava flows located in the highlands between Laguna Fea and Laguna Negra comprise the eastern section of this volcanic field. They have a complex post-Pleistocene history, including successive eruptions between 24 and ≤ 2 ky and the formation of multiple silicic domes (Figure 2; Singer et al., 2014; Sruoga, Elissondo, Fierstein, García, González, & Rosas, 2015; Andersen et al., 2017). The Barrancas-Colorado fluvial basin drains the eastern part of the volcanic field and may have relocated Laguna del Maule obsidian. To assess the fluvial transport of obsidian from the highland outcrops to the lowlands, we surveyed the basin of the Barrancas and the upper segment of the Colorado River, encompassing 110 km between the seasonal Andean highlands at 2500 and the eastern lowlands at 850 masl (Figure 1).

The Barrancas basin is divided in two segments characterized by different geomorphic regimes. The upper section extends between its source in the Lagunas Fea and Negra (2500-2400 masl) and the Laguna Cari Lauquen (1450 masl), where a rock avalanche that occurred at 2.2 ± 0.6 ka (Costa & González Díaz, 2007) created a natural dam and a large paleolake that lasted until AD 1914, when it catastrophically failed due to erosion (Groeber, 1916; González Díaz & Di Tommaso, 2011). Presently, the lagoon covers an area of ~5 km long, while the palaeolake spanned an area of nearly 20 km in length (see details below). The lower section of the Barrancas basin extends between this

natural dam and the river's confluence with the Grande River at 880 masl, where the Colorado River initiates.

In our survey of this vicinity, we targeted obsidian nodules contained in the fluvial deposits (Fernández et al., 2017). In each sampling location, four people conducted 150 m long transects running parallel to the river. Each survey unit covered ca. 1500 m² and was separated from the next by 200 m.

2.2 Sampling a Complex Ignimbrite Deposit: Cerro Huenul

Cerro Huenul obsidian comes from ash-fall tuff deposits with a broad and discontinuous spatial distribution (Barberena et al., 2011). It is deposited as nodules within ignimbrites associated with the Plio-Pleistocene Tilhué Formation that encompasses different volcanic eruptions occurring between 4 and 0.7 my (Durán et al., 2004; Narciso, Santamaría, & Zanettini, 2004; Folguera, Bottesi, Zapata, & Ramos, 2008; Barberena et al., 2011). The erosion of the matrix of these pyroclastic deposits produces lag concentrations of nodules of varying lithology including obsidian, usually clustered in gullies and other erosional landforms.

Originally known to be available in the lowlands, recent results indicate wider availability across the Andean landscape (Fernández et al., 2017). Despite the remarkable diversity recorded in terms of color, Cerro Huenul presents low geochemical variation (Giesso et al., 2011). Previous quantitative studies indicate that the nodules are subangular to subrounded reaching 10 cm along the major axis (Barberena et al., 2011, Table 1). Cerro Huenul obsidian is mostly black, although there are gray, brown and brown-black banded nodules. Most of the samples of this obsidian show some level of

translucency. It lacks inclusions and the knapping quality of this obsidian is always excellent.

In previous surveys, the strategy that we implemented was to target exposures of the Tilhué Formation (Barberena et al., 2011). More recently, we also recorded the presence of obsidian nodules during systematic archaeological surveys. This resulted in the collection of additional obsidian nodules from the area.

2.3 Geochemical Characterization of Obsidian

All obsidian source materials were analyzed using a combination of XRF (n=100) and NAA (n=88) following standard procedures at MURR Archaeometry Laboratory. This study exemplifies a stepwise approach in which XRF was initially used to determine the chemical compositions of the obsidian sources, and NAA was subsequently used to further evaluate sources that could not be statistically differentiated using concentration data for elements measured by XRF alone. XRF analysis was conducted using a Thermo Fisher Scientific ARL Quant'x energy dispersive spectrometer. The X-ray tube was operated at 35 kV with the current (in μA) automatically adjusted to maintain a dead time of 30% or less. Samples were counted for two minutes each, which permitted measurements for the following elements: Mn, Fe, Zn, Rb, Sr, Y, Zr, Nb, and Th. Normalization of the Compton scattering peak was used to account for differences in sample size and thickness. The XRF instrument was calibrated for analysis of obsidian by measuring a set of 40 well-characterized obsidian source samples previously analyzed by neutron activation analysis (NAA), inductively coupled plasma-mass spectrometry (ICP-MS), and XRF (see details in Glascock & Ferguson, 2012).

Eighty-eight of the 100 samples were analyzed by NAA in an effort to further resolve our finding that some sources could not be statistically differentiated using concentration values of elements measured by XRF alone. NAA procedures have been described in detail elsewhere (Glascock et al., 1998). Two thermal neutron irradiations were performed to collect data on elements that produce short-, medium-, and long-lived radioisotopes. NIST standard reference materials and in-house quality control samples (SRM 278 Obsidian Rock) were tested concurrently with all unknown samples. Two aliquots of each obsidian specimen were prepared for short and long irradiation by extracting small fragments from each. They were weighed into high-purity polyethylene vials (~100 mg) for short irradiation procedure, or high-purity quartz vials (~200 mg) for long irradiation. The short procedure samples were irradiated via pneumatic tube system for 5 s in a flux of $8 \times 10^{13} \text{ n cm}^{-2} \text{ s}^{-1}$. Samples were each allowed to decay for 25 min. The gamma-ray energies for elements of interest that produce short-lived isotopes (Al, Ba, Cl, Dy, K, Mn, and Na) were measured by a high-purity germanium (HPGe) detector for 12 m. The long procedure aliquots were batch irradiated for 50 h in a flux of $5 \times 10^{13} \text{ n cm}^{-2} \text{ s}^{-1}$. After 7-8 days of decay, the radioactive samples were measured for 2000 s to obtain data on medium-lived isotopes (La, Lu, Nd, Sm, U, Yb), and again after 3-4 weeks for 8200 s to measure for long-lived elements (Ce, Co, Cs, Eu, Fe, Hf, Rb, Sb, Sc, Sr, Ta, Tb, Th, Zn, Zr). The spectral data were used to calculate elemental concentrations using in-house software and calibrated to NIST standard reference materials by the standard comparator method.

3 RESULTS

The results of our analyses are organized in four sections. The first three present the geoarchaeological results respectively for, respectively, new obsidian sources, Laguna del Maule, and Cerro Huenul, while the fourth presents the geochemical results for all obsidians.

3.1 Geoarchaeological Survey and New Obsidian Sources

Points 1 through 5 in Figure 1 indicate the locations of areas where new obsidian 'sources-chemical groups' were recorded. Location 1 corresponds to a new chemical type of very poor knapping quality, identified as Fuente Alba ($36^{\circ} 22.341'S$, $70^{\circ} 13.766'W$). This source is composed of highly hydrated small nodules (≤ 3 cm) with brittle fracture, which erode from a sedimentary deposit at 1770 masl. This deposit lies 300 m above the current level of the Barrancas River and is not associated with fluvial action. We also recovered a few small nodules (< 3 cm) of poor knapping quality in the locality Laguna Chacaicó (point 2 in Figure 1; $36^{\circ} 24.186'S$, $70^{\circ} 28.534'W$). Very small and hydrated nodules embedded in old ignimbrite deposits were collected in the locality of Paraje Los Tachos (point 3 in Figure 1; $36^{\circ} 40.960'S$, $70^{\circ} 33.738'W$). This obsidian would not be suitable for knapping.

Finally, southwards from the Varvarco Tapia Lagoon and in the upper basin of the Varvarco River we recorded the presence of widespread ignimbrite deposits containing abundant obsidian nodules with sizes reaching up to 30 cm along the major axis (points 4 and 5 in Figure 1; $36^{\circ} 30.078'S$, $70^{\circ} 35.835'W$). Based on the macroscopic characterization of 90 nodules, we observe that this obsidian is mostly black but can also

be grey (5%). The surface texture is generally smooth. Most of the samples have mineral inclusions and inherent fractures, leading to a rock that can be described as of poor to good quality (Aragón & Franco, 1997).

In summary, three of the four contexts where we recorded previously unknown obsidian (Fuente Alba, Laguna Chacaicó, Paraje Los Tachos) contain raw material of poor to very poor knapping quality. Considering that we did not observe any debris associated with human activity, and that we have not found these chemical types during the wide geochemical characterization of archaeological materials conducted so far (Fernández et al., 2017), it seems likely that these obsidians were not significantly utilized as tool stone in the past.

The Varvarco source represents a different situation, since the obsidian recovered is of good knapping quality, very abundant and, more importantly, contextually associated with evidence of human quarrying and initial nodule reduction. The location of this source in the Varvarco basin, connected to the archaeologically important Neuquén River basin, make it an important finding of high priority for future research (Fernández, Leal, Klesner, Della Negra, MacDonald, Glascock, & Barberena, 2018).

3.2 Geoarchaeological Survey of the Barrancas–Colorado River Basin: Laguna del Maule Obsidian

Here we present our results related to the distinct volcanic and geomorphic expressions located along 110 linear km of the Barrancas-Colorado fluvial basin between 2300 and 850 masl (Figure 1). Our survey initiated in the large obsidian flows located in the highlands between Laguna Fea and Laguna Negra (2300-2000 masl, Figure 2).

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Having inspected the entire area between these lagoons, we selected for geochemical analysis three large blocks with different macroscopic characteristics (point 6 in Figure 1). The area known as Pampa del Rayo is a wide pyroclastic plain with a maximum age of 14 ky (Fierstein, Sruoga, Amigo, Elissondo, & Rosas, 2012) located along the Barrancas River between 3-6 km from the obsidian flows (Sruoga et al., 2015). There we sampled angular blocks available in the river bars, some of which reach 40 cm along the major axis (points 7, 8 and 9 in Figure 1: $36^{\circ} 12.435'S$, $70^{\circ} 24.384'W$ and $36^{\circ} 13.756'S$, $70^{\circ} 24.831'W$). We characterized the geochemistry of nine nodules.

The Cari Lauquen lagoon (1450 masl) was a large paleo-lake during the last ca. 2300 years, and this created a different geomorphic regime within the basin from what is found there today (Costa & González Díaz, 2007; Figure 1). Sampling units 1, 2, and 3 (1217-1202 masl) are located 55 km downriver from the primary obsidian flows and 9 km from the Cari Lauquen dam (point 10 in Figure 1: $36^{\circ} 35.335'S$, $70^{\circ} 5.535'W$). We did not observe obsidian nodules in these three units totaling 4500 m² of the floodplain. Sampling units 4 and 5 are located 72 km from the outcrops and 26 km from Cari Lauquen, in the mouth of the Huaraco Creek (point 11 in Figure 1: $36^{\circ} 42.235'S$, $69^{\circ} 58.584'W$). In unit 4 we retrieved a large number of rounded and sub-rounded obsidian nodules ranging between 4 and 8 cm along the major axis, while in unit 5 we recovered only one nodule. Outside of the sampling units we recorded a maximum nodule size of 10 cm.

Sampling units 6 through 11 are located between 80-90 km from the obsidian outcrops and 35-45 km from Cari Lauquen in the left side of the floodplain,

corresponding to Mendoza Province (point 12 in Figure 1). In sampling units 6 and 7 we recovered obsidian nodules reaching up to 10 cm along the major axis. Intriguingly, these nodules are angular and were associated with a localized ignimbrite deposit (Figure 3), which suggests local deposition associated with ash-fall instead of fluvial transport. In sampling units 8 through 11 ($36^{\circ} 47.644'S$, $69^{\circ} 54.920'W$) we did not observe obsidian nodules.

Finally, we surveyed the upper Colorado River with 100 m sampling in units 14 and 15 (point 13 in Figure 1: $36^{\circ} 55.452'S$, $69^{\circ} 46.259'W$), located 110 km downriver from the obsidian flows and 60 km from Cari Lauquen. We recovered a large number of obsidian nodules in the fluvial bars adjacent to the river, five of which were geochemically characterized.

3.3 Geoarchaeological Survey of the Tilhué Ignimbrites: Cerro Huenul

The Tilhué Formation, originally defined as Andesita III by Groeber (1933), encompasses ash-fall deposits associated with the activity of different volcanic centers during the Plio-Pleistocene (see Figure 2 in Barberena et al., 2011). Our previous research indicates that not all of these deposits contain obsidian of the Cerro Huenul chemical type. In the context of a regional project of systematic archaeological surface survey by means of transects we have recorded the presence of obsidian nodules in different geomorphic contexts of the locality Barrancas-Buta Ranquil in northern Neuquén (indicated in Figure 1).

Here we present new results for the mid-section of the Buta C6 Creek (points 14 and 15 in Figure 1). Including the localities previously reported (Dur6n et al., 2004; Barberena et al., 2011), we currently have geoarchaeological information on the presence of obsidian nodules in 29 different locations (Supplementary Material). These locations encompass a large and discontinuous area of the Colorado River at 850 masl, which erodes the Tilhu6 ignimbrites, up to the highlands of the Buta C6 Creek at 2000 masl. We have also recorded the fluvial transport of small obsidian nodules by the Buta C6 Creek, constituting another geomorphic context where this obsidian could have been obtained in the past.

We selected 29 nodules from these contexts for geochemical characterization (confirming their assignment to Cerro Huenul, see below). This updated database combining systematic field survey and geochemical characterization is the basis for a new analysis of the spatial structure of the Cerro Huenul source.

3.4 Geochemical Assessment of Intra and Inter Source Variation

Tables 1 and 2 show the means and standard deviations of elements measured for each obsidian source for XRF and NAA, respectively. The full results are presented as Supplementary Material. The criteria we use to define a geochemical group as representative of a source follows the principles of the provenance postulate: that the elemental, isotopic, or mineralogical variability between sources or chemical groups must be greater than the variability within a source or compositional group (Weigand, Harbottle, Sayre, 1977; Glascock & Neff, 2003).

In Figure 4 we present scatterplots of concentration values for obsidian source samples in northern Neuquén province. Figure 4a shows concentration values for rubidium versus strontium obtained by means of XRF (n=100) and Figure 4b shows cesium versus hafnium values obtained by means of NAA (n=88).

In the case of XRF, Cerro Huenul and Fuente Alba types are easily differentiated, while the sources Laguna del Maule 1-Laguna Negra, Laguna del Maule 2-Río Barrancas, and Varvarco exhibit significant overlap (as shown in this projection and seen in other element pairs). Some additional resolution for these otherwise overlapping sources is observed through the examination of the element ratios Mn/Fe, Zr/Rb, Rb/Mn, and Zr/Th. However, the differentiation observed among these three sources is not strong as compared to Cerro Huenul and Fuente Alba types, and a larger data set is required to confidently assign geochemical source group by XRF for the Laguna del Maule 1-Laguna Negra, Laguna del Maule 2-Río Barrancas, and Varvarco. In an effort to further resolve those sources, we referred to the NAA-generated data set to examine other element pairs, which show clear separation of the previously unresolved source groups (Figure 4b).

The ability to differentiate between sources Laguna del Maule 1-Laguna Negra, Laguna del Maule 2-Río Barrancas and Varvarco is a critical finding as it has important implications for detecting seasonal mobility and selective access to resources. Since the archaeological survey developed jointly with this geoarchaeological research has recently widened to include the Varvarco area, a strategy combining different geochemical tools will be implemented to optimize analytical resolution and minimize costs.

4 DISCUSSION

The combination of macro-regional geoarchaeological survey and systematic geochemical characterization provides a basis for reassessment of northwestern Patagonia's obsidian 'source-scape' (Figure 5). In addition to the discovery of the new Varvarco source (fully described in Fernández et al., 2018), this discussion is organized around two key issues: (1) an analysis of the availability of Laguna del Maule obsidian types at different altitudes and the processes affecting its distribution, and (2) the spatial distribution of the ignimbrite-associated Cerro Huenul obsidian type. By integrating results related to these issues, we improve the definition of their respective areas of availability and propose a new framework for the analysis of archaeological distributions. Our conclusions affect previous interpretations of lithic provisioning and circuits of mobility across the Patagonian landscape.

4.1 Deconstructing Laguna del Maule: The Incidence of Volcanic and Fluvial Processes

Interestingly, all 12 of the samples coming from primary and secondary contexts in the upper Barrancas basin were assigned to the chemical type Laguna del Maule 1-Laguna Negra. This includes three samples from the primary obsidian flows in Laguna Negra and nine samples from fluvial blocks recovered in the river between 3 and 6 km from the flows. The geological and geochemical data from these localities confirm the fluvial transport of obsidian eroded from the primary outcrops. Accordingly, the geochemical results available for the ignimbrite deposits indicate a remarkable similarity

with the obsidian flows (Hildreth, Godoy, Fierstein, & Singer, 2009). In terms of the regional geology (Andersen et al., 2017), it is likely that the Laguna del Maule 1-Laguna Negra type corresponds to the Group I of Las Coloradas source south of Laguna del Maule in Chile, as defined by Seelenfreund et al. (1996) on the basis of PIXE-PIGME. Analyzing nodules from that area by NAA will directly test this hypothesis.

On the other hand, all 27 of the nodules analyzed from the mid-lower Barrancas and upper Colorado River basin are assigned to the Laguna del Maule 2-Río Barrancas type. These nodules were recovered from the fluvial bars of the Barrancas and Colorado Rivers and, in the case of sampling 9, from an ignimbrite deposit (Figure 3). In this latter case the obsidian nodules are angular to very angular and appear not to have been subject to significant fluvial transport.

To summarize, our database indicates that the Laguna del Maule 1-Laguna Negra type is present in the highlands of the Barrancas River, while the nodules analyzed for the lowlands of the Barrancas and Colorado Rivers are assigned to the Laguna del Maule 2-Río Barrancas type. The results of sampling 9 suggest that this obsidian would have been deposited in the lowlands as part of ash-fall volcanoclastic deposits, rather than being transported from the highlands by fluvial action. While additional findings might require minor adjustments to our understanding of this non-overlapping availability of chemical types, it is likely that the predominance of Laguna del Maule 1-Laguna Negra in the highlands and Laguna del Maule 2-Río Barrancas in the lowlands reflects the true distribution of these types. This preliminary spatial pattern along the fluvial basin of the

Barrancas-Colorado provides a testable working hypothesis for future expansions of our research program.

4.2 Cerro Huenul: The Spatial Structure of a Complex Ignimbrite Source

As mentioned, the 29 nodules selected from different geomorphic and geologic locations within the Barrancas-Buta Ranquil region produced XRF and NAA data consistent with the Cerro Huenul type, indicating its widespread availability, from the highlands of the upper Buta C6 Creek in the Tromen volcanic field (2000 masl) to the lowlands in the Colorado River area (850 masl, Figure 5). This region spans a broad altitudinal belt, connecting the perennially available lowlands with the seasonally available highlands. As previously described, we confirmed the association of this obsidian with ash-fall deposits of the Tilhué Formation. Additionally, we documented the fluvial transport of small obsidian nodules by the Buta C6 Creek connecting the highlands and the lowlands, as well as the presence of Cerro Huenul type obsidian in the floodplain of the Colorado, a river that erodes the ignimbrites. At a specific location along the Colorado River, we recorded the simultaneous availability of Cerro Huenul obsidian, locally eroded from the ignimbrites, with Laguna del Maule 2-Río Barrancas obsidian, transported by the river (point 13 in Figure 1).

5 CONCLUSIONS: GEOARCHAEOLOGICAL INSIGHTS FOR LITHIC TECHNOLOGY AND HUMAN SPATIAL ORGANIZATION

By synthesizing geoarchaeological and geochemical data, we have presented an updated reconstruction of the areas of availability of Cerro Huenul, Laguna del Maule 1-Laguna Negra, Laguna del Maule 2-Río Barrancas, and Varvarco obsidian types (Figure

5). This refined and elaborated obsidian ‘source-scape’ for northwestern Patagonia provides a foundation for the assessment of prehistoric patterns of lithic provisioning, transport, and discard. We present preliminary results of the application of our geoarchaeological framework to an archaeological database composed of 1109 artifacts from the Barrancas–Buta Ranquil region geochemically characterized by XRF (see Figures 1 and 5). These artifacts were selected from a regional sample that is the product of combined systematic surface survey, test-pits and excavations (results in: Barberena et al., 2011: N= 39; Fernández et al., 2017: N= 266; unpublished results: N= 804). While some of the samples were collected from surface contexts and have not been directly dated, the regional sequence, projectile point typology, and stratigraphic provenience of the samples from the sites Cueva Huenul 1 and Cueva Yagui suggest a late Holocene age (last 2500 cal years, Barberena, 2015; Barberena, Prates, & de Porras, 2015).

Based on our results, Cerro Huenul obsidian can be considered a local rock in this region, since it is located <10 km from all of the archaeological sites sampled (Figure 5). It is immediately available (<1 km) from the localities Cueva Huenul and Puesto Cuello-Cueva Yagui, which provide 67.2% (N= 745) of the archaeological sample analyzed. Accordingly, Cerro Huenul would provide the ‘baseline’ for lithic provisioning in this region.

Our preliminary results also indicate that Laguna del Maule 2-Río Barrancas type is discontinuously available along the Barrancas-Colorado basin and would be located between 5 and 25 km from the archaeological sites in our study region (Figure 5). Laguna del Maule 1-Laguna Negra, on the other hand, would be available at a minimum distance

of 65 linear km from this region, and considerably farther following least-cost paths (Barberena et al., 2017). Limited as these categories are (Gamble, 1993), Laguna del Maule 2-Río Barrancas can be considered as 'local' in terms of hunter-gatherer mobility, while Laguna del Maule 1-Laguna Negra should be considered 'non-local' (Gould, 1980; Meltzer, 1989; Civalero & Franco, 2003).

Consistent with expectations provided by our revised source-scape, Cerro Huenul obsidian dominates both stratified and surface sites, accounting for 92.9% of the obsidian artifacts (N= 1030). This is the baseline signal referred to above, within which more nuanced spatial patterns can be assessed. Laguna del Maule 2-Río Barrancas accounts for 5.7% (N= 63) of the assemblage and Laguna del Maule 1-Laguna Negra constitutes 1.4% (N= 16). The difference in the representation of the two Laguna del Maule types is consistent with the geoarchaeological evidence presented and conforms to a distance-decay distributional pattern.

In the current geoarchaeological framework, the relatively small number of Laguna del Maule 1-Laguna Negra artifacts implies a connection to the highlands, whether by direct or indirect access. This is contrary to previous work, which suggested wider transport of Laguna del Maule obsidian (*sensu lato*) from the highlands to the lowlands (Barberena et al., 2011; Giesso et al., 2011; Salgán et al., 2014), and invites a comparison of technological properties of the Laguna del Maule 1-Laguna Negra and Laguna del Maule 2-Río Barrancas assemblages, a new line of study that emerges from our results. Considering that localized trips provide access to highland settings with high-ranked food resources during the summer, movement to the distant highlands where

Laguna del Maule 1-Laguna Negra obsidian is available as primary outcrops, entailing much higher energetic costs (Barberena et al., 2017), would not be efficient from an economic perspective. On the other hand, this large-scale mobility may have played a ‘non-utilitarian’ role (Whallon, 2006) by providing access to the Pacific watershed with a whole new set of ecosystems and human groups with whom to interact.

However, our preliminary results are not conclusive as to how frequent large scale ‘vertical’ movement might have been, and the distinct possibility remains that different obsidian types were sequentially used for different purposes throughout their use lives as people moved through annual rounds across the landscape (see Jones et al., 2003). Consequently, it is possible that the distributions of Cerro Huenul, Laguna del Maule 1-Laguna Negra and Laguna del Maule 2-Río Barrancas obsidian types are not isomorphic with human home ranges and may represent only a fraction of them.

This macro-regional geoarchaeological research program addressing an obsidian source-scape provides a foundation for integrating the archaeological record of different regions across northwestern Patagonia and southern Chile (Stern, Pereda, & Aguerre, 2012; Campbell, Stern, & Peñaloza, 2017; Méndez, Stern, Nuevo Delaunay, Reyes, Gutiérrez, & Mena, 2018). Our short-term plans for future analyses include calibrating the geochemical results of distinct methods (PIXE-PIGME, LA-ICP-MS, XRF, NAA) used since the 1990’s (Seelenfreund et al., 1996; Durán et al., 2004; Giesso et al., 2011). Presently, our capacity to integrate results produced by different methods over the last 20 years is hampered by issues of comparability. In our attempts to resolve this, we have to account for the significant compositional heterogeneity of some of these

sources due to the presence of microliths in the obsidian groundmass, which may contribute to the geochemical variability within single nodules (De Francesco, Barca, Bocci, Cortegoso, Barberena, Yebra, & Durán, 2018). At an archaeological level, we will assess the technological properties of archaeological assemblages from the Barrancas-Buta Ranquil region in light of the results of our geochemical analyses. This will permit evaluating the role of direct and indirect mechanisms of access to the sources, which is a necessary step to produce more nuanced interpretations of prehistoric mobility and social interaction (Freund, 2013; Smith & Harvey, 2018). Going forward, our research will also articulate with ongoing studies of the formal variability and archaeometry of rock art (Barberena et al., 2017; Romero Villanueva, 2018). Building on this interdisciplinary research framework, we expect to track the prehistoric movement of objects and information, and to assess the spatial extent and nature of the social networks deployed by past human groups in this complex and fascinating region of the Patagonian Andes.

Acknowledgments

This research is funded by CONICET and Agencia Nacional de Promoción de la Ciencia y la Tecnología from Argentina (Projects PIP 0301, PICT 2014-0940, PICT 201-0062).

This work was also supported in part by NSF grant (1621158) awarded to the Archaeometry Lab at MURR. We acknowledge the Subsecretaría de Cultura de la Provincia del Neuquén. This research is possible due to the support from Juvenal Urrutia, Paulina Valenzuela, Javier Siegel, Hugo Zalazar, and the communities from Barrancas and Buta Ranquil (Neuquén Province, Argentina). Carina Llano, Agustín Castillo, Claire Holubowskyj and J. Pablo Aguilar helped during fieldwork. Nathan L. Andersen

provided helpful comments on the geology of the Laguna del Maule volcanic field. Three anonymous reviewers and Jamie Woodward provided insightful inputs that contributed to improve this paper. The authors declare no conflict of interest.

References

- Andersen, N.L., Singer, B.S., Jicha, B.R., Beard, B.L., Johnson, C.M., & Licciardi, J.M. (2017). Pleistocene to Holocene Growth of a Large Upper Crustal Rhyolitic Magma Reservoir beneath the Active Laguna del Maule Volcanic Field, Central Chile. *Journal of Petrology*, 58(1), 85-114.
- Aragón, E.A., & Franco, N.V. (1997). Características de rocas para la talla por percusión y propiedades petrográficas. *Anales del Instituto de la Patagonia*, 25, 187-199.
- Barberena, R. (2015). Cueva Huenul 1 Archaeological Site (Northwestern Patagonia, Argentina): Initial Colonization and mid-Holocene Demographic Retraction. *Latin American Antiquity*, 26 (3), 304-318.
- Barberena, R., Hajduk, A., Gil, A., Neme, G., Durán, V., Glascock, M., Giesso, M., Borrazzo, K., Pompei, P., Salgán, L., Cortegoso, V., Villarosa, G., & Rughini, A. (2011). Obsidian in the south-central Andes: geological, geochemical, and archaeological assessment of north Patagonian Sources (Argentina). *Quaternary International*, 245, 25-36.

- Barberena, R., Prates, L., & de Porras, M.E. (2015). The human occupation of northwestern Patagonia (Argentina): Paleoecological and chronological trends. *Quaternary International*, 356, 111-126.
- Barberena, R., Romero Villanueva, G., Lucero, G., Fernández, M.V., Rughini, A. & Sosa, P. (2017). Espacios internodales en Patagonia septentrional: biogeografía, información y mecanismos sociales de interacción. *Estudios Atacameños*, 56, 57-75.
- Campbell, R., Stern, C.R., & Peñalosa, A. (2017). Obsidian in archaeological sites on Mocha Island, southern Chile: Implications of its provenience. *Journal of Archaeological Science: Reports*, 13, 617-624.
- Civalero, M.T., & Franco, N.V. (2003). Early human occupations in Western Santa Cruz Province, Southernmost South America. *Quaternary International*, 109, 77-86.
- Costa, C.H., & González Díaz, E.F. (2007). Age constraints and paleoseismic implication of rock avalanches in the northern Patagonian Andes, Argentina. *Journal of South American Earth Sciences*, 24(1), 48-57.
- De Francesco, A.M., Barca, D., Bocci, M., Cortegoso, V., Barberena, R., Yebra, L., & Durán, V. (2018). Provenance of obsidian artifacts from the Natural Protected Area Laguna del Diamante (Mendoza, Province Argentina) and upper Maipo valley (Chile) by LA-ICP-MS method. *Quaternary International*, 468, 134-140.
- Durán, V., Giesso, M., Glascock, M.D., Neme, G., Gil, A., & Sanhueza, L. (2004). Estudio de fuentes de aprovisionamiento y redes de distribución de obsidiana durante el Holoceno Tardío en el sur de Mendoza (Argentina). *Estudios Atacameños*, 28, 25-43.
- This article is protected by copyright. All rights reserved.

Eerkens, J.W., & Rosenthal, J.S. (2004). Are obsidian subsources meaningful units of analysis?: temporal and spatial patterning of subsources in the Coso Volcanic Field, southeastern California. *Journal of Archaeological Science*, 31(1), 21-29.

Ericson, J.E., & Glascock, M.D. (2004). Subsource characterization: Obsidian utilization of subsources of the Coso volcanic field, Coso Junction, California, USA. *Geoarchaeology*, 19(8), 779-805.

Fernández, M.V., Barberena, R., Rughini, A., Giesso, M., Durán, V.A., Cortegoso, V. Borrazzo, K., Lucero, G., Romero Villanueva, G., Garvey, R., MacDonald, B.L., & Glascock, M.D. (2017). Obsidian geochemistry, geoarchaeology, and lithic technology in northern Patagonia (Argentina). *Journal of Archaeological Science: Reports*, 13, 372-381.

Fernández, M.V., Leal, P., Klesner, C., Della Negra, C., MacDonald, B.L., Glascock, M.D., & Barberena, R. (2018). Obsidiana Varvarco: una nueva fuente en el noroeste de Patagonia (Neuquén, Argentina). Under review.

Fierstein, J., Sruoga, P., Amigo, A., Elissondo, M., & Rosas, M. (2012). Postglacial eruptive history of Laguna del Maule volcanic field in Chile, from fallout stratigraphy in Argentina. *AGU Fall Meeting Abstracts*, 31.

Folguera, A., Bottesi, G., Zapata, T., & Ramos, V.A. (2008). Crustal collapse in the Andean backarc since 2 Ma: Tromen volcanic plateau, Southern Central Andes (36°40'-37°30'S). *Tectonophysics*, 459, 140-160.

Freund, K.P. (2013). An assessment of the current applications and future directions of obsidian sourcing studies in archaeological research. *Archaeometry*, 55(5), 779-793.

Gamble, C. (1993). Exchange, foraging and local hominid networks. In C. Scarre & F. Healy (Eds.), *Trade and exchange in prehistoric Europe* (pp. 35-44). Oxford: Oxbow Books, Prehistoric Society & Société Préhistorique Française.

Giesso, M., Durán, V., Neme, G., Glascock, M.D., Cortegoso, V., Gil, A., & Sanhueza, L. (2011). A study of obsidian source usage in the central Andes of Argentina and Chile. *Archaeometry*, 53, 1-21.

Glascock, M.D. (2016). Geochemical sourcing. In A.S. Gilbert (Ed.), *Encyclopedia of Geoarchaeology* (pp. 303-309). Dordrecht: Springer Press.

Glascock, M.D., Braswell, G.E., & Cobean, R.H. (1998). A systematic approach to obsidian source characterization. In M.S. Shackley (Ed.), *Archaeological Obsidian Studies: Method and Theory* (pp. 15-65). New York and London: Plenum Press.

Glascock, M.D., & Ferguson, J.E. (2012). Report on the Analysis of Obsidian Source Samples

by Multiple Analytical Methods. University of Missouri-Columbia, Archaeometry Lab.

Glascock, M.D., & Neff, H. (2003). Neutron activation analysis and provenance research in archaeology. *Measurement Science and Technology*, 14, 1516-1526.

González Díaz, E.F., & I. Di Tommaso (2011). Geomorfología. In H.A. Leanza, C. Arregui & O. Carbone (Eds.), *Geología y recursos naturales de la provincial del*

Neuquén. *Relatorio del XVIII Congreso Geológico Argentino* (pp. 421-438). Buenos Aires: Asociación Geológica Argentina.

Gordón, F., Perez, S.I., Hajduk, A., Lezcano, M., & Bernal, V. (2017). Dietary patterns in human populations from northwest Patagonia during Holocene: an approach using Binford's frames of reference and Bayesian isotope mixing models. *Archaeological and Anthropological Sciences*, <https://doi.org/10.1007/s12520-016-0459-0>

Gould, R.A. (1980). *Living Archaeology*. Cambridge: Cambridge University Press.

Groeber, P. (1916). Informe sobre las causas que han producido las crecientes del río Colorado (territorios del Neuquén y La Pampa) en 1914. *Dirección General de Minas, Geología e Hidrología, Boletín 11*, Serie B (Geología), 1-29.

Groeber, P. (1933). *Confluencia de los ríos Grande y Barrancas (Mendoza y Neuquén). Descripción de la hoja 31c del mapa geológico general de la República Argentina*. Dirección de Minas y Geología, Boletín 38, Buenos Aires.

Hildreth, W., Godoy, E., Fierstein, J., & Singer, B. (2009). *Laguna del Maule volcanic field: Eruptive history of a Quaternary basalt-to-rhyolite distributed volcanic field on the Andean rangecrest in Central Chile*. Boletín 63. Servicio Nacional de Minería y Geología, Chile.

Hughes, R.L. (1998). On Reliability, Validity, and Scale in Obsidian Sourcing Research. In: A.F. Ramenofsky & A. Steffen (Eds.), *Unit Issues in Archaeology. Measuring Time, Space, and Material* (pp. 103-114). Salt Lake City: University of Utah Press.

Jones, G.T., Beck, C., Jones, E.E., & Hughes, R. (2003). Lithic Source Use and Paleoarchaic Foraging Territories in the Great Basin. *American Antiquity*, 68, 5-38.

Kay, S., Burns, W., Copeland, P., & Mancilla, O. (2006). Upper Cretaceous to Holocene magmatism and evidence for transient Miocene shallowing of the Andean subduction zone under the northern Neuquén Basin. In S. Kay & V. Ramos (Eds.), *Evolution of an Andean margin. A tectonic and magmatic view from the Andes to the Neuquén Basin (35°-39° S lat)* (pp. 19-60). New York: Geological Society of America Special Paper 407.

Kuhn, S.L. (2004). Upper Paleolithic raw material economies at Üçağızlı cave, Turkey. *Journal of Anthropological Archaeology*, 23, 431-448.

Llano, C., & Barberena, R. (2013). Explotación humana de especies vegetales en Patagonia septentrional: el registro arqueobotánico de Cueva Huenul 1 (Provincia de Neuquén, Argentina). *Darwiniana*, (1), 5-19.

Luedtke, B.E. (1979). The Identification of Sources of Chert Artifacts. *American Antiquity*, 44 (4), 744-757.

Meltzer, D. (1989). Was stone exchanged among eastern North American Paleoindians? In C.J. Ellis & J.C. Lothrop (Eds.), *Eastern Paleoindian lithic resource use* (pp. 11-39). Boulder: Westview Press.

Méndez, C., Stern, C.R., Nuevo Delaunay, A., Reyes, O., Gutiérrez, F., & Mena, F. (2018). Spatial and temporal distributions of exotic and local obsidians in Central Western Patagonia, southernmost South America. *Quaternary International*, 468, 155-168.

This article is protected by copyright. All rights reserved.

Millhauser, J.K., Rodríguez-Alegría, E. & Glascock, M.D. (2011). Testing the accuracy of portable X-ray fluorescence to study Aztec and Colonial obsidian supply at Xaltocan, Mexico. *Journal of Archaeological Science*, 38(11), 3141-3152.

Narciso, V., Santamaría, G. & Zanettini, J.C.M. (2004). *Hoja Geológica 3769-I, Barrancas. Provincias de Mendoza y Neuquén*. Buenos Aires: Instituto de Geología y Recursos Minerales, Servicio Geológico Minero Argentino. Boletín 253.

Romero Villanueva, G. (2018). Biogeografía humana y circulación de información en el norte del Neuquén. Un análisis arqueológico sobre la comunicación visual en grupos cazadores-recolectores del noroeste de Patagonia. PhD Diss. Facultad de Filosofía y Letras, Universidad de Buenos Aires.

Salgán, L., Gil, A. & Neme, G. (2014). Movilidad, aprovisionamiento y uso de obsidiana en El Payén, sur de la provincia de Mendoza, Argentina. *Comechingonia*, 18, 33-50.

Seelenfreund, A., Rees, C., Bird, R., Bailey, G., Bárcena, R., & Durán, V. (1996). Trace element analysis of obsidian sources and artifacts of Central Chile (Maule River Basin) and Western Argentina (Colorado River). *Latin American Antiquity*, 7, 7-20.

Shackley, M.S. (1992). The Upper Gila River gravels as an archaeological obsidian source region: Implications for models of exchange and interaction. *Geoarchaeology*, 7, 315-326.

Shackley, M.S., Morgan, L., & Pyle, D. (2018). Elemental, isotopic, and geochronological variability in Mogollon-Datil volcanic province archaeological

obsidian, southwestern USA: Solving issues of inter-source discrimination.

Geoarchaeology, 33, 486-497.

Singer, B.S., Andersen, N.L., Le Mével, H., Feigl, K.L., DeMets, C., Tikoff, B., Thurber, C.H., Jicha, B.R., Cardona, C., Córdova, L., Gil, F., Unsworth, M.J., Williams-Jones, G., Miller, C., Fierstein, J., Hildreth, W., & Vazquez, J. (2014). Dynamics of a large, restless, rhyolitic magma system at Laguna del Maule, southern Andes, Chile. *GSA Today*, 24(12), 4-10.

Smith, G.M., & Harvey, D.C. (2018). Reconstructing prehistoric landscape use at a regional scale: A critical review of the lithic conveyance zone concept with a focus on its limitations. *Journal of Archaeological Science: Reports*, 19, 828-835.

Sruoga, P., Elissondo, M., Fierstein, J., García, S., González, R., & Rosas, M. (2015). Actividad explosiva postglacial del centro Barrancas, Complejo Volcánico Laguna del Maule. (36° 05'S, 70° 30'O). Peligrosidad en Argentina. In *XIV Congreso Geológico Chileno* (pp. 49-52). La Serena: Sociedad Geológica de Chile.

Stern, C.R. (2004). Active Andean volcanism: its geologic and tectonic setting. *Revista Geológica de Chile*, 31, 161-206.

Stern, C.R., Pereda, I., & Aguerre, A.M. (2012). Multiple primary and secondary sources for chemically similar obsidians from the area of Portada Covunco, West-Central Neuquén, Argentina. *Archaeometry*, 54(3), 442-453.

Torrence, R., (2001). Hunter-gatherer technology: macro and microscale approaches. In C. Panter-Brick, R. Layton & P. Rowley-Conwy (Eds.), *Hunter-gatherers: an interdisciplinary perspective* (pp. 76-97). Cambridge, Cambridge University Press.

Weigand, P.C., Harbottle, G., & Sayre, E. (1977). Turquoise sources and source analysis: Mesoamerica and the southwestern USA. In T. Early & J. Ericson (Eds.), *Exchange Systems in Prehistory* (pp. 15-32). New York: Academic Press.

Whallon, R. (2006). Social networks and information: Non-“utilitarian” mobility among hunter-gatherers. *Journal of Anthropological Archaeology*, 25, 259-270.

Table 1. Means and standard deviations calculated from XRF values for obsidian sources from northern Neuquén (parts per million unless otherwise indicated).

	Cerro Huenul	L. Maule 1	L. Maule 2	Fuente Alba	Varvarco
Element	(n = 56)	(n = 43)	(n = 49)	(n = 5)	(n = 11)
Mn	647 ± 115	5774 ± 54	552 ± 57	826 ± 107	461 ± 27
Fe (%)	0.54 ± 0.05	0.78 ± 0.08	0.70 ± 0.08	3.34 ± 0.3	0.80 ± 0.07
Zn	24 ± 10	36 ± 8	25 ± 4	80 ± 6	25 ± 4
Rb	106 ± 9	163 ± 7	184 ± 10	144 ± 7	193 ± 9
Sr	91 ± 8	93 ± 18	77 ± 5	337 ± 19	104 ± 18
Y	13 ± 2	19 ± 1	18 ± 1	41 ± 2	19 ± 1
Zr	68 ± 7	178 ± 18	141 ± 6	476 ± 17	149 ± 6
Nb	13 ± 1	12 ± 1	12 ± 1	25 ± 1	13 ± 1
Th	9 ± 1	21 ± 3	25 ± 2	17 ± 1	28 ± 2

Table 2. Means and standard deviations calculated from NAA values for obsidian sources from northern Neuquén (parts per million unless otherwise indicated).

	Cerro Huenul	L. Maule 1	L. Maule 2	Fuente Alba	Varvarco
Element	(n = 36)	(n = 25)	(n = 57)	(n = 5)	(n = 9)
Na (%)	3.12 ± 0.10	3.59 ± 0.06	3.19 ± 0.12	3.91 ± 0.05	2.97 ± 0.03
Al (%)	7.12 ± 0.28	7.58 ± 0.26	7.15 ± 0.36	9.14 ± 0.41	7.10 ± 0.22
Cl	380 ± 57	748 ± 126	738 ± 113	1008 ± 51	989 ± 37
K (%)	3.11 ± 0.24	3.40 ± 0.13	3.60 ± 0.24	3.20 ± 0.23	3.86 ± 0.06
Sc	1.65 ± 0.05	2.31 ± 0.07	2.27 ± 0.06	13.5 ± 0.4	2.11 ± 0.08
Mn	662 ± 16	587 ± 13	501 ± 10	1133 ± 14	429 ± 9
Fe (%)	0.53 ± 0.02	0.79 ± 0.07	0.65 ± 0.02	3.56 ± 0.15	0.82 ± 0.02
Co	0.30 ± 0.07	0.25 ± 0.11	0.28 ± 0.05	3.35 ± 0.24	0.70 ± 0.09
Zn	28 ± 2	47 ± 6	33 ± 4	98 ± 6	35 ± 2
Rb	106 ± 3	156 ± 3	173 ± 4	132 ± 8	188 ± 3
Sr	122 ± 17	136 ± 34	86 ± 11	400 ± 25	116 ± 9
Zr	97 ± 7	208 ± 16	174 ± 7	424 ± 31	190 ± 7
Sb	0.14 ± 0.03	0.28 ± 0.02	0.32 ± 0.02	0.27 ± 0.03	0.40 ± 0.01

Cs	4.32 ± 0.13	4.51 ± 0.14	5.54 ± 0.10	5.73 ± 0.36	8.37 ± 0.10
Ba	686 ± 17	706 ± 25	653 ± 20	686 ± 40	591 ± 9
La	17 ± 1	33 ± 1	31 ± 1	46 ± 2	33 ± 1
Ce	33 ± 1	66 ± 2	59 ± 2	98 ± 5	64 ± 1
Nd	11 ± 1	23 ± 1	21 ± 2	41 ± 2	21 ± 1
Sm	2.35 ± 0.08	4.45 ± 0.10	3.86 ± 0.11	9.23 ± 0.36	4.11 ± 0.06
Eu	0.40 ± 0.02	0.75 ± 0.03	0.55 ± 0.01	2.08 ± 0.07	0.52 ± 0.01
Tb	0.31 ± 0.02	0.51 ± 0.02	0.41 ± 0.02	1.20 ± 0.11	0.44 ± 0.03
Dy	1.83 ± 0.24	2.91 ± 0.23	2.65 ± 0.15	7.38 ± 0.13	2.76 ± 0.12
Yb	1.42 ± 0.05	2.02 ± 0.06	1.85 ± 0.12	4.08 ± 0.21	2.04 ± 0.03
Lu	0.23 ± 0.02	0.37 ± 0.03	0.33 ± 0.05	0.63 ± 0.04	0.30 ± 0.01
Hf	2.51 ± 0.1	5.33 ± 0.30	4.37 ± 0.13	11.1 ± 0.7	4.84 ± 0.23
Ta	1.24 ± 0.03	0.95 ± 0.02	1.01 ± 0.02	1.37 ± 0.08	1.13 ± 0.01
Th	9.3 ± 0.3	19.9 ± 0.6	22.2 ± 0.4	17.0 ± 1.1	25.8 ± 0.4
U	4.0 ± 0.3	5.4 ± 0.3	6.2 ± 0.3	4.4 ± 0.4	6.3 ± 0.2

Figures

Figure 1. Study area and location of the obsidian source samplings. References: 1) Fuente Alba; 2) Laguna Chacaicó; 3) Paraje Los Tachos; 4) Varvarco sampling 1; 5) Varvarco sampling 2; 6) Laguna Negra; 7) Pampa del Rayo 1; 8) Pampa del Rayo 2; 9) Pampa del Rayo 3; 10) Río Barrancas samplings 1 to 3; 11) Río Barrancas-Arroyo Huaraco samplings 4 and 5; 12) Río Barrancas samplings 6 to 12; 13) Río Colorado samplings 1 and 2; 14) Mid-Buta C6 Creek (Puesto Cuello); 15) Mid-Buta C6 Creek (Puesto Chávez); 16) Cueva Huenul 1 archaeological site; 17) Puesto Cuello archaeological locality.

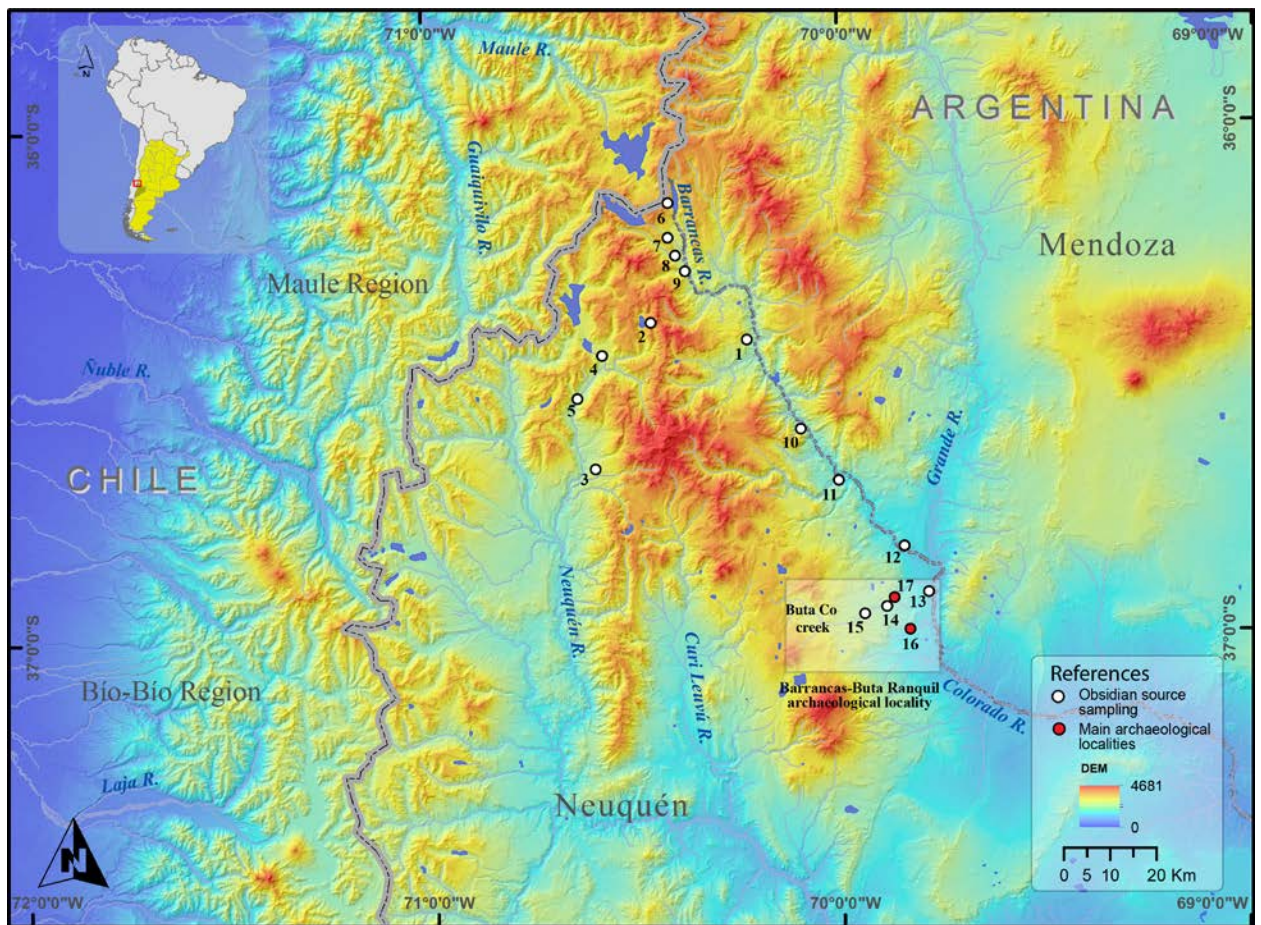


Figure 2. Laguna del Maule volcanic complex: a) Volcanic units (as defined by Andersen et al., 2017); b) Vitreous lava flow and blocks in Laguna Fea – Laguna Negra (point 6 in Figure 1); c) Obsidian block eroded from the flow.

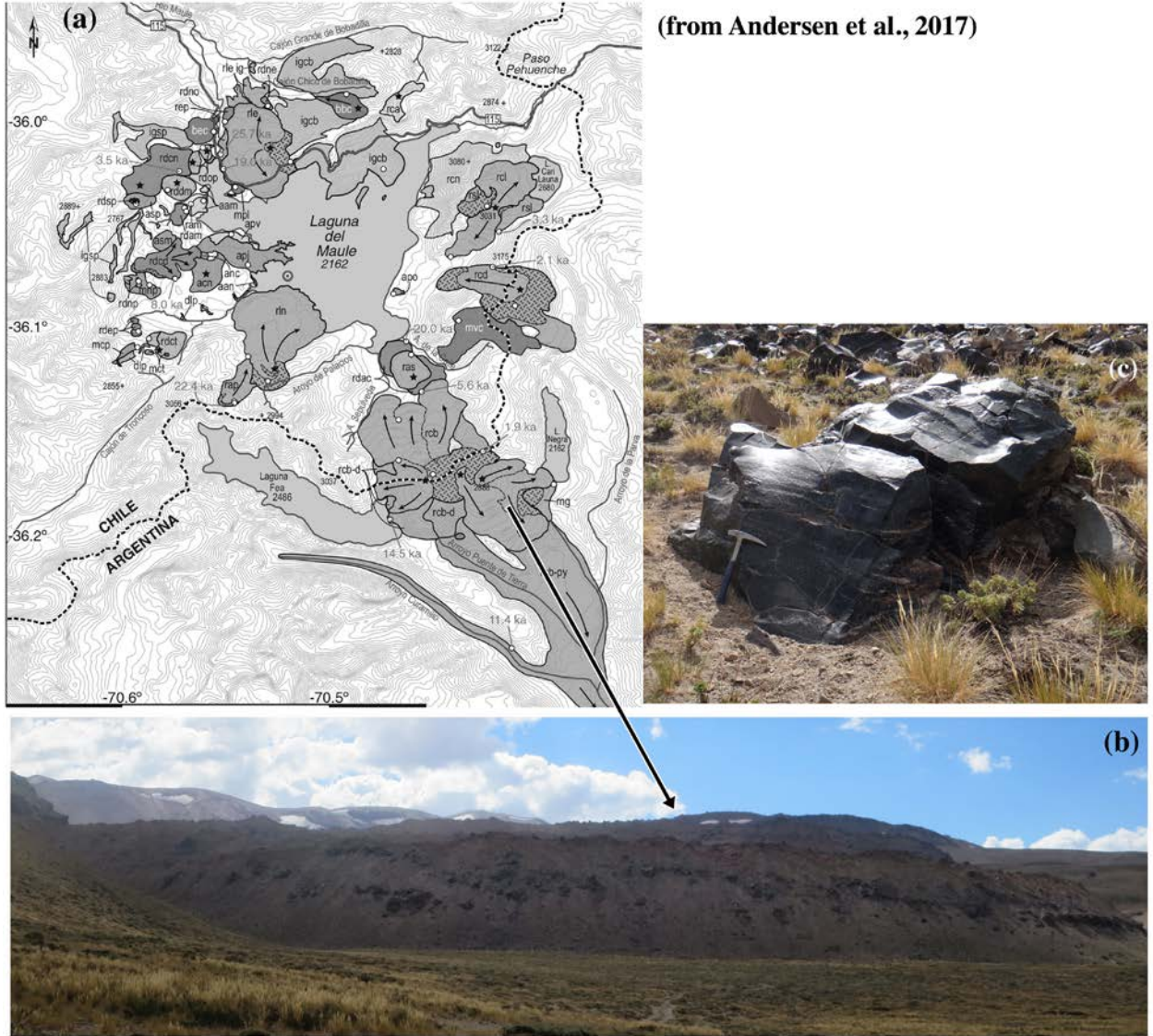


Figure 3. Ignimbrite deposit with angular obsidian nodules in the lower Barrancas River sampling 7.



Figure 4. Scatterplots for obsidian source samples in northern Neuquén province: 4a) rubidium versus strontium values obtained by means of XRF; 4b) cesium versus hafnium values obtained by means of NAA. Note: ellipses are at 90% confidence for each source.

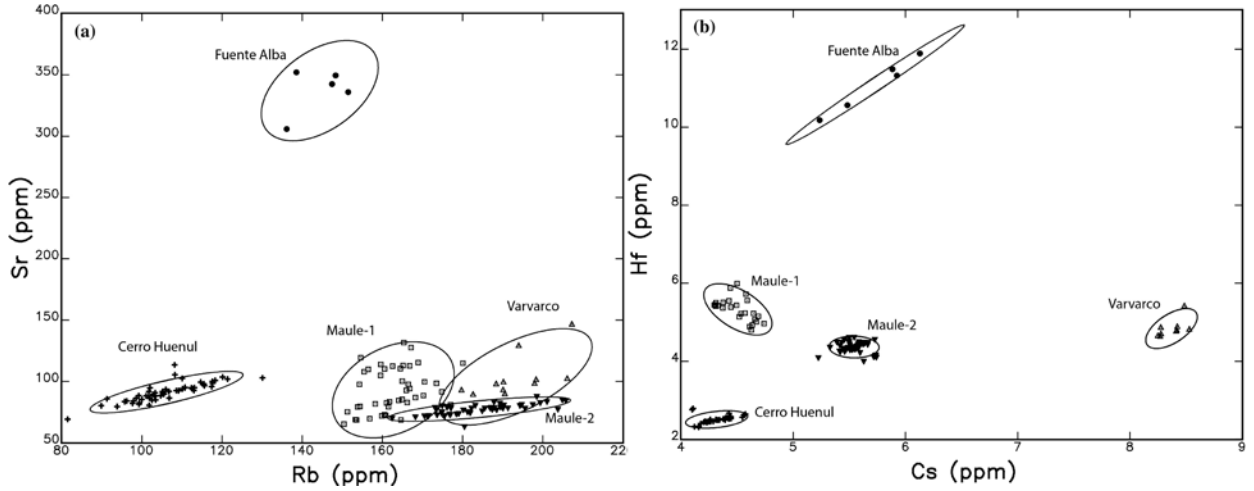


Figure 5. Areas of confirmed availability of the different chemical types (Laguna del Maule Maule 1-Laguna Negra, Laguna del Maule 2-Río Barrancas, Cerro Huenul and Varvarco) and archaeological locality Barrancas-Buta Ranquil.

