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# 17 de Marzo (Santa Cruz, Argentina): A new distal source of Pampa del Asador type black obsidian and its implications for understanding hunter-gatherer behavior in Patagonia

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ABSTRACT

Most obsidian artifacts from central and southern Patagonia were made of black obsidian from Pampa del Asador (PDA), an extended secondary source area centered at approximately 47°55′S and 71°08′W. Artifacts of obsidian from PDA have been found >600 km to both the northeast and south and along the Atlantic coast 300 km to the east of this major source area. Here we report a newly-discovered distal source of PDA-type black obsidian pebbles at 17 de Marzo (17M) located ~170 km southeast of the main PDA source area. ICP-MS trace element data confirm that the relatively small (≤48 mm) black obsidian pebbles from 17M are chemically similar to the four different types of PDA black obsidian. The dimensions of the pebbles compared to the sizes of PDA obsidian artifacts from archaeological sites in the vicinity of 17M, which date from as early as the late Pleistocene-Holocene transition, indicate that early hunter-gatherers could have used the pebbles from this distal secondary source of PDA obsidian to make tools. The pebbles appear to have been transported by fluvial-glacial processes along an ancient Chico River valley to their present site. 17M is part of the "Patagonian Gravel" deposits, which are widespread along the present Chico River valley suggesting that other distal PDA obsidian pebble sites along the river valley may possibly await discovery. The potential widespread availability of PDA obsidian pebbles along the Chico River drainage valley may help to explain why so many artifacts in this area were made of black PDA obsidian. Results obtained indicate that we can no longer assume that hunter-gatherers obtained raw PDA-type black obsidian only from PDA specific source. Black obsidian may have also been available, perhaps in pockets, over a considerable area east and up to ~170 km distant southeast of PDA.


## 1. Introduction

Obsidian artifacts have been recovered from many areas of Patagonia (Aguerre, 2003; Ambrústolo, 2011; Franco, 2002, 2004; Pallo and Borrero, 2015; Stern, 1999, 2004). Most black obsidian artifacts from central and southern Patagonia have been identified as coming from the area of Pampa del Asador (PDA), centered at approximately 47°55′ S and 71°08′W, in NW Santa Cruz province (Fig. 1; e.g., Espinosa and Goñi, 1999; Stern, 1999, 2000, 2004). Pampa del Asador is part of the fluvial-glacial sedimentary plateaus of the pampas of Patagonia (Ramos and Kay, 1992). Obsidian from PDA is present in the form of rounded black cobbles with a brown or gray weathering/alteration surface a few millimeters thick (Fernández and Leal, 2014). The primary source either no longer exists or has not been found. Some samples have been dated with ages ranging from 4.9 to 6.4 Ma (Stern, 1999, 2004), which coincides with the formation of some basaltic plateau lavas in the nearby Meseta del Águila area (Ramos and Kay, 1992). According to Stern (1999) and García-Herbst et al. (2007), there are at least four chemically different types of PDA obsidian (PDA1, PDA2, PDA3ab and PDA3c). Belardi et al. (2006) have recovered nodules of PDA-type obsidian in paleo-drainage channels and on an alluvial fan east of this pampa, expanding the area of availability of PDA obsidian to 47°58′S and 70°08′W.

Artifacts made from PDA obsidian have been found as far as Valdés Peninsula 800 km to the northeast of the main PDA source (Stern, 2004; Stern et al., 2000, 2013), and 600 km south along the Magellan Strait and further south on Tierra del Fuego (Morello et al., 2012; Stern, 2004; Stern et al., 1995a, 1995b). They have been recovered from numerous archaeological sites on both sides of the Andean range

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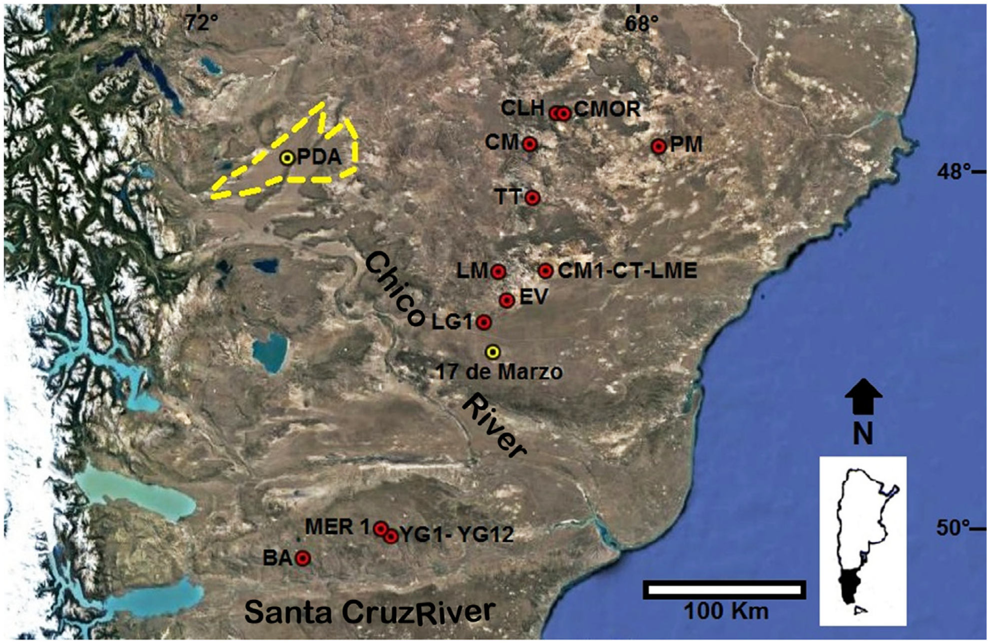


**Fig. 1.** Locations of obsidian sources (yellow circles) and archaeological sites (red circles) mentioned in the text shown on a Google Earth image. The dashed yellow line delimits the PDA alluvial cone. Obsidian sources are Pampa del Asador (PDA) and 17 de Marzo (17M). Archaeological sites: CLH-Cueva La Hacienda; CMor-Cueva Moreno; PM-Piedra Museo; CM-Cueva Maripe; LM-La Martita Cueva 4; EV-El Verano Cueva 1; LG1-La Gruta 1; CT-Cueva Túnel; LME-Cueva de La Mesada; CM1-Casa del Minero 1; TT-Cerro Tres Tetas Cueva 1; YG1-12–Yaten Guajen 1 and 12; MER1-Mercerat 1; BA-Bi Aike 3. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

dating from the Pleistocene-Holocene transition until the late Holocene (e.g., Ambrústolo, 2011; Durán et al., 2003; Fernández et al., 2015; Hermo, 2008; Méndez et al., 2012). To explain this wide distribution, different acquisition models have been postulated for different time periods at sites located far from known sources of obsidian (e.g., Civalero and Franco, 2003; Franco, 2014; Hermo, 2008; Pallo and Borrero, 2015).

Although additional sources of black obsidian have been suggested in some areas of central and southern Patagonia based on information from local inhabitants (e.g., Aguerre, 2003), none has so far been discovered. Here we report on a previously unknown secondary deposit of small black obsidian pebbles located at 17 de Marzo (17M) between the Deseado Massif and the Chico River, ca. 170 km southeast of PDA (Fig. 1). In this paper we report the results of ICP-MS trace-element chemical analysis of eight 17M obsidian pebbles and compare the results with chemical data for obsidians from the main PDA source area. We also analyze the characteristics of obsidian artifacts from archaeological sites to the north and south of the 17M obsidian source to evaluate the possibility of its utilization by local inhabitants.

## 2. Methods

The studies outlined here were conducted during work on projects seeking to understand the effect of environmental variability on the behavior of hunter-gatherers. Within this framework we conducted excavations, surface surveys of artifacts, and examined potential sources of lithic raw materials in an attempt to understand human behavior and circulation.

To understand the lithic regional resource base (Ericson, 1984), sampling was carried out in localities with different environmental characteristics selected based on geological attributes. Because of the large area involved, detailed sampling was undertaken in areas with varied characteristics such as, in the case of secondary sources, places where cobbles of different sizes (and potentially, different raw material) could be expected (Franco, 2002; Franco et al., 2012, 2015b).

Raw material sourcing was carried out through systematic sampling when time and volume of samples were not limited but when either was limited, sampling was unsystematic (e.g., Franco et al., 2012, 2015b). Raw material analysis involved both macroscopic and petrographic analysis and when possible, geochemical analysis (Franco, 2002; Franco and Aragón, 2004; Franco et al., 2015a, 2015b). When the 17M obsidian pebbles were first discovered, samples were collected randomly but during a second visit to the site they were collected by three team members walking in a direction from south to north and then from west to east across the plateau for 90 min. The focus of this sampling was entirely on obsidian; other raw materials were not collected.

ICP-MS (Inductively Coupled Plasma Mass Spectrometry) was used to obtain geochemical data for eight black obsidian pebbles recovered from the 17M secondary obsidian source. Laboratory methods were similar to those described by Fernández et al. (2015). The samples were powdered in a shatter box utilizing a tungsten carbide container, dissolved in a mixture of HF and HCl and analyzed by standard ICP-MS techniques using an ELAN DCR-E instrument in the Laboratory of Environmental and Geologic Sciences at the University of Colorado. Methods for ICP-MS are similar to those described by Briggs (1996). Trace element compositions are considered precise to $\pm 10\%$ at the $2\sigma$ probability level (Fernández et al., 2015).

In order to evaluate if the 17 de Marzo obsidian pebbles could have been used by hunter-gatherers to produce artifacts, pebble dimensions were compared with the dimensions of artifacts collected from areas to the north and south of the obsidian source. Other data would be needed to determine direct versus indirect procurement (for example Dibble, 1987; Franco, 1991, 1994, 2014; Ellis, 2011; Jones et al., 2012; Renfrew, 1977; Torrence and Swadling, 2008) but this was not the focus of this paper. Some researchers have even suggested that obsidian cobbles and pebbles –rather than artifacts- were provisioned and transported, at least during some time periods (Civalero and Franco, 2003).

## 3. Results

### 3.1. Geology and geochemistry

The 17M black obsidian source consists of rounded pebbles in gravels mantling the plateau between the Deseado Massif and the


**Fig. 2.** Location of the 17M source between the Chico River to the southwest and the Deseado Massif to the north.

Chico River (Figs. 1–5). The pebbles appear to be in deposits described by Darwin (1846) as "Rodados Patagónicos" or "Patagonian Gravels", which are found over broad areas of central and southern Patagonia and can occur outside and above the present fluvial valleys, where they form extensive gravel tablelands between the Andes and the Atlantic (Martínez and Coronato, 2008). These gravels have been variously interpreted as fluvial or fluvial-glacial deposits of late Miocene to Pleistocene age (e.g., Clapperton, 1993; Darwin, 1846; Feruglio, 1950; Martínez and Coronato, 2008; Martínez et al., 2009). Hein et al. (2011) have obtained $^{10}$Be and $^{26}$Al surface exposure ages for glacial sequences in the Lago Pueyrredón valley, near the main PDA source areas that indicate a very extensive Patagonian Ice Sheet at ca. 1.2 Ma. This finding suggests that the 17M gravels may be >1 Ma old and may even be of late Miocene-Pliocene age.

When the 17M obsidian source was first discovered, only 8 pebbles were collected, with sizes between 16 and 32 mm (samples A–H in Table 1, Fig. 6, see also Franco et al., 2014). However, during subsequent fieldwork 17 other samples (samples I–Y, Table 1) up to 48 mm in diameter were recovered (Franco et al., 2015b), four being larger than the largest pebble found during the initial visit to the site (Figs. 6 and 7, Table 1). Pebbles were found on the plateau surface and also at the edge of the plateau on slopes leading down to a wet meadow formed below the spring. Pebbles of smaller size were also recovered close to the wet meadow. The pebbles are mostly rounded to well-rounded,


**Fig. 3.** Topographic features at the 17M obsidian source. The wet meadow extends for ca. 800 m downslope from a small spring (48°59.63′ S, 69°19.94′ W) that emerges at a location just below the plateau edge and the main 17M obsidian source area. The water drains as an intermittent small surface stream southwest into the nearby, closed depression and then northwest to a seasonal lagoon visible in the satellite image. When we visited the lagoon it was dry with a hard, salt-covered sediment floor. The location of the wet meadow (WM) downslope of 17M is shown by the arrow.

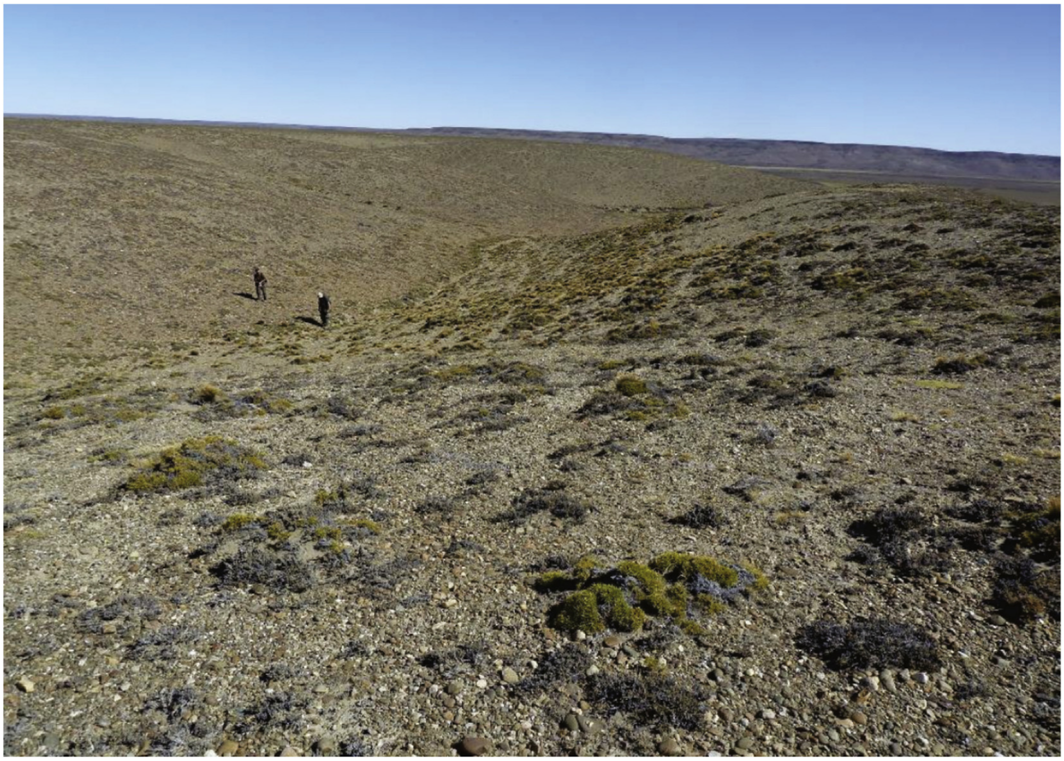

**Fig. 4.** Extensive plateau in fluvial-glacial "Patagonian Gravels" at the 17M secondary obsidian source. Obsidian pebbles of different shape and size were found in the gravel deposits which mantle the plateau.

black obsidian and discoidal in shape (Figs. 5, 6 and 7, Table 1) (Powers, 1953; Zingg, 1935). The pebble surfaces are pitted by hemispherical hollows of variable size, something attributable to chipping and weathering during transport. Pebble cortexes are dull black but are often broken by a layer of reddish brown iron oxide coating the bases of the hemispheric pits that gives the pebbles a mottled black and reddish-brown appearance (e.g., see pebble A in Fig.7). In addition, isolated artifacts -including two fragments of bifacial stemmed projectile points made from obsidian- were found around the edge of the gravel tableland (Fig. 8), facing the wet meadow created by the spring, and the closed depression into which the water flows. These designs can be attributed to the Late Holocene in this area (Cirigliano, 2016; Gradin, 2000). In addition, an archaeological site, with pottery sherds and a so-called "Magallanes IV" (Bird, 1988) bifacial stemmed projectile point (Bird, 1988) were also identified close to the wet meadow; the presence of the sherd and the design of the bifacial projectile point suggest that the site belongs to the Late Holocene (Aschero, 1987; Cassiodoro and Tessone, 2014; Cirigliano, 2016; Guráieb, 2000, 2004; Franco et al., 2010a; Gradin et al., 1979).

The widespread distribution of the black obsidian pebbles across the gravel tableland at 17M, and their small size, argue against their transport to the area by hunter-gatherers, instead suggesting the existence of a true secondary obsidian source. Because obsidian sources are rare in Patagonia, and because of the presence of black obsidian in archaeological sites throughout central and southern Patagonia, the eight obsidian samples A–H initially recovered from 17M were analyzed by ICP-MS. The goal of this analysis was to determine if the 17M obsidian pebbles are geochemically similar to that of obsidian nodules from Pampa del Asador to the north (Table 2). If they are similar, this would suggest that 17M is a distal source of PDA-type obsidian transported by the Chico River, part of the upper reaches of which drain PDA. Alternatively, if these are chemically distinct obsidian, it would indicate that 17M could be a new, previously undiscovered source of black obsidian in southern Patagonia.

ICP-MS results (Table 3) for the eight obsidian pebbles from 17M show that they represent four chemically different obsidian types (Fig. 9), each of which is similar to one of the four chemical types of obsidian previously described from PDA (Fernández et al., 2015; García-Herbst et al., 2007; Méndez et al., 2012; Stern, 1999, 2004) namely PDA1 (C, D, and F), PDA2 (A, E, and G), PDA3ab (B), and PDA3c (H). Some small differences in the content of certain trace-elements (for example Ba and Rb in sample H compared to PDA3c) from the range for the known PDA obsidian are believed to reflect the small number of analyses available for the less common PDA3ab and PDA3c types (Table 2). The PDA and 17M secondary sources appear to be, consequently, geochemically indistinguishable, not only with

**Fig. 5.** Black obsidian pebble in "Patagonian Gravels" at the 17M source. The pebble is about 5 cm long and is also shown in Fig. 7(B).

**Table 1**
Dimensions, weights, shapes, and surface characteristics of the eight obsidian pebbles from 17 de Marzo, Patagonia. Shape according to Zingg (1935) and roundness according to Powers (1953). Selected pebbles are shown in Figs. 6 and 7.

| Sample OB14- | Dimensions (mm) | | | Weight (grams) | Shape | Roundness |
|---|---|---|---|---|---|---|
| | Length | Width | Thickness | | | |
| A | 29 | 19 | 10 | 7.9 | Bladed | Sub-angular |
| B | 36 | 28 | 18 | 25.4 | Discoidal | Rounded |
| C | 32 | 28 | 8 | 10.2 | Discoidal | Well-rounded |
| D | 25 | 19 | 7 | 6.00 | Discoidal | Sub-angular |
| E | 19 | 13 | 7 | 2.3 | Discoidal | Well-rounded |
| F | 26 | 23 | 7 | 5.9 | Discoidal | Rounded |
| G | 22 | 21 | 7 | 4.1 | Discoidal | Well-rounded |
| H | 16 | 14 | 5 | 1.6 | Discoidal | Rounded |
| I | 48 | 43 | 34 | 80.8 | Spherical | Well-rounded |
| J | 40 | 35 | 16 | 26.6 | Discoidal | Rounded |
| K | 36 | 35 | 9 | 14.5 | Discoidal | Rounded |
| L | 44 | 31 | 12 | 19.5 | Discoidal | Sub-rounded |
| M | 36 | 28 | 16 | 19.1 | Discoidal | Rounded |
| N | 34 | 23 | 8 | 8.0 | Discoidal | Rounded |
| O | 30 | 25 | 10 | 8.8 | Discoidal | Rounded |
| P | 32 | 28 | 8 | 8.4 | Discoidal | Well-rounded |
| Q | 35 | 34 | 9 | 11.7 | Discoidal | Sub-angular |
| R | 32 | 27 | 8 | 7.6 | Discoidal | Sub-angular |
| S | 24 | 19 | 9 | 4.2 | Discoidal | Sub-rounded |
| T | 26 | 22 | 6 | 4.6 | Discoidal | Well-rounded |
| U | 24 | 18 | 8 | 4.3 | Discoidal | Rounded |
| V | 20 | 22 | 9 | 4.5 | Discoidal | Sub-angular |
| W | 27 | 25 | 14 | 10.4 | Discoidal | Sub-angular |
| X | 25 | 18 | 2 | 5.6 | Discoidal | Sub-angular |
| Y | 22 | 19 | 7 | 3.6 | Discoidal | Sub-rounded |

respect to the individual obsidian types, but also with respect to the presence of the same four types of obsidian in each source area.

We therefore conclude that the smaller 17M pebbles do not represent a new source of chemically distinct obsidian, but rather a distal source of PDA-type black obsidian pebbles that were eroded from the larger collection of nodules found in the main PDA secondary source areas and transported by fluvial-glacial processes associated with the Chico River drainage system >170 km to the southeast, possibly along an ancient Chico River valley that was much wider than now, or was located to the north of the present valley. Kuenen (1956) has shown in laboratory experiments that obsidian pebbles can lose as much as two-thirds of their weight when transported over a gravel surface by water for a distance equivalent to 115 km, so they could lose even more weight along the 170 km separating PDA from 17M. This may help to explain the roundness of the 17M pebbles and also their smaller size (ca. <4.8 cm) compared with cobbles in the PDA source area, where there are some cobbles >10 cm in diameter (Espinosa and Goñi, 1999) and some >20 cm (personal observation, C. Stern). We think it remarkable that in a sample size of only eight pebbles, all four PDA obsidian types are represented. This suggests substantial mixing of nodules from the secondary sources in the main PDA area, consistent with transportation by fluvial-glacial processes ~170 km southeast from PDA to 17M.

### *3.2. Archaeology*

Because the obsidian from PDA and from 17M is geochemically indistinguishable, it is very difficult to know which source was used by hunter-gatherers in the past. In trying to evaluate the possibility that the 17M source was used, three possible lines of evidence were considered: 1) artifact size; 2) percentage of obsidian artifacts; and 3) amount of cortex. Previous research suggests that these variables decrease at increasing distance from the obsidian source (e.g., Cortegoso, 2014; Franco, 2004, 2014; Renfrew, 1977). However, Bradbury and Carr (1995) have shown experimentally that the number of cortical flakes in archaeological assemblages may be more related to the size of the nodules reduced than to reduction activities. Also, in the case of obsidian in central and south Patagonia, the presence of cortex cannot be directly used to evaluate distance to the source, as the transport of nodules -instead of the transport of artifacts- by hunter-gatherers has been suggested (Civalero and Franco, 2003), at least during some periods.

In addition, it should be remembered that the quantity and size of artifacts recovered from archaeological sites is also related to site function, as well as to the use-life and curation rate of the artifacts (Cortegoso, 2014; Franco, 2004, 2014; Shott and Sillitoe, 2004). Because of this, information from different sites is needed in order to evaluate the case.

It should be remember also that, in the case of hunter-gatherers, special trips are not needed in order to obtain raw material. Procurement of raw materials while other tasks are being carried out, i.e. embedded provisioning strategies (Binford, 1979), has been documented among hunter-gatherers. Although obsidian pebbles from 17M have small sizes and are not available in huge quantities, they could have been obtained by hunter-gatherers during their daily activities near the sites.

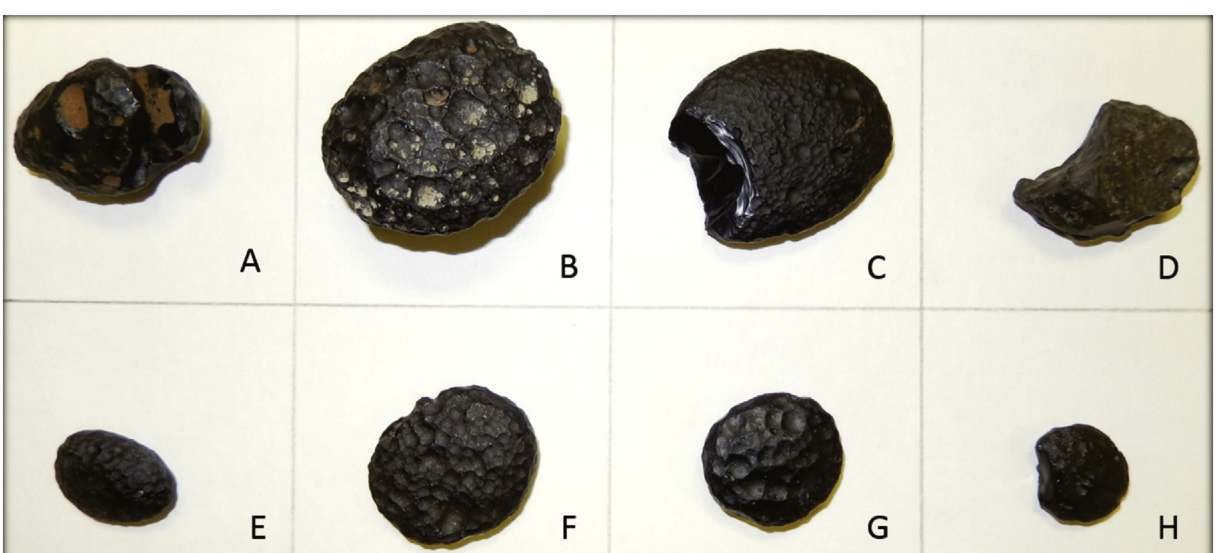


**Fig. 6.** The eight obsidian pebbles (A–H) recovered from 17 de Marzo when the source was first discovered (the squares are 5 × 5 cm). Descriptive and geochemical data for these pebbles are given in Tables 1 and 3.


**Fig. 7.** Examples of pebbles recovered during the second phase of fieldwork at 17M. The largest pebble in (A), at top left, is Pebble I; this is enlarged in (B) to show surface detail. The scales are in cm so Pebble I is 48 mm long.

The characteristics of obsidian artifacts recovered from sites relatively close to 17M, in the southern part of the Deseado Massif and in the canyons in basalt north of the Santa Cruz River, have been documented by Franco et al. (2015a). In this paper, we complement this information with data from archaeological sites in the central and southern Deseado Massif that are farther from 17M (Fig. 1). The information is presented in chronological order from the oldest to the youngest sites in the area. Sites younger than 1000 years BP were not included because during this period, the Spanish conquest and the introduction of horses brought significant changes in mobility and living conditions (Cirigliano, 2016; Goñi, 2000, 2013;). In addition, because some sites have important sedimentation hiatuses or formation problems (Brook et al., 2015; Mosquera, 2016; Salemme and Miotti, 2008), some time periods had no site information, and some sites could not be included in the data for a particular period, even though the site may have been occupied at that time.

Given these limitations, we present below an overview of what happened during the Holocene at sites both close to and further from the 17M source, and we specifically compare information from sites in the Deseado Massif with those located in the canyons in basalt close to the Santa Cruz River.

*3.2.1. 11,500 to 10,000 years BP*

Sites used during this late Pleistocene-early Holocene transition period include Cerro Tres Tetas Cueva 1 (Paunero, 2000a, 2003a; Paunero and Castro, 2001; Paunero et al., 2007); Casa del Minero 1 (Paunero,


**Fig. 8.** Locations where obsidian pebbles (purple balloons) and obsidian artifacts (red pins) were found. Note that the artifacts were recovered close to the edge of the gravel plateau, which forms the northeastern margin of the closed depression into which water flows, as well as in an archaeological site close to the wet meadow (WM), which is indicated by the arrow, as well as in an archaeological site close to the wet meadow (WM), which is indicated by the arrow. The seasonal lagoon in the deepest, northwest part of the depression can be seen at upper left. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

**Table 2**
Mean concentration (in ppm), standard deviation (SD) and range of selected elements in the four obsidian types found at PDA. The number of samples (n) used to generate the data is given in parentheses. Data are from Stern (1999, 2004 and unpublished data), Méndez et al. (2012), and Fernández et al. (2015).

| Element | PDA1 (n = 210) | | | PDA2 (n = 52) | | | PDA3ab (n = 27) | | | PDA3c (n = 9) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Range | Mean | SD | Range | Mean | SD | Range | Mean | SD | Range |
| Ti | 776 | 33.1 | 570–1079 | 705 | 22.4 | 647–773 | 1384 | 162 | 1144–1665 | 734 | | 734 |
| Mn | 288 | 12.9 | 233–309 | 236 | 14.7 | 195–267 | 354 | 33 | 299–394 | 234 | | 234 |
| Rb | 196 | 5.3 | 176–222 | 232 | 11.2 | 211–259 | 178 | 9 | 159–193 | 144 | 3.2 | 137–148 |
| Sr | 34 | 2.8 | 29–38 | 3.0 | 1 | 2–6 | 56 | 13 | 37–76 | 42 | 4.8 | 36–50 |
| Y | 33 | 2.4 | 28–37 | 46 | 3.1 | 38–52 | 28 | 2.4 | 24–34 | 14 | 1.6 | 12–16 |
| Zr | 132 | 5.2 | 119–141 | 139 | 4.8 | 132–149 | 251 | 25 | 221–290 | 108 | 11 | 88–126 |
| Nb | 26 | 2.9 | 20–37 | 27 | 3.2 | 28–36 | 27 | 2.8 | 24–33 | 21 | 0.7 | 20–22 |
| Cs | 10.1 | 0.3 | 9.1–11.2 | 12.2 | 0.6 | 10.7–13.3 | 6.0 | 0.5 | 5.0–6.7 | 6.2 | 0.1 | 5.9–6.3 |
| Ba | 236 | 24.5 | 199–287 | 17 | 8.2 | 7–34 | 537 | 35 | 480–594 | 476 | 15 | 446–493 |
| Hf | 5.5 | 0.7 | 4.3–7.7 | 6.3 | 0.9 | 5.5–6.5 | 7.0 | 0.7 | 5.9–7.8 | 3.4 | | 3.4 |
| Th | 18.7 | 1.5 | 15.8–22.3 | 19.1 | 1.6 | 16.7–20.3 | 21.5 | 1.6 | 18.6–24.3 | 21.2 | 0.5 | 20.5–21.9 |
| U | 5.5 | 0.6 | 4.7–6.2 | 6.1 | 0.4 | 5.5–6.8 | 5.6 | 0.4 | 4.9–6.3 | 4.7 | 0.2 | 4.4–5.1 |
| La | 37.9 | 2.3 | 32.8–43.1 | 23.7 | 1.9 | 19.6–27.2 | 42.2 | 1.2 | 39.3–44.2 | 35.7 | 1.2 | 33.3–36.6 |
| Ce | 70.8 | 4.6 | 64.3–83.6 | 56.3 | 3.8 | 46.8–63.4 | 79.8 | 2.4 | 74.3–82.5 | 58.3 | 1.2 | 55.9–59.3 |
| Pr | 7.99 | 0.62 | 6.55–9.77 | 6.86 | 0.7 | 5.77–7.83 | | | | | | |
| Nd | 31.1 | 1.9 | 26.9–35.1 | 27.9 | 1.1 | 26.6–32.5 | 28.4 | 1.4 | 25.5–31.0 | 18.5 | 3.0 | 16.1–23.4 |
| Sm | 6.72 | 0.38 | 5.75–7.94 | 7.75 | 0.31 | 6.67–8.08 | 5.98 | 0.30 | 5.5–6.7 | 3.10 | 0.12 | 2.91–3.26 |
| Eu | 0.34 | 0.02 | 0.21–0.68 | 0.09 | 0.01 | 0.06–0.10 | 0.71 | 0.20 | 0.49–1.17 | 0.27 | 0.04 | 0.23–0.34 |
| Gd | 8.45 | 0.40 | 6.01–10.0 | 9.25 | 0.41 | 8.24–10.7 | | | | | | |
| Tb | 1.06 | 0.08 | 0.86–1.19 | 1.36 | 0.09 | 1.18–1.58 | 0.85 | 0.5 | 0.79–0.95 | 0.39 | 0.03 | 0.35–0.43 |
| Dy | 5.91 | 0.35 | 5.23–6.45 | 7.81 | 0.57 | 7.08–9.08 | | | | | | |
| Ho | 1.11 | 0.07 | 0.98–1.24 | 1.56 | 0.12 | 1.33–1.76 | | | | | | |
| Er | 3.49 | 0.2 | 2.82–3.99 | 4.69 | 0.28 | 4.18–5.21 | | | | | | |
| Tm | 0.44 | 0.04 | 0.33–0.56 | 0.61 | 0.04 | 0.53–0.73 | | | | | | |
| Yb | 3.40 | 0.2 | 2.61–3.71 | 4.65 | 0.2 | 3.81–5.05 | 3.08 | 0.19 | 2.69–3.45 | 1.59 | 0.19 | 1.39–1.86 |
| Lu | 0.46 | 0.04 | 0.44–0.60 | 0.66 | 0.05 | 0.44–0.60 | 0.47 | 0.07 | 0.33–0.58 | 0.27 | 0.04 | 0.19–0.32 |
| La/Yb | 11.1 | 0.6 | 10.5–11.9 | 5.2 | 0.6 | 4.8–6.2 | 13.7 | 0.7 | 12.3–15.4 | 22.7 | 2.2 | 19.5–24.9 |
| Y/Cs | 3.3 | 0.3 | 3.0–3.4 | 3.8 | 0.3 | 3.4–3.9 | 4.6 | 0.3 | 4.1–5.2 | 2.2 | 0.15 | 2.0–2.3 |

2000b, 2003b; Paunero et al., 2005; Skarbun, 2011), Cueva Túnel (Skarbun, 2011), Piedra Museo (Cattáneo, 2005; Miotti, 1996; Miotti et al., 1999; Miotti and Salemme, 2004) and La Gruta 1 (Brook et al., 2015; Franco et al., 2010b) in the Deseado Massif. Cerro Tres Tetas Cueva 1 and La Gruta 1 are the only sites with evidence of obsidian utilization. At Cerro Tres Tetas, which is ca. 97 km from 17M and 114 km from the eastern side of the PDA alluvial fan, obsidian represents only 1.02% of the total sample of artifacts (Paunero and Castro, 2001).

**Table 3**
Elemental composition (in ppm) of eight obsidian pebbles from 17M.

| Lab # | CS 8001 | CS 8002 | CS 8003 | CS 8004 | CS 8005 | CS 8006 | CS 8007 | CS 8008 |
|---|---|---|---|---|---|---|---|---|
| Sample # | OB14-A | OB14-B | OB14-C | OB14-D | OB14-E | OB14-F | OB14-G | OB14-H |
| Type | PDA2 | PDA3ab | PDA1 | PDA1 | PDA2 | PDA1 | PDA2 | PDA3c |
| Ti | 908 | 1822 | 930 | 916 | 799 | 966 | 803 | 953 |
| Mn | 231 | 457 | 287 | 281 | 209 | 282 | 225 | 246 |
| Rb | 224 | 155 | 194 | 191 | 235 | 210 | 222 | 157 |
| Sr | 11 | 90 | 44 | 40 | 6 | 38 | 7 | 52 |
| Y | 45 | 26 | 33 | 32 | 46 | 33 | 47 | 13 |
| Zr | 148 | 292 | 136 | 141 | 148 | 146 | 155 | 110 |
| Nb | 34 | 31 | 26 | 25 | 33 | 27 | 31 | 16 |
| Cs | 12.0 | 4.9 | 9.9 | 9.9 | 12.7 | 10.5 | 11.7 | 6.2 |
| Ba | 73 | 536 | 379 | 299 | 80 | 254 | 68 | 392 |
| Hf | 5.8 | 7.5 | 4.8 | 5.0 | 6.1 | 5.2 | 6.3 | 3.4 |
| Pb | 23.8 | 18.1 | 21.4 | 21.8 | 23.5 | 22.4 | 22.3 | 16.6 |
| Th | 17.5 | 19.0 | 17.9 | 18.8 | 19.6 | 19.8 | 19.3 | 21.1 |
| U | 6.6 | 5.8 | 5.8 | 5.8 | 7.0 | 6.3 | 6.8 | 5.5 |
| La | 22.8 | 40.2 | 37.1 | 37.6 | 22.7 | 39.0 | 26.4 | 33.6 |
| Ce | 52.8 | 74.6 | 72.2 | 72.3 | 53.5 | 79.5 | 59.9 | 58.2 |
| Pr | 6.55 | 7.95 | 7.97 | 8.17 | 6.89 | 8.79 | 7.07 | 5.51 |
| Nd | 26.4 | 29.3 | 29.3 | 29.1 | 26.8 | 32.1 | 27.7 | 17.2 |
| Sm | 7.27 | 5.39 | 6.12 | 6.23 | 7.20 | 6.70 | 7.39 | 3.10 |
| Eu | 0.18 | 0.74 | 0.34 | 0.25 | 0.18 | 0.24 | 0.18 | 0.24 |
| Gd | 8.84 | 6.43 | 7.26 | 7.50 | 9.14 | 7.71 | 9.17 | 3.72 |
| Tb | 1.23 | 0.72 | 0.94 | 0.87 | 1.38 | 1.03 | 1.27 | 0.33 |
| Dy | 7.62 | 4.52 | 5.72 | 5.53 | 8.14 | 6.02 | 7.45 | 2.39 |
| Ho | 1.49 | 0.86 | 1.05 | 1.09 | 1.64 | 1.16 | 1.52 | 0.43 |
| Er | 4.76 | 2.86 | 3.25 | 3.23 | 5.00 | 3.66 | 4.66 | 1.46 |
| Tm | 0.60 | 0.37 | 0.45 | 0.43 | 0.68 | 0.45 | 0.62 | 0.15 |
| Yb | 4.31 | 2.81 | 3.00 | 3.15 | 4.59 | 3.42 | 4.35 | 1.46 |
| Lu | 0.54 | 0.38 | 0.39 | 0.44 | 0.56 | 0.47 | 0.57 | 0.17 |
| La/Yb | 5.3 | 14.1 | 12.4 | 11.9 | 5.0 | 11.9 | 6.1 | 22.2 |
| Y/Cs | 3.8 | 5.3 | 3.3 | 3.2 | 3.6 | 3.1 | 4.0 | 2.1 |

There are no data about artifact size and completeness, but geochemical data confirm that one artifact is PDA-type black obsidian (Stern, 2004). According to Paunero (2003b) different activities took place in different areas at this site, including hide and bone processing (Paunero, 2009). La Gruta 1 is the closest site to the 17M source, being only ca. 18 km away. The only obsidian flake recovered is smaller (<15 mm long; 4.08% of the total sample) than many of the obsidian pebbles found at 17M (Franco et al., 2015a) and it does not have cortex. Both the size of the artifact and the lack of cortex may be related to the logistic function of the site, where final-stage manufacturing activities took place (Brook et al., 2015; Franco et al., 2010b). Given that the 17M source is only 18 km from La Gruta 1, obsidian pebbles could have been obtained from 17M as part of embedded everyday activities (sensu Binford, 1979), as it might well have been within the home range of hunter-gatherers living at these latitudes (Binford, 2001; Kelly, 1995).

*3.2.2. 9500 to 7000 years BP*

There are many more archaeological sites dating to this early Holocene time period, not only in the Deseado Massif but also in the canyons in basalt north of Santa Cruz River (Table 4). In the Deseado Massif, evidence of human occupations dating to this period has been found at Piedra Museo UE2, level 2 (Miotti et al., 1999; Salemme and Miotti, 2008), Cueva Maripe (Hermo, 2008; Miotti et al., 2014), Casa del Minero 1 (Paunero, 2009), Cueva de La Mesada (Paunero, 2000b; Paunero et al., 2005), Cueva de La Ventana (Paunero, 2000b; Paunero et al., 2005), La Martita Cueva 4 (Aguerre, 2003), El Verano Cueva 1 (Durán et al., 2003), La Gruta 1 (Franco et al., 2010b, 2013) and La Gruta 2 (Franco et al., 2013). In canyons in basalt north of the Santa Cruz River, the oldest occupation of Yaten Guajen 12 has been attributed to this period (Franco, 2008; Franco et al., 2014).

In the central Deseado Massif, black obsidian was used at Cueva Maripe, but because of the homogeneous sediments it is not possible to discriminate artifacts corresponding to this period from those dating between 7000 and 3500 years BP (Hermo, 2008; Hermo and Magnin, 2012; Miotti et al., 2015). At Piedra Museo, a special activity site (Salemme and Miotti, 2008), PDA-type black obsidian (Stern, 1999) reaches 2.28% of the artifacts, and included both projectile points and debitage (Cattáneo, 2005).

Franco et al. (2015a) noted that for the sites near the southern margin of the Deseado Massif the percentage of obsidian artifacts increased during this time period, as well as the number of tool classes for which obsidian was used. Obsidian projectile points were recovered both at La Martita Cueva 4 and at El Verano Cueva 1 (Aguerre, 2003; Durán et al., 2003). At La Martita Cueva 4, black PDA-type (Stern, 1999) obsidian was also used for end-scrapers, side-scrapers, triangular projectile points, bifacial artifacts, and bifacial reduction flakes (Aguerre, 2003). Debitage up to 120 mm long was recovered from this site (Aguerre, 2003), suggesting that the hunter-gatherers using La Martita Cueva 4 knew about the main PDA obsidian source and used obsidian from it (Franco et al., 2015a). During this period, cortex was only identified on obsidian from La Martita Cueva 4. According to Aguerre (2003), the high percentage of endscrapers suggests the importance of hide working, while the diverse artifact assemblage indicates that it was used for multiple activities. In the case of El Verano Cueva 1, lithics suggest that the site was a base camp, even though the faunal remains recovered do not necessarily support this interpretation (Durán et al., 2003).

Cueva de La Mesada, in the southern Deseado Massif, was only used for short-term activities (Paunero, 2009) and the small percentage of obsidian may reflect how the site was used. Only small-size debitage was recorded, and cortex was not identified (Skarbun, 2011).

There is no information for La Gruta 1, near the southern margin of the Deseado Massif, for this period because of a hiatus in the sediment record between ca. 9000 and 3000 years BP, possibly due to erosion of the shelter floor (Brook et al., 2015). Nor does the nearby La Gruta 2 rock shelter provide information due to the short and complex sediment sequence there.

At Yaten Guajen 12, located north of the Santa Cruz River, there is a higher frequency of obsidian artifacts (23%) than at other sites closer to PDA. Franco et al. (2015a) have suggested the possibility of direct procurement and there are three possible reasons to explain this high percentage: a) the existence of another source of black obsidian closer to the site; b) the local scarcity of very high quality rocks, in contrast to the situation in the Deseado Massif; and c) a strong preference for obsidian because of its properties, such as higher flint-knapping quality and light weight. Artifacts are smaller than the pebbles available at 17M, opening up the possibility that hunter-gatherers obtained black obsidian from this area or from PDA. Only a small area of this site has

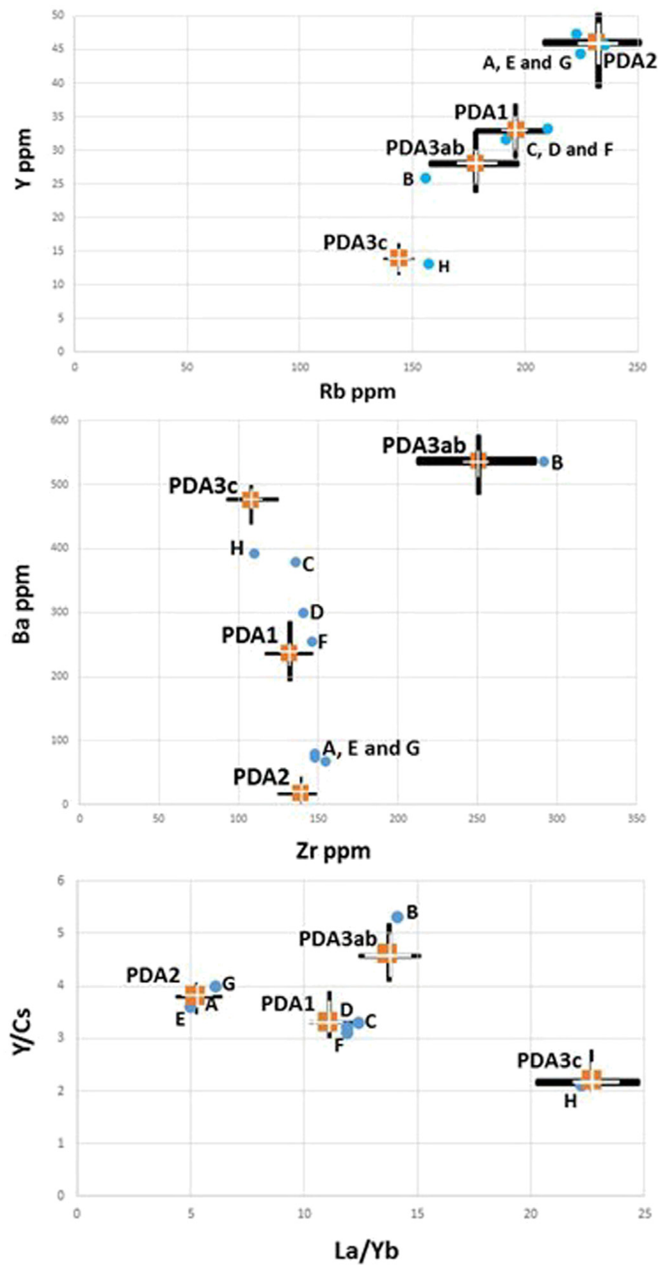


**Fig. 9.** Plots of Y versus Rb (top), Ba versus Zr (middle),and Y/Cs versus La/Yb (bottom) for the eight samples of obsidian from 17M (blue dots; labeled A-H as in Tables 1 and 3) compared to the average (orange squares; standard deviations indicated by white bars and range of all analyses by black bars; Table 2) of the four types of obsidian from PDA (Stern, 1999, 2004; García-Herbst et al., 2007; Méndez et al., 2012; Fernández et al., 2015). Plots show that the eight samples of obsidian from 17M include four chemically different types, each of which is similar to one of the types from PDA, and no samples that are unambiguously distinct from PDA obsidian. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

been excavated and there is not enough information at present to indicate the function of the site.

*3.2.3. 7000 to 3500 years BP*

The archaeological data suggest that there was a hiatus in occupation at some sites in the Deseado Massif between 7000 and 5500 or 6000 years BP, possibly because of arid conditions (Brook et al., 2015; Mosquera, 2016). In addition, Salemme and Miotti (2008) mention the importance of volcanic eruptions at this time. The archaeological hiatus could be related to the depopulation of some areas and/or changes in mobility patterns (i.e. Brook et al., 2015; Hermo and Magnin, 2012; Miotti et al., 2014; Mosquera, 2016; Salemme and Miotti, 2008). After the hiatus, humans are present at Cueva Maripe (Miotti et al., 2007, 2014), Cerro Tres Tetas Cueva 1 (Paunero, 2003a), Casa del Minero (Skarbun, 2011), Cueva de La Mesada (Paunero, 2000b), Cueva de La Ventana (Paunero, 2000b) and La Martita Cueva 4 (Aguerre, 2003). There was a change in artifact technology with the introduction of blades and "bolas de boleadora" (Aschero, 1987; Cardich et al., 1973; Crivelli Montero, 1979; Hermo, 2008; Hermo and Magnin, 2012; Menghin, 1952; Miotti et al., 2014). In the central part of the Deseado Massif, Mosquera (2016) has related the distribution of sites and this technological change with new strategies linked to the reoccupation of these spaces. There is, so far, no evidence that the basaltic spaces north of Santa Cruz River were occupied at this time.

There is little quantifiable data for this time period (Table 5). Information from Cueva Maripe cannot be used, although blades made from obsidian are frequent. Different tool types have been recovered from Casa del Minero 1 and Cueva de La Mesada, both near the southern margin of the Deseado Massif. Multiple activities took place at these sites (Skarbun, 2011). Debitage <20 mm and <40 mm long was recovered from these sites, including final-stage bifacial or retouched flakes, implying that the obsidian could have been obtained from either the 17M or PDA sources. Obsidian from Casa del Minero 1 had no cortex, but it was present on Obsidian from Cueva de La Mesada.

**Table 5**
Obsidian at archaeological sites dating in the period ca. 7000–3500 years BP.

| Period | ca. 7000–3500 years BP | |
|---|---|---|
| Site | Casa del Minero | La Mesada |
| Site abbreviation | CM1 | LME |
| Site location | Southern Deseado Massif | |
| % Obsidian artifacts | 8.90 | 2.01 |
| Artifact types[a] | Deb | Deb-Bl |
| Maximum length (mm) | <20 | <40 |
| Cortex | No | Present |
| References | Skarbun (2011) | Skarbun (2011) |

[a] Artifact types: Deb-Bl = debitage with blades.

*3.2.4. 3500 to 1000 years BP*

In the late Holocene period, black obsidian is present at sites both in the Deseado Massif (Cueva La Hacienda, Cueva Maripe, Cueva Moreno, La Gruta 1; see Table 6) and in the canyons in basalt north of the Santa Cruz River (Bi Aike 3, Mercerat 1, Yaten Guajen 1 and 12). During this time period Cueva Maripe was a multiple activity site, while Cueva La Hacienda and Cueva Moreno were sites where specific activities took place (Hermo, 2014). Evidence from Cueva La Hacienda and Moreno suggests that obsidian cobbles, generally <10 cm long, were procured (Hermo, 2014). Obsidian with cortex was present only at some sites.

Most of the information from the canyons in basalt has already been published (Franco et al., 2015a, 2015b) and so is not included here. There was no obsidian dating to this period at Yaten Guajen 1, but obsidian artifacts were 2.85% of total artifacts at Bi Aike 3 and 12.42% at Mercerat 1. The frequency at Mercerat 1 is higher than percentages for sites in the central and southern Deseado Massif (Table 6). The number of tool classes is as high in the canyons as in the Deseado Massif, although blades were found in the Deseado Massif. During this time period, cortex is present on artifacts at Mercerat 1 (Franco et al., 2015a), where the highest frequency of black obsidian artifacts was identified, suggesting the introduction of nodules. Unfortunately, there is no information about the function of the sites located in the canyons in basalt.

The archaeological site close to 17M that we discovered during field research has both obsidian tools and pottery sherds (Franco and Vetrisano pers. obs.) and appears to date to this period. However, we don´t have chronological information so the site is not included in any of the tables.

*3.2.5. Summary of the archaeological evidence*

At sites with obsidian, the percentage of artifacts made of this raw material varies from 2.01–12.41% at sites in the southern Deseado Massif, 2.28–10% in the central Deseado Massif, and 2.85–23.71% in the canyons in basalt north of the Santa Cruz River (Tables 4–6). These percentages attest to the variable use of obsidian from site to site, though the high values for the some sites (Yaten Guajen 12, Mercerat 1) in the canyons in basalt suggest a local or easy access to a source. In fact, other lines of evidence, including rock art motifs, suggest significant contacts or movements between people using these sites and areas to the northwest, which are closer to the PDA obsidian sources (Cirigliano, 2016; Franco et al., 2015a;). This could mean that some or all obsidian from these sites was obtained from PDA. The percentage of cortex on artifacts varies from site to site, which is probably related not only to the distance to the source, but also to the size of the nodule (Bradbury and Carr, 1995) and the site function. In fact, except for the Late Holocene, cortex was only recorded at sites where multiple activities were carried out (i.e. La Martita Cueva 4, El Verano Cueva 1, Cueva Maripe, Cueva de la Mesada). Generally, tools are taken to logistic sites, where re-sharpening or final-stage manufacturing activities take place. In these cases, cortex is not expected. On the contrary, in multiple activity sites, the presence of different stages of tool manufacture allows for higher frequencies of cortex.

The large obsidian artifacts from La Martita cueva 4, in the southern Deseado Massif, suggest that humans using this site knew of the main PDA obsidian sources, and used material from them, as early as ca. 9000–7000 years BP. In fact, it is likely that the PDA source was known to most inhabitants of the Deseado Massif around this time. We can assume that knowledge of the PDA sources was transmitted

**Table 4**
Obsidian at archaeological sites in the Deseado Massif and Basalt Canyons (YG 12) dating in the period ca. 9500–7000 years BP.

| Period | ca. 9500–7000 years BP | | | | |
|---|---|---|---|---|---|
| Site | El Verano Cueva 1 | La Martita Cueva 4 | Cueva de La Mesada | Piedra Museo, unit 2, level 2 | Yaten Guajen 12 |
| Site abbreviation | EV | LM | LME | PM | YG 12 |
| Site location | Southern Deseado Massif | | | Central Deseado Massif | Canyons in basalt |
| % Obsidian artifacts | 6.44 | 12.41 | 2.56 | 2.28 | 23.71 |
| Artifact types[a] | Pp/Deb | Scr/Es/Pp/Bif/Deb | Deb | Pp/Deb | Es/Co/Deb |
| Maximum length (mm) | No data | <120 | <20 | No data | <25 |
| Cortex | No data | Present | No | No data | No |
| References | Durán et al. (2003) | Aguerre (2003) | Skarbun (2011) | Miotti et al. (1999); Cattáneo (2005) | Franco et al. (2015a) |

[a] Artifact types: Co = core; Deb = debitage; Es = endscraper; Pp = projectile point; Scr = scraper.

**Table 6**
Obsidian at archaeological sites in the Deseado Massif dating in the period ca. 3500–1000 years BP.

| Period | 3500–1000 years BP | | | |
|---|---|---|---|---|
| Sites | La Gruta 1 | Cueva La Hacienda | Cueva Maripe | Cueva Moreno |
| Site abbreviations | LG1 | CLH | CM | CMOR |
| Site location | Southern Deseado Massif | Central Deseado Massif | | |
| % Obsidian artifacts | 2.36 | 10 | 2.35 | 7.40 |
| Artifact types[a] | Deb | Deb | Deb-Bl/tool* | Deb |
| Maximum length (mm) | 10 | No data | No data | No data |
| Cortex | No | Present | Present | Present |
| References | Cirigliano (2016) | Hermo (2014) | Hermo (2014) | Hermo (2014) |

* = no information about tool type was provided.
[a] Artifact types: Deb-Bl = debitage with blades; Deb = debitage.

across generations, except when one population was replaced by another.

However, this does not mean that the 17M source was not used as part of embedded strategies especially by hunter-gatherers using the southern margin of the Deseado Massif. In addition, during arid periods, local inhabitants probably abandoned the Deseado Massif, or changed their mobility strategies (Brook et al., 2015; Mosquera, 2016) to make use of areas closer to a reliable water source, such as the Chico River, which is a permanently-flowing stream. The area of 17M, located between the southern Deseado Massif and the Chico River, could have been part of their home ranges.

In any consideration of the use of 17M as a source of obsidian for hunter-gatherers, it is important to remember that obsidian artifacts have been recovered from the margin of the plateau where the obsidian pebbles were found. As mentioned, obsidian artifacts have also been found at an archaeological site near a wet meadow located a short distance downslope of the 17M source. Discovery of a “Magallanes IV” bifacial stemmed projectile point (Bird, 1988) and pottery sherds suggests a Late Holocene age for the archaeological site but we have no firm chronological data to confirm this.

## 4. Conclusions

The considerable time and energy invested in the establishment of a regional lithic database has resulted in the discovery of a new secondary source of black obsidian, which could have been used by hunter-gatherers since their initial exploration of southern Deseado Massif. Our geochemical analysis of the 17M pebbles and analysis of archaeological data from sites in the region have allowed us to draw the following conclusions:

a) The 17M obsidian is geochemically indistinguishable from the major PDA secondary obsidian sources.

b) Our discovery of a new obsidian source ~170 km southeast of PDA, associated with the widespread “Patagonian Gravel” deposits, opens up the possibility that there are additional distal sources of black PDA obsidian between PDA and 17M that await discovery.

c) The maximum diameter of pebbles so far recovered from 17M is 48 mm, so they are smaller than many pebbles at the main PDA secondary sources. We suggest that the transport of the 17M pebbles was largely by fluvial-glacial processes associated with expanded glaciers in the Andes in the past.

d) Available data suggest that the 17M obsidian pebbles may have been used by hunter-gatherers at La Gruta 1, ca. 18 km distant, probably as a result of an embedded strategy of procurement (sensu Binford, 1979). The lack of cortex may be related to the logistic activities carried out at the site (Brook et al., 2015; Franco et al., 2010b).

e) The higher frequency of Holocene artifacts made from obsidian at some sites in the basalt canyons north of the Santa Cruz River, raises the possibility that: 1) there are other obsidian sources in the area that have not yet been discovered, or 2) that hunter-gatherers had different ways of using these spaces or different behaviors with respect to black obsidian due to its special properties (brightness, lack of impurities, and/or high flint-knapping quality).

f) Most importantly, the17M obsidian source changes our understanding of the behavior of hunter-gatherers in central and southern Patagonia. We can no longer assume that these hunter-gatherers obtained raw PDA black obsidian from a specific source; instead we must realize that black obsidian may have been available, perhaps in pockets, over a considerable area east and southeast of PDA, up to ~170 km distant. Additional surveys are clearly necessary for us to fully understand raw material availability in this enormous area.

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