Andean Past

Volume 6 Article 14

2000

The Puzolana Obsidian Source: Locating the Geologic Source of Ayacucho Type Obsidian

Richard L. Burger
Yale Univeristy, richard.burger@yale.edu

Michael D. Glascock
University of Missouri Research Reactor, glascockm@missouri.edu

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Richard L. Burger
Yale University
and
Michael D. Glascock
University of Missouri Research Reactor

Introduction

In the study of Andean obsidian carried out by Richard Burger and Frank Asaro in the 1970s at the Lawrence Berkeley Laboratory (LBL), only two chemical types of obsidian were encountered among the Preceramic artifacts recovered by Ayacucho-Huanta Archaeological-Botanical Project (Burger and Asaro 1977, 1978, 1979). These were assumed to correspond to two geological sources of volcanic glass. One of these obsidian types, referred to as the Ayacucho Type, constituted about 12% of the 66 Preceramic artifacts from Ayacucho that were tested. Artifacts of this chemical type came from a range of Ayacucho Basin Preceramic sites located in varying habitats and temporal placements. Burger and Asaro concluded that the Ayacucho Type was one of eight obsidian types utilized in the Central Andes, but its geologic source remained unknown. Although a large sample of sites and artifacts was included in the initial study, including many specimens from Junín to the north of Ayacucho and Andahuaylas to the east of Ayacucho, artifacts of Ayacucho Type obsidian were never encountered in samples from outside of the Ayacucho Basin (Figure 1). This led Burger and Asaro to hypothesize that obsidian of the Ayacucho Type came from a "local" source within the Basin. This hypothesis, while reasonable, led inevitably to the question of why, if it was true, another chemical type (known as Quispisisa) from outside the Ayacucho Basin was used throughout prehistory more frequently within the valley than the Ayacucho Type.

The trace element composition of Ayacucho Type Obsidian was originally based on X-Ray Fluorescence (XRF) analysis of eight obsidian flakes from R.S. MacNeish's excavations at Preceramic sites in Ayacucho. These artifacts came from the sites of Ac102 (Ayamachay), Ac158 (Puente Cave), and Ac500 (Chupas Cave) (Burger and Asaro 1978: table 4). Four of these same flakes from Ayamachay, Chupas Cave, and Puente Cave also were analyzed by long-Neutron Activation Analysis (NAA) in order to provide precise compositions for additional trace elements (Burger and Asaro 1978: table 1). Knowledge of the Ayacucho Type's chemical composition was further refined by the XRF analysis of five obsidian flakes from the Early Horizon mound of Chupas (Ar23) (Burger and Asaro 1982).

Over the subsequent two decades, until 1999, no new information came to light on the source of Ayacucho Type Obsidian or why it was not more widely used. The present article provides empirical evidence which places the location of the source of Ayacucho Type obsidian in the zone between Chupas and Cerro Campanayocc within the central Ayacucho Basin. Data are offered which confirm this identification through NAA of source samples at the Missouri University Research Reactor. The new information raises the possibility that the specific geologic nature of this obsidian

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deposit with its intrinsic limitations was responsible for the source not being utilized intensively during most of Andean prehistory. The case study of Ayacucho Type Obsidian helps us to understand the more general pattern of dominant and minor obsidian sources in Prehispanic Peru, and it suggests the great importance ascribed to high quality lithic material by the early settlers of the Andes.

Location of the source

During the 1980s and early 1990s, political instability in the Ayacucho region discouraged the search for obsidian sources, but with the return of peace to the area, it was possible to pursue questions left unresolved in earlier decades. In April 1999, Burger, accompanied by Peruvian archaeologist José Pinilla, traveled to the city of Ayacucho to follow up on leads concerning the location of the obsidian source known as Quispisisa (Burger and Glascock 2000). Ayacucho archaeologist José Ochatoma put them in contact with mining engineer Blas Cárdenas, who had an intimate knowledge of the local geology. In the ensuing discussions, Blas Cárdenas referred to the presence of obsidian nodules in a layer of volcanic tuff recognized locally as a *puzolana*.[1] According to Blas Cárdenas, this geological stratum begins at the southern edge of the city of Ayacucho and continues for many kilometers to the south. He had observed that concentrations of obsidian inclusions within the *puzolana* layer varied, but they were particularly dense above the hamlet of Chupas where the geological layer had been cut by the recent construction of the Cachi Canal. In his Ayacucho office, Blas Cárdenas showed Burger and Pinilla examples of unworked nodules from the *puzolana* stratum and the quality of this volcanic glass appeared to be extremely high. However, none of the nodules was larger than 4 cm on a side.

On April 22, 1999 Burger, Pinilla, and Ochatoma drove to the section of the Cachi Canal described by Blas Cárdenas. Chupas is located approximately 7 km to the south of Ayacucho and 7.5 km northwest of the town of Chiara at approximately 3500 meters above sea level (masl), about 250 m in elevation above Chupas (Figure 2). Numerous obsidian nodules and flakes were scattered along the flat ground that comprises the platform of the canal. Nodules of volcanic glass also could be observed *in situ* eroding out of the layer of light tuff; this stratum was over 20 meters thick (Figure 3). Most of the nodules were only 1 cm on a side but some that were 3-4 cm on a side were also encountered, although they were not common. Above the layer of rhyolitic tuff was a deposit of poorly sorted materials with angular stones, which appeared to be of glacial origin. Burger, Pinilla, and Ochatoma walked for 1.5 km along the standing geological profile and confirmed that this pattern continued unchanged. There was no worked obsidian nor was there degraded or flawed volcanic glass (which typically shows inclusions, cracking, or bubbles). Many of the nodules had black streaking and a few had reddish coloration due to iron impurities. A large sample of the nodules was taken for analysis at the Missouri University Research Reactor to determine whether their trace element chemistry matched that of the Ayacucho Type artifacts.

In subsequent discussions at the Universidad Nacional de San Cristóbal de Huamanga several local archaeologists commented that small obsidian nodules also could be found on the slopes immediately to the south of the city of Ayacucho. On April 23, 1999, a short trip was made with archaeologist Martha Cabrera Romero to Cerro Campanayocc, located 3 km south of Ayacucho, in order to evaluate information that the northern continuation of the

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[1]*puzolana* (Spanish), pozzolana (English), or *pozzuolana* (Italian) is a type of volcanic ash named for the geological type deposit near Pozzuoli on the Bay of Naples (*OED* 1999, *s.v.*). Although the term is employed in Roman archaeology and in the building and cement industries to refer to construction material taken from pozzolana deposits, these usages are not evoked in the present nomenclature [*Editor's note*].

geological stratum of rhyolitic tuff contains obsidian nodules. Located 3 km northeast of the Chupas exposure and at 3400 masl, the layer looked very similar to that encountered the day before. A road cut had exposed over 10 m of the *puzolana* stratum and similar inclusions were encountered (Figure 4). Once again, most of the nodules measured approximately 1 cm on a side, but larger nodules of high quality obsidian 3 cm on a side were sometimes found. The cut was examined for about 1 km in a southerly direction and this pattern continued. Once again, the obsidian varied from black to clear with black streaks and it was of uniformly high quality. In geologic terms, it is unweathered and unretrograded. As in the Chupas exposure, no worked obsidian was found.

Jay Ague, a Yale geologist specializing in petrology, had the opportunity to examine the obsidian samples taken from the Chupas and Cerro Campanayocc exposures (Figure 5). He concluded that they looked very similar and, judging from the photographs of the exposures, appeared to come from the same the same deposit, although until NAA results were available, alternative explanations could not be ruled out. Ague observed that both samples included banded obsidians which result from flow processes. He also noted that the obsidian recovered is basically globs of molten silicate of the kind which form in heterogeneous magma chambers containing silicate melt and crystals. The obsidian nodules have irregular sides which are rounded but not entirely round; in fact, most have some flat irregular sides probably due to the conditions in which they hardened. The general rounding may have come from being blown out of the volcano.

It was possible to locate the two collection sites within the region's geology using the INGEMMET monograph on the Ayacucho Quadrangle (Morche *et al.* 1995). Both groups of samples had been taken from the Miembro Inferior of the Ayacucho Formation (Nm-Ay1) in the deposit referred to as *puzolana* (*Ibid.*:81). The *puzolana* layer is reported to be composed mostly of volcanic glass, quartz crystals, feldspars, and some pumice clasts. It is almost horizontal in position and reaches 30-50 m in thickness in some spots (*Ibid.*:81). In the monograph's account, the Formation resulted from explosive volcanic activity. This pattern of activity tends to produce viscous products such as those responsible for the obsidian nodules recovered, according to Jay Ague (personal communication, May 1, 1999). On the geological map (27-ñ), this formation is shown as mid-Miocene in date, and in an appendix of radiometric dates (Morche *et al.* 1995: 105), seven K-Ar dates are included for the Ayacucho Formation, ranging from 6.0±0.6 to 7.7±0.2 million years ago (mya). One measurement (AYA-81-08) is of special interest because was taken on obsidian in tuff. It yielded a date of 7.6±0.2 mya (Megard *et al.* 1984).

Above the Miembro Inferior of the Ayacucho Formation lies the more effusive formation known as the Miembro Superior. This apparently incorporated at least one obsidian flow in the zone of Chaupiorcco (Figure 2) (Morche *et al.* 1995:42). The authors note that there is a conspicuous relation of a hydrothermal anomaly in the area with the presence of a rhyolitic obsidian flow (*Ibid.*:40-41). At the time of Richard S. MacNeish's work in Ayacucho, MacNeish provided Burger with pieces of geologic obsidian from the Tukumachay area 10 km north of Chaupiorcco (Burger and Asaro 1978: 65; MacNeish personal communication 1999). The obsidian from near Tukumachay had been naturally altered, perhaps by hydrothermal activity, thus producing cracking and discoloration. Its cloudy and opaque appearance was due to the devitrification of the original glass. This obsidian source material stands in marked contrast to the obsidian collected in the older *puzolana* stratum to the north. The source samples from near Tukumachay would have been inappropriate for the production of artifacts because the structural flaws in the material prevented it from being chipped in a controlled manner.[2] NAA analysis (845 X BURG 60) at LBL of a sample of source obsidian collected from near Tukumachay demonstrated that its chemical composition did not match either that of the Ayacucho Type or that of Quispisisa obsidian (Burger and Asaro 1977:39-40, 65-71).

In contrast, as will be seen in the following section, the samples collected near Chupas and Cerro Campanayocc analyzed at MURR were both found to have the same composition as the Ayacucho Type obsidian artifacts characterized at LBL. Because the layer with the obsidian inclusions extends over a broad area, we suggest that this source of Ayacucho Type Obsidian be referred to in the future as the Puzolana Obsidian Source after the distinctive geological layer in which the nodules are encountered.

Neutron Activation Analysis of Puzolana obsidian samples at MURR

Sample preparation

Two artifacts and ten source samples attributed to Puzolana were analyzed by NAA in this study. The two artifacts (*i.e.*, PUE1 and PUE7) are obsidian flakes from the site of Puente Cave. PUE1 was found in Zone XIII (12-6), while PUE7 was recovered from Zone XII (12-5a). Garcia Cook and MacNeish (1981:105) estimate the date of these zones as 6900±150 BC and 6500±200 BC, respectively. Both were originally analyzed at Lawrence Berkeley Laboratory and classified as belonging to the Ayacucho Type (Burger and Asaro 1977:61). Four source samples from the Chupas exposure and six source samples from the Cerro Campanayocc exposure were analyzed for the first time for comparison with the two obsidian artifacts from Puente Cave. All twelve samples in this study were prepared for neutron activation analysis by first cleaning the surfaces using tap water and a toothbrush. Acetone and ethyl alcohol were used to remove all identification markings made with ink and/or fingernail polish from the surfaces. The cleaned specimens were cut with a diamond-edged trim saw and gently reduced to smaller fragments of 10-25 mg size using a clean ceramic mortar and pestle. Individual fragments were sorted under a magnifying glass to remove those with inclusions, crush fractures, or metallic streaks. Analytical samples were prepared for the two separate irradiations procedures employed at MURR by weighing them into the polyethylene vials and quartz vials used for short and long irradiations, respectively. For the short irradiations, a 100 mg aliquot of fragments was used, and for long irradiations, a 250 mg aliquot of fragments was used. In both instances, sample weights were recorded to the nearest 0.01 mg. Along with the source samples, reference standards were similarly prepared from SRM-278 Obsidian Rock and SRM-1633a Fly Ash (Glascock *et al.* 1998).

Irradiation and measurement

Neutron activation analysis of obsidian at MURR involves one or two irradiations followed by one or three measurements, respectively, to measure between 6 and 27 elements. The first procedure employs a short irradiation in sequential fashion of the samples in polyethylene vials for five seconds in a neutron flux of 8×10^{13} n cm^{-2} s^{-1} followed by a 25 minute decay and 12-minute count with a high-purity germanium (HPGe) detector. By measuring the emitted radioactive gamma rays and comparison to the standards, the concentrations of up to six elements (*i.e.*, Ba, Cl, Dy, K, Mn, and Na) can be determined. This short irradiation procedure at MURR is frequently called our abbreviated-NAA procedure and is often satisfactory to determine sources for a large percentage of artifacts in most geographic regions (see Glascock *et al.* [1994] for more information). The second procedure involves a long irradiation of the quartz vials in batches of approximately 30 unknowns along with standard refer-

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[2] The outcrop of obsidian at Chaupiorcco has not been sampled, but the presence of hydrothermal activity there may have had a negative impact on this deposit of volcanic glass.

ence materials for 70 hours in a neutron flux of 5×10^{13} n cm^{-2} s^{-1} which is followed by a pair of measurements. The first count after long irradiation occurs one week after the end of irradiation for 2000 seconds and the second count takes place about four weeks later for three hours on each sample and standard. The long irradiation procedure enables measurement of seven elements during a first count: Ba, La, Lu, Nd, Sm, U, and Yb; and fifteen additional elements during the second count: Ce, Co, Cs, Eu, Fe, Hf, Rb, Sb, Sc, Sr, Ta, Tb, Th, Zn, and Zr.

Results

The individual NAA data listing element concentrations for the ten source samples and the two artifacts from Puente Cave attributed to the Puzolana Source are shown in Table 1. Table 2 lists the means and standard deviations for the specimens. It is notable that relative to other obsidian sources in Peru, there is a greater spread in element concentrations for the Puzolana artifacts.[3] In particular, the elements Mn and Na often used in the abbreviated-NAA method show much larger coefficients of variation for Puzolana. Bivariate plots of Mn vs Na, Mn vs. Ba,nd Cs vs Hf are presented in Figures 6-8 showing the Puzolana artifacts relative to other obsidian sources in Peru. The plot with the short-lived elements Mn and Ba in Figure 7 differentiates Puzolana from all sources except Andahuaylas Type A. The long-lived elements Cs and Hf plotted in Figure 8 are successful in separating Puzolana from all of the other sources. The match between the artifacts and source samples is excellent and allows the identification of the Puzolana deposit as the source of raw material for the two Ayacucho Type Obsidian artifacts tested here and the other prehistoric artifacts analyzed in the earlier LBL study.

Chemically heterogeneous sources have been documented previously in Ecuador (Asaro *et al.* 1994), Guatemala (Braswell and Glascock 1998), and other parts of the world (*e.g.* Bowman *et al.* 1973). Additional field geology would be necessary to explain the chemical heterogeneity observed in the Puzolana Source unworked nodules and the prehistoric artifacts produced from raw materials recovered at this source. Nevertheless, it has been observed that large pyroclastic eruptions resulting in massive ash-flow sheets with obsidian inclusions sometimes are characterized by chemically heterogeneous obsidian. This is the result of combining materials from different portions of a chemically zoned magma chamber (Braswell and Glascock 1998:359; Hughes and Smith 1993:85). The Puzolana Source may be an example of this process.

Discussion

The evidence presented indicates that Ayacucho Type Obsidian occurs naturally in the mid-Miocene *puzolana* layer in the form of small irregular nodules. The layer in which they can be collected stretches for at least three kilometers from near the southern edge of the modern city of Ayacucho to the hamlet of Chupas north of Chiara. Although the obsidian glass forming these nodules is of high quality, most are too small to be used for tools. The procurement of the largest nodules, measuring 3-4 cm, would have required considerable searching and/or excavation along eroded slopes. Moreover, even the largest of the nodules would not have been adequate for producing some implements. By way of contrast, nodules from the Quispisisa source in central Ayacucho near Sacsamarca, some 85 km to the south, are often ten times the dimensions of those from the Puzolana Source (Burger and Glascock 2000). This difference would have been important for many kinds of tools, including large projectile points and scrapers. It is likely that this size differential

[3] Some suggestion of the Puzolana source's chemical variability can be seen in NAA measurements reported (Burger and Asaro 1977: 65-71) for the five Ayacucho Source artifacts analyzed.

in the source material was responsible for the preference so often shown for Quispisisa obsidian, despite the considerable distance from which it had to be brought.

Despite the inherent limitations of the Puzolana Source, it was sometimes used by the hunters and gatherers of Ayacucho during the Preceramic Period, constituting eight of the sixty-six Preceramic artifacts sampled. This was true even for sites in the Ayacucho Basin located to the north of the modern city of the same name. The earliest evidence of exploitation of the Puzolana Source comes from Ac158 (Puente Cave) in the Thorn Forest Riverine Ecozone, where it appeared in zones VII, XII, XIII dated to 5050-4750 BC, 6700-6300 BC, and 7050-6750 BC, respectively (Garcia Cook and MacNeish 1981: figure 4-10). Obsidian from the Puzolana Source was also exploited by the occupants of Ayamachay in the Thorn Forest Scrub Ecozone from zone VI dated to the Chihua Phase (3600-3000 BC) (MacNeish 1981: figure 5-7) and from zone D-1 of Ac500 (Chupas Cave) in the Humid Woodland Ecozone dated to 3400-2500 BC (Vierra 1981:141, figure 5-28). At the present time, we do not know the specific locus or loci where obsidian nodules were being collected, but all four of these Preceramic sites are within 25 km of the *puzolana* layer in which the obsidian nodules can be recovered (Figure 9). Clearly, the exploitation pattern of the Puzolana Source was a local one during the Preceramic.

It is equally important that obsidian from the more local Puzolana Source was not detected in our obsidian artifact samples from four sites (Ac100 [Pikimachay], Ac300 [Ruyru Rumi], Ac335 [Jaywamachay], and Ac351 [Tukumachay]). This absence could be a function of the relatively small sample analyzed, but it is interesting that the two sites located in the High Puna Ecozone lacked obsidian from the Puzolana Source. In contrast, obsidian artifacts made of raw material from the Quispisisa Source were present at all seven of the Preceramic sites studied in Ayacucho. It is also worth noting that the obsidian flakes tested from the archaeological site of Tukumchay all came from the Quispisisa Source rather than from the nearby low-quality deposit of volcanic glass sampled by MacNeish near Tukumachay or the local Puzolana Source to the north.

In several respects, the above results are consistent with the results of our ongoing work elsewhere on obsidian procurement in the Central Andes. The findings illustrate that those very few sources of high quality obsidian that exist in Peru were located and exploited at an early date (*cf.* Sandweiss *et al.* 1998) while obsidian of low quality was systematically ignored by manufacturers of lithic artifacts. Despite the portrait of the early hunters and gatherers of the Early and Middle Preceramic Periods as leading circumscribed and isolated lives adapted to local resources, the obsidian sourcing data from Ayacucho suggests a considerable degree of contact by the early occupants with areas outside the valley.

The opportunistic exploitation in Ayacucho of a local obsidian source featuring small nodules while at the same time favoring a more distant obsidian source which featured larger nodules is similar to the pattern recently chronicled for the Carahuarazo Valley in southern Ayacucho. Residents there exploited obsidian from the local Jampatilla Source while at the same time importing large quantities of volcanic glass from the more distant Quispisisa Source (Burger *et al.* 1998).

In the Ayacucho Valley, the pattern of dual obsidian procurement from the Quispisisa and Puzolana sources continued at least until the Early Intermediate Period (1-500 A.D.). For example, the sample of obsidian (n = 12) analyzed from the late Early Horizon/Early Intermediate Period site of Chupas (Burger and Asaro 1982, 1993:211) excavated by Augusto Cruzatt included 11 samples from late Early Horizon strata. Six of these were from the nearby Puzolana Source, while five were from the Quispisisa Source. The single sample tested from the upper Early Intermediate Period layer came from the Puzolana Source. Apparently, this strategy had changed by the Middle Horizon (500-900 A.D.), judging from a large sample of obsidian flakes (n = 52) analyzed from the preeminent regional urban center of Huari (Ar 4). During this time, utilization of the local Puzolana Source appears to have been discontinued in favor of the intensive exploitation of material from the Quispisisa Source (Burger and Asaro 1977:27, 32, 36) which accounted for 96% of the obsidian utilized. To understand this shift would require an exploration of the mechanisms used for provisioning a large city such as Huari and the role of the state in these processes.

Acknowledgements

We gratefully acknowledge the assistance of José Pinilla, José Ochatoma, and Martha Cabrera during the fieldwork, and of Jay Ague in our treatment of the geological context. We also acknowledge funding from the National Science Foundation Archaeometry Program Grant (SBR 9802366) to MURR and additional support from the Yale University Provostial Research Fund. We also want to express our appreciation to Rosemary Volpe for producing the maps and to Sharon Rodriguez for assistance in the preparation of the manuscript.

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Sample ID	*Ba (ppm)*	*La (ppm)*	*Lu (ppm)*	*Nd (ppm)*	*Sm (ppm)*	*U (ppm)*	*Yb (ppm)*	*Ce (ppm)*	*Co (ppm)*
RLB355	201	18.7	0.122	12.4	2.61	5.29	0.831	37.7	0.123
RLB357	278	21.1	0.120	12.9	2.76	5.37	0.782	40.9	0.161
RLB358	279	20.4	0.113	13.2	2.59	5.53	0.802	38.3	0.154
RLB359	277	20.6	0.121	13.8	2.62	5.45	0.814	41.5	0.161
RLB360	199	19.3	0.124	11.1	2.60	5.50	0.877	38.6	0.127
RLB361	278	20.9	0.128	12.8	2.72	5.52	0.809	40.4	0.161
RLB362	204	19.0	0.123	12.3	2.61	5.66	0.878	37.4	0.129
RLB363	197	19.1	0.115	11.7	2.36	5.70	0.774	36.3	0.143
RLB364	202	19.2	0.122	12.0	2.62	5.81	0.787	38.5	0.126
RLB365	205	19.9	0.124	13.6	2.71	5.82	0.837	38.1	0.129
PUE1	234	21.6	0.110	12.3	2.26	5.59	0.755	39.9	0.159
PUE2	247	21.9	0.117	12.2	2.29	5.83	0.765	40.2	0.185

Sample ID	*Cs (ppm)*	*Eu (ppm)*	*Fe (%)*	*Hf (ppm)*	*Rb (ppm)*	*Sb (ppm)*	*Sc (ppm)*	*Sr (ppm)*	*Ta (ppm)*
RLB355	3.80	0.325	0.498	3.81	120	0.247	1.78	52	2.06
RLB357	3.70	0.360	0.524	3.85	116	0.238	1.75	76	2.03
RLB358	3.60	0.333	0.502	3.67	122	0.253	1.65	67	1.95
RLB359	3.74	0.374	0.530	3.89	118	0.243	1.77	67	2.06
RLB360	3.89	0.332	0.512	3.94	123	0.243	1.82	46	2.09
RLB361	3.67	0.354	0.520	3.81	146	0.225	1.73	69	2.00
RLB362	3.78	0.324	0.498	3.81	121	0.247	1.77	50	2.06
RLB363	3.81	0.291	0.490	3.72	118	0.247	1.63	54	1.96
RLB364	3.87	0.323	0.504	3.87	119	0.241	1.80	45	2.09
RLB365	3.81	0.332	0.508	3.93	119	0.246	1.81	47	2.08
PUE1	3.63	0.299	0.502	3.87	117	0.257	1.57	57	1.90
PUE2	3.85	0.303	0.511	3.85	118	0.264	1.59	62	1.89

Sample ID	*Tb (ppm)*	*Th (ppm)*	*Zn (ppm)*	*Zr (ppm)*	*Cl (ppm)*	*Dy (ppm)*	K (%)	*Mn (ppm)*	*Na (%)*
RLB355	0.282	14.9	35	114	674	1.58	4.32	512	2.75
RLB357	0.272	14.7	35	127	748	0.95	4.04	496	3.24
RLB358	0.258	14.1	36	115	647	1.61	3.58	443	3.40
RLB359	0.289	14.9	36	128	697	1.19	4.64	491	2.73
RLB360	0.267	15.2	36	123	767	1.24	3.81	514	3.12
RLB361	0.260	14.6	35	121	757	1.59	5.27	489	2.91
RLB362	0.262	14.8	35	129	726	1.50	4.31	507	2.94
RLB363	0.236	14.9	31	117	724	1.16	3.61	476	3.21
RLB364	0.257	15.2	35	121	646	1.69	3.50	515	3.27
RLB365	0.262	15.1	35	116	634	1.47	3.66	514	3.24
PUE1	0.226	15.2	30	129	589	0.83	3.83	453	3.16
PUE2	0.223	15.3	31	112	488	1.22	3.62	461	3.20

Table 1. Element concentrations in obsidian nodules from the Chupas and Cerro Campanoyocc outcrops of the Puzolana Source and obsidian artifacts from Puente Cave (*ppm = parts per million*).

Element	*Mean*		*Standard deviation*	*% Standard deviation*	*Minimum*	*Maximum*
Ba (ppm)	233	±	36	15.5	197	279
La (ppm)	20.1	±	1.1	5.4	18.7	21.9
Lu (ppm)	0.120	±	0.005	4.3	0.110	0.128
Nd (ppm)	12.5	±	0.8	6.2	11.1	13.8
Sm (ppm)	2.56	±	0.17	6.5	2.26	2.76
U (ppm)	5.59	±	0.18	3.2	5.29	5.83
Yb (ppm)	0.809	±	0.040	5.0	0.755	0.878
Ce (ppm)	39.0	±	1.6	4.0	36.3	41.5
Co (ppm)	0.146	±	0.020	13.5	0.123	0.185
Cs (ppm)	3.78	±	0.09	2.3	3.60	3.89
Eu (ppm)	0.329	±	0.025	7.5	0.291	0.374
Fe (%)	0.508	±	0.012	2.3	0.490	0.530
Hf (ppm)	3.84	±	0.08	2.1	3.67	3.94
Rb (ppm)	121	±	8	6.5	116	146
Sb (ppm)	0.246	±	0.010	4.0	0.225	0.264
Sc (ppm)	1.72	±	0.09	5.1	1.57	1.82
Sr (ppm)	58	±	10	18.0	45	76
Ta (ppm)	2.02	±	0.07	3.6	1.89	2.09
Tb (ppm)	0.258	±	0.020	7.9	0.223	0.289
Th (ppm)	14.9	±	0.3	2.3	14.1	15.3
Zn (ppm)	34	±	2	6.5	30	36
Zr (ppm)	122	±	6	5.2	112	129
Cl (ppm)	675	±	81	12.0	488	767
Dy (ppm)	1.34	±	0.28	20.9	0.83	1.69
K (%)	4.02	±	0.53	13.2	3.50	5.27
Mn (ppm)	489	±	26	5.2	443	515
Na (ppm)	3.10	±	0.21	6.9	2.73	3.40

Table 2. Descriptive statistics for ten source geologic samples from the Puzolana Source and two artifacts from Puente Cave (*ppm = parts per million*).

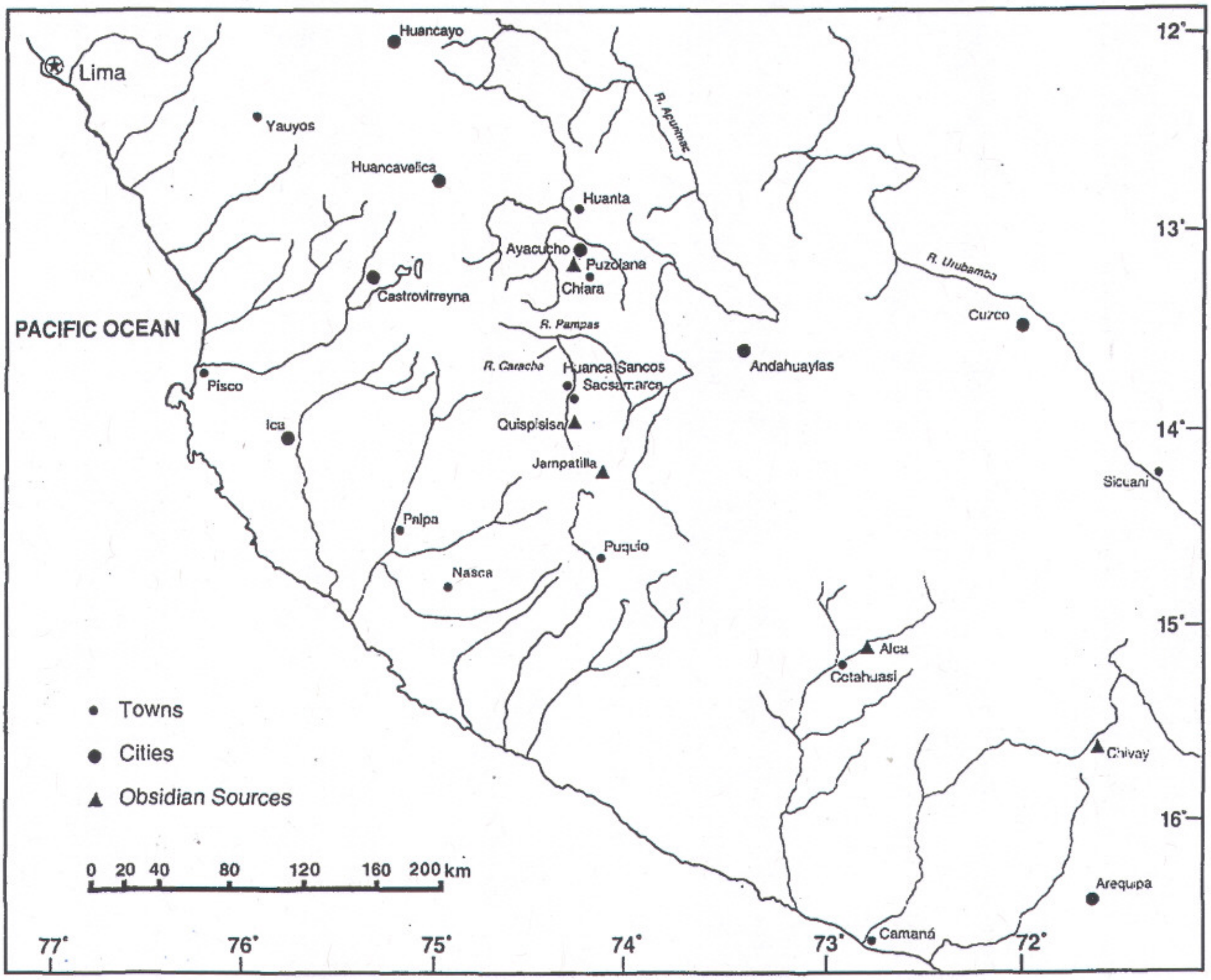

Figure 1. Map of Peru's southern highlands illustrating the location of the Puzolana Source and the other geographical features mentioned in the text. *Map by Rosemary Volpe.*

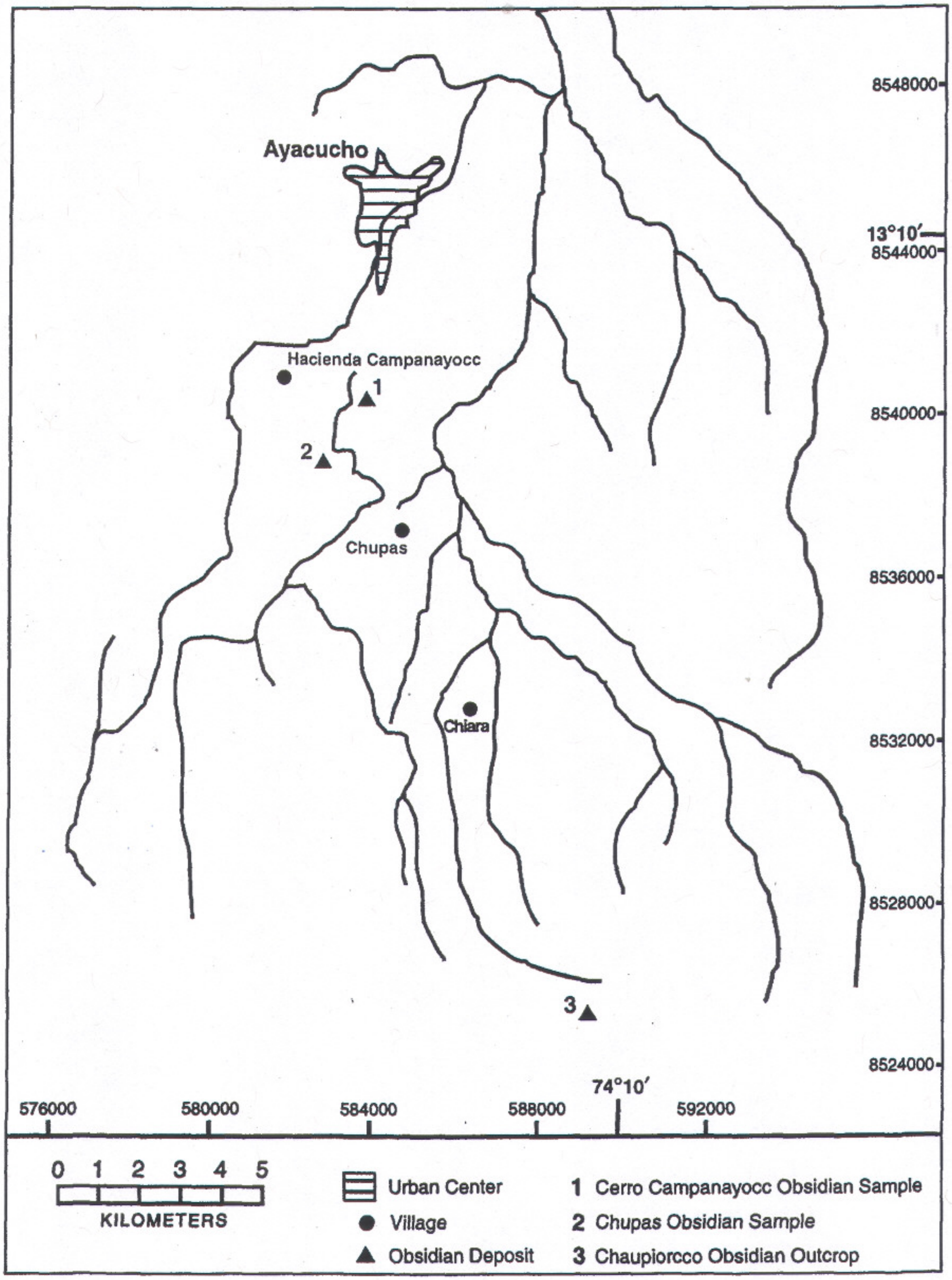

Figure 2. Detail map showing the loci where nodules of the Ayacucho Type were recovered and indicating the extent of the geological stratum referred to as the Puzolana Source. *Map by Rosemary Volpe.*

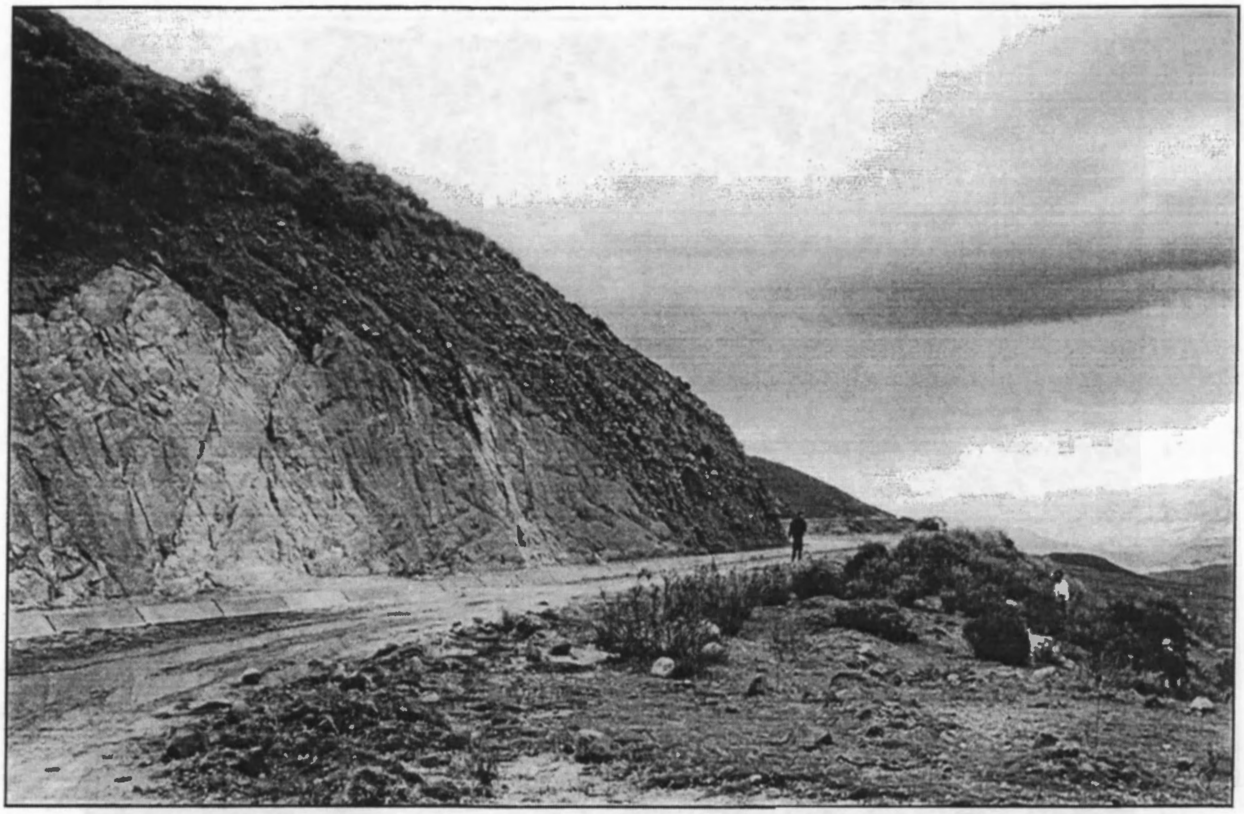

Figure 3. Viewed near the village of Chupas, the thick *puzolana* stratum is cut by the Cachi Canal and overlain by glacial deposits. The Ayacucho Basin is visible in the distance. *Photograph by Richard L. Burger.*

Figure 4. At Cerro Campanayocc, immediately to the south of the city of Ayacucho, the same *puzolana* stratum was found to contain obsidian nodules similar to those recovered at Chupas. *Photograph by Richard L. Burger.*

Figure 5. The largest size grade of the obsidian nodules collected from the *puzolana* layer above Chupas. *Photograph by William Sacco.*

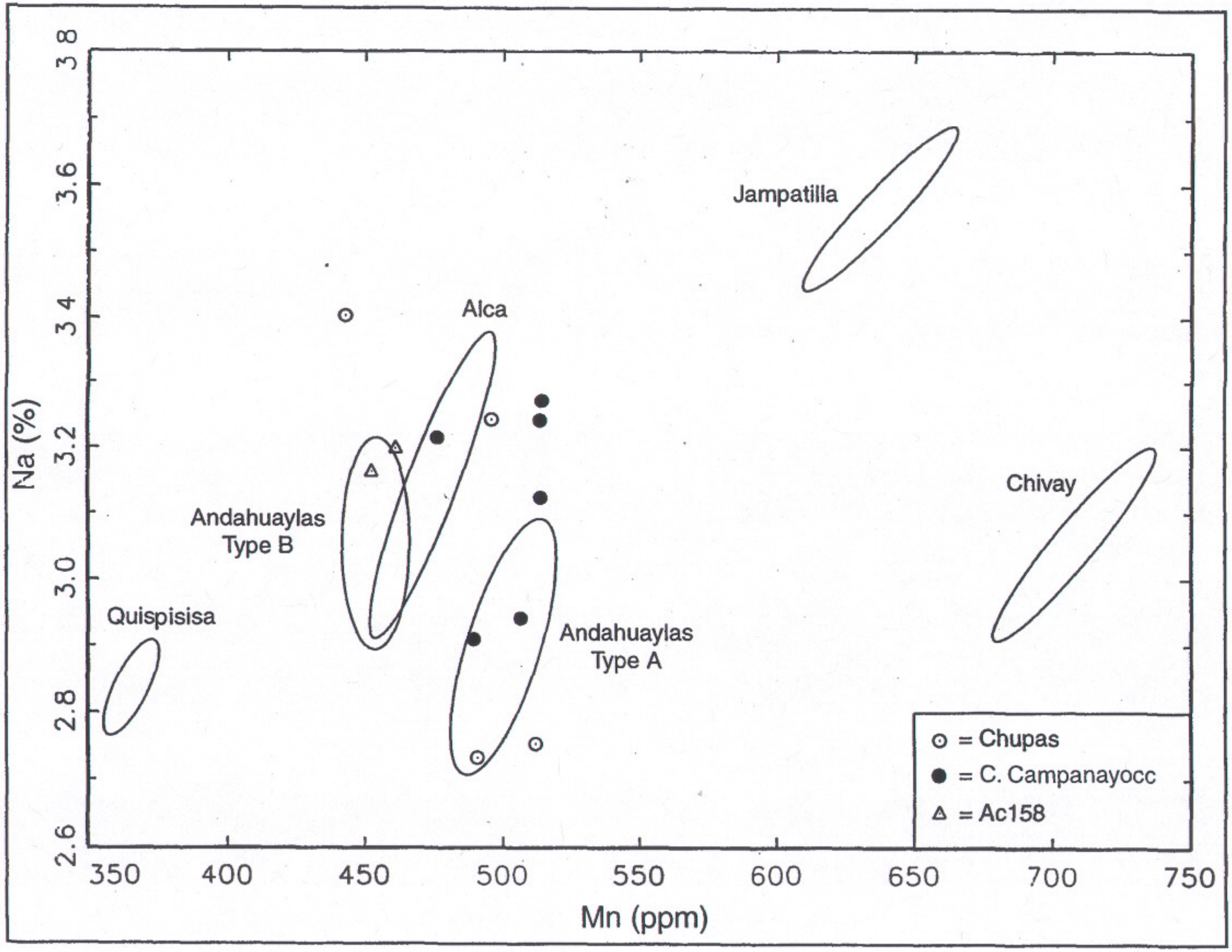

Figure 6. Bivariate plot of Mn versus Na for Puzolana Source specimens and artifacts relative to other obsidian sources in southern Peru with 95% confidence ellipses surrounding each source group except Puzolana. (No ellipse has been generated for Puzolana in this graph because of the source's extreme heterogeneity.)

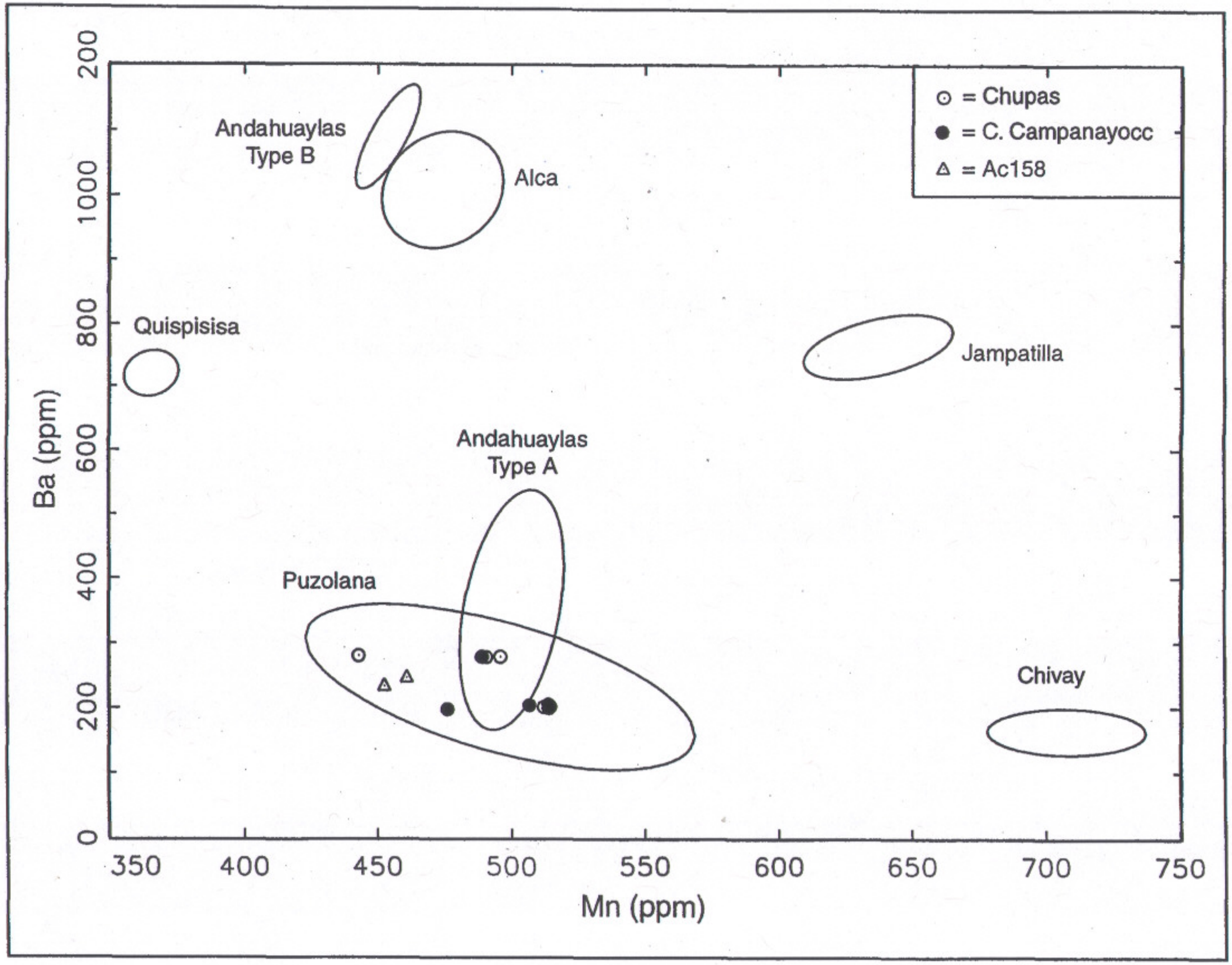

Figure 7. Bivariate plot of Mn versus Ba for Puzolana Source specimens and artifacts relative to other obsidian sources in southern Peru with 95% confidence ellipses surrounding each source group.

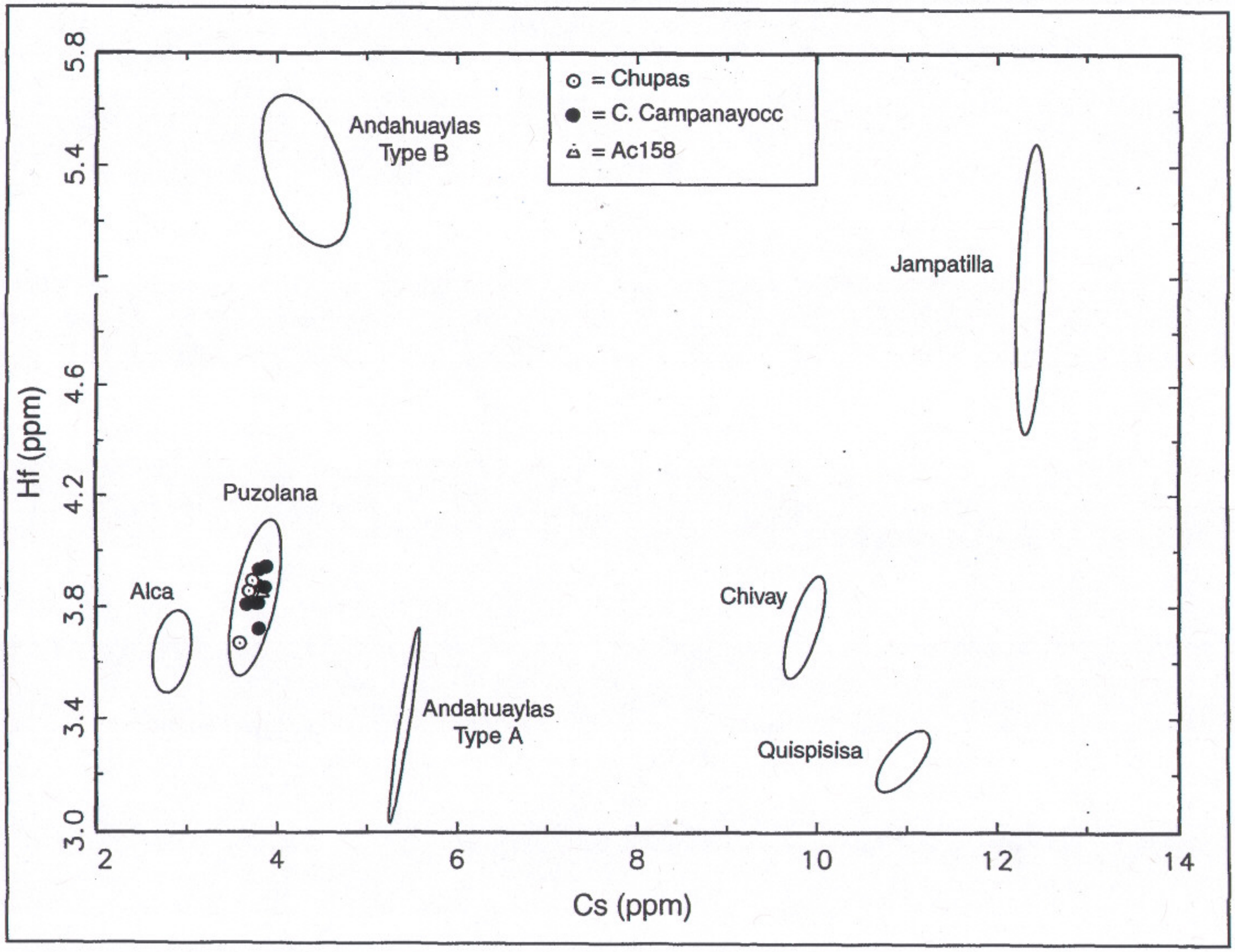

Figure 8. Bivariate plot of Cs versus Hf for Puzolana Source specimens and artifacts relative to other obsidian sources in southern Peru with 95% confidence ellipses surrounding each source group.

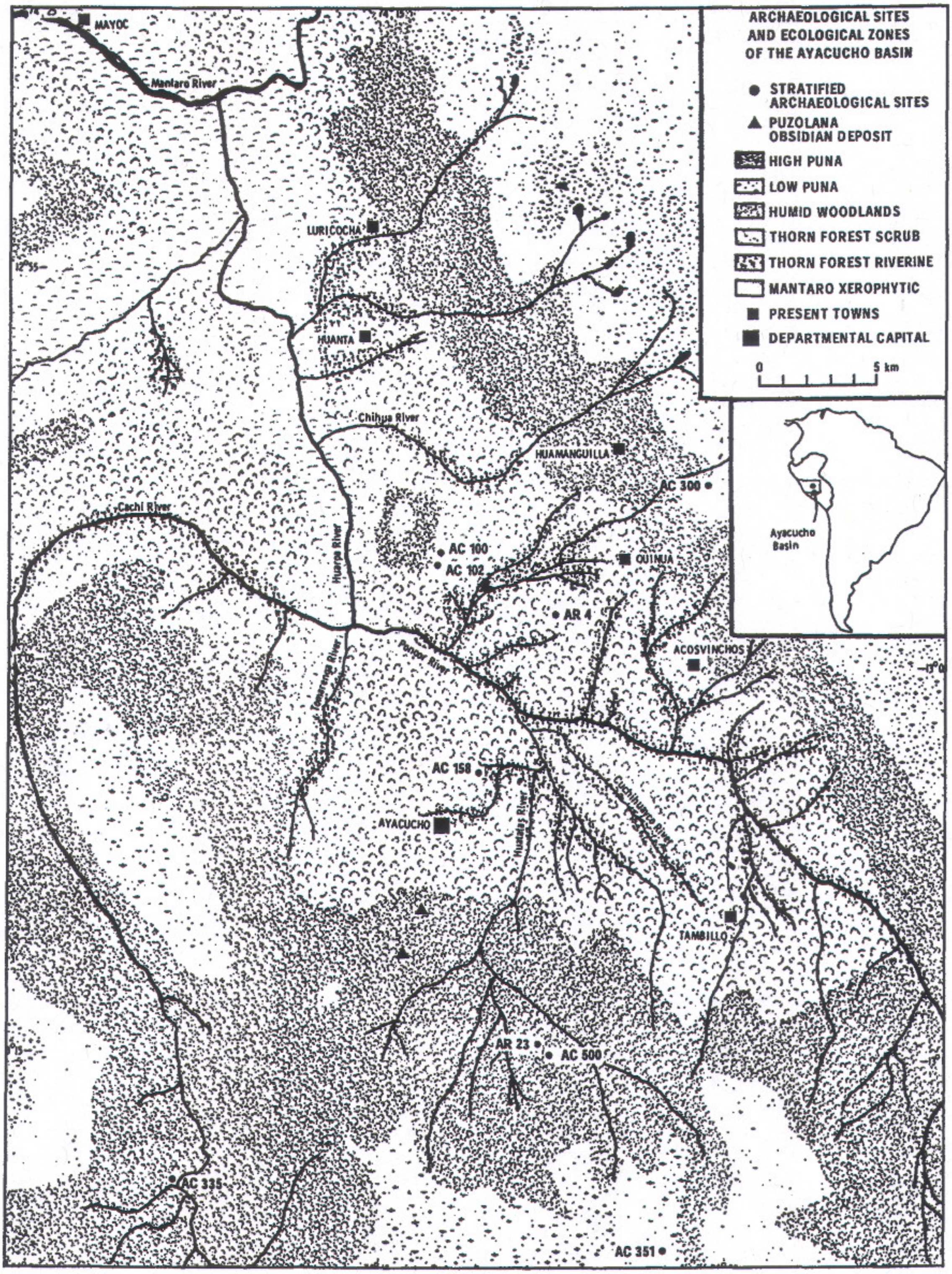

Figure 9. Location and ecozones of Preceramic sites excavated by the Ayacucho Huanta Archaeological Botanical Project in relation to the Puzolana Obsidian Source (after MacNeish *et al.* 1975: figure 1).