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Macusani obsidian from southern Peru: A characterization of its elemental composition with a demonstration of its ancient use

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ABSTRACT

Transparent obsidian artifacts have been reported for the northern Lake Titicaca Basin. Based on instrumental neutron activation analysis (INAA) of these artifacts a distinct chemical group was identified. Yet, the location of the source of transparent obsidian in the southern Andes remained unreported in the archaeological literature. This paper reports on the chemical composition and geographic location of a source of transparent obsidian from the Macusani region of Peru. Through the use of INAA and portable X-ray fluorescence (PXRF) we demonstrate that Macusani obsidian or macusanite comprises (at least) two chemical groups. One of these groups was used for making artifacts during the Archaic Period. Artifacts made of this obsidian were found more than 120 km from the source and yet, one-third of the obsidian artifacts encountered at Macusani were from the non-local source of Chivay which is 215 km to the southwest.

1. Introduction

In many parts of the ancient world, obsidian, because of its workability, was a valued commodity for making chipped stone tools. Since the terminal Pleistocene obsidian has been an important material in the southern Peruvian Andes (Burger et al., 2000; Glascock et al., 2007; Grosjean et al., 1997; Nunez et al., 2002). In this paper, we report the location and elemental composition of a source of visually striking clear and transparent volcanic glass that was used for making chipped stone tools since at least Late Archaic times.

Obsidian sourcing studies allow one to describe and model local and long-distance interaction through the exchange of portable and valuable objects (Burger et al., 2000:268). In southern Peru and northern Bolivia, the elemental signatures and locations of nine anthropogenically exploited obsidian sources have been established: Alca (Cotahuasi) (Burger et al., 1998a), Chivay (Colca), Puzolana (Ayacucho) (Burger and Glascock, 2000; Tripcevich, 2007), Jampatilla (Puquio) (Burger et al., 1998b), Lisahuacho (Andahuaylas A) (Glascock et al., 2007), Potreropampa (Andahuaylas B) (Glascock et al., 2007), Aconcagua (Puno) (Aldenderfer, 1999:383), Sora Sora (Bolivia) (Brooks et al., 1997:450), and Quispisisa (Ayacucho) (Burger and Glascock, 2000) (Fig. 1). Also reported in the archaeological literature are the compositions and locations of four obsidian sources that were not used for making chipped stone tools (Glascock et al., 2007): Cerro Ticllago, Yanarangra, Uyo Uyo, and Caylloma.

Of the 1696 obsidian artifacts from Peru that have been analyzed and assigned to a known source, 94% derived from the Chivay, Quispisisa, and Alca sources (Glascock et al., 2007:529–530). In the highlands of Peru, south of the Department of Ayacucho, most of the analyzed obsidian artifacts derive from either the Chivay or Alca sources. Still, it is "clear that in this region several other types of obsidian were utilized on a limited basis" (Burger et al., 2000:274). The identification of rare obsidians when large collections are

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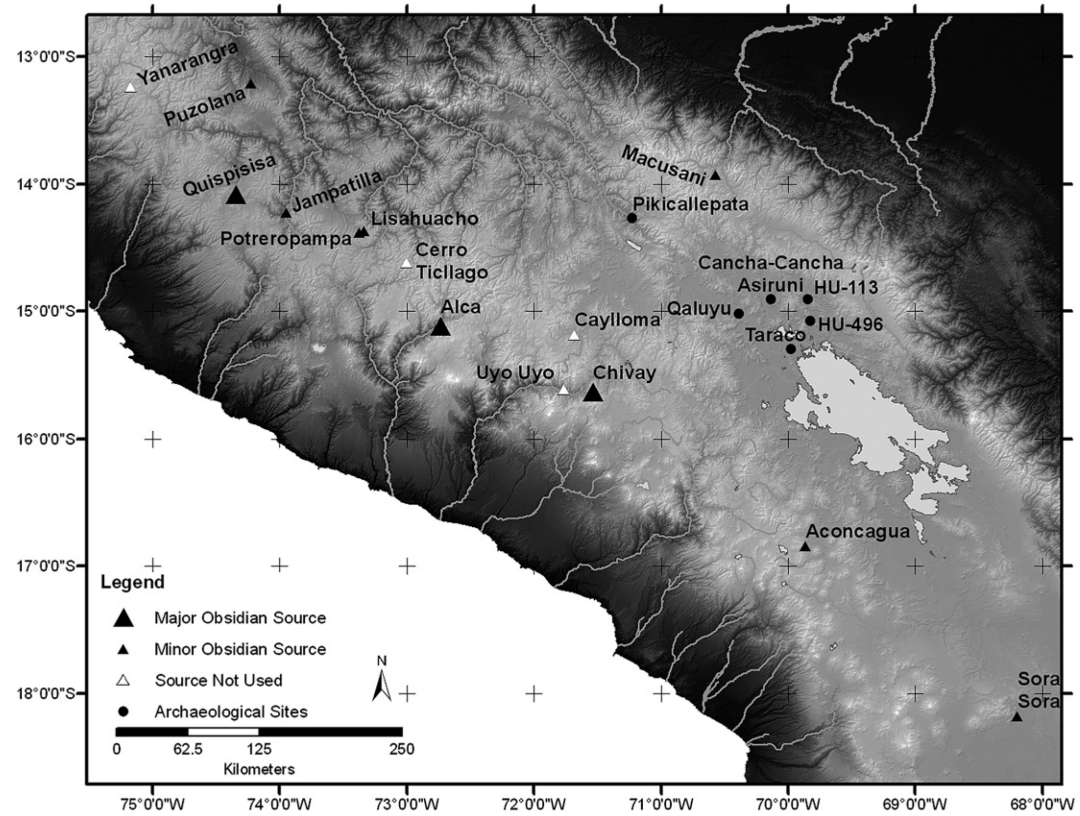

Fig. 1. Map of the Central Andes showing known obsidian sources and archaeological sites with obsidian artifacts that are mentioned in the text.

screened "presents an interesting phenomenon which has received little attention in the literature" (Burger and Asaro, 1978:67). These anomalies may occur in "contact zones between the obsidian and the adjacent non-igneous geologic formations," they may come from "igneous formations with small patches or inclusions of obsidian," or they may be "long-distance imports from unsampled regions" (Burger and Asaro, 1978:67). Identifying the source locations of rare obsidians is of anthropological interest because it permits the definition of additional points of articulation in regional trade networks.

This paper details new observations regarding one type of rare and transparent obsidian from the southern Andes.

2. Examples of transparent obsidians in the archaeological record of the southern Andes

In the literature on archaeological obsidians in the south-central Andes, more than five examples of artifacts produced from transparent obsidian have been reported. The analysis of five of such artifacts revealed that they formed an identifiable chemical group that was termed Rare 9 Type obsidian (Burger et al., 2000). Although the Rare 9 Type obsidian was not recognized in the original Lawrence Berkeley Laboratory instrumental neutron activation analysis (INAA) study undertaken in the 1970s, it was identified in subsequent analyses (Burger and Asaro, 1977; Burger et al., 2000:291). The material is reportedly "chemically similar to, but distinct from, Chivay Source obsidian" (Burger et al., 2000:296), and the geologic source of this material remains unknown.

The earliest reported archaeological instance of Rare Type 9 obsidian occurs at the type-site of Qaluyu in the far northern Titicaca region, during the Early Qaluyu phase (ca. 1300 BC) (Burger et al., 2000:289 Table III). The artifact is a triangular concave based projectile point (Burger et al., 2000:290 Figure 295, specimen "d" (292B/296–296, 8061-$)). In Karen Mohr-Chávez's Unit C at Qaluyu, "one additional transparent point (visually like Rare 9 Type)" was reported. However, based on NAA it was suggested that the material was "apparently not obsidian" (Burger et al., 2000:298). Another Rare Type 9 obsidian artifact was recovered from excavations of Early Horizon (ca. 1500–200 BC) contexts at Taraco, a major early settlement in the northern Lake Titicaca Basin. The artifact is a "[u]tilized flake with ground edge from a late Early Horizon level at Taraco (31B/36, 7013→)" (Burger et al., 2000:316–317, Figure 310 artifact (h)). Rare Type 9 obsidian also has been reported from Early Horizon contexts at Pikicallepata and Cancha Cancha Asiruni (Burger et al., 2000:310). "[Alfred] Kidder recovered colorless obsidian from a Late Chiripa level as well as from Early Tiahuanaco levels at Tiahuanaco (K. Chávez and Chávez, n.d.-a, b); it is tempting to speculate that they could be Rare 9 Type, which is also colorless" (Burger et al., 2000:319). Thus with one possible exception from Tiwanaku, the transparent Rare Type 9 obsidian is reported from the northern Titicaca Basin, and its use is limited to ca. 2000–200 BC.

In August of 2005, Speakman and Popelka-Filcoff used portable X-ray fluorescence (PXRF) to analyze all of the obsidian bifaces and projectile points that had been recovered during pedestrian surveys of the Huenque (Klink, 1998, 2005), Ilave (Aldenderfer and de la Vega, 1996; Klink and Aldenderfer, 1996), lower Ramis (Stanish and Plourde, 2000), and Huancané (Stanish and Plourde, 2000) drainages of the Lake Titicaca Basin (Craig et al., 2007). The collection includes two bifacial artifacts from the sites of HU-496 and HU-113 in the Huancané region that were both made from a visually striking transparent natural glass. The specimen HU-496 is a Late-Terminal Archaic stemmed projectile point that shows evidence of retouch. The piece from HU-113 is a broken and unfinished non-diagnostic biface.

Initial results of PXRF screening indicated that 1) the composition of the two Huancané artifacts were similar and 2) they did not correspond to any of the south-central Andean sources with data recorded at the University of Missouri Research Reactor (MURR). Because of the exceedingly high Rb concentrations (>1000 ppm) measured for these artifacts, we initially thought there was a possibility that the artifacts may have originated from a northwest Argentine source. The reason for this was that at the time the only obsidian known (to us) from the Andes to have Rb values in excess of 600 ppm was from Argentina. Additionally, there is one unknown Argentine obsidian source that has Rb values in excess of 1000 ppm. If HU-496 and HU-113 were from Argentine obsidian sources, this would have been evidence of exceedingly long-distance trade. Consequently, more detailed INAA characterization of the HU-496 and HU-113 specimens was undertaken and the results confirmed that the two transparent obsidian artifacts did not correspond with any obsidian that previously had been analyzed at MURR.

In 2007, we fortuitously identified a report that provided NAA data for numerous obsidian sources, including one type from Peru referred to as Macusani (MacDonald et al., 1992). At the same time, we also discovered that samples of Macusani obsidian were housed in the rock and ore collections of the Department of Mineral Sciences at the Smithsonian's National Museum of Natural History. Our subsequent investigation revealed that this glass had been known to geologists for more than eighty years, especially in the area of fission track dating. The source has a complex geologic history that involved multiple eruptions. We review this geologic history because it helps to explain the chemical variability exhibited by the obsidians from the source. Interestingly the source does not seem to be well known to archaeologists. Although Macusani obsidian was mentioned in passing by Hughes (1998), to our knowledge, the use of Macusani obsidian to make chipped stone tools had never been published—although the title of a recent presentation by Louis Fortin (2006) would seem to indicate that artifacts made from Macusani obsidian are known to a few archeologists working in Peru. In 2008, a visit was made to the Macusani Basin to identify the exact location of Macusani obsidian deposits and to collect samples of the material for elemental characterization and comparison to the HU-496 and HU-113 specimens. During this excursion to the Macusani area, numerous anthropogenically-unaltered obsidian pebbles and fourteen obsidian artifacts were encountered (Fig. 2).

3. Research area and geology of the Macusani obsidian source

Having a mean elevation of 4400 m above sea level, the Macusani Basin is a quadrilateral depression that is formed by the 5000–6000 m peaks of the Cordillera Oriental (Cheilletz et al., 1992:309). The Macusani area is underlain by Paleozoic rocks. To the north, there are Carboniferous, Permian, and intrusive pre-cretaceous rocks. To the south, there are upper cretaceous sedimentary rocks (Barnes et al., 1970). Sillar flows are present throughout much of the Macusani region. These flows are part of the extensive ash-flow deposits that mantle the slopes and high plain of the Andes mountains in Peru, Bolivia, Chile, and Argentina (Barnes et al., 1970:1540). The Macusani volcanics of the Meseta de Quenamari Field largely consist of unwelded, crystal rich rhyolitic ash-flow tuffs that contain a mixture of ash- and lapilli- sized pyroclastic fragments that include pumice shards and lithic debris. The lithic debris largely consists of very low-grade or unmetamorphosed pelites, quartzites, and limestone (Cheilletz et al., 1992:310).

The first reports of Peruvian transparent natural glass to surface in the academic literature described a material called "Paucartambo glass". Found as pebbles made of transparent natural glass with a slight yellow-green tint with distinctive etching on the surface, they were considered tektites (Linck, 1926). Based on the appearance, crystal inclusions, specific gravity, and refractive index Paucartambo glass was found to be identical to Macusani obsidian. Given these similarities it is thought that what had initially been described as "Paucartambo glass" was probably from the Macusani area and not from Cuzco (Martin and de Sitter-Koomans, 1955). Thus, "Paucartambo glass" (Linck, 1926) is likely Macusani obsidian or macusanite (which has also been referred to as "Macusani glass") (Pichavant et al., 1987:360).

It was not until the mid-1930s that natural glass from the Macusani region was first described, and in these early studies the material was attributed to an igneous rather than a celestial origin (Martin, 1934; Heide, 1936; Martin and de Sitter-Koomans, 1955). Though still in the mid-1960s studies were published in which it was proposed that Macusani obsidian exhibited a composition that was "intermediate between that of sedimentary and igneous rocks"; that "this Peruvian glass is unique", and it was "still not possible to formulate an acceptable theory about its origin" (Elliott and Moss, 1965:424).

Macusani obsidians occur in a variety of colors which include translucent-green, opaque milky-green, translucent pale yellow, or opaque red-brown spots irregularly dispersed in a translucent-green matrix (Bigazzi et al., 1997; Pichavant et al., 1987). Some specimens of macusanite are layered or flow banded (Barnes et al., 1970:1541). Opacity in the milky-green varieties is caused by the presence of "abundant fluid inclusions of strongly irregular shape" (Pichavant et al., 1987:360).

Macusanite pebbles are most frequently encountered along seasonal streams in fluvio-glacial sediments on the southern border of the Macusani ignimbrite field (Poupeau et al., 1993a:297). Previously, Macusani obsidian was first reported from Caluyo Mayo (Barnes et al., 1970), later at Chilcuno Chico (Arribas and Figueroa, 1985; Valencia and Arroyo, 1985), and then at Samillia (Poupeau et al., 1993a). Though it had been established that macusanite was not a tektite, based on its presence in reworked fluvio-glacial sediments the origin of the material was still not well established.

In 1964, a Macusani obsidian pebble that had been recovered from Caluyo Mayo was among the first materials ever dated by means of the fission track method; the initial age estimate was 4.3 ± 0.4 Ma (Bigazzi et al., 2005:586; Fleischer and Price, 1964:758 Table 753; Fleischer et al., 1965; Poupeau et al., 1993a:301). In the late 1960s, a Macusani obsidian pebble from Caluyo Mayo and a biotite separate from the ash-flow tuffs were dated by the K–Ar method, and the results indicated ages of 4.2 ± 1.5 and 4.1 ± 1 Ma respectively (Barnes et al., 1970:1543). Due to similarities in the chemical and mineralogical composition and the ages of the deposits, it was concluded that the Macusani obsidian and the ash-flow tuffs probably originated during the same volcanic episode (Barnes et al., 1970:1545). ^{40}Ar/^{39}Ar dating indicates that the ignimbrites of the Macusani Field erupted in three brief episodes: 10 ± 1, 6.8–8, and 4 ± 1 Ma (Cheilletz et al., 1990:343). The ash-flow tuffs are the youngest eruptive system of the Cordillera de Carabaya segment of the Central Andean Inner Arc (Cheilletz et al., 1990:341–342; Cheilletz et al., 1992:309).

Rb–Sr dating of two pebbles from Chilcuno Chico produced an age of 4.9 Ma (Pichavant et al., 1987:366). Rb–Sr dating of a macusanite pebble from Caluyo Mayo produced an age of 4.4 Ma (Pichavant et al., 1987:366). This result is in good agreement with FT and K–Ar ages from the same deposit (Barnes et al., 1970). In one study, fission-track plateau ages for Macusani obsidian samples collected from Caluyo Mayo and Chilcuno Chico ranged from 6.7 ± 0.3 to 7.0 ± 0.4 Ma (Cheilletz et al., 1992:311). In another study, FT plateau ages were determined for six Macusani obsidian pebbles from Chilcuno Grande. Five of the samples clustered around 7 ± 1 Ma

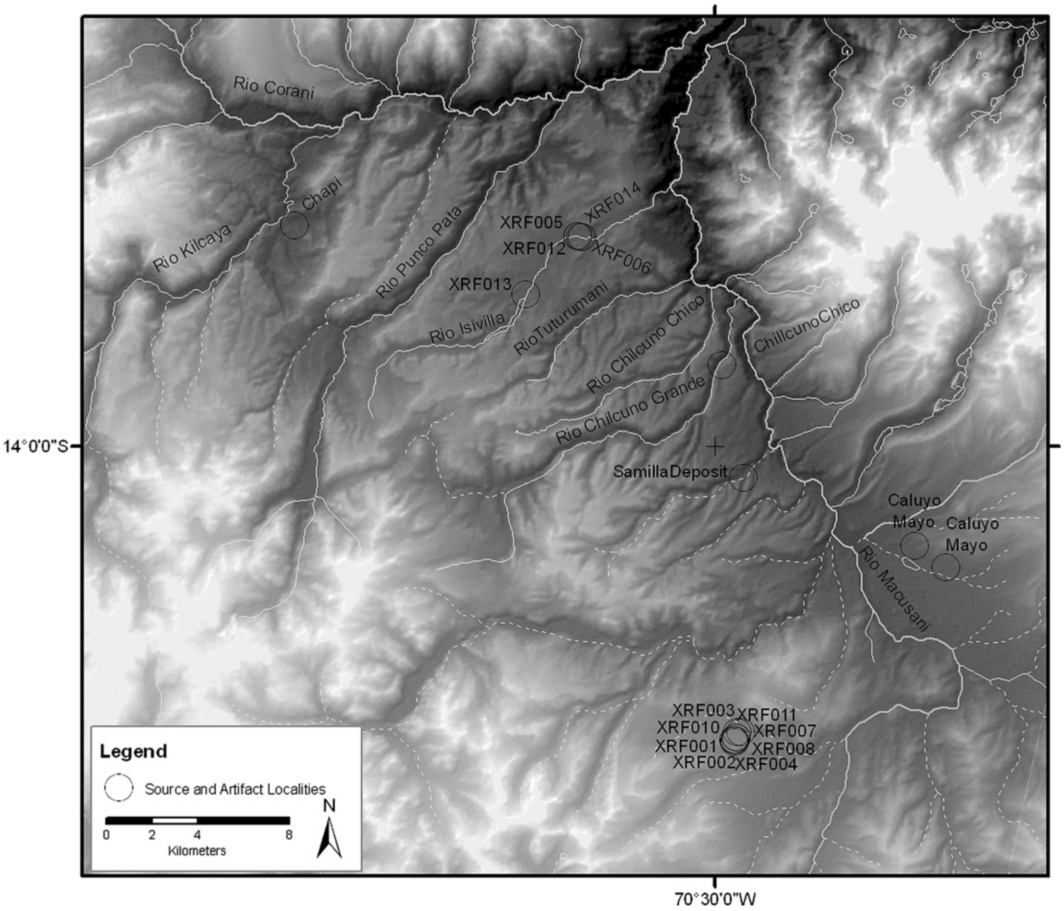

Fig. 2. Map of the Macusani obsidian source showing the location of source samples and archaeological artifacts mentioned in the text.

while the sixth sample produced an age of 4.76 ± 0.18 Ma (Poupeau et al., 1993b:502). Plateau ages for Macusani obsidian pebbles from the Caluyo Mayo area are 5.36–6.06 Ma (Poupeau et al., 1993b). These results are in agreement with prior FT age estimates of 5.52 ± 0.26 Ma and K–Ar estimates age estimates of 5.67 ± 0.1 Ma for these samples (Poupeau et al., 1992).

It has been suggested that Macusani obsidian should be used for an inter-laboratory fission track age calibration standard (Balestrieri et al., 1996; Bigazzi, et al., 1997; McCorkell and Naeser, 1990; Miller and Wagner, 1981). However, the reference age is not well constrained. Fission-track plateau ages for Macusani obsidian pebbles range from 4.3 to 7.9 Ma (Miller et al., 1990; Miller and Wagner, 1981; Naeser et al., 1980; Poupeau et al., 1993a,b, 1992). K–Ar ages from 4.2 ± 1.5 to 5.67 Ma have been reported (Barnes et al., 1970; Poupeau et al., 1992).

FT, K–Ar, and ^{40}Ar/^{39}Ar ages indicate that the Upper-Miocene volcanic activity of the Macusani ignimbrite field was largely concentrated between 6.7 and 8 Ma, and this might have persisted to as late as 4.7 Ma with the volumetrically less important magmatism responsible for the Macusani obsidian formation (Poupeau et al., 1993a:303). FT plateau ages indicate that the Macusani obsidian producing volcanism occurred 4.8–6.9 Ma, possibly in the form of discrete events (Poupeau et al., 1992:295). Macusani obsidians may have resulted from different volcanic eruptions (Poupeau et al., 1992), and this could explain the differences in ages (Osorio et al., 2003:411). Thus, though Macusani obsidian may have formed during a single event that occurred around 5.5 ± 1 Ma, it is also possible that multiple deposits formed in discrete events during this time (Poupeau et al., 1993a:303). Slight variations in the chemical compositions among different pebbles suggests that Macusani obsidian may have formed in different eruptions (Poupeau et al., 1993a:303).

In 1988, inclusions of Macusani obsidian were found in ash-flow tuffs in the Chapi and Chilcuno Chico areas; these inclusions have only been observed in tuffs that belong to the upper cooling units (Pichavant et al., 1987:360). Examples of Macusani obsidian that are encountered as inclusions in the ash-flow tuffs are observed to be of the translucent-green variety, the surfaces are finely etched, and the pebbles are generally of a smaller size (<2 cm) (Pichavant et al., 1987:360). In the Chapi area, obsidian clasts up to 5 cm in size were found interbedded within the ash-flow tuffs (Cheilletz et al., 1992). From this observation, it was suggested that the Macusani obsidians found in fluvio-glacial sediments are either tephra ejecta that have remobilized from the ash-flow tuffs or are remnants of flow deposited glass located on the upper-most unit of the volcanic sequence that has subsequently eroded (Cheilletz et al., 1992:310). That the pebbles have a slightly flattened ovular shape and an etched surface, supports the model that Macusani obsidian fragments were erupted as clasts within the air-fall tephra. Following this, alluvial and glacial alterations separated the inclusions from the host tuff and resulted in the pebbles' deposition in fluvio-glacial stream sediments (Pichavant et al., 1987:369). Flow deposited obsidian has not been reported in the Macusani region.

Based on Sr and O isotopes, Macusani obsidian can be divided into two groups. One group consists of samples obtained from Chilcuno Chico and Caluyo Mayo while the other group consists of samples from the Chapi inclusions. Each of these groups was probably formed by different magma (Pichavant et al., 1987:369).

The Chilcuno Chico and Caluyo Mayo samples have higher $^{87}Sr/^{86}Sr$ ratios than either of the two inclusions from Chapi (Pichavant et al., 1987:365, Table 365).

4. Sample location and description

We investigated two areas within the Macusani Basin for the presence of both natural obsidian deposits and artifacts. The first location was about 11 km south of the town of Macusani, near the pueblo of Accoyo. Here a sparse lithic scatter that included both clear transparent and black obsidian artifacts was encountered along about 500 m of the southern edge of a 7.0 ha *bofedal* (moor). The surface scatter included temporally diagnostic projectile points, bifaces, edge-modified flakes, cortical biface thinning flakes, and general debitage. The second study area was located about 22 km northwest of the town of Macusani, along the active floodplain of the Rio Isivilla. In this locality, numerous anthropogenically-unaltered pebbles of clear pale-green transparent obsidian were encountered. Several cortical flakes and a projectile point made out of a visually similar pale-green transparent material were also found in the same context. A single biface thinning flake of clear yellow-green material with red banding was recovered from Rio Isivilla (sample XRF ID006). In addition, a single black obsidian flake also was encountered in the floodplain of the Rio Isivilla. A clear slightly yellow-green color dominates the materials encountered near Accoyo and in the sediments of the Rio Isivilla. Between the two sampling locations, a total of fourteen obsidian artifacts were encountered.

5. Methods of elemental analysis

As indicated above, samples from HU-496 and HU-113 were analyzed by INAA at MURR using standard analytical parameters (e.g., Glascock et al., 2007). All fourteen obsidian artifacts and a sample of 6 unmodified Macusani obsidian pebbles were analyzed at the Smithsonian's Museum Conservation Institute with a Bruker Tracer III–V handheld XRF instrument. An additional 6 macusanite specimens from the Smithsonian Institution's rock and ore collection were also included in the analysis. XRF analyses of the obsidian artifacts permitted quantification of the following elements: manganese (Mn), iron (Fe), rubidium (Rb), strontium (Sr), zirconium (Zr), and niobium (Nb). All obsidian samples were analyzed as unmodified samples. The Tracer III–V is equipped with a rhodium tube and a SiPIN detector with a resolution of ca. 170 eV FHWM for 5.9 keV X-rays (at 1000 counts per second) in an area of 7 mm^2. All analyses were conducted at 40 keV, 15 mA, using a 0.076-mm copper filter and 0.0305 aluminum filter in the X-ray path for a 200-s live-time count. The spot size on this particular instrument is ca. 4.0 mm diameter which facilitates analysis of smaller artifacts. Peak intensities for the above listed elements were calculated as ratios to the Compton peak of rhodium, and converted to parts-per-million (ppm) using linear regressions derived from the analysis of 15 well characterized obsidian samples that previously had been analyzed by NAA and/or XRF.

6. Results of elemental analysis

The results of elemental characterization of the HU-496 and HU-113 samples as determined by means of INAA are reported in Table 1. Compositional data derived from the PXRF analyses of the 6 anthropogenically-unmodified pebbles obtained from Peru for this study, the six samples obtained from the Smithsonian's rock and ore collection, and the fourteen artifacts are reported in Table 2.

Comparison of the INAA data generated for artifacts from HU-496 and HU-113 with data presented in MacDonald et al. (1992) confirms that these artifacts are indeed made from Macusani obsidian (Table 1). XRF analyses also indicate that the source samples we collected have a different chemical signature than those housed at the Smithsonian (Table 2). This was expected given that differences in fission track dates for Macusani obsidian, as discussed above, indicate multiple glass forming eruption events, and the possibility of different chemical signatures. The Smithsonian Macusani obsidian samples also are cobble/fist sized whereas the Rio Isivilla samples collected by us are approximately half the size (or smaller). To denote the differences in composition, we are referring to the two different chemical signatures as Macusani-1 and Macusani-2, which correspond to the Smithsonian collection that come from Caluyo Mayo and to our Rio Isivilla samples, respectively. Of the fourteen obsidian artifacts from the Macusani Basin that were analyzed, nine (64%) were crafted out of material obtained from the Macusani-1 source and five (36%) were made out of material obtained from the Chivay source (Fig. 3). Given that the Macusani-1 obsidian occurs in a larger package size, it is not too surprising that all of our Macusani obsidian artifacts have the Caluyo Mayo (e.g., Macusani-1) chemical signature.

Table 1
Elemental concentrations of artifacts HU-113 and HU-496 analyzed by INAA at MURR and the macusanite sample analyzed by MacDonald et al. (1992).

Element	HU-113	HU-496	Macusani[a]
Al (%)	8.99	7.81	8.28
K (%)	2.95	2.91	2.97
Mn (%)	0.05	0.05	0.06
Na (%)	3.10	2.80	3.10
Ba[b]	<25	<25	<50
Ce[b]	0.24	0.32	3
Cs	524	529	503.0
Dy	0.5	1.0	n.r.
Eu	<0.02	<0.02	<0.04
Fe	3993	3965	3498
Hf	1.4	1.7	1.3
La[b]	0.33	0.34	1
Lu	<0.04	<0.04	0.04
Nd[b]	<2.0	<2.1	<20
Rb	1102	1111	1100
Sb	4.5	4.6	3.9
Sc	2.4	2.5	2.3
Sm[b]	0.5	0.6	1.5
Sr	<5	<5	1
Ta	21.2	21.4	22.1
Tb	0.1	0.2	0.17
Th	1.9	1.7	1.3
U	28.8	37.2	16.9
Yb	0.3	0.5	0.3
Zn	94.1	94.9	106.0
Zr[b]	<50	<50	28

[a] Values from MacDonald et al. (1992).
[b] MURR values corrected for U-fission product interference (Glascock et al., 1986).

7. Discussion

INAA and PXRF elemental analysis of artifacts and natural glass pebbles provide the first demonstration that prehispanic peoples of the south-central Andes used Macusani obsidian for making chipped stone tools. Prior studies suggested that Macusani obsidian comprised at least two chemical groups, and it was proposed that this chemical variability likely represented glass deposits that formed during different eruptive events. Our results confirm the presence of two chemical groups at the Macusani obsidian source. Whatever geologic processes caused this compositional heterogeneity, we were able to document that material from at least one of these chemical groups was used for making chipped stone artifacts. Given the nature of this geologic deposit, the identification of

Table 2
Elemental concentrations of source rocks and artifacts from the Macusani region analyzed by PXRF.

Lab ID	Chem. group	Sample type	Mn	Fe	Rb	Sr	Zr	Nb
SI-2143-20	Macusani-1	Source	566	4284	1138	5	10	36
SI-2143-37	Macusani-1	Source	397	4430	1172	5	7	37
SI-2143-27	Macusani-1	Source	421	4367	1175	6	5	35
SI-2143-25	Macusani-1	Source	465	4398	1205	4	9	39
SI-2143-23	Macusani-1	Source	475	4166	1173	5	11	37
SI-2143-12	Macusani-1	Source	514	4448	1198	5	8	37
		Mean	473	4349	1177	5	8	37
		Std Dev	56	97	22	1	2	1
MAC22-1	Macusani-2	Source	646	3276	1349	8	4	34
MAC22-2	Macusani-2	Source	657	3262	1356	8	5	34
MAC22-3	Macusani-2	Source	532	3287	1315	6	4	28
MAC22-4	Macusani-2	Source	665	3260	1354	9	12	36
MAC23-1	Macusani-2	Source	654	3190	1366	8	5	36
MAC23-2	Macusani-2	Source	530	3418	1403	7	8	36
		Mean	614	3282	1357	8	6	34
		Std Dev	59	68	26	1	3	3
XRF001	Chivay	Flake	712	4979	241	40	66	16
XRF002	Chivay	Flake	616	4737	226	35	69	13
XRF003	Chivay	Edge-modified Flake	568	4993	238	47	66	15
XRF004	Chivay	Serrated 5C Projectile Point	593	4940	245	39	68	15
XRF005	Chivay	Flake	499	4776	234	40	64	15
XRF006	Macusani-1	Biface Thinning Flake	291	4381	1229	4	10	33
XRF007	Macusani-1	Edge-modified Cortical Flake	351	4166	1150	5	4	32
XRF008	Macusani-1	Cortical Flake	351	4129	1135	3	7	33
XRF009	Macusani-1	Biface Fragment	283	4076	1128	2	2	33
XRF010	Macusani-1	Flake	438	4234	1168	3	13	33
XRF011	Macusani-1	Serrated 4D Projectile Point	367	3999	1139	4	13	34
XRF012	Macusani-1	Serrated 4H Projectile Point	392	4153	1155	5	5	36
XRF013	Macusani-1	Edge-modified Cortical Flake	450	4136	1115	5	6	33
XRF014	Macusani-1	Cortical Biface Thinning Flake	312	4715	1136	0	2	26

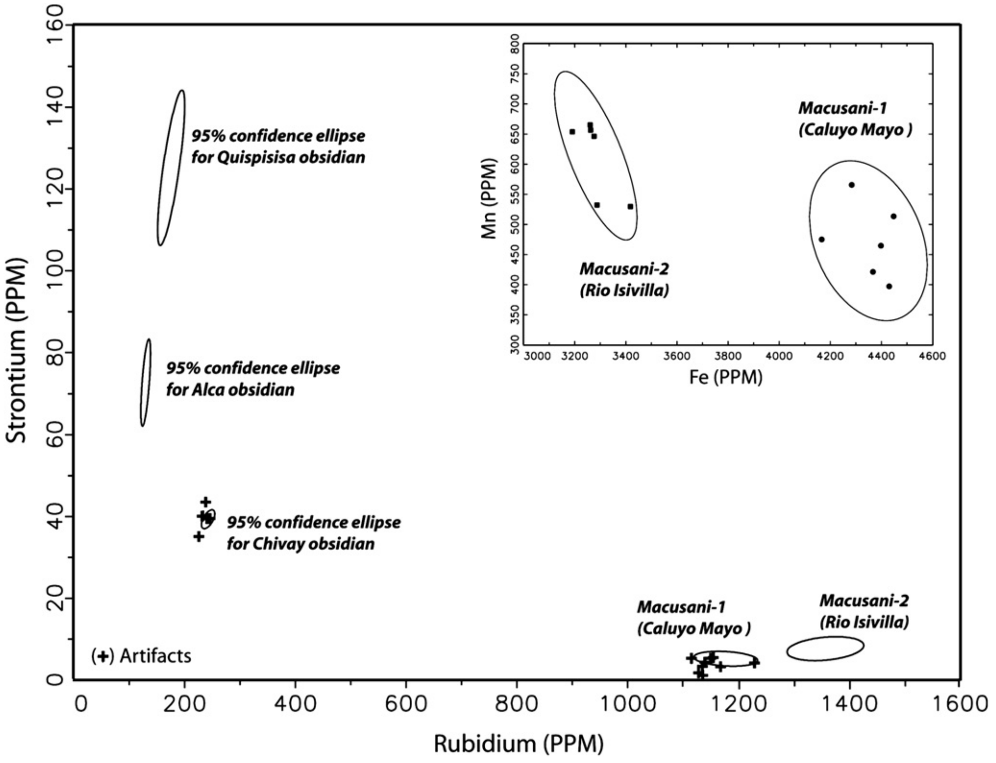

Fig. 3. Rubidium–strontium plot of source rocks and artifacts from the Macusani region analyzed by PXRF. The ellipses surrounding each group are drawn at the 95% confidence level. Confidence ellipses for Alca, Chivay, and Quispisisa are calculated using data published in Glascock et al. (2007). *Inset:* Iron–Manganese plot showing additional separation of the geologic samples assigned to the Macusani-1 and Macusani-2 chemical groups.

multiple chemical groups of clear obsidian in archaeological assemblages from the south-central Andes can be expected.

The other nine anthropogenically exploited sources (Quispisisa, Jampatilla, Lisahuacho, Potreropampa, Puzolana, Alca, Chivay, Aconcagua, and Sora Sora) and the four known geologic sources which were not exploited for tool raw materials (Yanarangra, Uyo Uyo, Caylloma, and Cerro Ticllago) are all located on the western side of the Andes in an "arching line between 3000 and 5000 m above sea level" (Tripcevich, 2007:181, Figure 183–185, 331, Figure 184–112). Based on the present evidence, Macusani obsidian is the only source located on the eastern cordillera that was exploited for producing chipped stone tools.

The discovery of three temporally diagnostic Archaic projectile point forms (HU-496, XRF011, and XRF012) crafted out of Macusani obsidian indicates that exploitation of this source dates to preceramic times. One of these points was encountered in the Late Titicaca Basin (HU-496), and it indicates that Macusani obsidian was transported long distances (>120 km) from the source during the Archaic. Synthesis of prior research indicated that evidence for the use of Rare Type 9 obsidian chemical group appears first during Early Qaluyu (ca. 1300 BC) (Burger et al., 2000:289 Table III). If the Rare Type 9 group corresponds to Macusani obsidian, then this material was used from the Archaic to the Formative Period. Burger et al. (2000) state that even Rare 9 Type obsidian, which is always visually distinct because of its transparency, looks like another type that is chemically similar to, but distinct from, Chivay obsidian. Given the unusually high Rb concentration for Macusani obsidian, it is clear that Macusani obsidian is not chemically similar to Chivay obsidian. This raises the question of whether a second geologically/geographically discrete source of colorless obsidian exists in Peru. Unfortunately, we will not know the answer to this question until such time that we have the opportunity to analyze/reanalyze some of the translucent obsidian artifacts that have been reported in the literature.

Three obsidian projectile points were found in the Macusani Basin. XRF011 and XRF012 are stemmed forms that are morphologically and temporally diagnostic to the Late Archaic. XRF012 exhibits an expanding stem. This type has a known distribution that is restricted to the Cuzco Basin (Bauer, 2007; Bauer et al., 2007; Klink, 2007) and the northern and eastern parts of the Lake Titicaca Basin. Despite systematic pedestrian survey, this expanding stemmed form has not been encountered in either the Rio Ilave (Aldenderfer and de la Vega, 1996; Klink and Aldenderfer, 1996) or Rio Huenque (Klink, 1998, 2005) drainages. XRF004 is a triangular concave base form. This type spans the Archaic–Formative transition (ca. 2000–1500 BC), and in the Andean highlands it exhibits a very cosmopolitan distribution.

Intriguingly, all three of the projectile points found at the Macusani source were serrated. HU-496 is heavily retouched, and it is not possible to determine if it was serrated at one point. HU-113 is not serrated, but it is also a simple biface and is not a well-formed projectile point. It has been noted that in the Rio Ilave drainage, projectile points made out of obsidian are serrated or denticulated significantly more often than projectile points made out of other materials (Craig, 2005:683–688). The fact that three of the five macusanite bifaces we analyzed are serrated is consistent with this previously noted trend.

Even at the Macusani source, one-third of all the obsidian artifacts that we encountered were crafted out of material that derived from the Chivay source. Chivay is located 215 km to the southwest, across the altiplano, on the western cordillera. Thus, non-local obsidian was desirable to those inhabiting the Macusani region. This observation reinforces the argument that in the south-central Andean highlands, obsidian was a chipped stone raw material that was desired for largely social reasons (Aldenderfer, 2005; Craig, 2005; Frye et al., 1998). The Macusani Basin must have been articulated with exchange networks that crossed the altiplano and linked to the Chivay source. The Macusani Basin is the farthest toward the Ceja de Selva or eastern slopes of the Andes in which the presence of Chivay obsidian has thus far been documented. We envision three scenarios to explain the presence of Chivay obsidian in the Macusani Basin: 1) people from Chivay traveled directly to Macusani; 2) people from Macusani traveled to Chivay; and/or 3) people from Macusani exchanged with third parties who had access to sufficient quantities of Chivay obsidian that they were willing to trade it away. Further work is required to evaluate these models of exchange.

8. Concluding remarks

It has been suggested that the visual attractiveness and physical properties that yield sharp-edged, conchoidal fractures would have added to the appeal of a given obsidian source material (Glascock et al., 2007:522). Macusani obsidian is visually striking; it is relatively free of phenocrysts and other inclusions. Thus, based on these criteria one would expect that Macusani obsidian would have been highly desirable. Macusani obsidian only occurs as smaller sized clasts in ash-flow tuff or in fluvio-glacial stream beds. Only Macusani-1 obsidian, which occurs in larger sized clasts than Macusani-2, was used for making chipped stone artifacts. Though a potentially desirable source of material, the small package size of raw materials from the Macusani obsidian deposit would have rendered difficult the kind of intensive exploitation that has been observed at major obsidian sources, such as Chivay (Tripcevich, 2007:583–584, 687–743). Still, the presence of multiple Macusani obsidian artifacts in the northern LTB indicates that the material was transported more than 120 km away from the source. This serves as an indication that Macusani obsidian was articulated with long-distance trade networks and was probably a highly desired material which was only available in relatively small quantities.

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