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The Abra del Toro rock shelter, northwestern Argentina, a space occupied by hunter-gatherers that was hit by the large 4.2 ka Cerro Blanco eruption

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ABSTRACT

Occupation sites have been rarely found during research on the prehistorical hunter-gatherer populations in the Andean intermontane valleys. Some reasons are the intense anthropization of the landscape and the scarce research efforts. Recent work opens new perspectives at the Abra del Toro rock shelter in the Yocavil valley (province of Catamarca, Argentina). Stratigraphy of rock shelter shows a 1 m thick volcanic ash deposit formed by wind transportation from primary ash-fall deposits. Geomorphological, sedimentological, textural, glass and mineral content, bulk chemical composition, and radiocarbon dating prove the tephra derived from the 4.2 ka BP eruption of the Cerro Blanco Volcanic Complex in the southern Puna. This is the world's largest documented volcanic eruption in the past five thousand years, and it covered the archeological site surroundings with an approximately 1-meter-thick ash-fall layer. Throughout the stratigraphic sequence of the Abra del Toro rock shelter, we can hypothesize that there were three main occupational moments: two hunter-gatherer moments, separated by the record of the large volcanic eruption, and a latern agro-pottery period. The evidence of the catastrophic volcanic event in the Abra del Toro rock shelter makes it possible to predict future impact on the contemporaneous communities.

1. Introduction

There is a dearth of information regarding prehistoric foraging societies from the intermontane longitudinal valleys of the South-Central Andes. These valleys and ravines east of the Puna have provided very little data to date and, therefore, present the most eminent unknowns about the modes of occupation of the territory. In comparison, the knowledge base regarding hunter-gatherers lifeways is disproportionately greater for the southernmost Andean highland than for the prehistoric inhabitants of mesothermal valleys. Despite the extreme climatic conditions, most studies related to the chronology of the Upper Pleistocene-Holocene have been developed in the highlands of the Puna (Restifo et al., 2019). These studies have provided a solid record of hunter-gatherer occupations for the entire Holocene (Aschero & Hocsman, 2011; Hocsman, 2002, 2006; Hoguin, 2016; López & Restifo, 2017; Yacobaccio, 2017).

Why the evidence of Early and Mid-Holocene occupation in the mesothermal valleys is so scarce? Undoubtedly, one reason is the sparse and discontinuous research on the subject, especially in comparison to that carried in the neighboring sectors of the Puna. In the particular case of the southern Calchaquí valleys, the presence of hunter-gatherers was recorded mainly through the analysis of stone assemblages found in surface sites, consisting of bifaces and projectile points located in quarry workshops (Cigliano et al., 1962). Such research efforts have been resumed over the last decade. For example, Somonte and Baied (2013, 2017) and Carbonelli (2015) applied the VML (varnish microlamination) technique to date stone artifacts (a layer of desert varnish covered their exposed flake scars). This line of research determined that the use of quarry workshops dates back to a timeframe spanning at least between 13,150 and 9,400 a BP (Somonte & Baied, 2017). This date range is, so far, the oldest estimated occupation for the region.

Moreover, work conducted along the middle-lower basin of the Los Corrales River led to the discovery of a stone workshop with abundant surface material (PV1 Workshop) (Martínez et al., 2013). The site was a residential base with instrument manufacturing and maintenance areas. One dating effort in the oldest excavation layer yielded an age of 8,058–8,293 a cal BP, making this the oldest radiocarbon record in a region neighboring the Puna (Martínez et al., 2013). These pieces of evidence constrained and traced back the age of human occupation in the Andean intermontane valleys near the Puna before the Mid-

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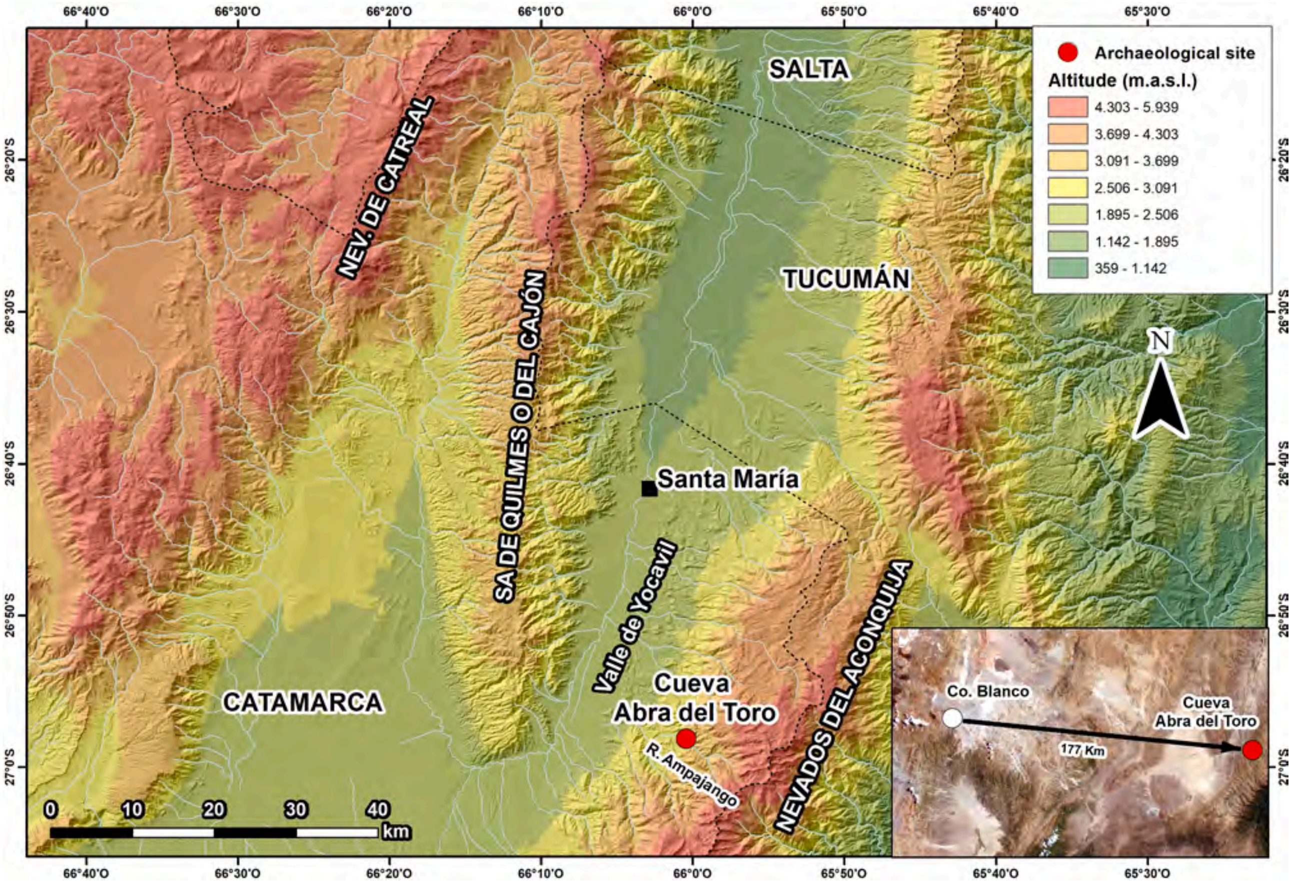

Fig. 1. Map of the Abra del Toro rock shelter in the Yocavil valley, Province of Catamarca, NW of Argentina and distance of Cerro Blanco caldera.

Holocene. However, questions remain about why Mid-Holocene occupation sites are so scarce in these valleys.

The stratigraphic sequences in rock shelters and caves are exceptional archives of prehistoric geomorphological, environmental, and occupation processes (Martini et al., 2021; Morley & Woodward, 2011). As in the Abra del Toro rock shelter, few archaeological sites show human activity before and after an eruption. Examples are the occupations in southern Alberta (Oetelaar, 2021; Oetelaar & Beaudoin, 2005, 2016) and Neanderthals in Ginosa in southern Italy (Marciani et al., 2020; Spagnolo et al., 2016). As an archaeological site affected by the eruptions, the Abra del Toro rock shelter shows an exceptional context because it presents the occupation dates immediately after the natural disaster. The sites in rocky shelters with a stratigraphic record are excellent windows to observe short but successive occupations before and after natural disasters.

Multiple studies have analyzed volcanic eruptions and their impact on prehistoric populations in South America. In the specific case of Colombia, the study of volcanic eruptions has produced fruitful geoarchaeological investigations (Cano Echeverri, 2018; Cano Echeverri et al., 2013); particularly in the persistence of their impact on the memory and cosmogony of current indigenous populations (Pardo et al., 2021; Patiño & Monsalve, 2019).

Closer to the study area, an example of the influence of volcanic eruptions on prehistoric populations can be found in La Payunia, in the south of the province of Mendoza, where volcanic activity 8,000–7,000 a BP affected the human population, the depopulated of large sectors of the eastern plain (Durán et al., 2017). Argentine Patagonia also contains a long tradition of research on human mobility in the past concerning volcanic eruptions (Durán et al., 2017; Prieto et al., 2013; Serna et al., 2020).

In this paper, we present the research at the Abra del Toro rock shelter site, which provides novel data on two topics: firstly, it affirms the presence of hunter-gatherer occupations in the Andean intermontane valleys for the Middle Holocene, and secondly, it establishes the connection between these occupations and the largest eruption known globally during the last 5,000 years (Fernandez-Turiel et al., 2019).

2. Study area

The Yocavil or Santa María valley is a North-South intermontane tectonic basin located in the northern end of the Sierras Pampeanas of northwestern Argentina. Its western limit is formed by the Sierra de Quilmes or del Cajón (4,700 m a.s.l.) and the eastern boundary is formed by the Cumbres Calchaquíes (4,700 m) and the Sierra de Nevados del Aconquija (5,500 m). The Yocavil Valley is crossed from south to north by the Santa María River and shows a strong asymmetry transversally. The western slope is shorter and steeper than the eastern one. The relief combines mountains with an igneous-metamorphic basement (Upper Proterozoic-Upper Paleozoic) in the highlands, surrounded by piedmonts developed on Neogene sediments, with valleys filled with recent fluvial and aeolian sediments (Ballato et al., 2019; Bossi et al., 2001; Georgieff et al., 2017). The latter sediments are mainly Holocene and form a complex system of glacis, alluvial fans, fluvial terraces and aeolian deposits (Sampietro Vattuone et al., 2018; Sayago et al., 2012).

We are in a seismogenic area where, since 1973, have been documented five earthquakes of magnitude ≥ 5 (Gutiérrez et al., 2021). The neotectonics activity associated with this seismicity is recorded in the Holocene materials and also contributes to modeling the landscape's geomorphology (e.g., retrograde erosion, landslides) (Gutiérrez et al., 2021).

The Abra del Toro rock shelter is located in a passage between mountains or *abra* (Fig. 1), in the Yocavil valley, province of Catamarca,

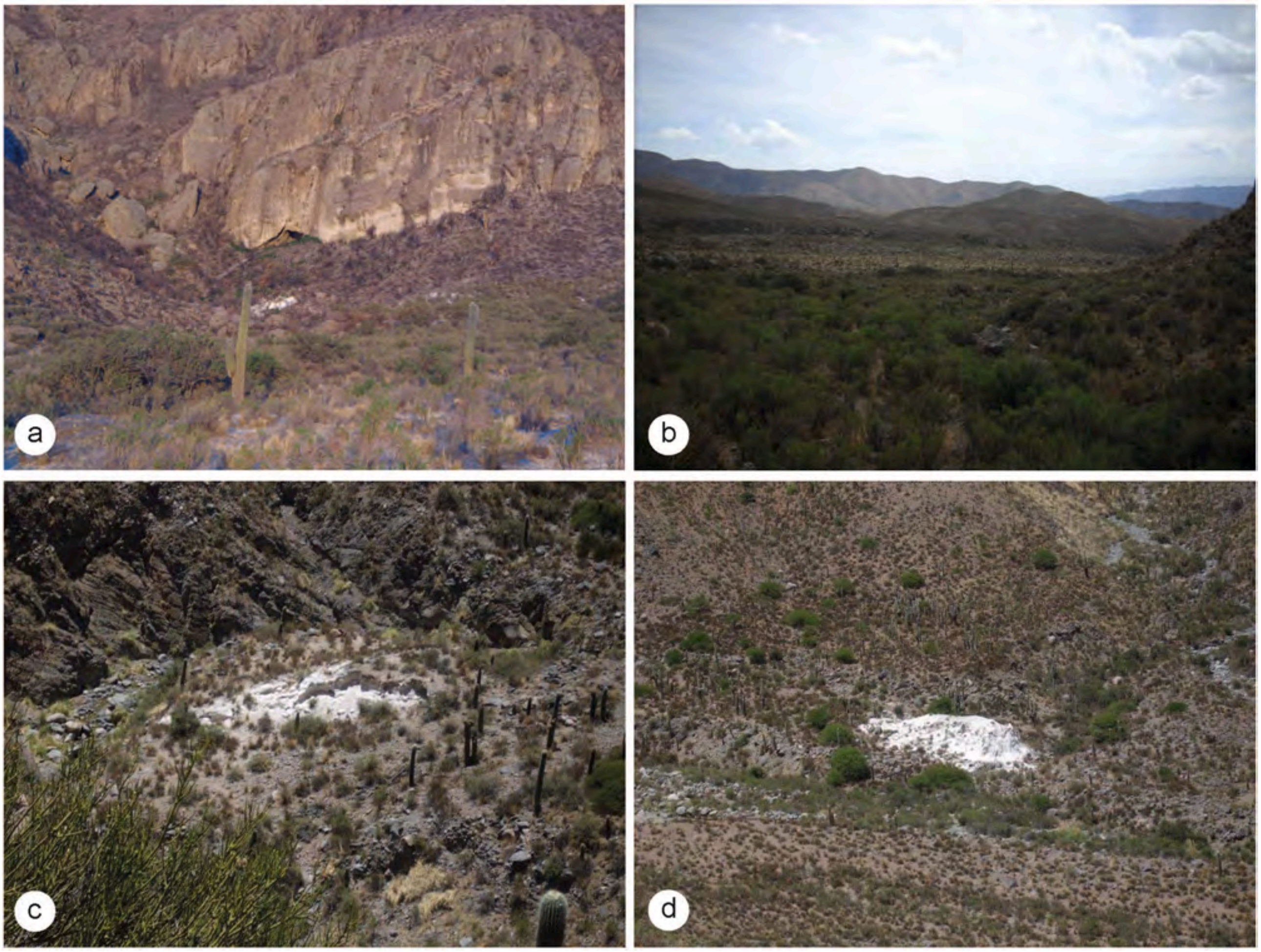

Fig. 2. Mountain slope where the Abra del Toro rock shelter is located (a) and surrounding landscape (b). This photo (b) was taken from the rock shelter. The bottom pictures (c – d) show the volcanic ash-fall deposits from the 4.2 ka BP eruption of the Cerro Blanco Volcanic Complex near the Abra del Toro rock shelter.

in the northwest of Argentina, near the source of the Ampajango river and two hundred meters from one of its tributaries, the river del Toro. Its location is: Lat S 26° 58′ 07.3″ Long W 66° 00′ 27.3″.

It should be noted that near the source of the Ampajango river, in the valley of one of its tributaries, La Horqueta, in the summit of Mount Aconquija, there are rock glaciers (Ahumada et al., 2013). These have guaranteed a permanent water supply in these arid and semiarid regions throughout the Holocene, acting as regulators of water resources. In other words, given their altitude, they provide a basic water flow without which many river beds would remain dry for long periods.

The rock shelter stands in a natural passage that connects the bottom of the Yocavil valley and its semiarid foothills with the humid sector on the western slope of the Aconquija ranges in Tucumán Province. The disparity in climate and resources available on each side of the mountain remained during the Holocene (Osterrieth et al., 2019). Scattolin & Korstanje (1994) have summarized the evidence of communication between both sectors: the Tafí construction pattern, also found in sites on the western slope, and the presence of vegetable resources, such as the wild bean, which usually grows in humid areas and was found at the Loma Alta site (Pochettino & Scattolin, 1991). In addition, the dispersion of ceramic styles is one of the strongest signs of interaction between both sides (Spano, 2011).

The rock shelter is located in an East-West oriented ravine which shelters it from northward and southward winds and is close to an alluvial plain system at 3,600 m above sea level. In addition, its relatively high position provides excellent visibility of the mountain passage (Fig. 2).

2.1. Volcanic eruptions at the regional scale

Three large Holocene volcanic eruptions have been recorded in the southern Puna affecting the region under study. The oldest one took place at ca. 7,820 a BP in the Cueros de Purulla volcano; another in the Cerro Blanco Volcanic Complex at ca. 4,200 a cal BP, and the most recent one occurred after 1,770 a BP (Fernandez-Turiel et al., 2019) and probably comes from the Nevado Tres Cruces The Cerro Blanco eruption happened during the transition from the Mid-Holocene (Northgrippian Stage) to the Upper Holocene (Meghalayan Stage) (International Commission on Stratigraphy, 2018; https://www.stratigraphy.org/index.php/ics-news-and-meetings/125-formal-subdivision-of-the-holocene-series-epoch).

Fernandez-Turiel et al. (2019) have determined the age of the Cerro Blanco eruption by radiocarbon dating of peat found underneath ash deposits in Tafí del Valle, which yielded an age of 4,971 to 4,72780 a cal BP, coal in a palaeosol underlying an ignimbrite at the Quebrada de Las Papas, with an age of 4,524 to 4,299 a cal BP, and charred material within an ignimbrite in Laguna Aguada Alumbrera, with an age of 4,414 to 4,160 a cal BP. Such results allow the authors to constrain the oldest possible age of this explosive eruption that hit the Tafí valley and its surroundings (Fernandez-Turiel et al., 2012, 2014). Eruption modeling led these researchers to consider that the volcanic plume spread > 100 km^3 of ash across a territory of about 500,000 km^2 covering mainly the Argentine provinces of Catamarca, Tucumán, and Santiago del Estero. These values indicate that, according to the VEI or Volcanic Explosivity Index (Newhall & Self, 1982), this was an eruption of VEI-7 magnitude,

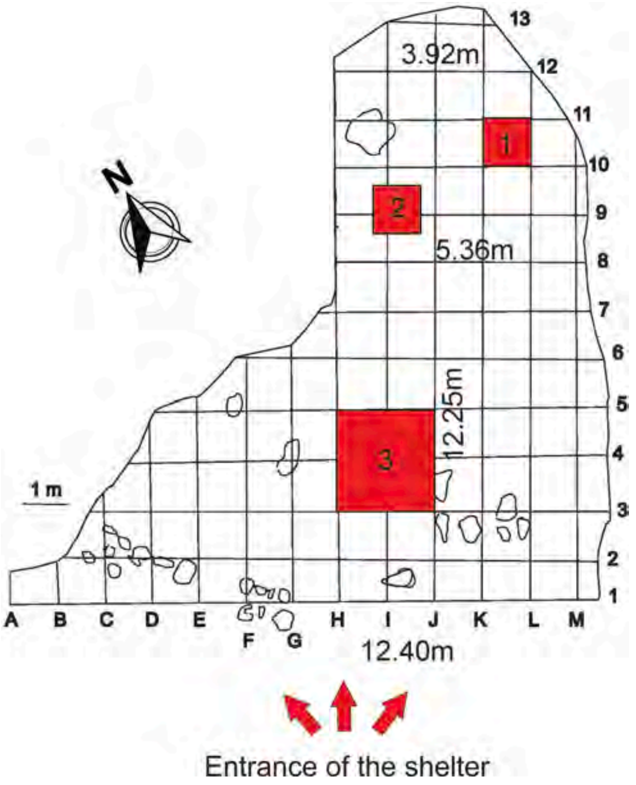

Fig. 3. Abra del Toro rock shelter floor plan. The 4 m^2 excavation grid and the two 1 m^2 test pits mentioned in the text are displayed. Excavation unit HI-8/9, was the focus of this research, and the deepest one.

making it the largest documented eruptive event of the past five millennia in the Central Volcanic Zone of the Andes and one of the greatest ones during the Holocene globally, Global Volcanism Program, (2013).

Ash deposits from the Cerro Blanco Volcanic Complex have been found in many localities of Catamarca, Tucumán and Santiago del Estero (provinces of Argentina), e.g., Laguna Blanca, Corral Quemado, Santa María, Tafí del Valle and Termas del Río Hondo (Fernandez-Turiel et al., 2019; Peña Monné & Sampietro Vattuone, 2018). The main arguments to establish such a correlation are (a) compositional similarity of the ashes, (b) stratigraphic and geomorphological relations, (c) geochronological consistency, and (d) the geographical distribution of outcrops of ash-fall deposits concerningthe location of the eruptive source in the Cerro Blanco area (Fernandez-Turiel et al., 2019).

3. Methods

As part of our fieldwork, we laid out a 4 m^2 excavation grid on the rock shelter floor and dug out two 1 m^2 test pits (Fig. 2). The excavation process was stratigraphic, following the Harris (1991) and Carandini (1997) guidelines. Each stratigraphic unit was considered a single deposit/erosion event, and large volume deposits were divided into artificial levels. Excavation unit HI-8/9, the focus of this work, was fully excavated and was the pit deepest one.

Two bone fragments (specimens AA111231 and AA111230) were radiocarbon dated by AMS (Accelerator Mass Spectrometry) at the Arizona University AMS Laboratory. Their ages were calibrated using the OxCal 4.2 software (Bronk Ramsey, 2009) and ShCal13 (Hogg et al., 2013) calibration curve.

The morphology and chemistry of ash particles were studied under a scanning electron microscope (SEM). Mineralogy was determined by X-ray diffraction (XRD). Both studies were carried at the Geosciences laboratory (CSIC), Barcelona. Concentrations of major and trace elements in bulk volcanic ash samples were determined by high-resolution inductively coupled plasma mass spectrometry (HR-ICP-MS). Previous geological studies described the methods used to characterize volcanic ash in detail (Fernandez-Turiel et al., 2019, 2021a). Organic matter content was determined indirectly by organic carbon quantification using the method of Walkley & Black, (1934).

The lithic material was analyzed techno-morphologically following the methodological guidelines and typological classification of Aschero (1975, 1983) and the revisions used for bifacial artifacts of Aschero & Hocsman (2004). Although our sample size we have is relatively small (N = 78), it allows us to recognize some trends in the lithic group.

Analysis of animal bones covered biologic and taphonomic variables later tallied by the Number of Specimens (NSP, NSP%) and the Number of Identified Specimens (NISP, NISP%) (Lyman, 2008). In addition, specimens were classified into five body-size classes (Izeta, 2007): 1–2, small animals (e.g., rodents); 3, medium-sized vertebrates (e.g., lesser rhea); 4, big vertebrates (e.g., camelids); 9, indeterminate size.

4. Results

4.1. *The rock shelter*

The shelter site is located on an alluvial fan deposited on top of Caenozoic sediments of the Santa María Group, relatively dated as Pleistocene (Ballato et al., 2019; Georgieff et al., 2017 and references thereof). These sediments are made up of bedrock metamorphic rock pebbles, which are not cemented, and their thickness varies between 20 and 30 m.

The Abra del Toro rock shelter entrance, which faces the SW, is 12.40 m wide. The shelter is 12.25 m deep and 4.95 m high at its highest point (Fig. 3). As the shelter deepens, it narrows, and the ceiling gets lower. Walls are made up of clastic rock.

Besides anthropogenic materials, stratigraphic deposits include sediments transported into the rock shelter by wind action. In addition, the shelter overhang contains detritus formed by material detached from the walls and ceiling collapsed, which is found mainly in the uppermost layers of our excavation. Finally, heavy treading by the human groups who occupied the rock shelter consolidated some deposits while removing others (Fig. 4).

4.2. *Stratigraphy*

Excavation of unit HI/8–9 reached a depth of 2.32 m (Fig. 5). A humid, dark reddish-brown soil (5YR3/3 of Munsell Color Chart) was developed directly on top of the underlying wall rock, with a maximum thickness of 20 cm. The organic matter value in this soil (1.16 %) was among the highest in the entire sequence. The sediments of this unit come from surface sedimentation of outer materials and those falling from the rock shelter's roof and walls. This stratigraphic unit records the first occupation of the rock shelter, contains no ceramic objects, and it is considered to be prior to the eruptive event.

Radiocarbon dating of skeletal faunal remains by AMS (Accelerator Mass Spectrometry) yielded 4,582 ± 29 years BP. Their 95 % probability age ranges between 5,445 and 5,057 a cal BP, establishing thus the oldest stratigraphic record of prehispanic occupation in the Santa María Valley.

Above these findings, the rock shelter reveals a set of stratigraphic layers, coarsely planar bedded, white sub-horizontal lens, composed of volcanic ash (Fig. 5, in grey). This volcanic ash deposit is about 80 cm thick, and no evidence of occupation has been found up to its upper limit, where sediments have been removed and mixed, probably due to anthropic factors. The nondisturbance of this deposit may indicate a fast rate of sedimentation.

In this set of layers, the amount of organic matter content (0.08 %) is the lowest of the entire stratigraphic series. In the ash deposit, particles of 20–100 μm occur more frequently (Fig. 6a). Glass prevails on ash, and

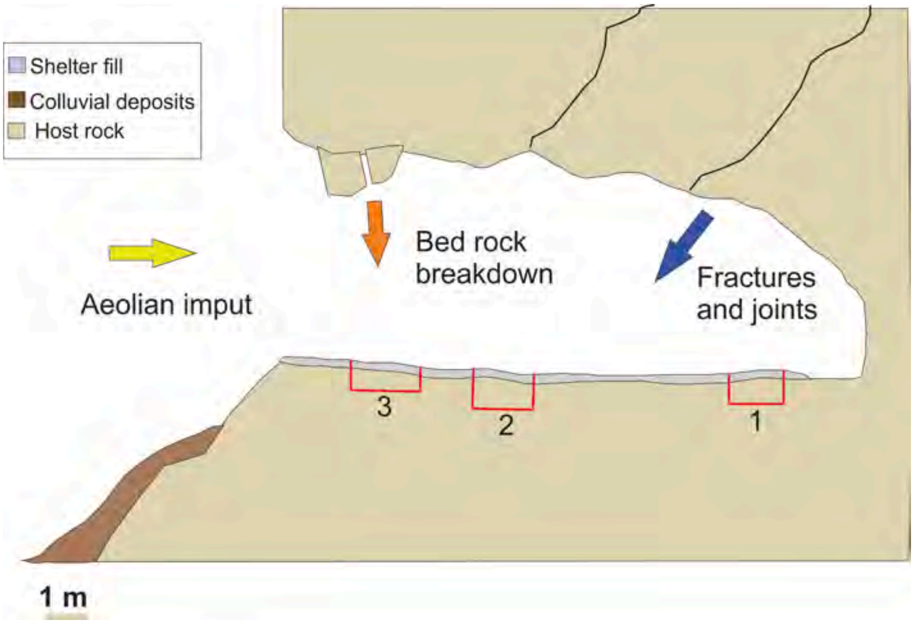

Fig. 4. Synthesis of the main depositional processes active in Abra del Toro rock shelter. The excavation test pits in Fig. 3 are indicated as reference.

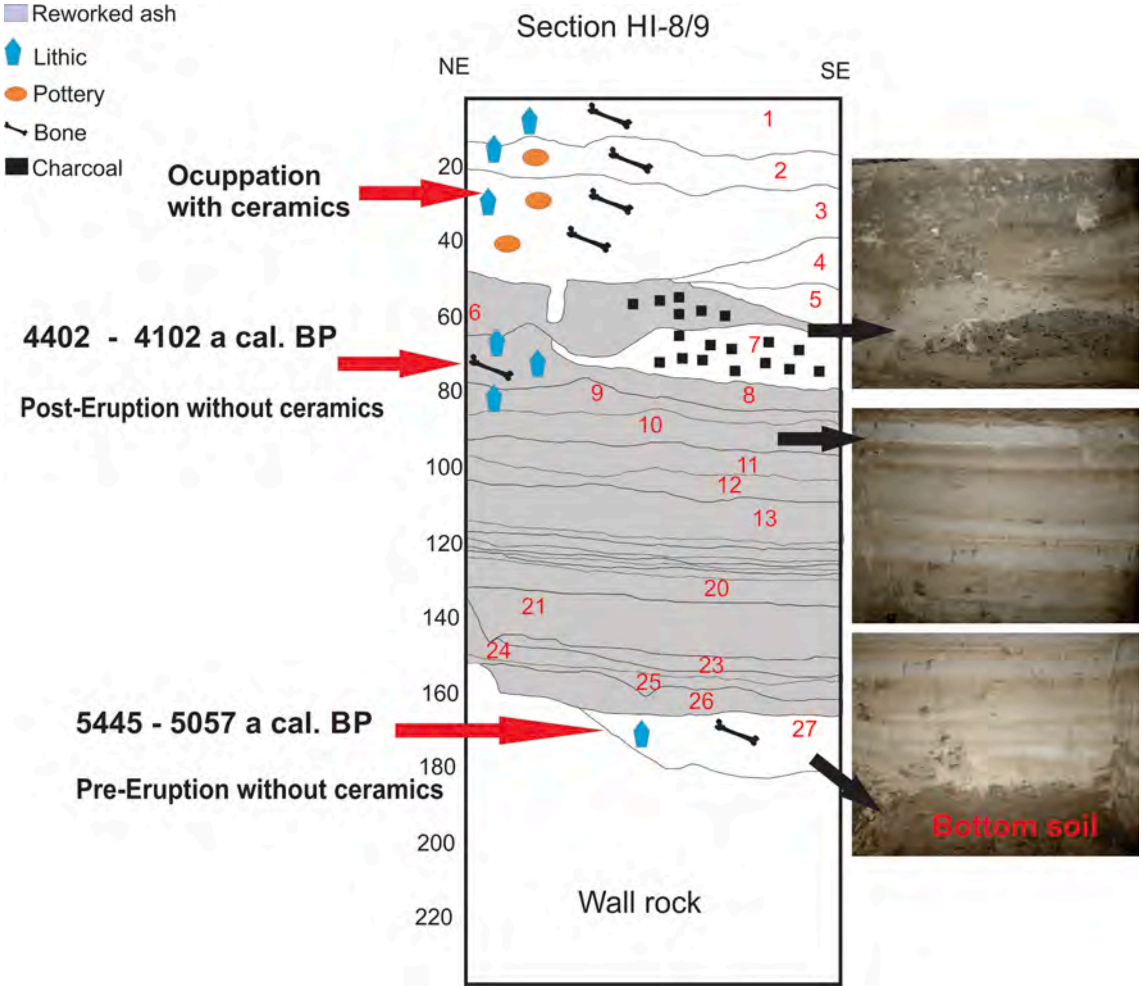

Fig. 5. Stratigraphic cross-section of Unit HI-8/9 NE profile. The grey area indicates the volcanic ash deposit associated with the 4.2 ka eruption of the Cerro Blanco Volcanic Complex.

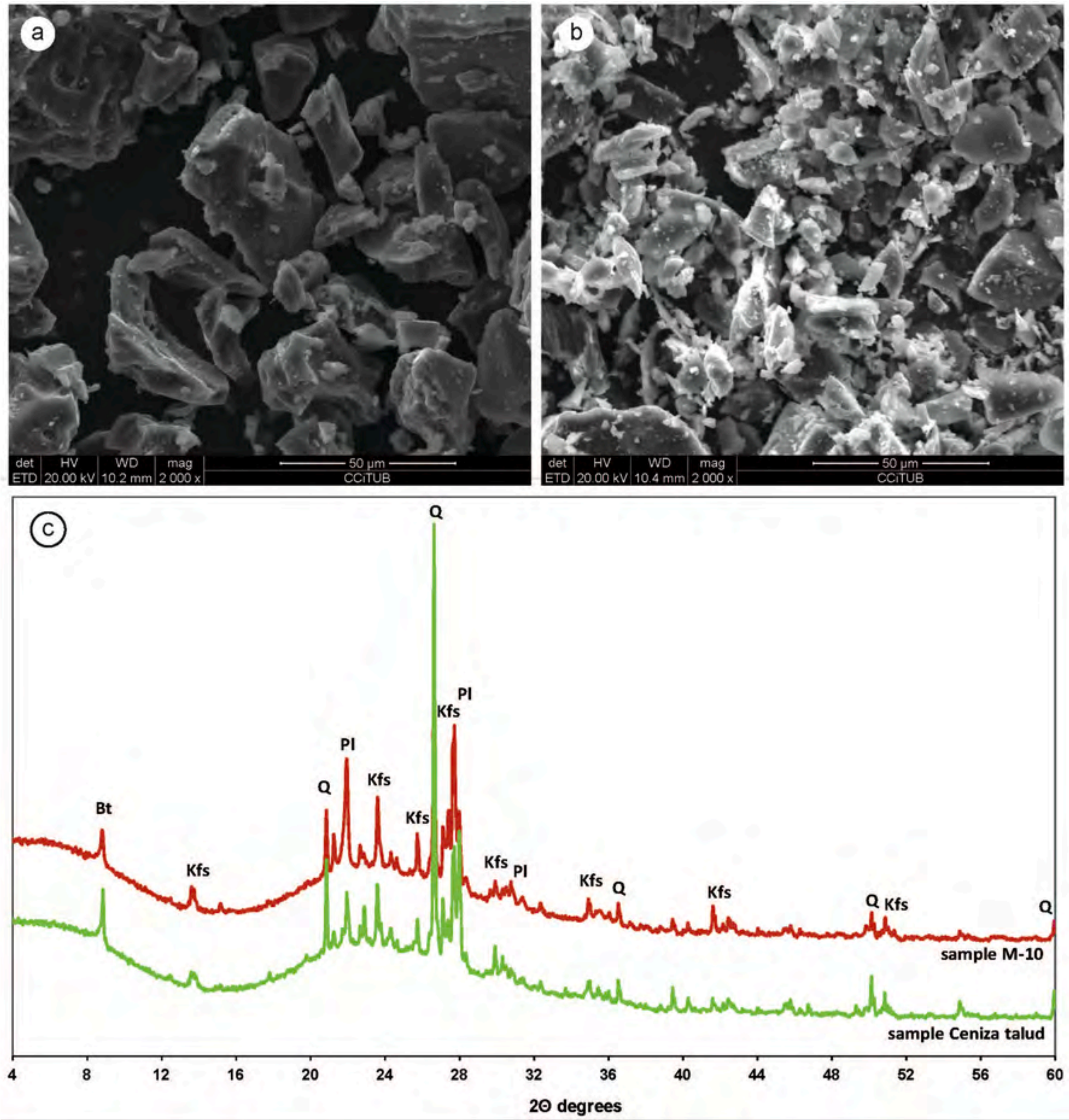

Fig. 6. SEM microphotographs of volcanic ashes from a) layer 10 in archaeological excavation unit H/I-8/9, and b) an external ash-fall deposit. c) Comparison of X-ray diffractograms of both ashes (samples M−10 and Ceniza Talud, respectively).

crystals consist of quartz > feldspars > biotite > spinel (Fig. 6c). The bulk composition of major elements is rhyolitic (76.80 SiO_2 %; 6.63 $Na_2O + K_2O$ %), and the trace elements with the highest concentrations are Rb (335 μg g^{-1}), Li (110 μg g^{-1}), Ba (59 μg g^{-1}), and Zr (53 μg g^{-1}) (Table 1). Some trace elements (e.g., Ni, Sb, Pb, Th, and U) present concentrations slightly lower than the previous data. Instead, the LOI values are somewhat higher. These features are attributed to minor variations in the relative content of glass and minerals in the fallout ash deposits.

In the vicinity of the Abra del Toro rock shelter, it should be stressed that lie scattered remains of a white volcanic ash-fall deposit (Fig. 2). They are found at the top of the local stratigraphic sequence and sometimes show very incipient soil development. It is up to 2 m thick and it contains an approximately 10 cm thick parallel lamination base level which sits beneath a massive level with no internal structure (Fig. 7). This stratigraphic structure is different from the deposit inside the rock shelter. Another difference is grain size, which shows a greater tendency to bimodality on the outside, whereas the inner ash presents a much larger content of fragments measuring a few micrometers (Fig. 6a and 6b). In contrast, there are similarities in that glass prevail over crystals, with quartz > feldspars > biotite > spinel (Fig. 6c), and in that the chemical bulk composition of major elements is rhyolitic (76.07 % SiO_2 m/m, 6.53 % $Na_2O + K_2O$ m/m), while trace elements with highest concentrations are Rb (329 μg g^{-1}), Li (97 μg g^{-1}), Ba (74 μg g^{-1}), and Zr (57 μg g^{-1}) (Table 1). The bulk composition of both inside and outside ashes is consistent with the composition of Cerro Blanco ash (Fernandez-Turiel et al., 2021a) (Table 1).

We also conducted radiocarbon AMS dating of the first organic remain found in the ash deposit's last layers in the rock shelter (camelid scapula in layer 8). This is the first organic remains recorded spatially and chronologically after the eruption. The result was 3,834 ± 27 a BP, with a 95 % probability calibrated age between 4,402 and 4,102 a cal BP. This level points out the second period of rock shelter occupation, post-eruption, and still without ceramic content. According to the zooarchaeological analysis, the scapula belonged to a camelid and bear no butchering marks (Fig. 8a). The scapula is unfused, and belongs to a very young animal (under 18 months).

The second occupation modified the upper section of the ash deposit.

Table 1

Comparison of the bulk chemical compositions of volcanic ash from layer 10 in the archaeological excavation unit H/I-8/9 (Muestra 10) and an external ash-fall deposit (Ceniza Talud) with the composition of the 4.2 ka Cerro Blanco ash (Fernandez-Turiel et al., 2021a). LOI, loss on ignition.

Parameter	Unit	Sample 10 (inside)	Ceniza Talud (outside)	Cerro Blanco ash (n = 27 samples)			
				min	max	mean	median
SiO_2	% m/m	76.80	76.07	72.08	78.02	75.15	75.56
Al_2O_3	% m/m	11.16	11.82	10.94	13.26	11.94	11.86
T-Fe_2O_3	% m/m	0.62	0.83	0.49	2.01	1.04	0.95
MnO	% m/m	0.06	0.06	0.06	0.09	0.08	0.08
MgO	% m/m	0.15	0.24	0.14	0.77	0.31	0.26
CaO	% m/m	0.60	0.66	0.60	1.65	0.83	0.75
Na_2O	% m/m	2.67	2.96	3.23	4.22	3.60	3.60
K_2O	% m/m	3.96	3.57	3.55	4.70	4.03	3.99
TiO_2	% m/m	0.12	0.16	0.10	0.26	0.16	0.14
P_2O_5	% m/m	0.02	0.03	0.01	0.06	0.02	0.02
LOI	% m/m	3.83	3.61	1.31	3.66	2.92	2.94
Li	μg/g	109.75	97.42	40.96	133.87	103.00	106.92
Be	μg/g	6.09	5.87	4.46	6.52	5.56	5.63
Sc	μg/g	4.45	5.34	3.48	6.99	4.87	4.76
V	μg/g	5.66	9.78	2.26	33.06	7.23	5.74
Cr	μg/g	2.61	3.19	4.49	21.24	9.01	7.22
Ni	μg/g	1.50	1.81	2.00	11.44	3.94	2.83
Cu	μg/g	2.83	4.15	2.95	12.99	5.50	4.84
Zn	μg/g	37.76	41.87	26.93	111.13	37.12	31.77
Ga	μg/g	16.97	17.83	17.52	22.19	19.94	19.89
Ge	μg/g	1.72	2.08	0.41	2.07	1.01	0.84
As	μg/g	4.53	4.97	4.16	8.43	5.84	5.75
Rb	μg/g	335.46	329.36	286.03	538.49	464.34	492.12
Sr	μg/g	30.24	29.80	17.60	93.62	43.85	36.68
Y	μg/g	17.94	19.83	16.61	21.40	19.46	19.65
Zr	μg/g	52.85	57.06	50.79	89.70	61.76	58.90
Sn	μg/g	2.27	2.51	1.69	6.91	2.44	2.00
Sb	μg/g	0.45	0.52	0.77	2.40	1.14	1.14
Cs	μg/g	23.50	22.12	22.25	31.55	27.20	26.88
Ba	μg/g	58.92	73.85	22.80	152.68	76.44	68.44
La	μg/g	14.51	17.73	14.06	28.70	18.52	17.91
Ce	μg/g	32.11	37.92	30.21	59.50	41.16	40.05
Pr	μg/g	3.67	3.95	3.88	10.65	4.86	4.55
Nd	μg/g	12.03	15.19	12.73	21.83	16.71	16.47
Sm	μg/g	2.86	3.29	2.60	5.26	3.53	3.48
Eu	μg/g	0.24	0.31	0.22	0.79	0.33	0.29
Gd	μg/g	2.82	3.34	2.48	4.03	3.45	3.49
Tb	μg/g	0.40	0.45	0.38	0.96	0.46	0.43
Dy	μg/g	2.50	2.84	2.39	3.57	2.75	2.71
Ho	μg/g	0.44	0.48	0.41	1.00	0.51	0.48
Er	μg/g	1.50	1.62	1.41	2.17	1.64	1.62
Tm	μg/g	0.30	0.32	0.26	0.59	0.34	0.33
Yb	μg/g	2.02	2.14	1.77	2.84	2.51	2.57
Lu	μg/g	0.33	0.35	0.31	0.70	0.45	0.47
Hf	μg/g	2.63	2.86	2.79	4.54	3.83	3.94
Pb	μg/g	26.25	26.69	30.07	39.18	35.79	35.87
Th	μg/g	19.67	21.36	23.88	31.89	28.82	28.81
U	μg/g	17.07	16.82	17.26	26.09	22.28	23.13

The degree of bioturbation is high (*sensu* Taylor & Goldring, 1993) with the re-working of sediments and where the boundaries between the different layers intermingle and are un-clear. The occurrence of medium stone blocks cannot be attributed to rockfalls from the roof: they are artifacts, manuports, transported by the populations, whose lithology from that of the rocky shelter. Similar records have been detected at the earliest prehistoric occupation of rock-shelters following an eruption (Martini et al., 2021; Spagnolo et al., 2016; Torrence, 2016). Several investigations worldwide show that a large amount of accumulated ash facilitates the preservation of material remains, often ephemeral, of hunter-gatherer societies (Sauer et al., 2018).

Finally, among the most relevant findings in the recent deposits, lying stratigraphically on top of the scapula dated to the period specified above, there are many ceramic remains with carved decorations, including straight and undulated lines and combed designs (Fig. 8b). According to the ceramic design analyses conducted in the region, these ceramics could date from the first millennium of our era (Oliszewski et al., 2018; Spano, 2011). Organic matter content increases towards the surface, 1.28 % in the uppermost deposit vs. 0.28 % in deposit 4. Faunal taxonomic diversity of specimens is higher in the deposits nearing the rock-shelter floor. One hundred forty-three specimens from the agro-pottery context were analyzed, and 58 % were identified (NISP = 83) to a relevant taxonomic rank, including birds, rodents, and camelids.

4.3. Lithic technology

At the first occupation level, finds included various instrument and debitage remains and even a lanceolate projectile point (Fig. 8c) (Table 2). The design of this point resembles those of the Middle Holocene of the Puna, such as the Af-D type described by Moreno (2011) in Antofalla, dated between 4,150 and 3,450 a BP, and the morphological specimen of Peñas Chicas 4 defined by Hocsman (2006) and Hocsman & Babot (2018) in Antofagasta de la Sierra, dated between 4,500 and 3,000 a BP.

The rest of the lithic material consists of an instrument with a scraper edge and internal flakes (Table 2). The absence of cores and the characteristics of these wastes would indicate (in a preliminary way) that activities related to the maintenance and reactivation of cutting edges

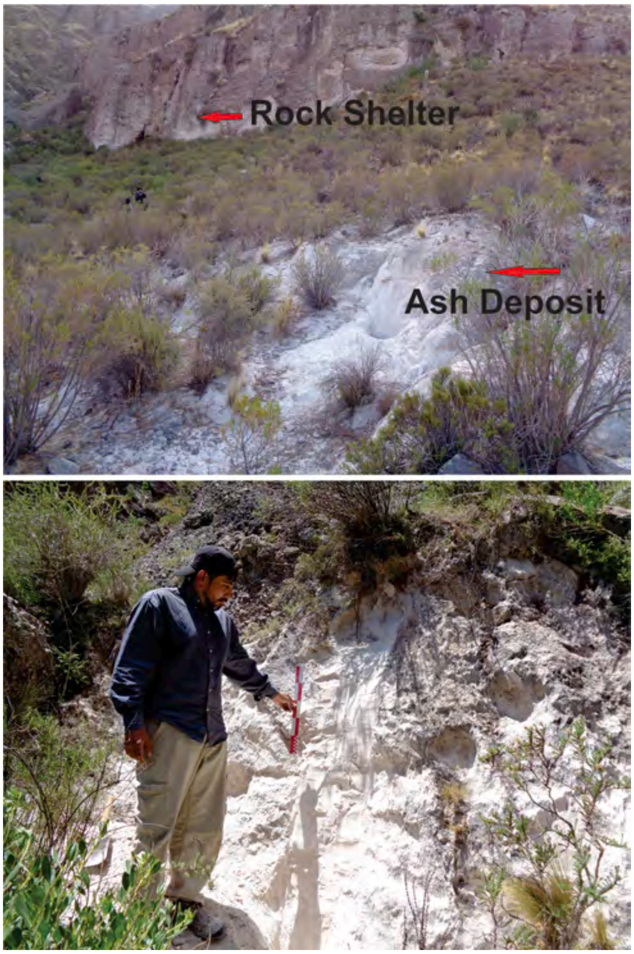

Fig. 7. Ash-fall deposit in the slope close to Abra del Toro rock shelter.

are being carried out. The raw material used is local, composed of andesite rock and quartz. Both lithic resources are available in the vicinity of the site, in the form of boulders in river beds or as nodules in the ravine walls (Table 2).

The second level of human occupation, the post-eruption aceramic assemblage, the return of hunter-gatherers, was technologically characterized by large artifacts (Table 2). There was debitage at the same depth where the dated camelid bone was found, a notched flat flake, and two fragments of an undifferentiated nodule. In addition, large-sized stone artifacts were present; a large polyhedral core, a discoidal core, and a polished artifact probably used for grinding, each lying a few centimeters above and below the dated scapula, respectively. The cores are considered amorphous since they do not present prepared platforms, nor a morphology that allows the extraction of base shapes of predetermined sizes and shapes. However, core flakes within the carving debris indicate an intention to reactivate the cores. The raw material used is again andesite, except for the milling device. The support of this unformalized artifact is a metamorphic rock, schist. This rock is fully available in the surrounding landscape.

The lithic material found in the agro-pastoral occupation with ceramic shows highests number of artifacts. Undifferentiated flakes are common in the predominant carving debris and could be extracted from cores by isolated flaking. Nor do we find formalized technology for the production of instruments at this occupation level. Although most of the wastes correspond to internal flakes, we also find external flakes and core reactivation flakes. With these data, it is possible to think that the flaking of cores was another activity carried out during this occupation. We believe that the lack of formalized artifacts at this and previous occupations is a sampling bias owing to the small excavation surface. However, an element to be highlighted is the continuity in the consumption of local lithic resources. The presence of allochthonous raw material has not been identified throughout the sequence.

4.4. Faunal analysis

Faunal remains amount to 247 specimens: 107 specimens were identified to a relevant taxonomic rank and body size (Table 3), in

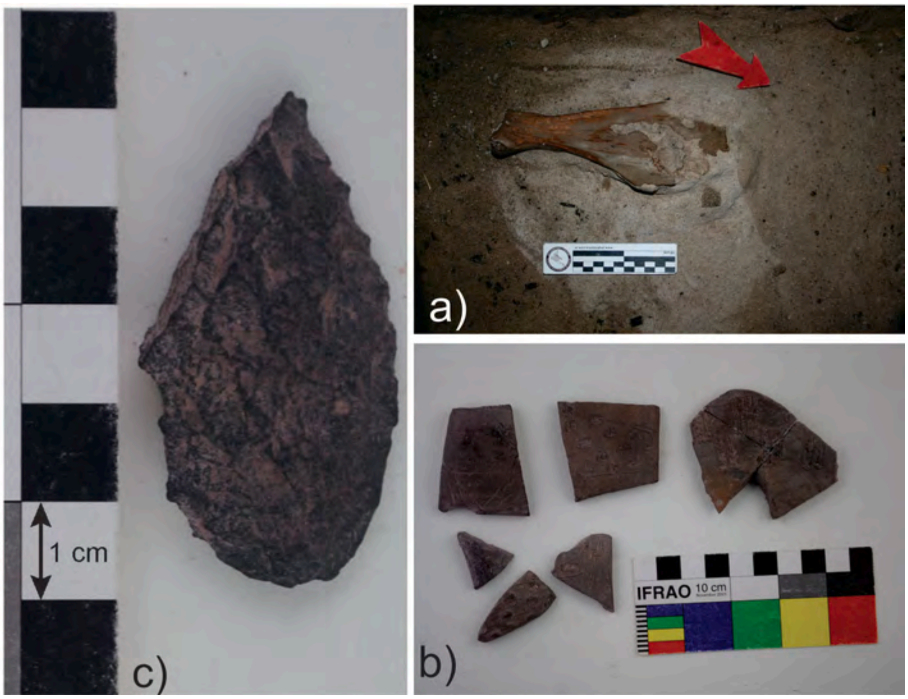

Fig. 8. a) Camelid scapula from layer 8 found at the top of the ash deposit and dated between 4,402 and 4,102 cal a BP (95 % probability). b) Ceramics recorded from the last occupation of the shelter. c) Lanceolate projectile point found at the bottom soil level of unit HI-8/9.

Table 2
Distribution of lithic material recorded in the three occupational periods of Abra del Toro rock shelter.

Artifactual categories	Pre-eruption without ceramics	Post-eruption without ceramics	Occupation with ceramics
Cores			
Pyramidal		1	1
Discoidal		1	
Prismatic			1
With isolated flaked			4
Subtotals		2	6
Debitage			
External flakes			1
Internal flakes	17	6	24
Reactivation flakes			
Core reactivation flakes		2	1
Flakes	3	2	10
Subtotals	20	10	36
Grinding artifacts			
Single hands mill		1	
Tools			
Projectile point	1		
Side scraper	1		
Subtotals	2		
Totals by occupation	22	13	42

Table 3
Number of identified specimens tallied by taxon, body size, and archaeological deposit.

Taxon	**Body size**	**NISP**			
		Pre-eruption without ceramics	**Post-eruption without ceramics**	**Occupation with ceramics**	**Total**
Artiodactyla	3–4	1			1
Artiodactyla	4	2		1	3
Camelidae	4	5	1	1	7
Lama sp.	4	2		1	3
Lama glama	4		1		1
Rodentia	1	11		67	78
Microcavia sp.	1	1			1
Ctenomys	1			1	1
Myomorpha	1			2	2
Cricetidae	1			3	3
Aves	1			3	3
Aves	1–2			2	2
Aves	2			2	2
Total		22	2	83	107

Table 4
Number of unidentified specimens (NSP$_{indet}$) tallied by body size and archaeological deposit.

Body size	**NSP$_{indet}$**			
	Pre-eruption without ceramics	**Post-eruption without ceramics**	**Occupation with ceramics**	**Total**
1			16	16
2		2		2
2–3	1		1	2
3	4		1	5
3–4	8		3	11
4	12		2	14
9	27	26	37	90
Total	52	28	60	140

addition, 50 taxonomically non-diagnostic specimens were identified to body size 1–4 (Table 4). The pre-eruption aceramic and the ceramic layers produced the largest assemblages. Rodentia is the most frequent order, followed by Artiodactyla, in both cases, but Camelidae is the most abundant family of the pre-eruption aceramic assemblage. Rodent bones are very small, and those few identified to a lower taxonomic rank belong to characteristically small families and genera. The post-eruption aceramic assemblage is small, accounting for only two identified specimens (Camelidae). The ash deposit was sterile.

Taphonomic traces and fractures were quantified by the number of specimens (NSP), excluding those of indeterminate body size (class 9). Quantification of weathering was restricted further, counting only specimens of body size 3–4. Non-cultural traces were scarce: root etchings amounted to NSP%$_{1\text{-}4}$ 8.5, 25.0, and 9.4 of pre-eruption aceramic, post-eruption aceramic, and ceramic assemblages, respectively. Rodent gnawing marks amount to NSP%$_{1\text{-}4}$ 2.0 of the pre-eruption aceramic assemblage, and carnivore marks account for NSP%$_{1\text{-}4}$ 2.8 of the ceramic assemblage. Ten percent (NSP%$_{3\text{-}4}$) of bones of medium and big vertebrates from the pre-eruption aceramic and the ceramic layers exhibited any weathering.

The fracturing of green bones was identified for a fraction of specimens coming from both the pre-eruption aceramic (NSP%$_{3\text{-}4}$ 9, NSP% 3–4 26) and ceramic layers (NSP%$_{3\text{-}4}$ 2, NSP%$_{3\text{-}4}$ 22). In addition, one specimen showing percussion striae from each of these layers (NSP 2) and one bone with scraping marks from the pre-eruption aceramic layer were also identified. Sixty-six specimens (NSP%$_{3\text{-}4}$ 72) from the pre-eruption aceramic assemblage show a reddish-dark hue that could indicate thermal alteration, but other surface modifications often associated with combustion, such as crackling and exfoliation, are lacking. It should be noted that thermal alteration can occur within the sedimentary matrix (e.g., under a hearth).

Table 5 summarizes the anatomical profiles of Camelidae by layer (NISP by element). The profiles consist of appendicular bones only. Camelidae specimens are scarce, and hence the construction of survivorship profiles is not feasible; however, it is worthy of note that specimens of animals under 36 months were recorded for the three assemblages.

5. Discussion

5.1. Origin of the tephra layer

According to geomorphological, sedimentological, textural, glass and mineral content, and bulk chemical composition criteria (Table 1), the ash deposited in the rock shelter correlates with the external primary ash fall deposit near the archaeological site and the Cerro Blanco

Table 5
Number of specimens identified as Camelidae tallied by anatomical element and archaeological deposit (NISP$_{camelidae}$).

Element	**NISP$_{camelidae}$**			
	Pre-eruption without ceramics	**Post-eruption without ceramics**	**Occupation with ceramics**	**Total**
Scapula		1	1	2
Radius-Ulna	1			1
Cuneiform		1		1
Femur	2			2
Talus			1	1
Metapodial	1			1
First phalanx	3			3
Total	7	2	2	11

Table 6

Radiocarbon ages related to Cerro Blanco ash. Ages of Abra del Toro rock shelter from this paper; the rest from Fernandez-Turiel et al. (2019). Calibrations were performed with OxCal v4.4.4 (Bronk Ramsey, 2009); atmospheric data from Hogg et al. (2020).

Location	Position	Material	Uncalibrated age (a BP)	Calibrated age (cal a BP) 95.4 % probability	
				from	to
Abra del Toro - HI-8/9-Layer 8	overlying	bone animal	3834 ± 27	4402	4102
Laguna Aguada Alumbrera	whithin	charred material	3880 ± 30	4414	4160
Las Papas	underlying	charred vegetation	3970 ± 30	4524	4299
Arroyo Las Perillas	underlying	peat	4290 ± 40	4971	4727
Abra del Toro - HI-8/9-Layer 27	underlying	bone animal	4582 ± 29	5445	5057

eruption ash (Fernandez-Turiel et al., 2019; Fernandez-Turiel et al., 2021b)). The chronostratigraphic data is coherent with the age of the eruption of Cerro Blanco. Results of dating below (5,445–5,057 a cal BP) and above (4,402–4,102 a cal BP) of the inner ash deposit are also consistent with the age of the eruption (4,410–4,150 a cal BP) obtained by Fernandez-Turiel et al., 2019) (Table 6).

We propose that the multiple-layer ash deposit was formed after the ash-fall from the Cerro Blanco eruption, remains of which can be identified outside the rock shelter (Figs. 2 and 7). The fallout ash deposit was removed, and the tephra was carried inside the rock shelter by wind action. The rock shelter became a sedimentary trap for ash.

According to the magnitude of the eruption, ash fell from an altitude of several kilometers, creating a layer over 60 cm thick across the study area.

The wind transported ash from the primary external deposit and accumulated it in the entire inner space of the rock shelter. This process occurred during the eruption and especially afterward. Because of the orientation and size of the rock shelter entrance and its morphology, volcanic ash was part of the stratigraphic record (Figs. 4 and 5).

The origin of this ash deposit cannot be attributed to a direct vertical ash fallout, meaning that it is a remobilized deposit. The primary deposit has two subunits, a lower one of < 20 cm of alternating, parallel, very thin ash beds and an upper one, without gradation, with poorly defined stratification that can reach 2 m in the studied area (Fig. 7). In contrast, the excavated profile has lenticular stratification with local lateral discontinuities in the thickness. This bedding is interpreted as produced by a prevailing wind where ash deposition exceeds erosion, and the wind can transport many fine particles. Another indication is that the contact plane with the wet bottom layer of the stratigraphic profile is irregular and wavy. For example, ash deposits of this type were described in the Oscurusciuto rock shelter (Martini et al., 2021; Marciani et al., 2020). This bedding contrasts with laminated ash layers deposited by water, e.g., the Pelekita Cave with tephra from the Minoan Santorini eruption and the Magura cave with ash from the Campanian eruption (Bruins et al., 2019).

Other features indicating the aeolian origin of the shelter's ash deposit are the different granulometry concerning the primary deposit and the occurrence of non-volcanic elements (Dominguez et al., 2020). For example, we have observed silicophytoliths and diatoms in some excavated layers in the upper part of the reworked ash deposit.

The entry of ash by wind action is continuous until the deposits of the surrounding landscape are ended (Morley & Woodward, 2011). The ash-fall deposits in the landscape have a poor preservation potential, and this moment is not too far from the eruptive event (Martini et al., 2021).

We consider that the reworked ash deposit of the shelter formed immediately after the eruption, probably during a short period, between some years to some tens of years, according to the eruption date and the first date obtained overlaying the reworked ash deposits. This time range constitutes a *terminus ante quem* of the first visits to the shelter after the eruption. This estimate is preliminary, and further work in the excavation is necessary to determine more accurately the recovery period following the Cerro Blanco eruption.

In addition to aeolian inputs, high-energy rainfall events can promote the transfer of fine sediments from the external environment into the rock shelter through fissures in the roof and walls (Martini et al., 2021) (Fig. 4). This input will always be minimal compared with the aeolian considering the dimension of the rock shelter entrance.

5.2. *Rock shelter occupation*

Throughout the stratigraphic sequence of the Abra del Toro rock shelter, we can hypothesize that there were three main occupational moments at the Abra del Toro rock shelter: two hunter-gatherer moments, separated by the record of a large volcanic eruption, and an agro-pottery moment.

5.2.1. *Pre-eruption - hunter-gatherers*

The isochronic value of tephra is noteworthy (Riede et al., 2020), and is a time marker of site occupation. The oldest occupation moment by hunter-gatherers seems to be evidenced by the items found in unit HI-8/9, in the layer sitting directly on top of the original rock shelter floor. The dating of this layer is 5,445–5,057 a cal BP.

Above, we find remobilized ash deposit, with lenticular stratification and local lateral discontinuities in the thickness. Why did so much ash deposit with no other intervening material? The ash deposition must be a relatively fast process (Marciani et al., 2020), which is corroborated by the age of the bone found above the ash deposit (4,402–4,102 a cal BP), consistent with that of the explosive eruption (4,140–4,160 a cal BP). This fact indicates that the inner ash deposit build-up occurred relatively fast and continuously and prevailed over any other sedimentation process. The deposition of reworked ashed could have happened in a timeframe spanning years to some decades, perhaps up to 100–200 years. In addition, the eruption impact could cause the migration of the population to areas with unaffected resource situations (Riede, 2019; Vanderhoek & Nelson, 2007).

The Holocene eruptions of Mount Mazama (7.7 ka ago) and Cerro Blanco (4.2 ka ago) are very similar in terms of their magnitude (VEI 7) and volume of ash erupted (~170 km^3) (Buckland et al., 2020; Fernandez-Turiel et al., 2019; Oetelaar & Beaudoin, 2016). This similarity allows us to compare the impacts on the landscape in the short, medium, and long term, thanks to the investigations carried out in Mount Mazama (Oetelaar, 2021; Oetelaar & Beaudoin, 2005, 2016).

5.2.2. *Syn-eruption*

Although the rock shelter is located ~ 175 km east of the Cerro Blanco Volcanic Complex, the former occupants of the Abra del Toro rock shelter encountered a perturbed atmosphere due to the advance of the eruptive plume and the ash-fall out. It is possible that they heard the distant sound of the explosions and could glimpse the eruptive column. The estimated plume height of the eruption was 27 km (Fernandez-Turiel et al., 2019). Bearing in mind the great extension of the plume that emerged from Cerro Blanco, it is possible to think that the darkness was intense for weeks, as happened in the eruption of the Mazama volcano (Oetelaar & Beaudoin, 2005). Ash accumulated in glacis, streams, and watercourses. Ash-fall inflicts severe damage on plants and animals, including blindness, malnutrition, and silicosis for animals. The animals and the prehistoric occupants suffered respiratory problems and irritation. In an eruption like that of Mazama, researchers argue that: "the volcanic aerosols can remain in the atmosphere for two or three years after the eruption and thus have a long-term impact on the regional and global climate" (Oetelaar & Beaudoin, 2005:295). If both eruptions are comparable, we think the climatic conditions during the seasons were altered, with colder temperatures than usual.

The modeled isopachs of tephra from the Cerro Blanco eruption point out an ash thickness of about 60 cm around the rock shelter (Fernandez-Turiel et al., 2019). However, Fernandez-Turiel et al. (2019) observed a secondary thickening of the Cerro Blanco ash-fall deposits related to the orography (the Nevados del Aconquija mountain range reaches 5,500 m in height; Fig. 1). This thickening is attributed to topographically induced turbulences, e.g., the breaking of lee waves, generated by winds passing over elevated topography beneath the eruption plume. Ash blanketing of highland, locally known as "*vegas*", was particularly problematic for camelid herds that could not feed on the pastures present there and could also have water quality problems have water quality problems. The ecosystems underwent great stress during and, above all, after the eruption.

The significant impacts of this amount of tephra fall on soil and vegetation could be (Oetelaar & Beaudoin, 2005; Riede, 2019): a large proportion of plant cover eliminated for more than one year; the vegetation canopy recovery after several decades; a generalized breakage and burial of grasses and other non-woody plants; a complete burial and removal of algae from the soil; tiny mosses and annual plants will only be present again in the local ecosystem after recolonization; some aquatic plants do not recover; the soil is revitalized in four to five years, plants extend roots and tephra integrates into A horizon. In addition, driven by wind, the long-lasting reworking of volcanic products significantly influences the geomorphology and prolongs the impacts of eruptions on exposed communities and ecosystems (Dominguez et al., 2020). On the other hand, a comparison of silicophytoliths in soils and palaeosols associated with the 4.2 ka Cerro Blanco eruption in Tafí del Valle and an older eruption (~7.8 ka BP) in Tolombón (Valle de Santa María) shows that these changes seem to have little effect on phytodiversity (Osterrieth et al., 2019).

The inner ash layer is devoid of animal remains, coinciding with the absence of material culture. This feature could mean a hiatus in human occupation and accumulation of bone refuse for large vertebrates. In addition, the hiatus evidenced by the absence of small rodents could also be a proxy of the environmental impact of the Cerro Blanco eruption on the Abra del Toro vertebrate fauna.

5.2.3. *Post-eruption - abandonment*

Based on the magnitude of the eruption as a critical variable that conditions the ash-fall extension and volume (Riede, 2019; Torrence & Grattan, 2002) as well as the distance to the vent (~175 km), we hypothesize that the Yocavil valley was abandoned after the Cerro Blanco Volcanic Complex eruption, since the ecosystem was severely stressed, becoming no longer sustainable for its inhabitants. Consequently, the population had to migrate to less severely affected areas. The isopach model of the eruption indicates that the area where most of the ash fell (0.20 m isopach) is elliptical. It extends 1,000 km along its W-E major axis and about 300 km along its N-S minor axis (Fernandez-Turiel et al., 2019). In this situation, according to the regional orography with huge ranges-oriented N-S, the most viable option for the population was to migrate about 200 km to the north or south of the area studied. The findings in the Abra del Toro point out evidence that the sités abandonment should have been relatively brief, ranging from some years to perhaps up to some hundreds of years.

Geomorphological studies indicate that the ash deposits from the Cerro Blanco eruption ended the first Holocene aggregation unit in the region (Sampietro-Vattuone et al., 2020; Sampietro-Vattuone & Peña-Monné, 2016). After the eruption, a change occurred in the geomorphological behavior of the valleys, starting a period characterized by the predominance of incision processes (Sampietro-Vattuone et al., 2020).

5.2.4. *Post-eruption – The return of hunter-gatherers*

The before-mentioned incision period was followed by a new aggregation period with the formation of paleosols under wetter conditions in the valleys (Sampietro-Vattuone and Peña-Monné, 2016: 674).

New excavations in the Abra del Toro shelter are necessary to clarify this time span. However, although a comprehensive analysis of the rock shelter's functional characterization is still required, the findings suggest that the site was "fitted with equipment" by the populations who occupied it after the volcanic event. The stratigraphic evidence in these layers shows that the removal and treading of ash altered the deposit. By way of hypothesis, it could be suggested that the new occupants reconditioned the rock shelter, starting the second period of occupation by hunter-gatherers. The fact that the dated camelid scapula and the stone artifacts are found at the same depth could be explained by a low sedimentation rate in the rock shelter.

An interesting fact that we want to mark is that this scapula fragment, along with other bone and lithic fragments, presented impregnated ash, evidencing the short time between the ash fall and the reoccupation of the site (cf. Oetelaar & Beaudoin, 2016). At that time, there was also a sudden change in the sedimentation rate, going from a rapid rate associated with the eruption to a later one that was much slower. As a result, a palimpsest did not originate, and the vestiges mentioned above can be observed (Marciani et al., 2020).

Before new data become available, we can introduce some observations. The first materials recorded after the massive ash deposit are large-sized stone artifacts, and coal remains. It is noteworthy that the raw material used is the same as before the eruption, establishing continuity in the using of space and resources. One case in point is the Willaumez Peninsula, Papua New Guinea, where subsequent abandonment and reoccupation of sites due to volcanic activity events has been recorded. There, Torrence (2016) interprets the finding of stone materials in deposits lying on volcanic ash, or even mixed with it, as the accumulation of material during a long time, resulting from minor human activity. Other evidence that indicates a minor occupation after the eruption are the absence of structures such as hearths, the low amount of faunal remains and lithic artifacts, and the abandoned nuclei without being depleted (Marciani et al., 2020).

After the large eruption that occurred ~ 4,200 a cal BP, the reoccupation of the rock shelter is consistent with our earlier statement about the site as a significant landscape space. In this sense, it should be taken into account that hunter-gatherer societies, whose subsistence depended on wild or semi-wild resources, may have had to wait for the vegetation to recover after the volcanic disaster to be able to resettle (Oetelaar & Beaudoin, 2016; Torrence, 2012). After the impact on the ecosystem, social mechanisms for transmitting group memory may have been put in place (Torrence, 2016), making it possible to find the rock shelter again.

Archaeological investigations in north-western Argentina construct hunter-gatherer societies as small groups, with social hierarchies sustained for a short time. This flexibility may have allowed decisions to be made quickly and would have given these groups effective migratory capacity (Larson et al., 2013; Riede et al., 2020). For prehistoric populations, volcanic eruptions impact the environment and represent specific moments to reorganize, diversify and connect with other populations; ultimately, a turning point (Pardo et al., 2021; Riede, 2019; Riede et al., 2020; Torrence, 2012, 2016). The response to these events could be subject to the collective memory of these social groups (Pardo et al., 2021). The frequency of these events is critical in this memory, and in our case, large explosive eruptions are rare. Only three significant events were recorded in the region throughout the Holocene.

Why did these societies return to rock shelter again and again? The predictive model carried out by Sauer et al. (2018) to find rock shelters that can be testimonies of the interaction between populations and the landscape, based on the Laacher See Volcano eruption, shows that the Abra del Toro rock shelter possesses three characteristics that favor their occupation: the orientation of the entrance (good visibility over the landscape, it is in the sun most of the day and in turn is protected by the ravine), the distance to water resources (200 m) and good accessibility (although the slope is 33°, terrane is not steep or inaccessible and the entrance can be reached by walking).

Rock shelters often offer protection from environmental catastrophes. The detailed study in layer 2 at the Cueva Salamanca 1 site shows that this site was regularly occupied and reoccupied during the dry Middle Holocene (Pintar, 2014). The environmental setting and the nearby biotic and mineral resources allowed to hypothesize that this site was an oasis within the climatic rigidity of the Puna (Pintar, 2014). Unlike what happens in Puna and despite recent contributions (Baied & Somonte, 2013; Carbonelli & Collantes, 2017; Somonte & Baied, 2013), there is not enough paleoclimatic information in the Andean intermontane valleys to properly characterize the relationship of hunter-gatherer societies with their environment. However, the presence of permanent water throughout the year and the altitude allow us to think about appropriate environments for human life from the early Holocene.

After the Mount Mazama eruption, an example of a rapid return to a space impacted by an eruption was observed at the Tuscany site in Alberta (Oetelaar & Beaudoin, 2016). Hunter-gatherers monitored the region and then returned to the same place as their ancestors. Another example is the open-air Stampede site, where groups of hunter-gatherers from the North American plain again occupy practically the same space after the eruption (Oetelaar & Beaudoin, 2016).

As a point of comparison, the studies on the ecosystem recovery after the 1883 Krakatau eruption in Indonesia show that this process lasted about one hundred years (Thornton, 1997; Torrence, 2012, 2016). The geoarchaeological works in La Payunia, Mendoza (Argentina), show that, although pyroclastic fallout from the Laguna del Maule Volcanic Complex affected large swathes of land, it did not lead to depopulation for thousands of years and, over that time, ecosystems recovered (Durán et al., 2017). In this context, archaeological records can be a handy tool to track the environmental regeneration processes and their ability to sustain hunter-gatherer populations (Torrence, 2012, 2016).

Two Camelidae specimens were identified for the post-eruption aceramic layer. Measurements of a cuneiform fall within the reference values of *Lama glama*, but this specimen could also belong to *L. guanicoe* or a transitional individual. The transitional specimen hypothesis would be consistent with reports of morphometric change among archaeological camelids from the Jujuy Puna dated to 4,100 a BP (Yacobaccio, 2001). Remains of animals aged under 12–18 months could indicate herding practices, but additional excavations and further analyses of samples from the rock shelter of Abra del Toro are needed for a finer-grain approach.

5.2.5. *Post-eruption – agro-potter communities*

Dating the camelid scapula in unit HI-8/9 suggests that the ceramic materials found in the most recent layers were deposited after 4,295–4,006 a cal BP. In other words, ceramic was deposited after this dating, acting as the *terminus post quem* (as defined by Barker, 1995). The patterns observed on ceramics suggest that the rock shelter was occupied during the agro-pottery period, and these strata correspond to the third and last occupation of the rock shelter. Although, in general, the ceramic assemblage bears designs known to pertain to the first millennium of our era, it includes others too. The combed designs are consistent with those found at the Morro de Las Espinillas site (Scattolin, 2007), aged about 1,100 a BP in Punta Colorada (Abaucán) and the Calchaquí Valley. They also match the San Rafael engraved pattern described by Raffino for these regions (Raffino et al., 1982). Similar patterns have also been found in the province of Santiago del Estero and are kept at the La Plata Faculty of Natural Sciences and Museum (Scattolin, 2007). Engraved objects were made using a variety of instruments. Natural disasters stimulate innovation, producing a new ideology that could be materialized in iconographic designs (Torrence, 2016).

A guiding hypothesis for future work is that stratigraphic layers in the Abra del Toro rock shelter could contain a local and perhaps regional response to a problem that extended beyond the Yocavil valley. Considering that three Holocene large-scale volcanic eruptions have been detected in the region (Fernandez-Turiel et al., 2019), the Abra del Toro rock shelter is an excellent site to observe the interaction between the use of space by prehistoric populations and environmental change over time (cf. Torrence, 2012). It is necessary to continue working on a regional scale to find other rock shelters containing evidence of such interaction to obtain a general pattern of human occupation in the lower eastern areas of the South-Central Andes.

6. Conclusions

For decades in the history of archaeological research, no attention was given to hunter-gatherer occupations in the mesothermal intermontane valleys of the South-Central Andes, particularly in the Yocavil or Santa María Valley. Excavation work at the Abra del Toro rock shelter provided stratigraphic evidence for dating the oldest occupation recorded in the valley. The available data make it possible to trace human occupation back to the Mid-Holocene and compare it with other regional sites.

The Abra del Toro rock shelter is the first archaeological case in which it is possible to analyze the relationship between a large-scale natural catastrophe and the prehistoric populations living in the Andean intermontane valleys of the southern Central Andes. This rock shelter's stratigraphy and archaeological remains contain the record of interactions between human communities and volcanism. Findings evidence the disturbance introduced by the ~ 4,200 a BP Cerro Blanco eruption on the Mid-Holocene hunter-gatherer community of the Yocavil valley. According to previous research, this volcanic event is the largest documented eruption in the Central Andes Volcanic Zone in the last 5,000 years.

The magnitude of the eruption and the differences between pre- and post-eruptive archaeological artifacts are the basis for hypothesizing that the site was abandoned after the eruption. This archaeological discontinuity suggests a change in the mobility of prehistoric groups: people must have migrated from the valley to places that had been less severely affected by ash-fall impacts. The modification and alteration of circulation paths in the low lands and the connection with areas at a higher altitude (e.g., Puna) is a research challenge that needs to be addressed on a macro-regional scale. The impacts of the environmental catastrophe caused by the volcanic eruption that happened ~ 4,200 years ago will require a cross-disciplinary strategy.

Although an accurate chronology for the Abra del Toro rock shelter is still pending, the place was occupied again after the eruption. Then, the rock shelter stands in a significant space in the landscape. The collective memory of prehistoric populations could pinpoint this rock shelter as a point of interest to return to. It remains to be determined when and how reoccupation occurred, an essential aspect for understanding how hunter-gatherer societies evolved in this landscape.

CRediT authorship contribution statement

Juan Pablo Carbonelli: Conceptualization, Methodology, Validation, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition. **Jose-Luis Fernandez-Turiel:** Conceptualization, Methodology, Validation, Investigation, Software, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition. **Carlos Belotti López de Medina:** Methodology, Validation, Investigation, Software, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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