frontiers | Frontiers in Earth Science

ORIGINAL RESEARCH
published: 05 July 2022
doi: 10.3389/feart.2022.897307

The Volcanic Landscapes of the Ancient Hunter-Gatherers of the Atacama Desert Through Their Lithic Remains

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Specialty section:
This article was submitted to Volcanology,
a section of the journal
Frontiers in Earth Science

Received: 16 March 2022
Accepted: 08 June 2022
Published: 05 July 2022

Citation:
Loyola R, Figueroa V, Núñez L, Vasquez M, Espíndola C, Valenzuela M and Prieto M (2022) The Volcanic Landscapes of the Ancient Hunter-Gatherers of the Atacama Desert Through Their Lithic Remains.
Front. Earth Sci. 10:897307.
doi: 10.3389/feart.2022.897307

Since ancient times Andean societies have formed an intimate relationship with volcanoes, the beginnings of which can be traced right back to the initial peopling of the region. By studying rocks used for stone tools and other everyday artifacts, we explore the volcanic landscapes of early hunter-gatherer groups (11,500–9,500 cal BP) of the highlands of the Atacama Desert (22–24°S/67–68°W). Petrological classification of the lithic assemblages of three Early Holocene archaeological sites showed the procurement of a great diversity of volcanic and subvolcanic rocks, including pumice, granitic rocks, micro-diorites, a large variety of tuffs and andesites, dacites, cherts, basalts, obsidians, among others. Field surveys enabled us to detect many of their sources related to volcanic features such as craters, maars, caldera-domes, lava flows, probable hydrothermal deposits, and ignimbrites. In these places, we also document large quarry-workshops and campsites from different periods, indicating intense and repeated human occupation over time. By comparing the artifacts with geological samples collected in the field, it was possible to assign the source of origin of a large part of the archaeological assemblages. Our data suggest that the volcanic features of the Atacama highlands were integrated into the mobility and interaction networks of ancient hunter-gatherer groups at an early date.

Keywords: volcanism, Andes mountains, hunter-gatherers, lithic raw materials, geoarchaeology

1 INTRODUCTION

In the Andes region, volcanism is a multidimensional phenomenon that permeates different aspects of the everyday life and worldview of human societies. In the Andean cosmovision, volcanoes represent deities that are the subject of devotion and offerings during both ceremonial occasions and everyday prayers. As was remarked by Harris and Bouysse-Cassagne, they are mediators that allow communication between the surface and the underworld known as the "*mancca pasha*" (Bouysse-Cassagne and Bouysse, 1984; Bouysse-Cassagne and Harris, 1987; Harris, 1987; Bouysse-Cassagne and Bouysse, 1988). In Inka times, volcanoes and the high peaks of the Andes range were the scenario of complex rites and human sacrifices known as *capaccocha* (D'Altroy et al., 2007; Reinhard and Ceruti, 2010; Mignone, 2010; Mignone, 2015). Volcanic features were also used as geographic markers for the observation of astronomical events and the reproduction of the annual cycle as the case of the Llullaillaco Volcano (Sanhueza, 2004). For pre- and post-Columbian communities, they were also geographical landmarks used for spatial orientation, especially by travelers and caravans that crossed the mountain passes and the Atacama Desert (Núñez and Dillehay, 1979; Berenguer, 2004). Eruptions were not only catastrophic disasters; they were complex events that affected recurrently the cultural dynamics in the past (Bouysse-Cassagne and Bouysse, 1984; Bouysse-Cassagne and Bouysse, 1988; Pärssinen, 2015).

In the highlands of the Atacama Desert (south-central Andes), research carried out over the last 20 years into the early peopling has revealed abundant lithic industries in stratified deposits (Núñez et al., 2002; Núñez et al., 2005). The lithic assemblages recovered in various archaeological sites include a wide variety of stone tools used for different purposes: hunting large and small game; grinding plants; processing fur, wood and pigment, and the manufacture of ornaments (Loyola et al., 2019a). These objects were tremendously important not only for subsistence but also for the reproduction of social life; they were even included as offerings in ceremonies and mortuary rites in later periods or used as exchange goods (Loyola et al., 2021). The sources and diversity of these rocks, mainly of volcanic and subvolcanic origin, give us clues about the early links of these ancient populations with Andean volcanoes. Beyond the catastrophic effects of eruptions, this record allows us to approach the relationship between the first hunter-gatherer societies and volcanism in their daily lives.

Using an interdisciplinary and geo-archaeological approach, we studied the lithic assemblages recovered from three archaeological sites dated between 11,500 and 9,500 cal BP: Tuina-5, Tulán-67 and Tambillo-1 (Núñez et al., 2002; 2005). After lithological classification of the lithic raw materials, surveys were carried out on wide spatial scales which allowed us to document at least 10 sources of lithic procurement in an area

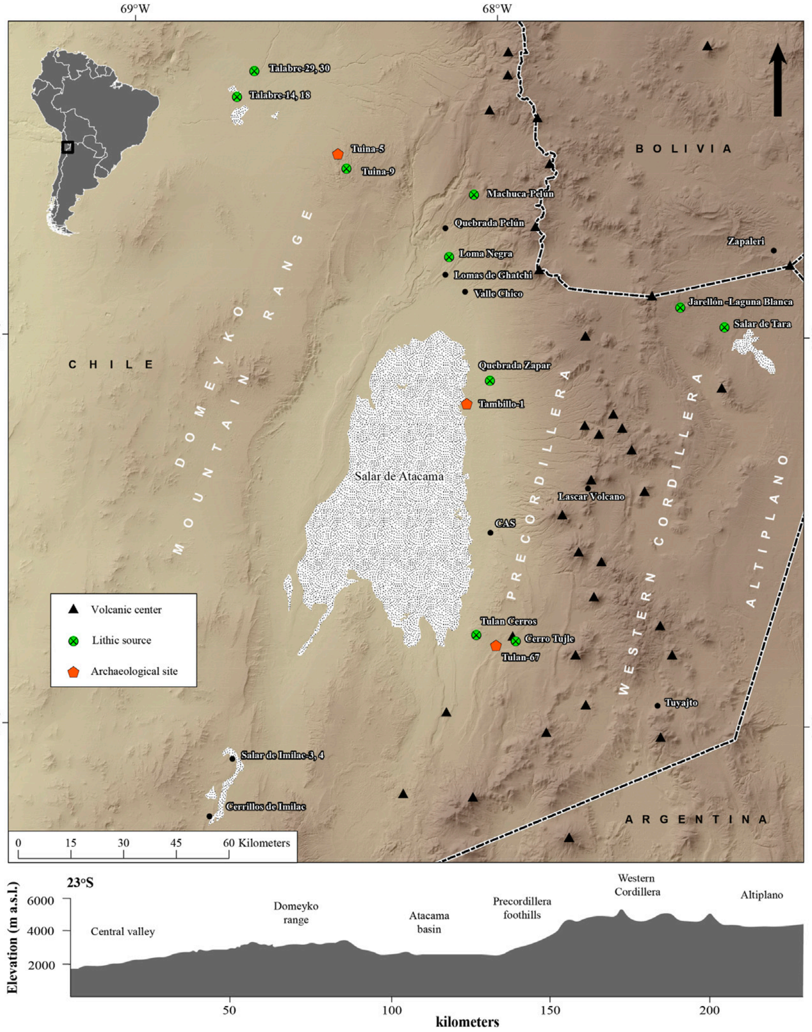


FIGURE 1 | Map of archaeological sites studied (red pentagons), lithic raw material sources (green circles), and principal volcanoes of the Atacama basin (black triangles).

TABLE 1 | Lithic assemblages studied, by archaeological site, stratigraphic layer, chronology and placement (after Núñez et al., 2005). Radiocarbon dates were calibrated using the ShCal020 curve (Hoggs et al., 2020) in OxCal software.

Site	Layer	^{14}C yr BP	Cal yr. BP	Site placement
Tuina-5	IV	10,060 + 70 9.840 + 110	11,830 – 11,260 11,705 – 10,779	Cave in dry ravine (3,200 m a.s.l)
Tambillo-1	I, II, and III	8,590 ± 130 8,870 ± 70	10,119 – 9,144 10,178 – 9,631	Open-air campsite in border of salt-flat (2,200 m a.s.l)
Tulán-67	VII	9,290 ± 100 BP	10,682 – 10,231	Rock-shelter in the border of Tulán ravine (2,580 m a.s.l)

of more than 10,000 km^2. Most of them correspond to volcanic and subvolcanic formations, resulting from the active volcanism of the Andes in different geological epochs. Comparison of the archaeological assemblages with geological samples recovered at the sources suggests the procurement and circulation of rocks across a vast high-mountain territory, and extending outside the region. The study of lithic industries will enable us to reveal a rich volcanic landscape that was frequented and internalized in the cognitive maps of the ancient human societies of the Atacama. Such episodes mark the beginning of a complex relationship between humans and volcanism, characterized by the resilience and innovation of Andean societies.

2 ARCHAEOLOGICAL BACKGROUND

Early hunter-gatherer societies inhabited the Atacama basin from 12,500 to 9,500 cal BP (Núñez et al., 2002; Núñez et al., 2005). Paleoenvironmental reconstructions indicate that during this period, the climate transitioned from the wetter conditions of the Late Pleistocene to a progressively more arid environment in the Holocene (Grosjean et al., 2001; Quade et al., 2008; Sáez et al., 2016). In this dynamic environment, pioneer Andean societies progressively populated the patches of available resources scattered over a contrasting environmental setting, ranging from 2,000 m a.s.l, where

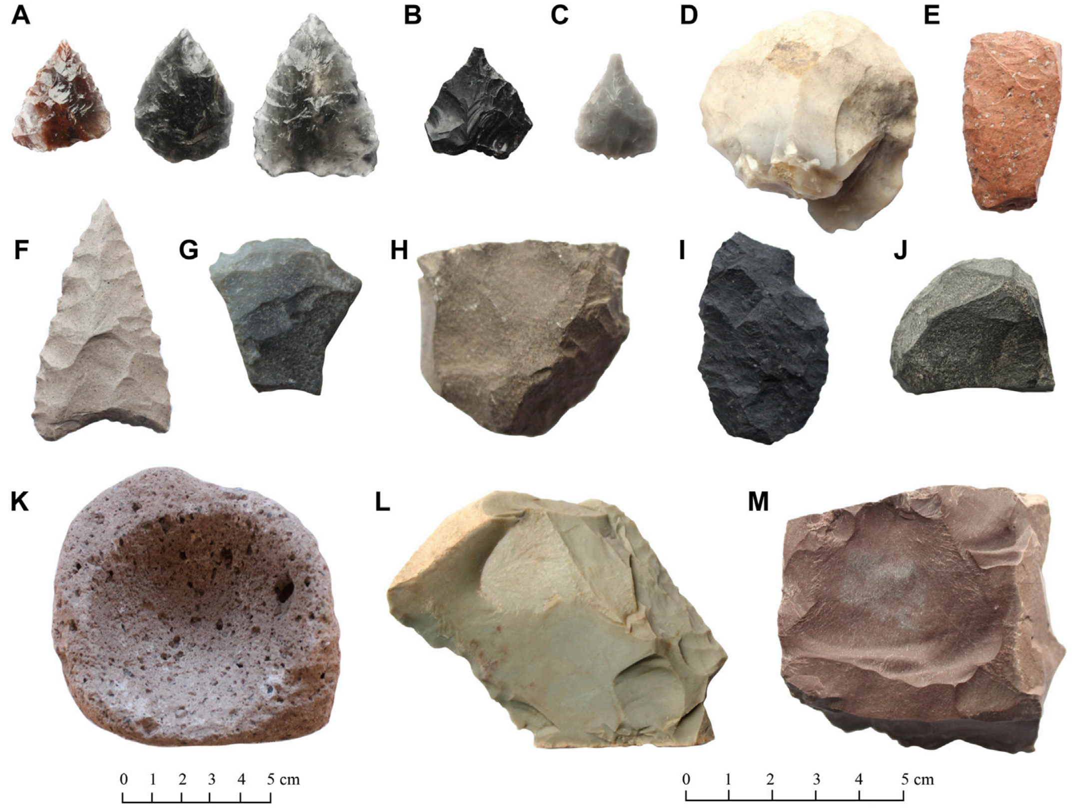


FIGURE 2 | Lithic assemblages and raw materials: **(A)** bifacial projectile points in gray translucent obsidian (Tuina-5 and Tambillo-1); **(B)** micro-perforator in shiny black obsidian (Tambillo-1); **(C)** bifacial perforator in opaque gray obsidian (Tulán-67); **(D)** end-scraper on white chert (Tuina-5); **(E)** side-scraper on red dacitic tuff (Tambillo-1); **(F)** bifacial projectile point on gray silicified tuff; **(G)** retouched flake on greenish ash dacitic tuff (Tambillo-1); **(H)** core on devitrified brown tuff (Tulán-67); **(I)** retouched piece on black andesite with crystals (Tambillo-1); **(J)** end-scraper on black aphiric andesite (Tulán-67); **(K)** container-mortar on gray-pink pumice (Tambillo-1); **(L)** retouched flake on epidotized siliceous rock (Tuina-5); **(M)** core on brown andesitic tuff (Tuina-5).

TABLE 2 | General rock classes and sub-varieties by archaeological site.

Rock classes and sub-varieties	**Tambillo-1**		**Tulán-67**		**Tuina-5**	
	n	**%**	***n***	**%**	***n***	**%**
Obsidian	1938	44.70	742	21.99	42	2,30
Translucent gray obsidian (OB-1)	429	9.89	14	0.41	39	2,14
Translucent brown obsidian (OB-2)	27	0.62	2	0.06		0
Opaque gray obsidian (OB-3)	33	0.76	659	19.53		0
Shiny black obsidian (OB-4)	1101	25.39	49	1.45	2	0,11
Shiny reddish-black obsidian (OB-5)	287	6.62		0		0
Shiny black-red obsidian (OB-6)	29	0.67	3	0.09		0
Translucent obsidian with fluid inclusions (OB-7)	5	0.12	4	0.12		0
Translucent obsidian (OB-8)	3	0.07		0		0
Translucent obsidian with black inclusions (OB-9)	2	0.05	3	0.09		0
Divers	18	0.42	8	0.24	1	0,05
Indeterminated	4	0.09		0		0
Siliceous rock	868	20.02	662	19.61	1296	70,97
White chert (SR-1)	553	12.75	108	3.20	407	22,29
Rock crystal (SR-2)		0	3	0.09		0
Green epidotized silicified rock (SR-3)	59	1.36	18	0.53	868	47,54
White chert with spots (dendritic habit) (SR-4)		0	2	0.06		0
White-yellow siliceous rock (SR-5)	1	0.02	310	9.19		0
Brown siliceous rock with reddish spots (SR-6)	2	0.05	33	0.98		0
Gray siliceous rock (SR-7)	44	1.01	24	0.71	3	0,16
Diverse	158	3.64	59	1.75	9	0,49
Thermo-altered	29	0.67	89	2.64	1	0,05
Indeterminated	22	0.51	16	0.47	8	0,44
Andesite	378	8.72	242	7.17	12	0,66
Black hornblende andesite (AN-1)	1	0.02	71	2.10		0
Black andesite white crystals (AN-2)	98	2.26	12	0.36		0
Black pyroxene andesite (AN-3)	78	1.80	2	0.06		0
Aphiric black andesite (AN-4)	8	0.18	121	3.59		0
Greenish hornblende andesite (AN-5)	122	2.81	2	0.06		0
Black andesite with tabular hornblendes (AN-6)	5	0.12	13	0.39		0
Divers	57	1.31	20	0.59	1	0,05
Indeterminated	9	0.21	1	0.03	11	0,60
Tuff	763	17.60	1483	43.94	324	17,74
Brown andesitic tuff (TF-1)	8	0.18		0	265	14,51
Devitrified cineritic tuff (TF-2)	187	4.31	1414	41.90	1	0,05
Red dacitic tuff with white crystals (TF-3)	300	6.92	11	0.33	53	2,90
Greenish brown dacitic tuff (TF-4)	81	1.87	2	0.06		0
Crystalline ash tuff (TF-5)	48	1.11		0		0
Pink tuff with flow (TF-6)	1	0.02		0		0
Gray-cream silicified tuff (TF-7)	26	0.60	11	0.33		0
Divers	100	2.31	9	0.27	4	0,22
Thermo-altered	3	0.07	14	0.41	1	0,05
Indeterminated	9	0.21	22	0.65		0
Dacite	35	0.81	5	0.15		0
Jaspoid	108	2.49	18	0.53	9	0,49
Quartzite	24	0.55	33	0.98		0
Basalt	38	0.88	89	2.64	33	1,81
Granitic rock	30	0.69	1	0.03		0
Micro-diorite	46	1.06		0	102	5,59
Mudstone	10	0.23	7	0.21	1	0,05
Pumice	16	0.37		0		0
Porphyry		0		0	3	0,16
Intrusive red rock	45	1.04		0		0
Green volcanic rock	2	0.05		0		0
Quartz	5	0.12	4	0.12	1	0,05
Thermo-altered	14	0.32	36	1.07	2	0,11
Indeterminate	16	0.37	53	1.57	1	0,05
Total	4336	100	3375	100	1826	100

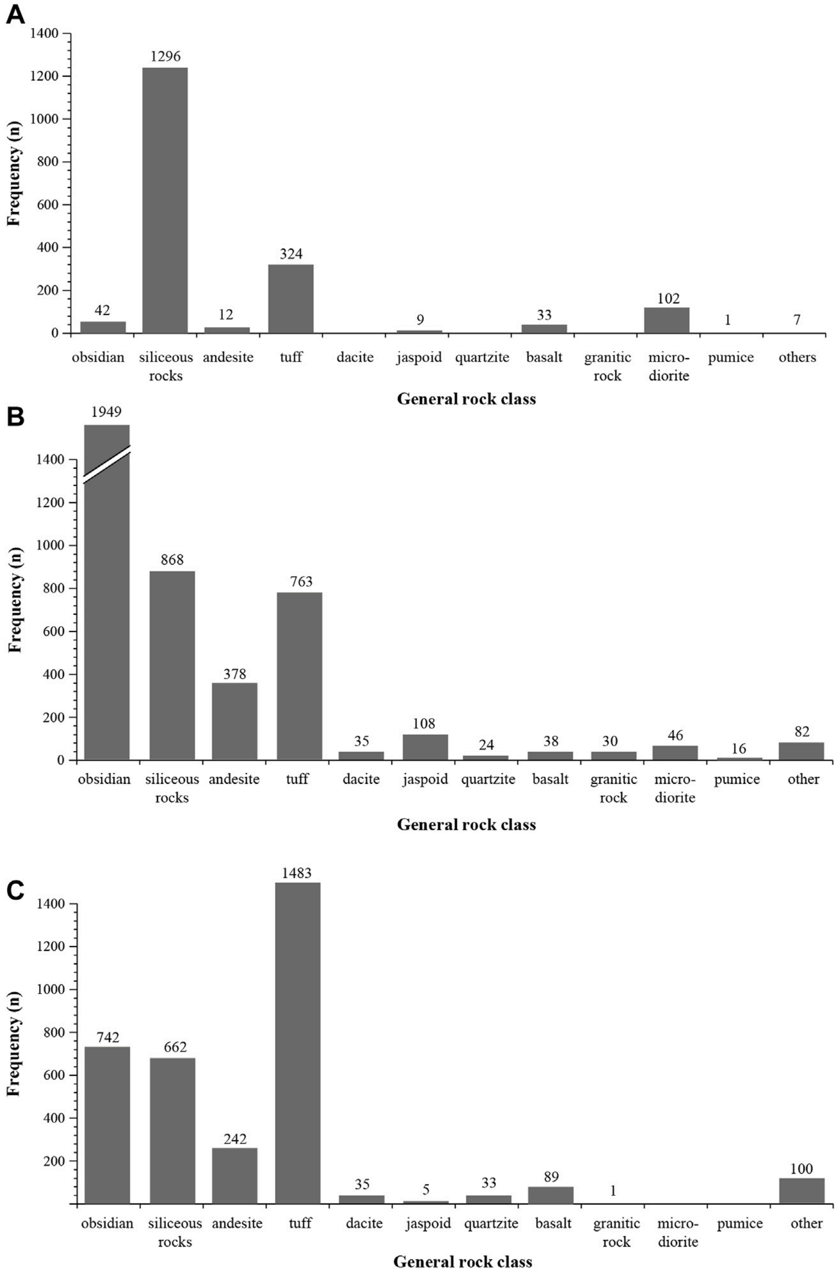


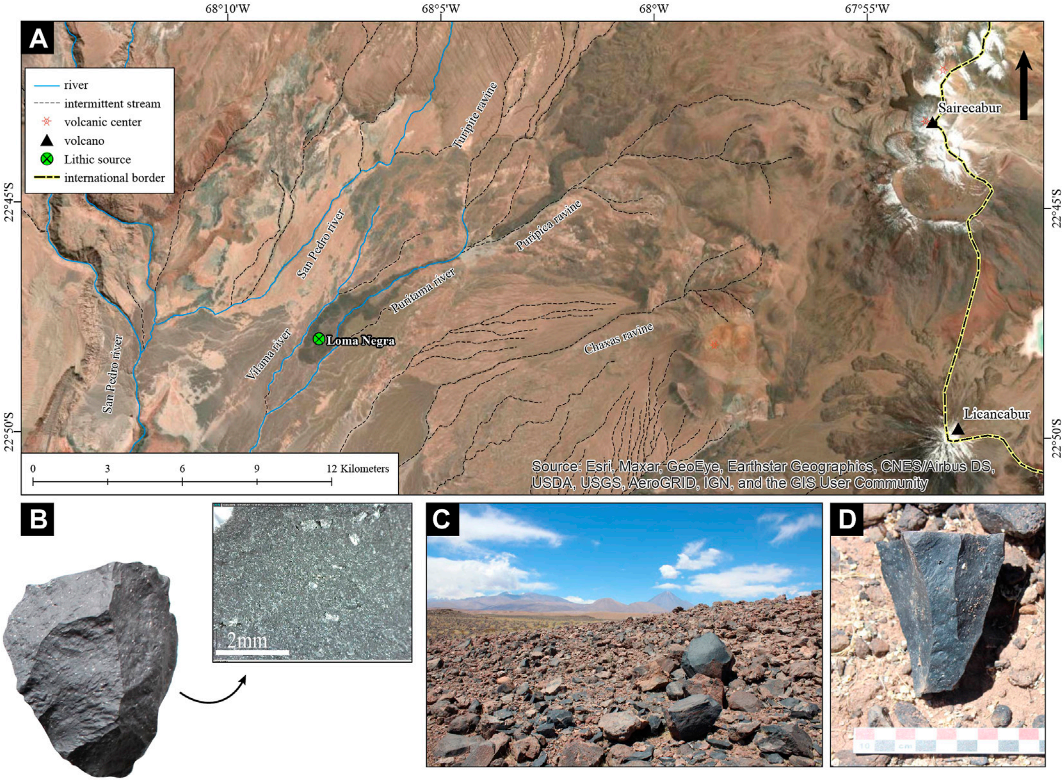
FIGURE 3 | Frequency of archaeological artifacts by rock class: **(A)** Tuina-5 (IV); **(B)** Tambillo-1; **(C)** Tulán-67(VII).

absolute desert predominates, to the more productive environmental patches of the Andes highlands above 4,000 m a.s.l. According to the evidence, the economy and subsistence of these groups were centered mainly on gathering plants in wetlands and hunting wild camelids such as the vicuña and the guanaco, as well as birds and rodents. Some evidence also reveals the consumption of the last remnants of extinct horse (Equidae) in Tuina-5 (Cartajena, 2003; Cartajena et al., 2006).

The Early Archaic Period is subdivided into two subphases. During the Tuina Phase (12,500 to 11,500 cal BP), the first human settlements occupied mainly caves and rock-shelters of the intermediate floors (2,700–3,200 m a.s.l) such as Tuina-1, Tuina-5, San Lorenzo-1, and Tulán-109 (Núñez et al., 2005). The evidence recovered at these sites suggests temporary occupations for logistical use as part of an initial peopling process (Loyola et al., 2019b). Diagnostic artifacts of this subphase are triangular non-stemmed Tuina projectile points and large retouched flake tools, anvils, and chopping tools. In the subsequent subphase Tambillo (11,500–9,500 cal BP), the human peopling process was consolidated. Archaeological sites of this period are more significant and denser due to more stable

TABLE 3 | Sources of lithic procurement identified in the Atacama basin.

Source	Rock class	Geoform	Geologic formation	Archaeologic evidence
Loma Negra–Puripica	Black hornblende andesite	Lava flow	Stratum-volcanoes III (Qv) (Pleistocene-Holocene)	Extensive area of workshops and knapping *loci*. An industry of blades and flakes, and circular structures were documented.
Machuca–Pelún	Gray and brown translucent obsidian	Caldera-dome (?)	Ignimbrite Puripicar (Pip)–Pliocene	Surface scatter of small nodules associated with ignimbritic formation. Scarce knapping evidence.
Jarellón–Laguna Blanca	Shiny reddish-black obsidian	Caldera-dome	Volcanic Complex II (c) (Plv)–Pliocene	Discrete knapping events of small nodules and blocks associated in some cases with stone structures and rock-shelters.
Salar de Tara	Shiny reddish-black obsidian	Ignimbritic flow	Filo Delgado ignimbrites (Plfd) (?)–Pliocene	Surface scatters of medium and small nodules in a large area with some evidence of *in situ* knapping.
Cerro Tujle	Black andesite	*Maar* crater	Volcanic Complex III (Qv)–Quaternary	Extensive quarry-workshop around the crater. Industry of flakes and blades in large blocks and fragments of black andesite.
Quebrada Zapar	Gray-pink Pumice	Ignimbritic flow	Cajón Ignimbrite (Pc)–Lower Pleistocene	Outcrop of subrounded and elongated pumice blocks on the edge of the Zapar ravine. No evidence of primary processing.
Tulán Cerros	Devitrified cineritic tuff	Outcrop on Hill top	Cerros Negros Formation (Pcn)–Pérmic?	Large, scattered quarry-workshops of variable extension of blade industry on block, circular structures and engraved plaquettes.
Salar de Talabre	Gray-cream silicified tuff	hydrothermal deposit (?)	Lasana Formation - Talabre Member (Ml2)/Middle Miocene–Lower Upper Miocene	Quarry workshops north of the salar (Talabre 29 and 30) and southeast of the current edge of the Salar de Talabre (Talabre 14 and 18). An industry of large flakes and bifaces predominates.
Cerros de Tuina	Green epidotized silicified rock and brown andesitic tuff	Hillside outcrop	Tuina Formation (Pt) (?)–Late Permian-Middle Triassic	Extensive quarry-workshop on a hillside with abundant material on the surface and a circular stone structure. Predominance of flake industry over medium size blocks and plaquettes.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

FIGURE 4 | Loma Negra-Puripica source: **(A)** geological context; **(B)** raw material sample; **(C)** quarry-workshop site; **(D)** discarded blade core of black andesite.

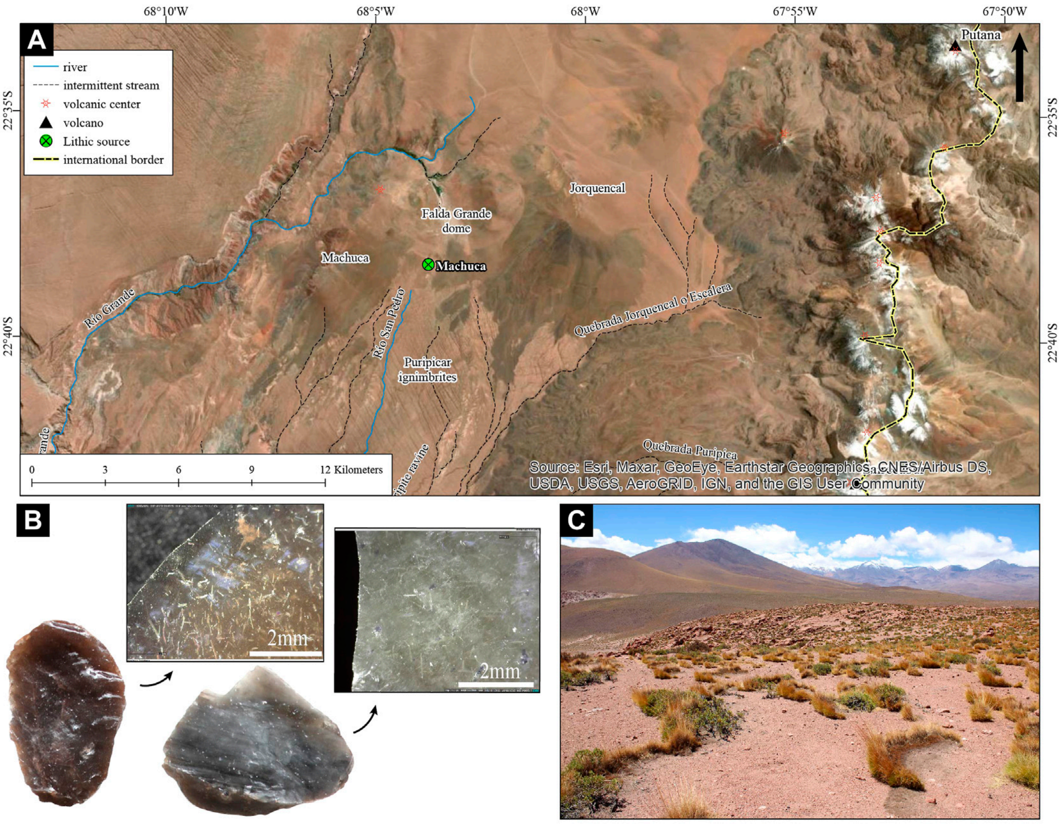


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FIGURE 5 | Machuca-Pelún source: **(A)** geological context; **(B)** raw material samples; **(C)** scatter area of raw materials.

residential occupations (Núñez et al., 2016). During this phase, the settlement system incorporated a greater diversity of inhabited environments, complemented by seasonal mobility between the desert lowlands and the Andes highlands (Loyola et al., 2019a). Evidence of this has been recorded in various sites such as Tambillo-1, Tulán-67, Tulán-68, Tulán-109, Aguas Calientes-I-1, Tara-2 and Tuyajto-1 (Núñez et al., 2005). The excavation of these sites has allowed the recovery of a profuse lithic industry, represented by triangular projectile points, obsidian drills, small nail-scrapers, and abundant grinding tools.

3 STUDY AREA: GEOLOGICAL AND LITHOLOGICAL SETTING

The Atacama Basin (21–22°S/67–68°W) is located within what is now known, in Chile's political-administrative system, as the II Region of Antofagasta (northern Chile). It corresponds to an extensive basin of more than 3,000 km^2, limited by the Domeyko range to the west and the Andes Mountains to the east. Geomorphologically, it is inserted in the great depression of pre-Andean salt flats. The study area presents three climates at different altitudinal levels, according to the Köppen-Geiger classification: cold arid with dry winter [BWk(w)], cold semi-arid with dry winter [Bsk(w)], and tundra with dry winter [ET(w)]. At the base level of the basin are extensive saline deposits composed mainly of halite, with a surface area of 1,100 km^2 and a depth of 900 m, surrounded by a marginal zone of saline silt of about 2,000 km^2 that forms the great Salar de Atacama (Atacama salt flat) (Alonso and Risacher, 1996). This large saline crust results from the intense evaporation of surface waters, including ponds and shallow lagoons around its borders. At its phreatic level, the Salar de Atacama is fed by a dendritic drainage network that descends from the Andes Mountains through deep ravines. Some small salt flats and high saline lakes are formed in sub-basins above 4,000 m a.s.l, such as Aguas Calientes, Tuyajto, Tara and Miscanti (Risacher et al., 2003). The lithological components of the Atacama basin and the distribution of volcanic rocks can be understood through the general morphostructure of the basin, as shown in **Figure 1**.

3.1 The Domeyko Mountain Range

The Domeyko mountain range in northern Chile runs from north to south with an average altitude of 3,000 m a.s.l. The study area is characterized by mountainous features, pediplanes and alluvial fans (Ramírez and Gardeweg, 1982). The local lithology comprises Upper Carboniferous to Permian ignimbrites and rhyolitic domes, Triassic lacustrine fossiliferous strata, and

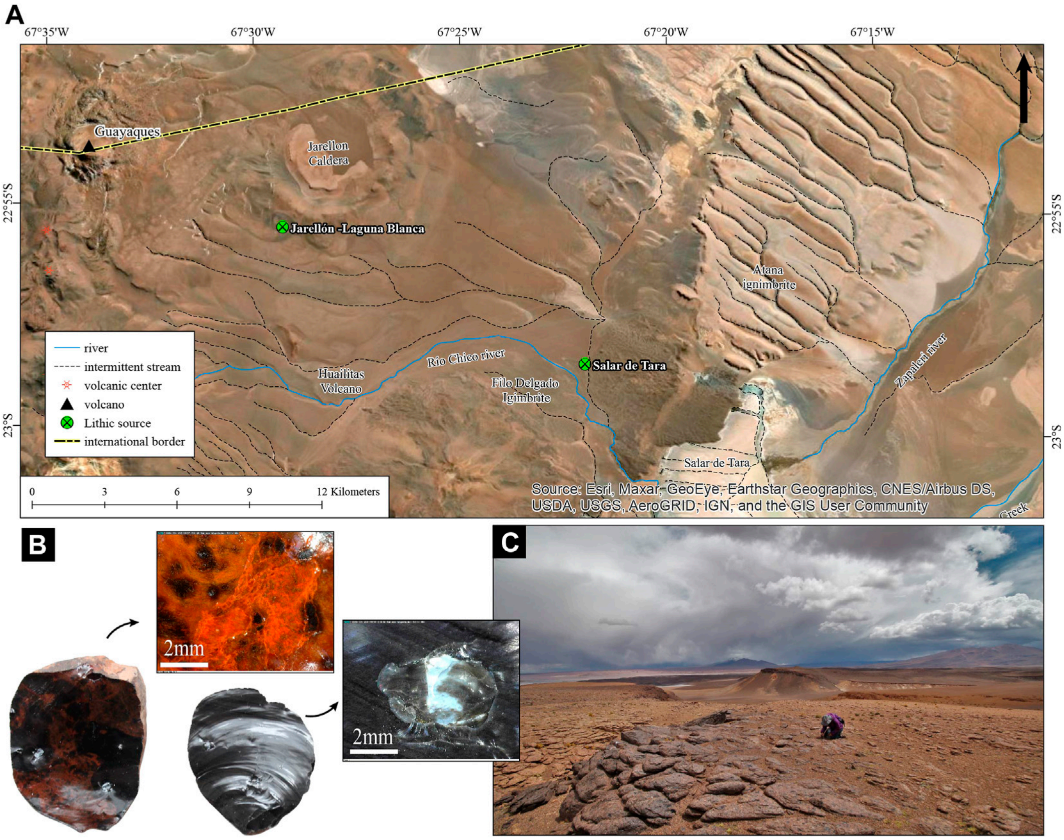

FIGURE 6 | Jarellón-Laguna Blanca source: **(A)** geological context; **(B)** raw material sample; **(C)** scatter area of obsidian samples.

Cretaceous to Miocene continental sediments (Marinovic and Lahsen, 1984; Mpodozis et al., 2005). To the northwest of the study area, the Cerros de Tuina range is associated with a set of inverse faults (Henríquez et al., 2014).

3.2 The Precordillera Foothills

The Precordillera rises from the low, flat terrain of the Salar de Atacama to the Andes highlands. It presents irregular topography with a slope of 3-5°o, dissected by a dendritic drainage network of ravines up to 200 m deep (Ramírez and Gardeweg, 1982), and by ranges of small hills such as Cas, Peine and Lila hills. Lithologically, it is characterized by outcrops of Paleozoic, Mesozoic and Cenozoic rocks that include sandstones and shales, andesites, dacites, and tuffs (Niemeyer, 2013).

3.3 The Andes Mountain Range

The Andes consists of an imposing mountain range that extends longitudinally from north to south, formed by volcanic features, domes, and hills set on the rhyolitic plateau. In the study area, this unit includes: 1) The Western Cordillera that reaches 6,800 m a.s.l, consisting mainly of Cenozoic volcanic rocks and characterized by a strip of stratovolcanoes overlying older ignimbritic layers (Allmendinger et al., 1997); and 2) the Altiplano or Puna, an extensive ingimbritic *plateau* that extends through northeastern Chile, Argentina, Peru, and Bolivia at a mean altitude of 4,000 m a.s.l (Isacks, 1988). Locally, the volcanic deposits are formed mainly by ignimbrites, volcanic complexes, and aerial pyroclastic deposits from the Upper Miocene to the Quaternary. The ignimbrites are made up of tuffs of different degrees of welding, mainly dacitic and rhyolitic in composition (Gardeweg and Ramírez, 1985). The stratovolcanoes and stratified volcanic sequences show an andesitic and subordinately basaltic and dacitic composition and, to a lesser extent, pyroclastic cones, domes, and subcircular structures (craters) of rhyolitic composition. Upper pre-Miocene intrusive and folded sedimentary rocks appear in erosion windows and isolated hills (Gardeweg et al., 1998).

4 MATERIALS AND METHODS

The lithic assemblages studied in this work were recovered from stratigraphic layers of three archaeological sites: Tuina-5, Tambillo-1, and Tulán-67 (Núñez et al., 2002; Núñez et al., 2005) (**Table 1**). In the first stage, a petrographic classification of the complete archaeological lithic assemblages was carried out. The object of this was to define general groups based on general rock classes and sub-varieties according to variables such as color,

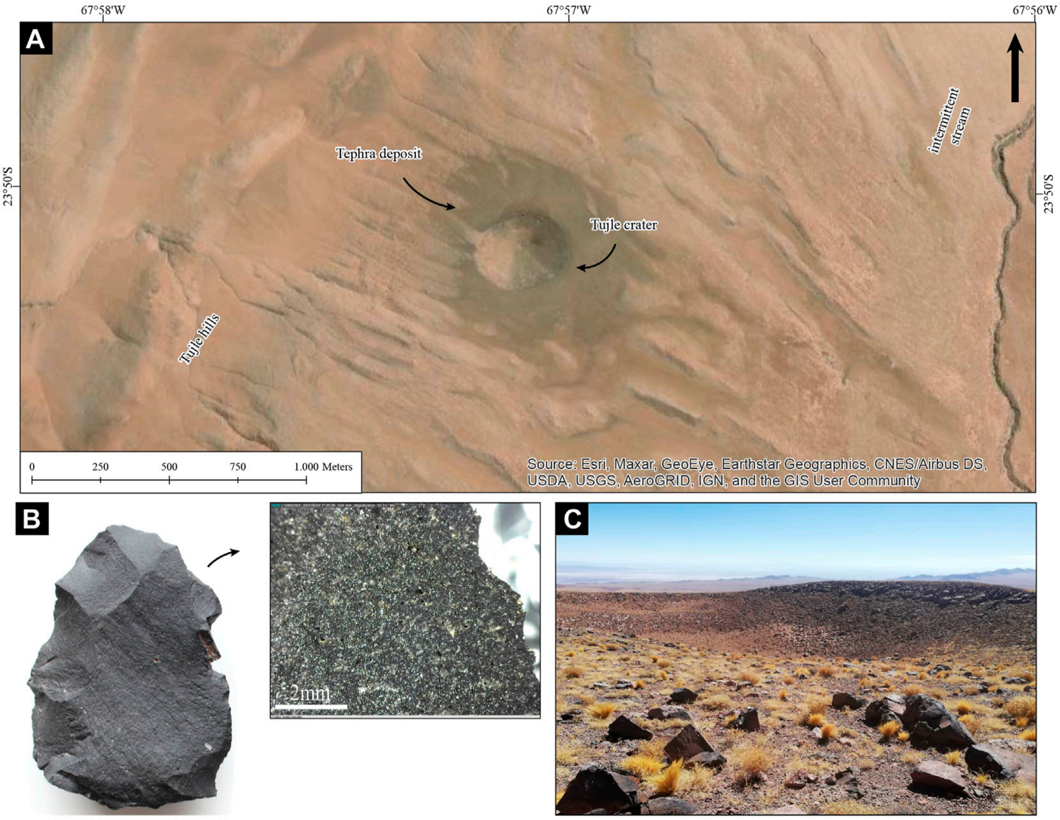

FIGURE 7 | Cerro Tujle source: **(A)** geological context; **(B)** raw material sample; **(C)** quarry-workshop site near to the crater border.

texture, granulometry, presence of impurities, and cortex, considering the existing local classifications[1,2,3].

The second stage consisted of locating and characterizing the raw material sources through directed surveys in the field. The archaeological and geological data of the Atacama basin and its surroundings were consulted to define areas of interest according to the lithologies observed and recognized in the archaeological lithic assemblages. The following data sourced were consulted: Calama sheet (1:250,000) (Marinovic and Lahsen, 1984), Zapaleri sheet (1:250,000) (Gardeweg and Ramírez, 1985), Toconao sheet (1:250,000) (Ramírez and Gardeweg, 1982), Chiu chart (1:50,000) (Blanco and Tomlinson, 2009), Lascar Volcano chart (1:50,000) (Gardeweg et al., 2011), San Pedro de Atacama chart (1:100,000) (Henríquez et al., 2014), Lila-Peine chart (1:100,000) (Niemeyer, 2013). Between 2019 and 2021, various field surveys were carried out and samples were taken from the sources identified. The archaeological artifacts and the geological samples recovered from the lithic procurement sources were compared in the third stage using a magnifying glass (30x) and a Dino-Lite digital microscope (30–250x). Lithological markers - understood as characteristic elements shared by rocks from the same outcrop-were defined that allowed the source of origin to be directly assigned.

5 RESULTS

5.1 Archaeological Assemblages and Lithic Raw Materials

The lithological classification of lithic assemblages identified a wide diversity of rocks, most of them of volcanic and subvolcanic origin, forming a rich and varied lithic assemblage (**Figure 2**). The main types identified were obsidian, cherts, and other siliceous rocks, andesites and tuffs, in addition to other minorities such as basalts, dacites, pumices, micro-diorites, and granitic and porphyritic rocks, among many others. A count of the rock classes and sub-varieties (with their respective codes used hereinafter) is presented in **Table 2**. Among the predominant rocks, obsidian was clearly much sought-after, being used mainly in the manufacture of projectile points and micro-perforators (**Figures 2A–C**). The

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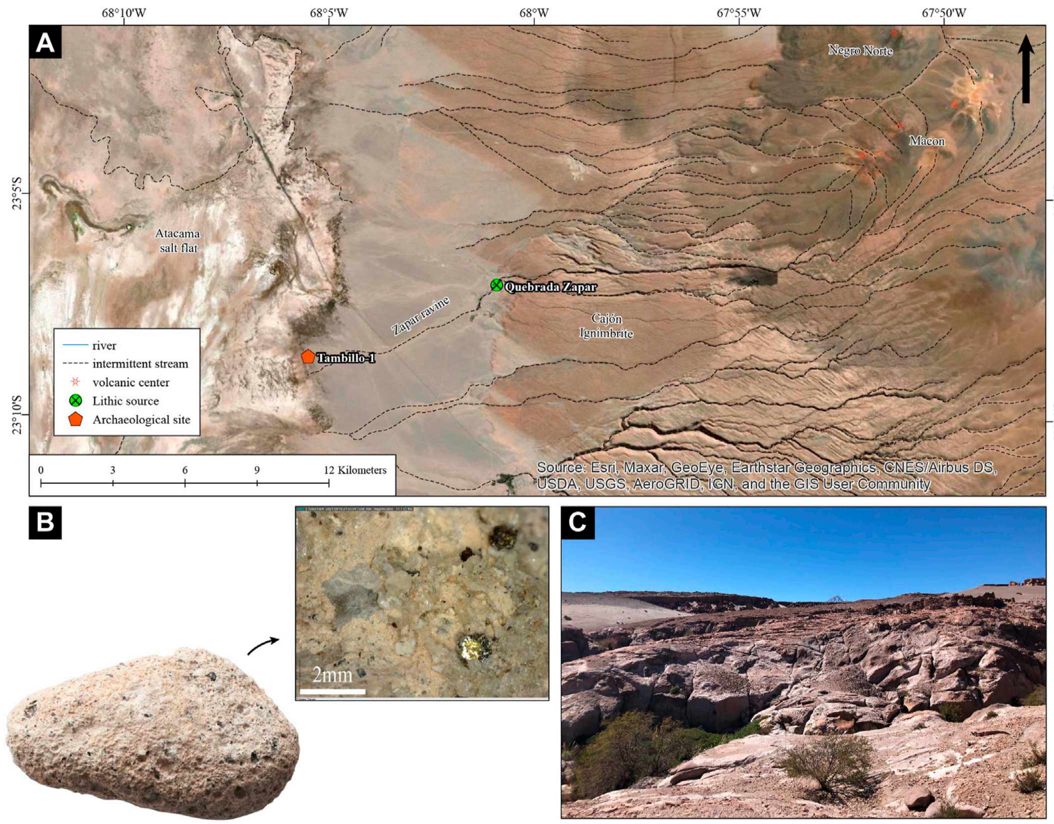


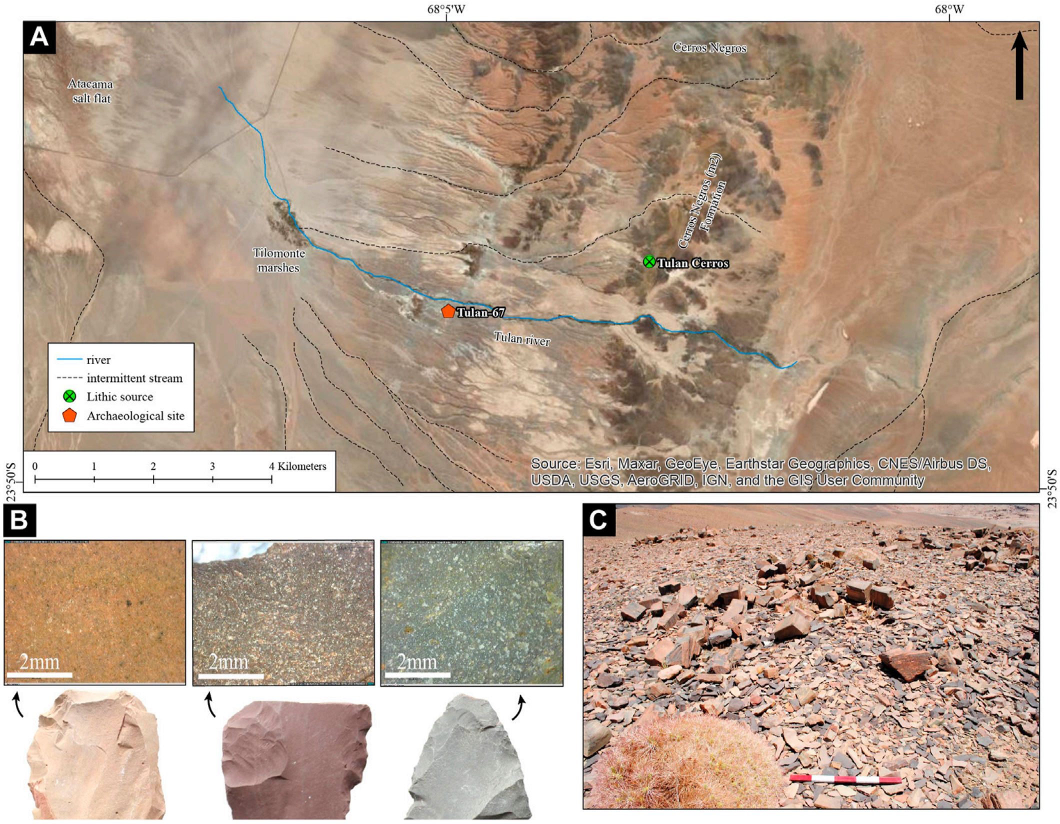
FIGURE 8 | Quebrada Zapar Source: **(A)** geological context; **(B)** pumice sample; **(C)** Zapar Ravine outcrops.

obsidian class breaks down into several sub-varieties, among which are shiny black (OB-4, **Figure 2B**), shiny reddish-black (OB-5), translucent gray (OB-1, **Figure 2A**), and opaque gray (OB-3, **Figure 2C**). The cherts and silicious rocks comprise several types of rocks but are mostly represented by a white chert with abundant vesicles and rough cortex (SR-1, **Figure 2C**), a white-yellow siliceous rock (SR-5), and a green epidotized silicified rock (SR-3, **Figure 2L**). They were used to produce retouched flake-tools and artifacts of various kinds such as end-scrapers, side-scrapers and also bifacial projectile points. The tuffs consist mainly of a red dacitic tuff with white crystals (TF-3, **Figure 2E**), a gray-cream silicified tuff with black inclusions (TF-7, **Figure 2F**), a brown andesitic tuff (TF-1, Figure 2m), a greenish brown dacitic tuff (TF-4, **Figure 2G**), and a devitrified cineritic tuff (TF-2, **Figure 2H**). The andesites are mostly composed of black hornblende andesites with white crystals (AN-1, **Figure 2I**), and aphiric black andesite (AN-4, **Figure 2J**). Another commonly present rock is the gray-pink pumice used in the manufacture of probable containers or mortars (**Figure 2K**).

There are important differences in the frequency of rock classes between sites. In Tuina-5, the predominant rocks are mainly white chert (SR-1), green epidotized siliceous rocks (SR-3) and red dacitic tuffs (TF-3) (**Figure 3A**). Obsidian is very scarce, occurring only in 31 pieces–all of the translucent gray variety (OB-1) with the exception of one shiny black (OB-4) obsidian flake. On the other hand, a greater diversity of rocks can be observed in Tambillo-1 (**Figure 3B**): obsidians are abundant, with shiny black (OB-4), translucent gray (OB-1), and opaque gray (OB-3) types predominating. Several varieties of chert, greenish ash tuff (TF-4), brown andesitic tuff (TF-1), and black hornblende andesite (AN-1), among others, were also recorded. Pumice artifacts, granitic rocks, and porphyries are present to a lesser extent. In Tulán-67, devitrified cineritic tuff (TF-2) and chert of the white-yellow (SR-5) variety predominate; there is also a significant frequency of aphiric black andesite (AN-4) and obsidian, particularly the opaque gray variety (OB-3) (**Figure 3C**).

5.2. Searching for the Volcanic Lithic Sources of the Atacama Basin

The directed surveys carried out based on geological and archaeological information have allowed us to document 10 lithic raw material procurement sources so far. Among the sources identified, various volcanic geoforms were distinguished: lava flows (Loma Negra-Puripica), volcanic domes and craters (Jarellón-Laguna Blanca and possibly Machuca-Pelún), maars (Cerro Tujle), ignimbrite flows (Quebrada Zapar and Ignimbrites of Filo Delgado), possible hydrothermal deposits (Salar de Talabre-14 and -18) as well as outcrops of continental sequences exposed in hilltops (Cerros de Tuina and Tulán Cerros). **Table 3** summarizes the lithic sources and their main characteristics. In all of them, we recorded evidence of primary processing in the form of cores, test



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

FIGURE 9 | Tulán Cerros source complex: **(A)** geological context; **(B)** raw material samples; **(C)** Tulán Cerros-2 quarry-workshop site.

blocks, abundant flakes, blades, and in some cases, stone-hammers and retouched tools. Some of them, such as Loma Negra, Cerros de Tuina, Tulán Cerros, and Cerro Tujle, are large quarry-workshop sites formed by extensive anthropic floors of continuous lithic material.

5.2.1 Loma Negra-Puripica

The Loma Negra-Puripica source consists of an extensive lava flow of more than 20 km descending from Sairecabur volcano in a southwesterly direction (**Figure 4A**). The southern segment corresponds to the Loma Negra quarry initially studied by Gustavo Le Paige (Le Paige, 1958; Orellana, 1962; Le Paige, 1963; Le Paige, 1964; Le Paige, 1970; Agüero, 2005), while the northeastern segment houses the workshops reported near the Puripica archaeological sites (Núñez, 1981; Núñez et al., 1999; 2005). The raw material consists of a dark gray to black hornblende andesite with white crystals (**Figure 4B**). It comes in the form of large non-transportable blocks up to several meters long, medium-sized blocks, and smaller angular fragments that form a continuous raw material floor (**Figure 4C**). At the site, an industry of prismatic and pyramidal unidirectional blade cores (**Figure 4D**) and large flakes predominates, with a few large bifacial pieces. The evidence is concentrated around denser knapping *loci* and some circular stone structures of the same rock. Geologically, the lava flow is part of the stratum-volcano complex III (Qv) that groups Pleistocene-Holocene volcanoes and lava flows (Marinovic and Lahsen, 1984). The source could be related to the Machuca (4,460 m a.s.l) and Jorquencal (4,971 m a.s.l) stratovolcanoes; and/or to the Falda Grande lava-dome, which could be an ancient emission center (Henríquez et al., 2014).

5.2.2 Machuca-Pelún

The first descriptions of local obsidian come from surveys carried out by Gustavo Le Paige in Quebrada Pelún (Le Paige, 1964). A secondary source of small nodules was later reported in the lower part of the ravine (De Souza et al., 2002). Other works reported larger nodules at the head of the ravine near the town of Machuca in the highlands, scattered in large areas and also deposited in offerings structures or *apachetas* on the road (Pimentel, 2008), which were later characterized geochemically by Seelenfreund et al. (2010a). The surveyed area of greatest density was found in a deflated area of 4,000 m^2 on the southwestern edge of an ignimbrite outcrop (**Figure 5A**). Small rounded and sub-rounded nodules of maximum diameter 5–12 cm were observed scattered on the surface. The obsidian is very heterogeneous but with a predominance of translucent gray and translucent brown sub-varieties (**Figure 5B**). We did not observe dense areas of primary processing in the form of quarry workshops, except for very scattered, isolated evidence of

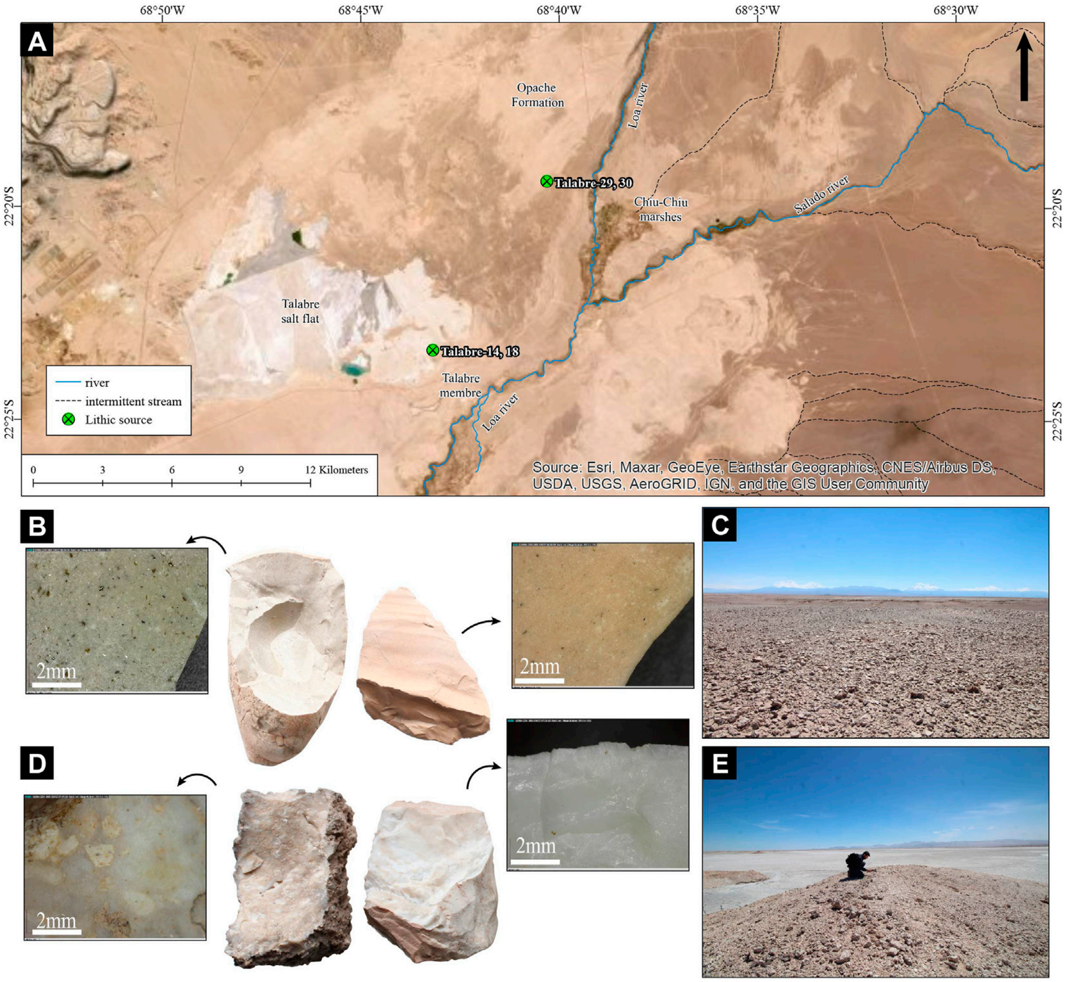


FIGURE 10 | Salar de Talabre source complex: **(A)** geological context; **(B)** raw material samples from Talabre-29 (left) and Talabre-30 (right) sites; **(C)** Talabre-30 quarry-workshop site; **(D)** raw material samples from Talabre-14 (right) and Talabre-18 (left) sources; **(E)** quarry-workshop site of Talabre-14.

knapping. The source appears to be spatially associated with an ignimbrite outcrop (**Figure 5C**) of the Puripica Formation (Guest, 1969; Henríquez et al., 2014).

5.2.3 Jarellón-Laguna Blanca and Salar de Tara

The Jarellón-Laguna Blanca obsidian source was first described by Seelenfreund et al. (2010b) as a primary source located on the slope of a collapsed caldera (**Figure 6A**). Geologically, the formation comprises dacitic and rhyolitic lavas (Gardeweg and Ramírez, 1985:63). Some interpretations suggest that the caldera formed due to a plinian eruption, which led to its collapse and the subsequent formation of the caldera (Seelenfreund et al., 2010b). Obsidian is available in eroded nodules of between 8 and 22 cm (**Figure 6B**) and blocks up to 70 cm near the flow edge of the northeast dome. Several knapping *loci*, stone parapets, and non-local obsidian offerings were recorded in the area (Seelenfreund et al., 2010b). A secondary source was also reported on the northwest edge of the Salar de Tara, located on a beach of lacustrine sedimentation (Seelenfreund et al., 2010a) (**Figure 6A**). We recorded several lithic scatters with abundant flakes, cores on natural nodules and bifacial projectile points on local obsidian. We sampled two areas to the northeast of the Hualitas volcano and recorded round nodules of shinny black and reddish-black obsidian (**Figure 6C**). We found slight evidence of exploitation in some lithic scatters associated with ephemeral stone structures. The obsidian nodules could be secondary transport from the Jarellón source, or could be related to the Hualitas stratum-volcano (5,010 masl) (Gardeweg and Ramírez, 1985).

5.2.4 Cerro Tujle

The Cerro Tujle source is a large quarry-workshop around a small volcanic crater 300 m in diameter and 70 m deep (**Figure 7A**). It was previously described as a meteorite crater (Ferrando, 1977), but later characterized as a maar-type volcanic crater produced by a phreatic-magmatic eruption (Ureta et al., 2018; Ureta et al., 2020a; Ureta et al., 2020b). The raw material occurs in large blocks and smaller angular fragments of black andesite available

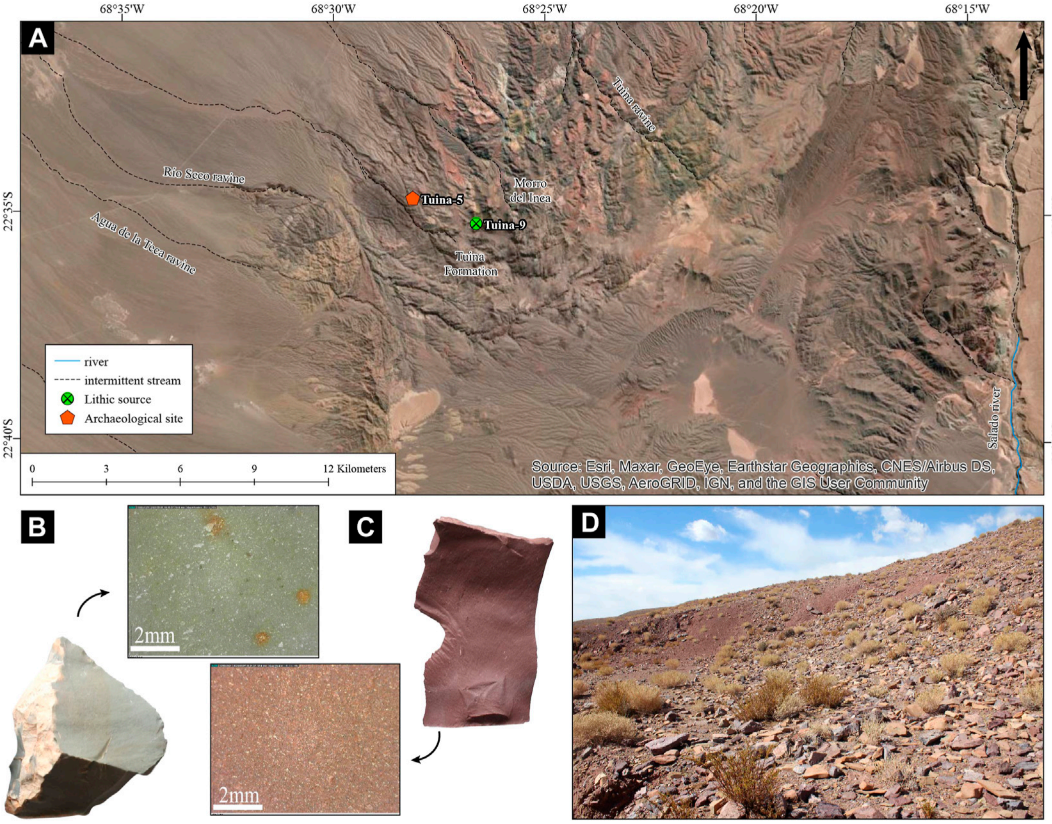


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FIGURE 11 | Cerros de Tuina: **(A)** geological context; **(B)** raw material samples; **(C)** raw material samples; **(D)** Tuina-9 quarry-workshop site.

around the tephra ring (**Figure 7B**). At the site, we observed many test blocks, cores, flakes, and especially large blades, and some bifacial pieces (**Figure 7C**). The formation was included within the set of stratum-volcanoes III of the Quaternary (Ramírez and Gardeweg, 1982).

5.2.4 Quebrada Zapar

On the eastern edge of Quebrada Zapar (**Figure 8A**), we found large, superficially scattered pumice fragments of up to 30–40 cm (**Figure 10B**). The fragments are of round and tabular morphology and consist of grey-pink pumice of dacitic composition (**Figure 8C**). The source would be linked to the Ignimbrite Cajón Formation (Pc) (Guest, 1968), which includes several levels of tuffs characterized by banded pumice (Henríquez et al., 2014). According to Marinovic and Lahsen (1984), the ignimbrite flows were emitted in a short period; they were attributed to the Purico volcano (5,703 masl) emission center, 30 km east of the site.

5.2.5 Tulán Cerros

Tulán Cerros consists of a large area north of Quebrada Tulán (2,850 masl), where veins form outcrops on top of the numerous hills of the landscape. More than 30 quarry-workshop sites have been reported in the upper part (Le Paige, 1964; Le Paige, 1970; Núñez, 1983) and several lithic scatters of the same raw material have been recorded in nearby areas (Barfield, 1969; Niemeyer and Schiapacasse, 1976) (**Figures 9A,B**). In recent surveys, we documented many quarry-workshop sites of variable extension where an industry of large bifaces, flakes, and blades predominates (**Figure 9C**). We observed lithic mortars on the surface, stone structures, and engraved plaquettes in some places. The raw material appears in erosion heights in the form of diaclassic blocks between 20 and 60 cm of green, reddish, brown, and light brown devitrified tuff (Loyola et al., 2016). The outcrop is probably related to the middle member of the Cerros Negros Formation (Pcn) (Niemeyer, 2013).

5.2.6 Salar de Talabre

The Salar de Talabre lithic workshops have been extensively studied (Le Paige, 1964; Lanning, 1967; Núñez 1967; Lanning, 1968; Lanning, 1970; Le Paige, 1970; Núñez 1983) (**Figure 10A**). The raw materials have been described as silicified tuff (Lewis-Johnson 1978) or vitreous rhyolitic tuff (Barfield, 1960), silicified limestone, and low-grade chert (Meltzer 1979). The Talabre-29 and 30 sites to the north of the basin (**Figure 10B**) consist of large open-air quarry-workshop sites on a plain where blocks and fragments of 20–40 cm of silicified gray, often cream, tuff form outcrops (**Figure 10C**). Geologically, the site is located in the Upper

TABLE 4 | Raw materials and assignment to local sources.

Raw material	Description	Assigned source	Code
Shiny black/reddish-black obsidian	Shiny black, fluid matrix with spherulitic devitrification, few plagioclase phenocrysts and cristobalite amygdales, often banded. Some samples show bands of iron oxide.	Tara /Jarellón-Laguna Blanca	OB-4 and OB-5
Translucent gray obsidian	The matrix is translucent, slightly yellowish gray to brown. It presents large violet plagioclase phenocrysts (0.5–1.5 mm), probably glass iron oxides, and elongated second generation plagioclase crystals often oriented. Some examples have dark and red dots. It shows scarce small greenish rectangular crystals, probably hornblendes altered to chlorites.	Machuca-Pelún	OB-1
Translucent brown obsidian	Brown translucent vitreous matrix with fluidal inclusions, brown spots, and scarce elongated plagioclase.	Machuca-Pelún	OB-2
Black hornblende andesite white crystals	Black to dark gray matrix with porphyritic, aphanitic texture, and characteristic white plagioclase phenocrysts in addition to subhedral hornblende and glass fragments. It shows moderate magnetic susceptibility and hornblendes had low alteration to chlorites.	Loma Negra-Puripica	AN-2
Aphiric black andesite	Black to dark gray matrix, aphiric texture with small plagioclase crystals and olivines.	Cerro Tujle	AN-4
Devitrified, cineritic tuff	Recrystallized cineritic tuff of light brown, brown, red and green color, with very fine grain size composed of quartz fragments, plagioclase, and crystals of calcite. In some cases, it presents dark minerals, probably biotites.	Tulán Cerros	TF-2
Green epidotized siliceous rock	Greenish gray texture with white spots, probably silicified plagioclase. Sometimes presents yellow patches of epidote.	Tuina-9	SR-3
Brown andesitic tuff	Brown matrix and fragmentary texture with pyroclasts of plagioclase, hornblende, and biotite. Present flow.	Tuina-9	TF-1
Gray-cream silicified tuff	Dacitic tuff with a greenish gray to pinkish color; presents fragmental texture with ash-sized pyroclasts of subhedral shape composed by plagioclase crystals, hornblende, biotite, embedded quartz and ferromagnesians with low alteration to iron oxides. The rock is generally silicified.	Talabre-29/30	TF-7
White chert	Greyish white matrix often with reddish spots of jarosite and abundant vesicles, chalcedony fillings, cleavages and a thick, rough cortex.	Talabre-14/18	SR-1
Pink pumice with flow	Greyish pink color and dacitic composition, with a vitroclastic texture, fragments of plagioclase, amphibole and pumice in a pumice matrix with glass fragments.	Quebrada Zapar (ignimbrite Cajón)	TF-6

Miocene-Upper Pliocene Opache Formation (MPo) (May et al., 2005; Blanco and Tomlinson, 2009). Some early work suggested that tuff formations originated from incandescent ash-falls on wet surfaces, probably lakes or swamps (Meltzer, 1979). The Talabre-14 and Talabre-18 quarry-workshops are located on the southeast margin of the current Talabre salt flat. In Talabre-14 (**Figure 10D**), we documented abundant evidence of knapping on waste-flakes and nodules of a white siliceous rock and beige chalcedony with significant impurities, vesicles, and very rough cortex (**Figure 10E**). In Talabre-18, large, semi-buried blocks of white chert of fair and mediocre quality were observed. The chert composition suggests a sedimentary origin, with possible recrystallization by low temperature hydrothermalism, but more studies are needed. Geologically, both sites are located in the Talabre Member (Ml2) of the Lasana Formation (Middle Miocene-Lower Upper Miocene) (Blanco and Tomlinson, 2009).

5.2.7 Cerros de Tuina (Tuina-9)

Tuina-9 consists of a workshop-quarry on the southern slope of Morro del Inca (3,608 masl) in the Tuina Mountain range (**Figure 11A**), where we find the most significant number of flakes and cores, and two stone structures. Diaclassic fragments and medium-sized plaquettes (20–40 cm) of an green epidotized siliceous rock are very abundant at the site (**Figure 11B**). We also documented a brown andesitic tuff in larger blocks (**Figure 11C**). The source seems to be related to the Lower Member of the Tuina Formation (PeTrt1) from the Upper Permian-Middle Triassic, mainly volcanic, consisting of andesites with frequent epidotization (**Figure 11D**) (Henríquez et al., 2014).

5.3 Identification of Lithic Raw Materials: Linking Sites and Sources

By comparing the archaeological artifacts with the raw material samples taken in the field we were able to assign the procurement sources. **Table 4** summarizes raw material assignments based on the recognition of the lithological markers defined in the geological samples. **Figure 12** shows the appearance of each variety at 50x. The shiny black obsidian (OB-4, **Figure 12A**) and reddish-black variety (OB-5, **Figure 12B**) was assigned to the Salar de Tara and Jarellón-Laguna Blanca sources, although it is impossible to separate them as they have the same geochemical signature and an identical visual appearance under the microscope. Together with the Zapaleri source (Yacobaccio et al., 2004), Jarellón-Laguna Blanca and Salar de Tara would form a homogeneous group of obsidian sources related to the same magmatic system (Seelenfreund et al., 2010a). In the case of Machuca-Pelún obsidian, two main sub-varieties were distinguished: OB-1 (**Figure 12C**) and OB-2 (**Figure 12D**) while the aphiric black andesite (AN-4, **Figure 12E**) corresponds to the Cerro Tujle maar. The devitrified cineritic tuff (TF-2, **Figure 12F**) in its three varieties (brown, light brown, and green) corresponds to the Tulán Cerros source complex. The green epidotized silicified rocks (SR-3) come primarily from the Tuina-9 source (**Figure 12G**), as does the brown andesitic tuff

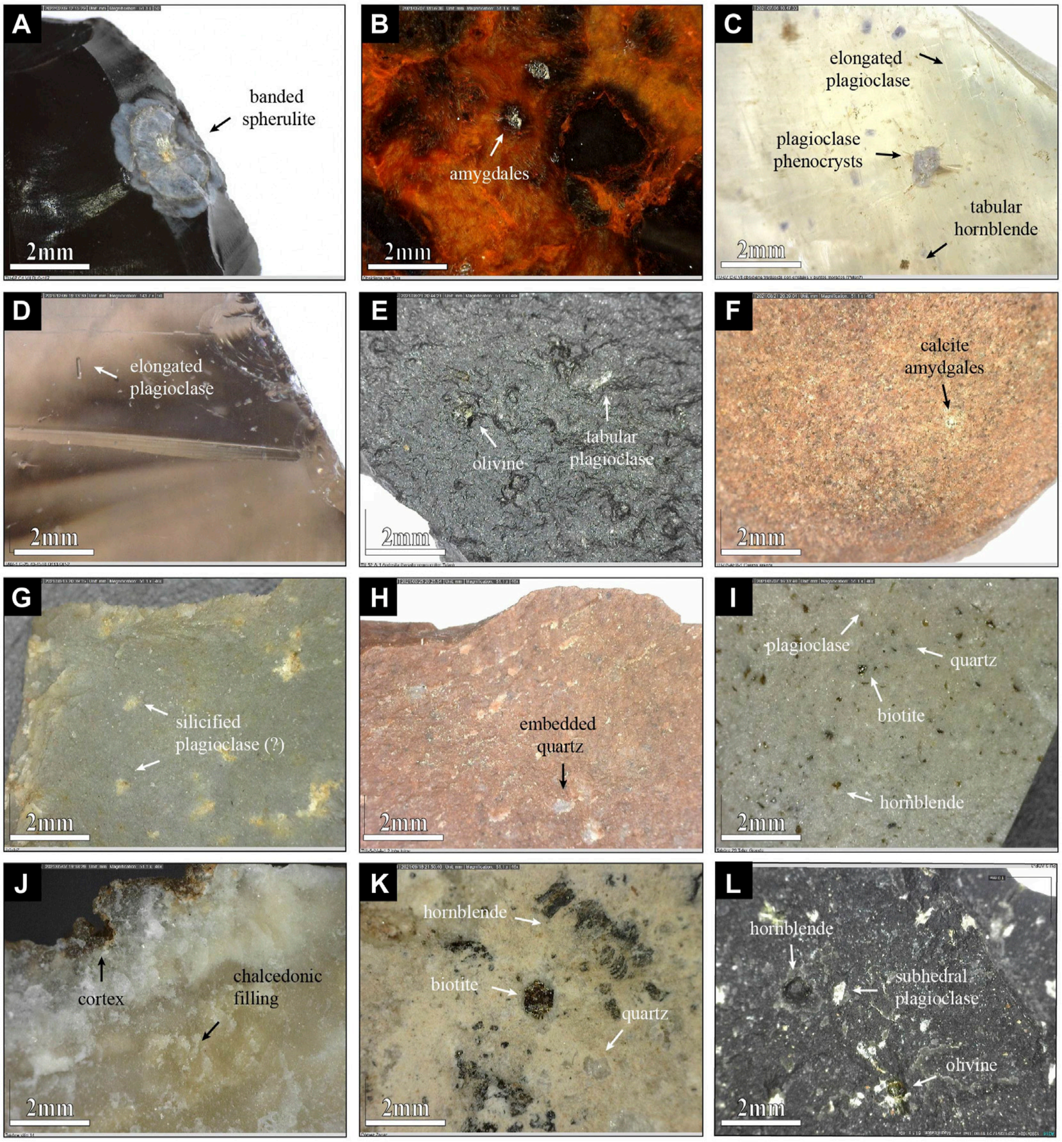

FIGURE 12 | Raw materials from known sources: **(A)**; shiny black obsidian (OB-4); **(B)** Shiny reddish-black obsidian (OB-5); **(C)** translucent gray obsidian (OB-1); **(D)** translucent brown obsidian (OB-2); **(E)** Aphiric black andesite (AN-4); **(F)** devitrified cineritic tuff (TF-2); **(G)** green epidotized silicified rock (SR-3); **(H)** brown andesitic tuff (TF-1); **(I)** gray-cream silicified tuff (TF-7); **(J)** white chert (SR-1); **(K)** gray-pink pumice; **(L)** black hornblende andesite (AN-1).

(TF-1, **Figure 12H**). The gray-cream silicified tuff (TF-7, **Figure 12I**) corresponds to the source of Talabre-29, 30. Among the wide variety of cherts, a good part of the white chert (SR1-1, **Figure 12J**) could be assigned to the Talabre-14 and 18 sources. The pumice, recorded in the Tambillo-1 site, was easily assigned to the Zapar source (**Figure 12K**) and the black hornblende andesites (AN-1, **Figure 12**L) are related to the Loma Negra-Puripica source.

Some lithic raw materials from unknown sources can be attributed to a local origin. The source of the opaque gray obsidian (OB-3, **Figure 13A**), recognized by its high content of hornblende and biotite, could be found near the Tulán ravine due to its higher frequency in Tulán sites. We also suspect that the black-red shiny obsidian (OB-6) with large grey amygdales (**Figure 13B**) comes from the Lascar volcano area (see **Figure 1**). Other obsidian pieces come from allochthonous sources in northwestern Argentina, as confirmed by XRF and NAA analyses (Loyola, 2020). The translucent obsidian (OB-8) shows reddish oxidized biotite crystals with a hexagonal shape (0.1–0.3 mm) that match with Salar del Hombre Muerto source (**Figure 13C**); while Ona-Las Cuevas obsidian presents characteristic fluid inclusions with biotite and oxidation (**Figure 12D**) and tabular hornblende crystals (**Figure 12E**) that match with our OB-7. Some few pieces of translucent obsidian with black inclusions (OB-9) of developed tabular hornblende (**Figure 12F**) come from the Alto Tocomar source

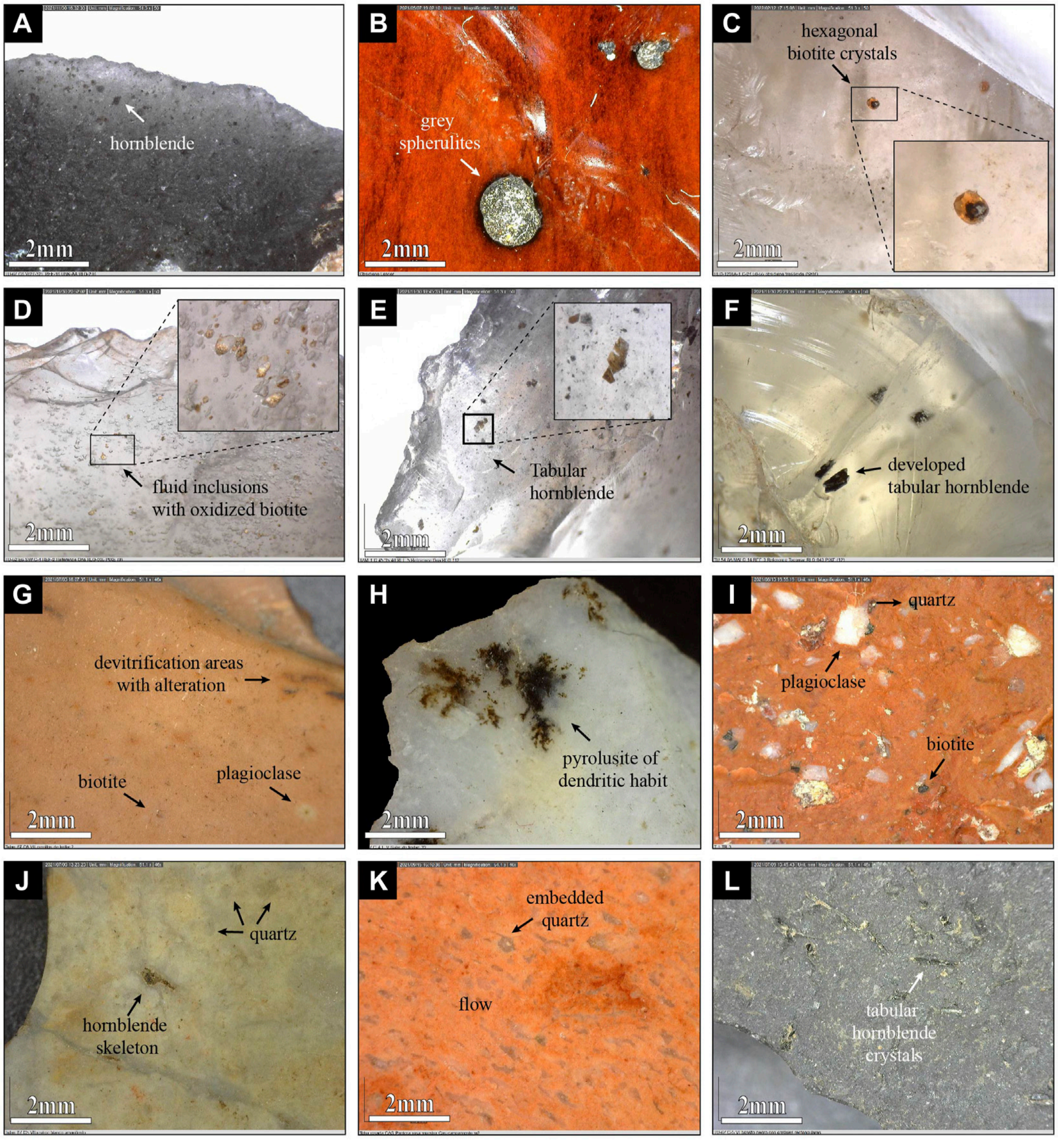

FIGURE 13 | Lithic raw materials from unknown and extra-local sources: **(A)**; opaque gray obsidian (OB-3); **(B)** Shiny black-red obsidian (OB-6); **(C)** translucent obsidian (OB-8); **(D)** translucent obsidian with fluid inclusions (OB-7); **(E)** translucent obsidian with inclusions (OB-7) **(F)** translucent obsidian with black inclusions (OB-9); **(G)** Brown siliceous rock with reddish spots (SR-6); **(H)** white chert with black spots (SR-4); **(I)** red dacitic tuff with white crystals (TF-3); **(J)** white-yellow silicified rock (SR-5); **(K)** Pink tuff whith flow (TF-6); **(L)** Black andesite with tabular hornblendes (AN-6).

in Salta, Argentina (see Yacobaccio et al., 2004). Two varieties of siliceous rocks–brown with reddish spots (SR-6, **Figure 12G**) and white with spots with dendritic habit (SR-4, **Figure 13H**) – were reported that would come from north of the Imilac basin (Cartajena et al., 2014; Loyola et al., 2019b). The source of the red dacitic tuff with white crystals (TF-3, **Figure 13I**) is also unidentified, but judging by its frequency it could be available at different points of the eastern border of the Atacama basin; it is most frequently found in archaeological sites near Tambillo and Aguas Blancas ravine (see **Figure 1**). The white-yellow siliceous rock (SR-5, **Figure 13J**) could come from a source located 5 km south of Tulán (Yacobaccio and Núñez, 1991). The pink tuff (TF-6, **Figure 13K**) is less abundant but probably comes from Cerros de CAS as well as a part of the gray basalt (Le Paige, 1970, see **Figure 1**). A common variety is a dark andesite with tabular hornblende crystals (AN-6, **Figure 13**L), the source of which is still unknown but presumably local. Finally, comparisons with museum collections make us think that the greenish brown dacitic tuff (TF-4) would come from the Lomas de Ghatchi (Le Paige, 1960; Le Paige 1963; Le Paige 1964) while the black pyroxene andesite (AN-3) is frequent in the quarry-workshops of Valle Chico ravine (Le Paige and Serracino 1974) (see **Figure 1**).

6 DISCUSSION

6.1 The Exploitation of Volcanic Rocks Among Early Andean Hunter-Gatherers

Analysis of the archaeological assemblages of Tuina-5, Tambillo-1, and Tulán-67 revealed that during the Early Archaic period, stone tools and other lithic objects were made from a wide variety of lithic raw materials of volcanic and subvolcanic origin. Such variability accounts for the use of rocks with different properties and qualities, from the sharpest and best quality, such as obsidian and siliceous rocks, to the most tenacious and resistant, such as andesite, tuffs and basalts, and even others as granite and pumice. Each of these rock classes seems to have been intended for particular categories of tools and objects, production of which required the application of specific know-how and knapping techniques, depending on its particular properties (see Nami, 2015).

However, several factors hindered lithological classification. One of them is the thermal alteration that introduces a series of physical-chemical changes in the artifacts that inhibit their identification, such as luster, rubefaction, calcination, cracking, plotids, and thermal fractures. Heat treatment is a technique widely used in prehistory to improve the quality of knappable rocks through controlled exposure to fire. However, thermal alterations can also result from accidental exposure to fire-pits or natural fires (Inizan and Tixier, 2000). In the sites, thermal alteration of lithic assemblages reaches 1,91% in Tambillo-1 (*n*=93), 0,82% (*n*=16) in Tuina-5 and 7,47% (*n*=247) in Tulán-67. Moreover, it is impossible at present to be sure whether this alteration is due to an intentional process to improve the quality of the raw material or is the involuntary result of exposure to heat sources, such as the several hearths documented at the sites. Further study is needed to explore how thermal alterations expressed in each

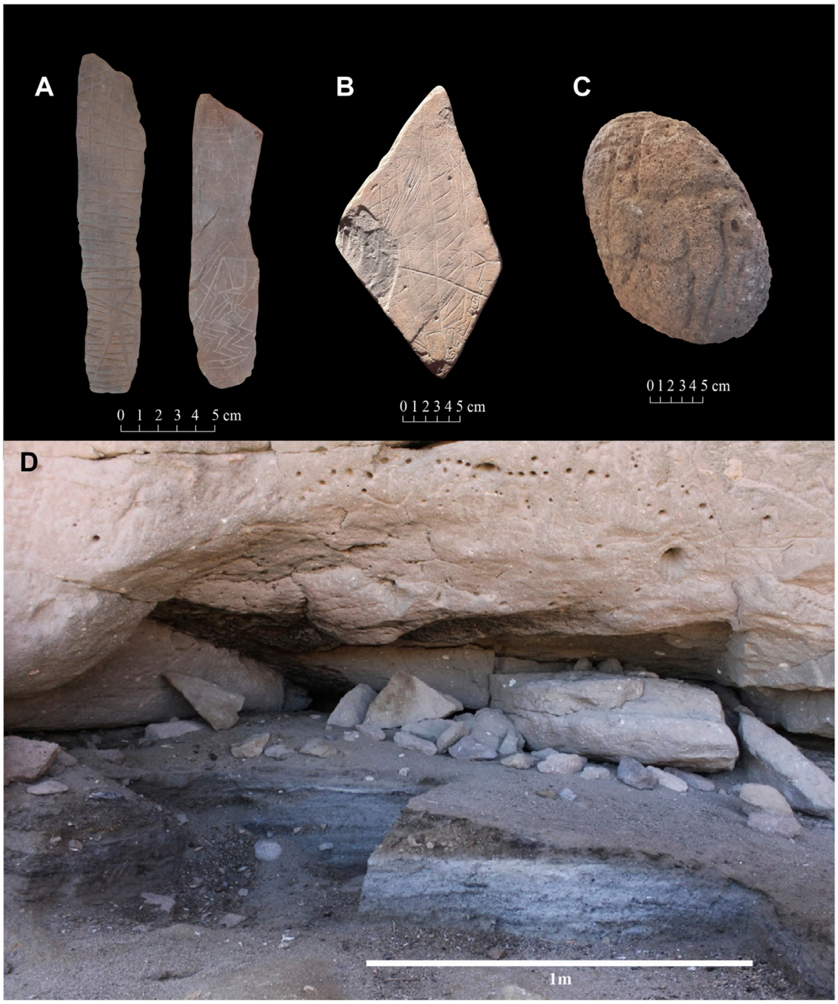

FIGURE 14 | Engraved lithics on volcanic rocks: **(A)** engraved blades with geometric motifs on devitrified cineritic tuff (Tulán Cerros-2 site); **(B)** engraved plaquettes from Tulán Cerros in devitrified cineritic brown tuff (collection of Gustavo Le Paige); **(C)** volcanic tuff with engraved camelid motif recovered from the initial occupation floor of the Puripica-1 site (Núñez 1983); **(D)** Late Early Archaic occupation in ash stratigraphic layer (light gray): site Tulán-109 (Núñez et al., 2005).

of the raw materials. On the other hand, assignment was also limited by the high fragmentation or small size of the samples: in some cases, the maximum length of the artifacts analyzed, such as pressure-retouching flakes, was no more than a few millimeters, preventing the conservation of lithic markers and other diagnostic features such as the cortex.

This high diversity of lithic raw materials probably reflects deep knowledge not only of the volcanic landscape and its rocks, but also the techniques necessary to work them. The exploitation of lithic resources among hunter-gatherers in the Atacama basin and adjacent basins has been addressed in various works (Le Paige, 1970; Serracino, 1975; Núñez et al., 2002; Loyola et al., 2021, among others). Judging by the descriptions and the availability of raw materials in the landscape, volcanic rocks have been a constant in Andean hunter-gatherer societies due to their wide availability and easy access, especially in high-altitude environments where their use persisted in later periods. The data obtained in this work suggest that human groups early integrated these resources into their social, economic, and technological sphere, developing a deep knowledge of their properties and characteristics. The application of technological and functional studies currently in progress will offer better understanding of raw material management, production techniques, and contexts of use.

6.2 The Procurement of Volcanic Rocks and the Lithic Sources

The procurement sources identified offer a first approach to the accessibility and availability of lithic resources in the Atacama basin. Several of these sources had been detected and characterized in different works dating back to the 1960s (Lanning, 1967; Lanning, 1968; Le Paige, 1970; Le Paige and Serracino, 1974; Núñez, 1983; Seelenfreund et al., 2010a; Seelenfreund et al., 2010b; Loyola et al., 2016); however, these works pursued other objectives and used different methodologies. Lithic studies of archaic sites have focused instead on understanding the technological management of resources and mobility patterns at site scale; we have little knowledge about sources of provenance. Conversely, there are several geochemical analyses and field characterizations in the case of obsidian (Seelenfreund et al., 2010a; Seelenfreund et al., 2010b) but with little application to early periods.

Our field surveys identified several lithic sources in the Atacama basin distributed in a vast and contrasting landscape ranging from 2000 to 4,500 m a.s.l. The sources detected are almost entirely volcanic and subvolcanic formations, such as lava flows, maars, craters, caldera-domes, ignimbrite flows, hydrothermal deposits, and outcrops of volcanic facies formed in different geological epochs. Each of them provides various kinds of rock. We documented large quarry-workshop sites in several of these places, with knapping evidence indicating intense and repeated human activity over several periods. The Loma-Negra and Puripica quarry-workshops are extensive areas of discarded material forming a continuous floor of lithic material, including stone structures. In Tulán Cerros, engraved plaquettes and blades have been recorded at the quarry-workshop sites; these provide evidence of symbolic practices (**Figures 14A,B**), although their chronology has not yet been well specified. Another exceptional engraved volcanic tuff was recovered from the initial occupation floor of Puripica-1 dated to 4,815 + 70 BP (5,651–5,320 cal BP) (**Figure 14C**), with one of the first manifestations of rock art in the area (Núñez, 1981; Núñez, 1983). The quarry-workshops of the Salar de Talabre are of medium intensity, but with an intense deposition of lithic materials. A similar pattern is found at Cerro Tujle, where the knapping activities were organized around the crater. The absence of evidence of exploitation in the Machuca-Pelún, Salar de Tara and Jarellón-Laguna Blanca sources is probably due to the greater dispersion of the raw material and to the fact that the nodules were collected and transported directly after being tested. Something similar could have happened in the case of the pumices that did not leave observable evidence of production.

The volcanic landscape of the Andean Puna provides a rich and diverse supply of lithic raw materials; however, these rocks are differentially available from limited sources, scattered throughout an arid and mountainous landscape. Human groups quickly integrated volcanic formations and their distribution into their cognitive maps; the archaeological evidence indicates that the sources were stable and recurrent nodes within the seasonal mobility cycle. These were not only spaces where hunter-gatherers carried out extractive activities, but were also occasions for social interaction and transmission of technical knowledge. Among early hunter-gatherers, obsidian appears to have been one of the most appreciated raw materials. The wide availability and distribution of obsidian allowed human groups to provision directly, both during their seasonal occupation of the highlands and from secondary sources on lower floors. This behavior persisted in societies that adopted agro-pastoralist ways of life in later periods. Thus, obsidian and other rocks continued to circulate and be exchanged over great distances (Berenguer, 2004; Yacobaccio, et al., 2004; Núñez, et al., 2007; Escola et al., 2016; Loyola et al., 2021).

6.3 The Volcanic Landscapes of the Early Hunter-Gatherers

By comparing the archaeological assemblages with samples collected in the field, potential sources of origin could be assigned to the lithic raw materials. This allows us to track the circulation of raw material between different microenvironments such as the Domeyko mountain range, the Precordillera foothills, the Altiplano, and even the eastern slope of the Andes. After a first evaluation, it can be suggested that the frequency of each raw material in the assemblages is directly related to the distance from its source. The lithic landscape, understood as the physical distribution and availability of rock resources (Gould and Saggers, 1985), offers a wide diversity of resources over variable distances. Most of the lithic raw materials come from sources in the immediate surroundings of the sites, whereas raw materials from more distant sources are transported to the settlements in smaller amounts and volumes. This differential distribution of raw materials can be directly related to the techno-economic zoning of the landscape. Sources in the immediate surroundings of the sites (<5 km) could be exploited as part of daily activities within the foraging area. The redundancy and intensity of activities in these spaces allowed the formation of large quarry-workshop sites such as Loma Negra, Tulán Cerros, and Cerros de Tuina. On the other hand, raw materials from more distant local sources (5–40 km), had to be supplied through other mechanisms; for example, through inter-settlement transport, within the seasonal mobility circuit, or even through specific logistical trips, leaving little evidence *in situ*, as is the case of Machuca-Pelún and Salar de Tara and Jarellón-Laguna Blanca. Rocks of allochthonous origin, especially trans-Andean obsidian, may have been obtained in smaller volumes by exchange or some other type of long-distance interaction.

The relationship between past societies and volcanism has generally been approached through the risk and impact of eruptive events (Torrence et al., 2000; Grattan et al., 2002; Shimoyama, 2002; Torrence and Grattan, 2002; Vanderhoek and Nelson, 2007; Torrence, 2014). In the Andes, a correlation between cultural changes and volcanic explosions in recent periods has been suggested (Bouysse-Cassagne and Bouysse, 1984; Pärssinen, 2015); however, we know little about early hunter-gatherer societies (Grosjean et al., 2007). Some works have discussed the consequences of volcanic events during the demographic bottleneck of the Middle Holocene period (Durán and Mikkan, 2009), and their effects on interaction networks and social organization (Aschero, 2016). Several catastrophic events and eruptions have occurred during the long sequence of human occupation in the Atacama Basin; in fact, volcanic ash layers interspersed with human occupations have been reported in Tulán-109 (2,900 m a.s.l) (**Figure 14D**), San Lorenzo-1 (3,000 m a.s.l), Tuina- 1 and -3 (3,000 m a.s.l), Miscanti-1 (4,200 m a.s.l) and Tambillo-6 (2000 m a.s.l), among others (Núñez et al., 2005; Núñez et al., 2018) but they have not yet been adequately studied. The Tulán-54 site, one of the oldest ceremonial centers in the region, was built on a dense layer of volcanic ash (Núñez et al., 2017). Local geological research has reported large-scale eruptions that could have formed the ash layers at archaeological sites. This is the case of the Tumbres eruption (9,100–9,300 cal BP), which produced an andesitic pumice fall deposit and a pyroclastic flow that extended for more than 10 km (Gardeweg et al., 1998). Likewise the Socompa devastating eruption (6,051 m a.s.l) produced a massive debris avalanche (7,200–6,200 cal BP) that extended for 40–50 km (van Wyk de Vries et al., 2001; Davies et al., 2010) with an ash fall area whose extent is still unknown. In the Argentine northwest, several Pleistocene and Holocene volcanic ash deposits have been reported, in some cases more than 4 meters thick (Fernández-Turiel et al., 2012).

These events must have occurred contemporaneously, and must have impacted early human societies not only through their direct consequences. Records of eruptions can persist for centuries in collective memory and oral tradition in the form of myths (Fox Hodgson, 2007). However, it has been argued that hunter-gatherer societies have a greater degree of resilience and tend to recover quickly from the sudden stress of explosive eruptions (Sheets 1999; Sheets, 2001). Volcanoes seem rather to have been recurrent nodes of interaction and mobility within the mobility cycle, and sources of raw materials from which to manufacture objects–not only tools for subsistence but also goods with a social and symbolic value, as in the case of rock art on ignimbrite formations (Núñez et al., 2017); obsidian projectile points were exchanged over great distances and deposited as offerings in ceremonies among late hunter-gatherers and early pastoralist groups (Loyola et al., 2020). Considering the continuity in the exploitation of these sources in later periods, knowledge of the landscape and its rocks must have been stored in oral tradition and shared cognitive maps in the long-term. It is therefore reasonable to suppose that this same knowledge probably laid the foundations for the development of the copper mining and lapidary technologies, for which the societies of the Atacama were widely recognized until recent times (Figueroa et al., 2013; Sapiains et al., 2022).

7 CONCLUSION

Andean societies developed and maintained a close relationship with volcanoes and high mountains from the beginning of peopling of the region in ancient times. Study of the lithic assemblages of three sites dated between 11,500 and 9,500 cal BP revealed the procurement and circulation of a wide variety of volcanic and subvolcanic rocks. These rocks were obtained from different formations and landforms, reflecting the high level of volcanism in the region both in the distant past and more recently that has modeled a steep relief with strong altitudinal contrasts. In these sites we also documented large quarry-workshop sites and even residential camps, evidence of the intensity of past human activities and their role within mobility and interaction networks.

The relationship between archaeological sites and procurement sources allows us for first time to trace the routes and distances traveled by individuals and groups during their daily activities and interactions in these landforms. From usual movements in the surroundings of the settlements or their seasonal displacements to the highlands, to the long-distance trips to the eastern slope of the Andes. Within these circulation networks at different scales, volcanoes were important nodes for their activities and movements. As it happens today, 10,000 years ago the volcanic features probably were already a fundamental part of the way of life of Andean societies in different dimensions–as sacred deities, economic resource areas, geographical and calendar markers, ritual settings and even recurrent habitats. Beyond the catastrophic consequences of eruptions, the andean societies and volcanism converge in still active and ancient "volcanic landscape", and the lithic record constitutes an exceptional archive of these social relations.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

The authors contributed in the following areas: RL: research conception and planning; laboratory analysis; field study; general writing of the article. VF: Conception and research design; field work surveys and general writing of the article. Field coordination and logistics. LN: Theoretical-methodological development of the archaeological research; participation in field work and general drafting of the manuscript. MaV: Field work (source sampling) and laboratory analysis (study of geological samples). CE: Field work and anthropological-archaeological background analysis for the preparation of the manuscript. Logistics and planning in the field. MiV: Methodological development; direction of the analysis of samples in the laboratory; theoretical corpus and developement of the geological background. MP: Conception and research design; carthograpy; environmental contextualization; graphic work and editing of the manuscript.

FUNDING

Funding for fieldwork and analysis was made possible by Wenner-Gren Dissertation Fieldwork Grant 3770214982, Fondecyt 1201603, and ECOS C19H05.

ACKNOWLEDGMENTS

First of all, we would like to acknowledge that this research was conducted on the traditional lands of the Lickanantay People. Also, we thank the Instituto de Investigaciones Arqueológicas y Museo (IIAM-UCN) that sponsored this research. We thank the Comunidad Atacameña de Toconao (CAT) who provided us with field and logistical support during this research as part of the associative research agreement between CAT and IIAM. Special thanks to Jimena Cruz, Macarena Oviedo, Luciano Oviedo, and Pamela Cruz for the management of lithic collections. We thank the Comunidad Atacameña de Toconao especially the Presidents Yermin Basques (2019–2020), and Luzvenia Catur (2021–2022). Finally, we would like to thank to Dr. Thérèse Bouysse-Cassagne and Dr. Philippe Bouysse, whose pioneering work on Andean volcanoes, conversations and contributions inspired this work.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.