The Alca Obsidian Source: The Origin of Raw Material for Cuzco Type Obsidian Artifacts

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Background

A collaborative study of the provenience of prehispanic obsidian artifacts from the Central Andes was initiated at the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL) in 1974 by archaeologist Richard L. Burger and nuclear chemists Frank Asaro and Helen V. Michel. During the first stage of this joint research (1974-1975), obsidian samples from 141 archaeological sites in Peru and Bolivia were studied. Thanks to the support of the US Energy Research and Development Administration, it was possible to analyze 812 artifacts by X-ray fluorescence (XRF) and 141 by instrumental neutron activation (INAA); these results constituted the first published consideration of obsidian source provenience and exchange in the Central Andes (Burger and Asaro 1977, 1978, 1979). INAA was utilized because of its high precision and accuracy for a large number of elements. The XRF technique was of lesser accuracy but acted to minimize the expense of running large numbers of samples from sites spanning the gamut of space and time. The source assignments by XRF were considered provisional until assignments of each representative source were confirmed by INAA; where ambiguity in XRF results existed, samples were rerun for definitive assignment using INAA.

In this initial study, eight major chemical types of Peruvian obsidian exploited in antiquity were identified on the basis of these analyses. Ninety-eight percent of the artifacts analyzed belonged to eight chemical groups, but at that time, only one group could be linked with samples said to come from a geological deposit of obsidian: the Quispisisa Source. These specimens were provided by Rogger Ravines from a quarry said to be near San Genaro in the south-central highlands of Peru. Five of the other types of obsidian, although not linked to specific deposits, had distributions that were limited to particular regions in our sample; this patterning suggested possible areas in which the sources might be located and provided the basis for the provisional names of the major chemical types (*i.e.*, Acarí Type, Andahuaylas A Type, Andahuaylas B Type, Ayacucho Type, Pampas Type). Two types of obsidian with unknown sources were present at archaeological sites in more than one region, and the provisional names of Cuzco Type and Titicaca Basin Type were assigned to them based on the areas where these chemical types most commonly occurred judging from our preliminary results. Of the obsidian artifacts analyzed in the initial study, the vast majority (81%) of the artifacts belonged to one of three groups: the Quispisisa Source, the Cuzco Type, and the Titicaca Basin Type. Artifacts of each of these three kinds of obsidian were distributed over a relatively broad geographical area, suggesting that obsidian from these sources was widely exchanged in pre-Hispanic times.

Despite explorations by Burger in the summer of 1974, the collaboration of Peruvian and U.S. archaeologists, and the dissemination of the findings in Spanish and English, little progress was made in identifying the unknown

source areas. Considering the state at that time of non-economic geology in highland Peru and the limited vehicular access to the high altitude zones where obsidian deposits occur, this was not surprising. Obsidian deposits were discovered at Sachaca and Yuri near the city of Arequipa by José Antonio Chávez Chávez and near Tukumachay, Ayacucho by the Ayacucho Basin Project directed by Richard S. MacNeish, but analyses of samples from the three deposits by INAA at LBNL showed that they were chemically dissimilar from the types of obsidian utilized for pre-Hispanic artifacts in these and other regions (Burger and Asaro 1977:65, 1979:315). Subsequently, a fourth obsidian deposit on Mt. Chachani in Arequipa was sampled by Chávez but it likewise did not match any of the chemical compositions of artifacts.

A second set of Peruvian obsidian was studied at LBNL in 1977/1978 with the support of the University of California Archaeological Research Facility, US Department of Energy, and NSF. Approximately 500 additional artifacts were analyzed using XRF and INAA, including samples from northern and southern Peru which had not been sampled previously. Thus far, only a portion of these results have been published (*cf* Burger 1980, 1981, 1984; Burger and Asaro 1993; Burger *et al.* 1984). In this second stage of research, 99% of the obsidian artifacts sampled came from the chemical types defined in the earlier study. The Rare 1 chemical type defined in the original study proved to be common at sites near the Peruvian-Bolivian border and it is now referred to as the Tumuku Type. One additional obsidian chemical group, provisionally dubbed the Chumbivilcas Type, was identified for the first time in the 1977/1978 study. The Tumuku Type and the Chumbivilcas Type are now considered as the ninth and the tenth chemical types of obsidian intensively utilized in pre-Hispanic Peru. This second round of research confirmed our earlier impression that high quality obsidian sources are uncommon in Peru. Nevertheless, the number of obsidian sources utilized in pre-Hispanic Peru far exceeds those exploited in neighboring Andean nations such as Ecuador (Burger *et al.* 1994; Asaro *et al.* 1994). Finally, it appeared after the second stage of research that most of the major chemical types exploited by prehistoric populations in Peru probably have now been delineated in the LBNL studies.

Locating the Geological Deposits of Cuzco Type Obsidian

The 1974/1975 and 1977/1978 studies at LBNL described above found that artifacts of the Cuzco Type constituted the overwhelming majority of the obsidian utilized in the Cuzco Valley (over 90% in most periods); obsidian of this chemical type also appears in low quantities in the Lake Titicaca drainage. Cuzco Type obsidian artifacts were rarely found in areas outside of the southern highlands of Peru. These findings suggested that the geological source for Cuzco Type obsidian should be sought in the Cuzco basin or in adjacent regions from which samples of archaeological artifacts of obsidian were not available.

In 1981, the mother of Peruvian archaeologist Isaac Pérez Angulo visited a possible primary source of geological obsidian located near the village of Yumasca on the northern slopes of Cerro Santa Rosa above the Cotahuasi River (also known as the Huarcaya River) in the northern portion of the Department of Arequipa (Figures 1 and 2). Sra. Angulo de Pérez collected a sample from an unmodified "obsidian boulder" for her son who then provided it to one of us (Richard L. Burger) for analysis. Preliminary studies at LBNL of two flakes from the boulder using XRF in 1984 suggested a chemical match with the Cuzco Type. These results pointed to the need for a more reliable sample at the putative obsidian deposit.

In July of 1984, Paul Trawick, at R.L. Burger's suggestion, was able to visit the obsidian source area during his long-term anthropological research in the Cotahuasi region. Trawick's visit confirmed the existence of a geological deposit of obsidian in the area near the town of Alca and he provided samples to Burger for analysis. The source samples were analyzed by INAA at LBNL in 1994. As re-

ported here, the results of these INAA analyses confirmed the match with the Cuzco Type artifacts. Although the discovery of the deposit in the Yumasca area has been mentioned previously (Burger and Asaro 1993:219-220), this article provides the first extended treatment of the geological source and the analytical results that permit a definitive identification of the Alca deposit as the source for the Cuzco Type obsidian.

The Alca Source: Location And Geology

The Alca source (2850 meters above sea level, masl) is located about 1 km west of the village of Alca, Cotahuasi Province, Department of Arequipa (Figure 2). The obsidian deposit at Alca has a general location of 15°8'31" S latitude, 72°45'30" W longitude. It is found 16 km to the northeast of the provincial capital at Cotahuasi and about 190 km northwest of the departmental capital, Arequipa. The city of Cuzco is located about 195 km to the northeast of Alca (Figure 1).

The headwaters of the Cotahuasi River lie on the upper slopes of the western face of the continental divide and its waters ultimately join with those of the Chicha River and the Morán River to form the Ocoña River before draining into the Pacific. Midway along its course, the Cotahuasi enters a chasm believed to be the world's deepest canyon (approximately 3,000 meters from rim to bottom, excluding the adjacent mountains, about twice the depth of the Grand Canyon). The ensuing arid gorge cuts off the densely settled highland drainage in which Cotahuasi and Alca are located from the distant lower valley of the Ocoña (Trawick 1994:24-27). The Cotahuasi area is located in a region of ancient volcanic eruption and tectonic uplift which extends far to the south, through the Departments of Arequipa and Tacna. In the Cotahuasi area, almost the entire Tertiary was dominated by volcanic processes which continued into the Quaternary. These processes were responsible for most of the rocks and topography of the area, although the landscape was modified by subsequent glacial activity (Olchauski and Dávila 1994). The modern village of Alca (2750 masl), like that of Cotahuasi (2683

masl), sits atop post-Pleistocene alluvial deposits which fill the narrow valley that had been eroded into earlier volcanic deposits by the Cotahuasi River. Located on the southern bank of the Cotahuasi River, Alca is overshadowed by cliffs and steep slopes of the older volcanic deposits which culminate 15 km to the east in the glaciated volcano Nevado Firuro (5498 masl). Large chunks of obsidian are found near Alca among the terraces along the valley bottom; they are the result of erosion from the source area above.

Trawick recovered the *in situ* obsidian source samples to the west of Alca, immediately below the annex of Cahuana. In this area, erosion had exposed Tertiary deposits, including a thick band full of rather densely concentrated obsidian nodules. This layer was exposed in a cliff face of a plateau that rises 200 m above the valley bottom. Immediately above the plateau and above the village of Cahuana is a pre-Hispanic ruin believed to be the Inca administrative capital of the area. The cliffs are composed of poorly-consolidated volcanic tuff, interspersed with nodules of obsidian; the largest observed by Trawick measured about 60 cm on a side, but many measured only 20 cm. The obsidian becomes evident as soon as one approaches the cliffs from the agricultural terraces on the left-hand side of the road. Many nodules lie among the eroded rocks and debris at the base of the escarpment. Looking up the cliff face, one can see that obsidian nodules are distributed rather evenly up to a point about 100 meters above the valley bottom, where a darker layer of rock and sediment is found. The obsidian samples tested at LBNL were taken from the layer of obsidian nodules itself (rather than the talus), 40 m to the left of a cave or a large hole where the material may once have been mined. This area contained a dense concentration of larger obsidian nodules, some black, others brown or red, and some multicolored.

It appears that the obsidian deposit extends all around the pueblo of Alca and up the Chococco River, a tributary of the Cotahuasi River. Trawick estimates that the deposits probably run for at least 1-2 km. Future investigation will be necessary to define more

precisely the extent of the deposit and to locate areas of pre-Hispanic quarrying and workshop activity.

The obsidian deposits occur within a Tertiary formation known as the Tacaza Group, dating to the Miocene. The Tacaza Group generally has a varied lithology, but it mainly corresponds to volcanic rocks, particularly pyroclastics, mixed with sediments; these deposits can reach 1500 meters in thickness. In the area around Alca, strata of the Tacaza Group also include ignimbrites and dacites. Studies of the Tacaza Group in the Orcopampa area to the east of the Cotahuasi quadrangle suggest a date of approximately 18.9-19.1 mya for this formation (Olchauski and Dávila 1994:24-26). It is worth noting that although the geology of this area is the subject of a recent monograph by Peru's Instituto Geológico Minero y Metalúrgico, this volume makes no mention of the obsidian deposits. This omission illustrates the ongoing need for problem-oriented fieldwork to locate the obsidian sources utilized in pre-Hispanic times.

Neutron Activation Analyses At LBNL

Two of the samples from the Alca Source collected by Trawick were analyzed at LBNL using INAA. These were obtained *in situ* from an exposed deposit of obsidian nodules referred to previously. The two samples, given the code names Rosa-1 and Rosa-2, were collected from the same band about 15 meters apart. The samples were measured utilizing the Luis W. Alvarez Iridium Coincidence Spectrometer (LWAICS) which produces more precise results for a number of elements than could be obtained by the INAA methodologies used at LBNL in the 1970s and early 1980s. Because of unusual laboratory problems, including unavoidable changes in the preparation room and ventilation system previous to sample preparation, it was necessary to go to special lengths to check levels of contamination that might arise in our samples, as well as to determine what precision was attainable.

Sample Preparation

Chips of obsidian were struck off each obsidian chunk with a plastic hammer with the sample completely shielded with plastic. The obsidian chips (from the interior of the chunks when possible) were ground to a rough powder with an agate mortar and pestle. The rough grinding was probably not sufficient to homogenize the samples. Samples of 50 or 100 mg weight were encapsulated in 0.020 cm thick Al foil, which was rated by its manufacturer as 99.9999% pure. The Al capsules were swabbed clean twice (three times if the samples were expected to contain Ir) with a cotton Q-tip wet with 200 proof ethyl alcohol. The purpose was to remove loose extraneous dust from the capsule surfaces which could become radioactive when irradiated and contaminate the LWAICS. The cleaned capsules were stacked in a quartz tube along with standards of Standard Pottery (Perlman and Asaro 1969), used for most elements, and DINO-1 (Alvarez *et al.* 1980) used for Ir, Se, and Zn. There were 9 quartz tubes in the irradiation, each containing 42 samples, and there were standards of about 24 and 50 mg weight at the bottom, center, and top of the tube containing the Alca source obsidian. The tubes were heated to about 190°C for several hours to drive off excess water from the samples. Later the tubes were heat-sealed under vacuum to reduce pressure build-up during irradiation in case residual water vaporized or CO_2 was emitted from carbonates. Each sealed tube was tightly wrapped with Al kitchen foil to facilitate heat transfer away from the tubes and the entire cluster of 9 tubes was wrapped with Al kitchen foil for the same reason. The samples were irradiated for 48 hours in the 10 mW Triga reactor of the University of Missouri at Research Park in Columbia, Missouri at a flux of 2.5×10^{13} neutrons per second per cm^2. Samples cooled for about one month, in which radioactive isotopes with half-lives much shorter than one month decayed away, and then the samples were returned to LBNL. One month was spent measuring standards, calibrating, checking interferences, and evaluating precisions, and then measurements on the samples were begun. Before measurement, each Al capsule was swabbed clean again

twice (three times if they were expected to contain significant Ir). The purpose of the cleaning was to remove any contamination which might have occurred if one of the sample capsules leaked, as well as any residual dust not removed in the cleaning before irradiation.

Methodology

The LWAICS is a gamma ray analyzer designed especially to measure abundances of the element iridium with high sensitivity (Alvarez *et al.* 1988; Michel *et al.* 1990, 1991). It also has been adapted to the measurement of other elements simultaneously with the Ir determination. It consists of two intrinsic 5 cm long by 5 cm diameter germanium detectors whose faces are 20 mm apart, and in that space are two high voltage shields, two vacuum seals, two temperature shields, a sample track, and the sample capsule which is being counted. Measurements generally can be made by gamma ray singles determinations or by coincidence measurements with two gamma rays with or without an anti-Compton shield (which can reduce the background of scattered radiation under the peaks). We used one detector, arbitrarily designated the B detector, for all of the singles measurements because its resolution was significantly better than that of the A detector. In the present experiments the anti-Compton shield was not used. The position of the capsule between detectors A and B can vary sufficiently to change the counting geometry in detector B for single measurements by about 2% and create that much uncertainty in the singles measurements. To remove this uncertainty, the intensity of the 1121 keV gamma ray of ^{46}Sc was measured with both detectors A and B for each sample, and from geometric considerations, the ratio of the intensities indicated the exact relative position of the capsule between the two detectors. For coincidence measurements with both detectors A and B, the geometry effects compensated and no corrections were necessary. Also small variations in position in the radial direction do not necessitate any corrections.

Pulsers feed into each detector and the ratio of the B detector output to the pulser input rate is roughly the singles detector efficiency. This ratio has an exponent parameter (0.929) that was evaluated empirically by comparing results with samples of known abundances but half or less of the counting rate of the standards. The coincidence efficiency is roughly the product of the A and B detector ratios. The B detector ratio for coincidence measurements also has an exponent parameter which was adjusted empirically to give the same answers for coincidence measurements as single measurements on ^{46}Sc radiations. This parameter, however, was dependent on the sample counting rate and in this work varied between 0.426 for samples counting less than 25,000 counts per second (cps) to 0.445 for samples counting 36,000 cps.

Results

Table 1 shows the results of our measurements for the 10 diagnostic elements measured in the two samples of Alca Source obsidian. The precisions of measurement, accuracies, and reasons for deciding that these particular elements were diagnostic are given later in this paper.

The average difference in abundance between the two source samples was 1.7% for the 9 elements with counting errors of about 1% or less and 1.6% for the 7 of those elements that were previously (Burger and Asaro 1977) well-measured in Peruvian artifacts belonging to the Cuzco Type chemical group. The average differences in abundance for the Rosa-1 and Rosa-2 source samples from Alca with the Cuzco Type artifact group are 1.7 and 2.1%, respectively. These are excellent agreements and demonstrate that the obsidian deposit in the Alca area is the source of the Cuzco Type chemical group. The extent to which we can distinguish between the samples of obsidian collected fifteen meters apart is discussed in the following sections.

Backgrounds And Contamination

We measured the background radiation in the LWAICS and calculated the background

for each sample from the sample weight. Table 2 shows the background levels for a nominal sample weight of 55.4 mg, the average of our two obsidian samples from Alca.

In order to determine the impurities in the 99.9999% pure Al foils and any we might have introduced in the laboratory, we ran 10 blank Al capsules with no samples inside them. In addition we unwrapped the two measured irradiated samples of Alca Source obsidian, split each one, repackaged them in non-irradiated Al, and remeasured each split. Table 2 also shows the mean and root-mean-square deviation for 14 elements in the 10 Al foils and the values for the Al capsules which contained samples Rosa-1 and Rosa-2 during the irradiation and initial measurements. The effect of residual obsidian powder in the Al capsules was determined from the abundances of those elements not expected to be impurities in Al, *e.g.*, Cs, Th, and Hf.

The weight of Al was assumed to be constant for each sample, and the constancy of the measured weights of the blank Al foils suggest that this assumption is accurate to 1%. Likewise the Sc abundance (which has a very small counting error) in the Al foils was constant to 1%, which suggests the Sc is indeed inherent within the Al foil from which the capsules are made. The data suggest that the Al foils also contain impurities of Zn, Co, Fe, and Sb with possible laboratory contaminations of some Sb and some Zn. The Se, however, appears in large part to be due to laboratory contamination.

Precision of Measurement

The gamma rays used are shown in Table 2. Tests on other obsidian have shown our overall results to have a precision for the best measured elements of the larger of 1% or the counting error. The present work discussed below is consistent with that determination.

Precisions can be an indicator of how closely artifacts should agree with very homogeneous sources if: 1) the artifacts originated from those sources; 2) both sets of measurements were calibrated with the same standards; 3) the same abundances were used for the standards; and 4) both sets of measurements were made in the same laboratory by the same techniques and methods. The highest quality comparisons can be made when artifacts and source samples are run in the same irradiation against exactly the same standard measurements.

If different values for standard abundances are used, but the standards were the same, it is a simple matter to recalibrate the results so that the same abundances were used for all standard measurements. If the same standards are used by two laboratories and the same abundances in the standards are used, the poorer of the precisions of measurements of the two laboratories for any element may be used as rough indices of what type of agreement one should expect. But measurement methodologies are usually not exactly the same, and differences can introduce discrepancies. Although we speak of average precision in this work, in reality each element has independent problems and should be considered independently. In comparing the present work with the LWAICS to previous INAA studies made at LBNL with conventional equipment, the methodology is different and the precisions are different. Generally, with the exception of those elements measured in the previous LBNL work with a very small high-resolution detector, *e.g.*, Eu, Hf, Yb, and Ta, the precisions of the LWAICS measurements should be better than those of the earlier LBNL work.

In the past we have used Ce abundances for determinations of provenience with the LWAICS. These abundances are measured with radiations from ^{141}Ce, which contain a component from the fission of ^{235}U. As we do not currently measure U abundances with the LWAICS, we cannot evaluate and remove the fission correction, which usually is about 0-3 parts-per-million (ppm). We can compare results quantitatively without correcting for fission if they are measured with the same reactor. Otherwise, as different reactors can produce slightly different proportions of ^{141}Ce due to ^{235}U fission, we would not expect exact agreement between uncorrected Ce abun-

dances of artifacts and the sources (irradiated in different reactors) from which they originated. In the present work, we are trying to measure with higher precision than previously and do not use uncorrected Ce abundances in the provenience determination.

Accuracy

When comparing results between two laboratories using different standards, the uncertainties in the abundances in the standards must be considered as well as the precisions of measurement. The last column of Table 1 shows the abundances of the elements in the standards used in the present work and also the one sigma estimates of the uncertainties in those abundances. In order to determine the percentage accuracy of our measurements, the square root should be taken of the sum of the squares of the precision (in percent) and the uncertainty in the standard (also in percent). Intercalibration between laboratories, which can greatly reduce these differences, becomes a necessity for precise work, but the intercalibration error must be carefully evaluated (Stross *et al.* 1983).

The samples Rosa-1 and Rosa-2 were each removed from their Al encapsulating foils, split into two portions and each portion re-encapsulated in non-irradiated Al and remeasured. (As indicated earlier, the irradiated Al foils were also measured.) The data are shown in Table 3. Selenium and Sb, which had previously been shown to be inordinately high in the Al foils from Rosa-1 and Rosa-2, are also variable in abundance in the splits of Rosa-1 and probably Rosa-2. We therefore consider that Se and Sb were probably contaminants in the samples introduced in the sample preparation procedure. Hafnium, which did not appear as a large contamination on the Al foils, definitely has different abundances in the splits of Rosa-1 and of Rosa-2. To demonstrate that this deduction is correct, we included in Tables 2 and 3 the independent determination of Hf abundances by both singles measurements with the 482 keV gamma ray and coincidence measurements with the 482 and 133 keV gamma rays. We concluded that part of the Hf was probably also a laboratory

contaminant in these experiments and did not use Hf for the provenience determination.

The abundances measured in split irradiated samples can be higher than the abundance before splitting, if volatile material, such as water, escaped from the samples during irradiation. On the other hand abundances can be lower if any extraneous bits and pieces of Al foil became mixed with the sample powder during splitting. However, all elements will be affected the same way by either of these two processes. By taking ratios of abundances both problems can be removed, and any error associated with weighing samples is removed. Table 4 shows the abundances of the parent and the split samples, all normalized to the abundance of Sc, 1.95 ppm, in the Cuzco Type chemical group of artifacts. For each element in Rosa-1 and Rosa-2 the mean value from the three measurements is calculated and also the root-mean-square deviation (RMSD). The square of the average counting error from the three measurements is subtracted from the square of the RMSD and the square root of this value divided by the mean abundance is an index of some of the residual errors of measurement. The residual error could reflect errors in sample positioning, improper subtraction of interfering elements which decay at different rates than the element of interest during the course of the measurement regime, heterogeneity in a 50 mg sample due to contamination or (infrequently) natural geochemical variations in obsidian, or measurement problems not yet understood at the level of precisions of a few tenths of a percent. Because the residual errors are so small, <0.7% for the best measured selected elements, we deduce that we probably do not have contamination problems for these elements. As Rb and Co, with larger counting errors than 1%, have root-mean-square deviations comparable (actually fortuitously smaller) than the counting errors, they also are unlikely to be contaminants at the levels at which they are measured.

There are other errors in addition to the residual error that affect the precision, such as errors in weights, in evaluations of gamma-ray efficiency as a function of radiation gross

count rate, and in evaluations of gamma-ray interferences. We estimate our precision to be about 1% on the average for the best measured elements. For nearly ideal comparisons, such as those made in Table 4, however, the root-mean-square deviations divided by the means average 0.50%, and this value can be used instead of 1%. The differences in element abundances are not significant at the 0.5% level [(Rosa-2 - Rosa-1)/Rosa-1] except for those of Fe and possibly Zn which differ by -2.4 and +1.6%, respectively. Cobalt and Rb (with counting errors greater than 1%) also appear to have larger deviations, 8.6 and 3.2% respectively, than expected from the counting errors. These deviations suggest a difference in element abundance pattern between the two samples collected 15 meters apart.

Three more samples of Yumasca source obsidian, Rosa-3, Rosa-4, and Rosa-5, were measured following an irradiation made about 11 months after Rosa-1 and Rosa-2 were irradiated. For the 8 elements with counting errors of less than 1% shown in Table 1, the average coefficient of variation for Rosa-3, Rosa-4, and Rosa-5 was only 0.6%, and the average difference from the Rosa-2 abundances was only 1.2%.

Archaeological Considerations

From the outset of our research over two decades ago, our approach to obsidian exchange has employed a pan-regional framework. This has generated a broad data base that permits the inference of shifting patterns of interaction which crosscut traditional cultural boundaries and ecological zones. This approach has also facilitated the location of the geological sources of raw material for obsidian artifacts. The determination that the Alca Source provided the obsidian for those communities using Cuzco Type obsidian artifacts has many ramifications for our understanding of cultural contact and exchange in pre-Hispanic Peru. A full diachronic treatment of these ramifications within a broad pan-regional framework is beyond the objectives of this article; however, this has been attempted elsewhere, in collaboration with Karen Mohr-Chávez and Sergio Chávez (Bur-

ger *et al.* n.d.). In this paper, we will focus more narrowly on the significance of this discovery from a more local perspective--that of the Cotahuasi area.

Despite its importance in Colonial, Republican, and contemporary Peru, the Department of Arequipa has received surprisingly little attention from most Peruvian and foreign archaeologists, and syntheses of Central Andean prehistory give scant attention to pre-Hispanic developments in Arequipa. Fortunately, a small number of regional archaeologists, most notably Máximo Neira and Eloy Linares Málaga, have spent decades laying the foundations of the archaeology of Arequipa, and a younger generation of local archaeologists, such as José Chávez Chávez, Augusto Belán Franco, and Pablo de la Vera Cruz, also have done much to advance research there. The publication of syntheses by Linares Málaga (1990) and Neira (1994) should make the prehistory of Arequipa more accessible, but knowledge of the region's archaeology still remains highly tentative (Máximo Neira, personal communication 1995).

The obsidian results reported in this article serve to focus our attention on the often-overlooked region of Cotahuasi, because one of the three most important obsidian sources exploited in pre-Hispanic Peru is located there. A pioneering archaeological reconnaissance of the Cotahuasi watershed by Chávez Chávez (1982) documented twenty-seven pre-Hispanic sites. Nine additional sites were subsequently located by Trawick (1994). Little evidence has been found thus far of an early occupation, but because obsidian from Alca was widely used at Marcavalle, Chanapata, and other sites in Cuzco during the late Initial Period and Early Horizon (Burger and Asaro 1979), it is likely that the Alca area may have been already inhabited. Without supplementary excavation, site surveys in the highlands frequently have difficulty documenting the period of early settlement, particularly when sites are occupied continuously for long periods.

At the present time, the first unambiguous evidence for permanent settlements in the

Cotahuasi area dates to the Middle Horizon. Significantly, two sites in the area, Collota near Cotahuasi and Mawka Llaqta in the upper end of the watershed have the distinctive architecture, known as orthogonal cellular, that is often viewed as the hallmark of Wari administrative centers (Isbell and McEwan 1991). In addition, smaller villages tentatively dated to the Middle Horizon by Trawick overlook substantial terracing and are associated with lengthy canal systems. Given the apparent ties of the Cotahuasi area to the Wari state, we should not be surprised to find that obsidian from the Alca Source appears at the Wari provincial centers of Jincamocco in Lucanas (Schreiber 1992) and Cerro Baúl in Moquegua (Moseley *et al.* 1991), as well as at the site of Wari itself. Even more striking were numerous projectile points of Alca Source obsidian recovered by Uhle and McCown in Huamachuco, far to the north of Wari (Burger and Asaro 1979). Considering the importance of the Alca Source prior to the Middle Horizon, it is possible that this raw material as well as the agricultural and other resources of the area were responsible for Wari interest in the watershed. The "chief town" in the Cotahuasi area immediately prior to the Inca invasion was located at Alca [Allca] and the critical battle to conquer this region took place there, according to Garcilaso de la Vega (Garcilaso 1966[1609]: 152-3).

Judging from earlier provenience studies, exploitation of the Alca Source continued into the Late Horizon: residents of Inca sites in the Cuzco Valley utilized tools of Alca Source obsidian even after the expansion of Tawantinsuyu. It is probably not coincidental that the Incas chose to locate their own center for administering the Cotahuasi watershed in the Alca area, on a steep fortified ridgetop that lies directly above the obsidian deposit. This site (known as Qhawana or Qhaqha), first documented archaeologically by Trawick (1994), features dwellings with trapezoidal doors and niches, as well as high gabled roofs. It has two plazas, each of which is flanked by large rectangular buildings. A portion of the paved stone Inca highway system passes through the site and then climbs up to the puna.

The sparse information summarized here suggests that the Cotahuasi watershed was an important locus of political power during the Middle Horizon and Late Horizon. Besides the area's significance as the source of rare high-quality volcanic glass for tools and other purposes, the drainage may have been a major supplier of gold, which occurs in unusually rich veins rather than alluvial accumulations and was apparently mined in pre-Hispanic times (Petersen 1970:68; Trawick 1994). Another local resource is rock salt, which was mined across the valley from Cotahuasi near the village of Huarhua (Llano 1904[1761]). This material continues to be highly valued and widely traded by pastoralists in the region today (Inamura 1981:72).

The movement of obsidian, gold, and salt in prehistoric times was facilitated by the Cotahuasi area's location along a natural route of communication between Cuzco and the Peruvian south coast. This route can be broadly described as follows. After crossing the lengthy puna to the south of Cuzco, the route descends the Cotahuasi or Huarcaya drainage, passing the source of Alca obsidian; below the town of Cotahuasi the road detours out of this drainage to avoid the deeply cut canyon mentioned previously, crosses a section of puna, and continues its descent along the Chala drainage immediately to the north. Unfortunately, the pre-Hispanic road system in this region remains poorly known (Hyslop 1984) and additional field work is necessary to confirm its use by Inca and pre-Inca peoples. Nevertheless, there are some suggestive data available.

In his study of the Inca road system, Victor von Hagen and his associates identified this route up the Chala River as the transverse road through Kunti Suyu along which fresh fish was brought to the Inca capital (von Hagen 1955:234-252). Hyslop likewise shows this route as one of the principal transverse coast-highland roads, although he did not carry out field work there (Hyslop 1984:262, 308). Von Hagen illustrates several views of the coastal section of the road. In these photographs the road can be seen to be wide, bordered with stones and with sections

of paved stairs. Although von Hagen did not document most of the highland section of the lateral road, he did trace a portion of it from where it splits off from the main coastal road and ascends the Chala valley through the Parcoy Canyon towards the sierra. From a low-flying airplane, he was able to observe a highland portion of this same road and viewed where it disappeared behind Lake Parinacochas, and then made its way toward Cuzco (von Hagen 1955:245). We know from both Garcilaso and later accounts that a road from Lake Parinacochas continues across the puna into the Cotahuasi drainage, from where it continues its ascent into the Cuzco region. Hiram Bingham's mule train followed this route during his 1911 explorations (Bingham 1922:50-75).

Long before, Garcilaso de la Vega (1966: 152-153) described how the Inca emperor Maita Capac advanced from Cuzco across the Apurímac River through Chumbivilcas province [Chumpivillca] encountering resistance at Villilli [Velille], then went across 16 leagues of high desert into the rugged Alca area. After defeating the local population, he continued down the Cotahuasi valley through the settlements of Taurisma and Cotahuasi before crossing into the neighboring drainage to visit Lake Parinacochas. It is possible that this same route was followed by pre-Inca travelers and was subsequently incorporated into the transverse Inca road.

Current use of this ancient route offers some insight into the journey required to transport Alca obsidian to the Cuzco basin. At the present time, the trip on horseback from Alca to Cuzco takes about six days (Trawick 1994:33). If the trip were made by llama caravans carrying loads of obsidian, the duration of the journey would more than double.

Thus, it would appear that the peoples of the Cotahuasi area played a significant role during much of Andean prehistory, not only as the herders of alpacas and llamas on the high pasture lands and the farmers of an oasis-like setting within the arid highlands of Arequipa, but also as the suppliers of obsidian and other rare raw materials. It remains for future in-vestigators to reveal more clearly the changing context within which the Alca Source of obsidian was mined and exchanged with the inhabitants of the Cuzco Valley and more distant regions.

Acknowledgments

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Table 1. Comparison of diagnostic element abundances[a] measured in Alca, Cotahuasi Province, Peru source samples with the previously measured Cuzco Type[b] chemical Group.

Element	Rosa-1 (X)	Rosa-2 (Y)	(X-Y)/Y (%)	Cuzco Type[b] (C)		(C-X)/Y(%)	(C-Y)/Y(%)	Standard[c] abundances		
Best-measured elements										
Sc	1.90	1.95	-2.6	1.95	± 0.03	+2.6	0.0	20.55	±	0.33
Th	14.9	15.1	-1.3	14.75	± 0.12	-1.0	-2.3	13.96	±	0.39
Cs	2.87	2.90	-1.0	2.90	± 0.13	+1.0	0.0	8.31	±	0.550
Fe %	0.574	0.571	+0.5	0.565	± 0.015	-1.6	-1.1	1.017	±	0.012
Eu	0.506	0.505	+0.2	0.495	± 0.010	-2.2	-2.0	1.291	±	0.034
Ta	0.904	0.914	-1.1	0.895	± 0.012	-1.0	-1.0	1.550	±	0.044
Rb	136.6 ± 1.7	143.2	-4.6	133	± 9	-2.6	-7.1	64.5	±	3.2
Average deviation (%)			**1.6**			**1.7**	**2.1**			
Elements poorly measured in either the Cuzco Type chemical group or Alca source samples										
Ce[d]	61.0	61.3	-0.5	59.0	± 1.4			80.3	±	3.9
Co	0.246 ±.009	0.233 ±.006	+5.6	0.22	± 0.07	-10.6	-5.6	14.06	±	0.15
Zn	37.4	38.8	-3.6					457	±	22

[a] Abundances are given in ppm except for those of Fe, which are given in percent (%). One sigma counting errors in this work are 1% or less unless a larger value is indicated.

[b] R. Burger and F. Asaro (1977). The published errors for the Cuzco Type obsidian group are the root-mean-square deviations for 24 artifacts. As some of the Rb measurements were based on flux monitors, those Rb values have been recalculated relative to the standard (Standard Pottery) used in the measurements. As suggested by Asaro *et al.* (1994), a correction of 0.048±.059 ppm was removed from the old LBL Co abundances.

[c] Standard Pottery (Perlman and Asaro 1969) was used to calibrate the abundances of all the listed elements, except Zn. The abundances and one-sigma uncertainties were taken from Perlman and Asaro (1971). The Rb abundances, however, have since been revised to the listed values. Zinc was calibrated versus the standard DINO-1 (Alvarez *et al.* 1982) and the abundance (in the Danish Cretaceous-Tertiary boundary sample) was reported in Alvarez *et al.* (1980). The accuracies of the measurements, which are useful for comparing with the work of other laboratories calibrated versus different standards, must incorporate both the precisions of the measurements and the uncertainties in the standard.

[d] Ce has not been corrected for [235]U fission in either the Cuzco Type chemical group or the Alca source samples.

Table 2. Background abundances from contamination in the LWAICS and the 99.9999%-pure Al encapsulating foil.[a]

Ele-ment	Energy of γ rays (keV)	LWAICS bkg		Averages for 10 empty capsules		Rosa-1 Al capsule	Rosa-2 Al capsule
Elements without obvious heterogeneous contamination in (or on) the Al encapsulating foils							
Sc	1121	0.006	± 0.000	0.372	± 0.004	0.391	0.375
Th	312	0.003	± 0.002	0.003	± 0.014		
Ce[b]	145	0.005	± 0.008	0.008	± 0.036		
Cs	796	0.007	± 0.000	0.000	± 0.000		
Fe %	1099	0.001	± 0.001	0.002	± 0.002	0.003 ± .001	0.002 ± .000
Eu	344-779	0.004	± 0.000	0.000	± 0.000		
Zn	1116	0.09	± 0.01	6.73	± 0.55	6.29 ± .12	5.90 ± .07
Ta	1189	0.001	± 0.000	0.000	± 0.000		
Rb	1077	0.0	± 0.3	0.0	± 0.3		
Co	1173-1332	0.055	± 0.003	0.017	± 0.011	0.018 ± .002	0.018 ± .002
Hf	482	0.000	± 0.001	0.004	± 0.010	0.000 ± .004	0.000 ± .002
Hf	133-482	0.000	± 0.000	0.002	± 0.003	0.000 ± .004	0.000 ± .002
Elements with obvious heterogeneous contamination in (or on) the Al encapsulating foils which may be due in part to laboratory contamination							
Sb	1691	0.002	± 0.001	0.083	± 0.006	0.168 ± .014	0.121 ± .011
Se (ppb)	136-265	7.3	± 0.9	17	± 22	133 ± 10	64 ± 4
Weight for abundance calc. (mg)		54.5		54.5		53.6	55.4
True weight (mg)				254.9	± 2.0[c]	256.0	259.2

[a] Abundances are given in ppm except for those of Fe, which are given in percent (%), and those of Se, which are given in parts-per-billion (ppb). Listed errors for individual samples are the best estimates of the one sigma values of the precision of the measurement. Where no error is given, the precision is estimated as 1%. The errors for the group of 10 empty Al capsules are root-mean-square deviations. Where two gamma ray energies separated by a hyphen are given for an element, radiations of those energies were used in coincidence measurements.

[b] Ce abundances have not been corrected for [235]U fission.

[c] Mean and root-mean-square deviation.

Table 3. Background abundances from contamination in the LWAICS and 99.9999%-pure Al encapsulating foil.[a]

Element	Energy of γ rays (keV)	Splits of irradiated Rosa-1 sample						Splits of irradiated Rosa-2 sample					
		Rosa-1 A			Rosa-1 B			Rosa-2 A			Rosa-2 B		
Weight (mg)		20.75			30.38			25.60			28.45		

Elements without obvious heterogeneous contamination in (or on) the Al encapsulating foils

Element	Energy of γ rays (keV)	Rosa-1 A			Rosa-1 B			Rosa-2 A			Rosa-2 B		
Sc	1121	1.964			1.977			2.000			1.933		
Th	312	15.25			15.33			15.500			15.010		
Ce[b]	145	62.9			62.9			63.400			61.300		
Cs	796	2.92			2.95			2.970			2.890		
Fe %	1099	0.591			0.598			0.588			0.572		
Eu	344-779	0.519			0.516			0.522			0.508		
Zn	1116	38.5			38.4			39.500			38.300		
Ta	1189	0.923			0.926			0.932			0.914		
Rb	1077	141.0	±	2.1	141.9	±	2.0	147.7	±	2.5	144.3	±	2.5
Co	1173-1332	0.263	±	0.012	0.262	±	0.009	0.241	±	0.010	0.236	±	0.010

Elements displaying heterogeneity within the irradiated samples of Rosa-1 or Rosa-2 but not appearing as a contaminant on the Rosa-1 or Rosa-2 Al encapsulating foils

Element	Energy of γ rays (keV)	Rosa-1 A			Rosa-1 B			Rosa-2 A			Rosa-2 B		
Hf	482	3.54			4.04			3.90			3.60		
Hf	133-482	3.57			4.03			3.88			3.58		

Elements displaying heterogeneity within the irradiated samples of Rosa-1 or Rosa-2 and also appearing as a contaminant on the Rosa-1 or Rosa-2 Al encapsulating foils

Element	Energy of γ rays (keV)	Rosa-1 A			Rosa-1 B			Rosa-2 A			Rosa-2 B		
Sb	1691	0.540	±	0.015	0.707	±	0.016	0.416	±	0.016	0.047	±	0.016
Se (ppb)	136-265	154	±	6	403	±	7	103	±	5	117	±	5

[a] Abundances are given in ppm except for those of Fe, which are given in percent (%), and those of Se, which are given in parts-per-billion (ppb). Listed errors for individual samples are the best estimates of the one sigma values of the precision of the measurement. Where no error is given, the precision is estimated as 1%. Where two gamma ray energies separated by a hyphen are given for an element, radiations of those energies were used in coincidence measurements.

[b] Ce abundances have not been corrected for [235]U fission.

Table 4. Element abundances[a] in Rosa-1 and Rosa-2 normalized to the same Sc abundance, 1.95 ppm, as found for the Cuzco Type chemical group of artifacts.

Element	Rosa-1							Rosa-2						
	Rosa-1	Rosa-1a	Rosa-1b	Mean	RMSD	A.C.E.[b]	E.r.[c] (%)	Rosa-2	Rosa-2a	Rosa-2b	Mean	RMSD	A.C.E.[b]	E.r.[c] (%)
Diagnostic elements measured with counting errors of less than 1%														
Th	15.23	15.14	15.12	15.16	0.06	0.02	0.4	15.10	15.11	15.14	15.12	0.02	0.02	0.0
Ce[d]	62.5	62.5	62.0	62.3	0.29	0.06	0.5	61.4	61.8	61.8	61.7	0.23	0.06	0.4
Cs	2.94	2.90	2.91	2.92	0.021	0.006	0.7	2.91	2.90	2.91	2.91	0.006	0.005	0.1
Fe %	0.588	0.587	0.590	0.588	0.0015	0.0007	0.2	0.572	0.573	0.577	0.574	0.0026	0.0006	0.5
Eu	0.518	0.515	0.509	0.514	0.0046	0.0039	0.5	0.506	0.509	0.512	0.509	0.003	0.003	0.0
Zn	38.3	38.2	37.9	38.1	0.21	0.16	0.4	38.9	38.5	38.6	38.7	0.21	0.16	0.3
Ta	0.926	0.916	0.913	0.918	0.0068	0.0053	0.5	0.916	0.909	0.922	0.916	0.0065	0.0048	0.5
Average (%)							**0.5**							**0.3**
Diagnostic elements measured with counting errors greater than 1%														
Rb	139.5	140.0	140.0	139.8	0.3	1.6		143.2	144.0	145.6	144.3	1.2	2.5	
Co	0.252	0.261	0.258	0.257	0.005	0.009		0.233	0.235	0.238	0.235	0.003	0.008	

[a] Abundances are given in ppm except for those of Fe, which are given in percent (%).

[b] A.C.E = Average Counting Error of obsidian sample measurements.

[c] E.r. = Error residue = 100 * [Square Root (RMSD^2 - A.C.E.^{2})] / Mean

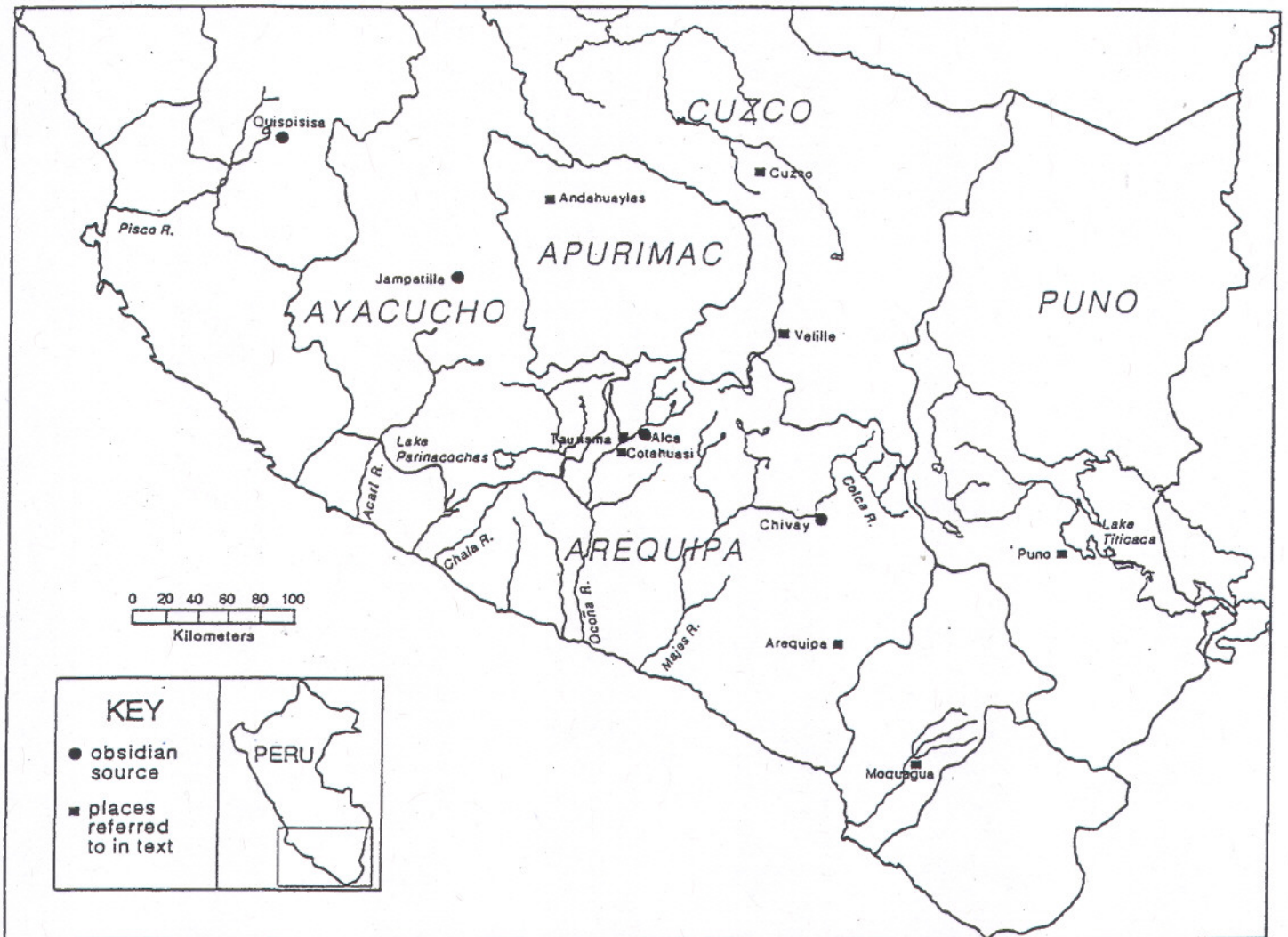[d] Ce abundances have not been corrected for ^{235}U fission.

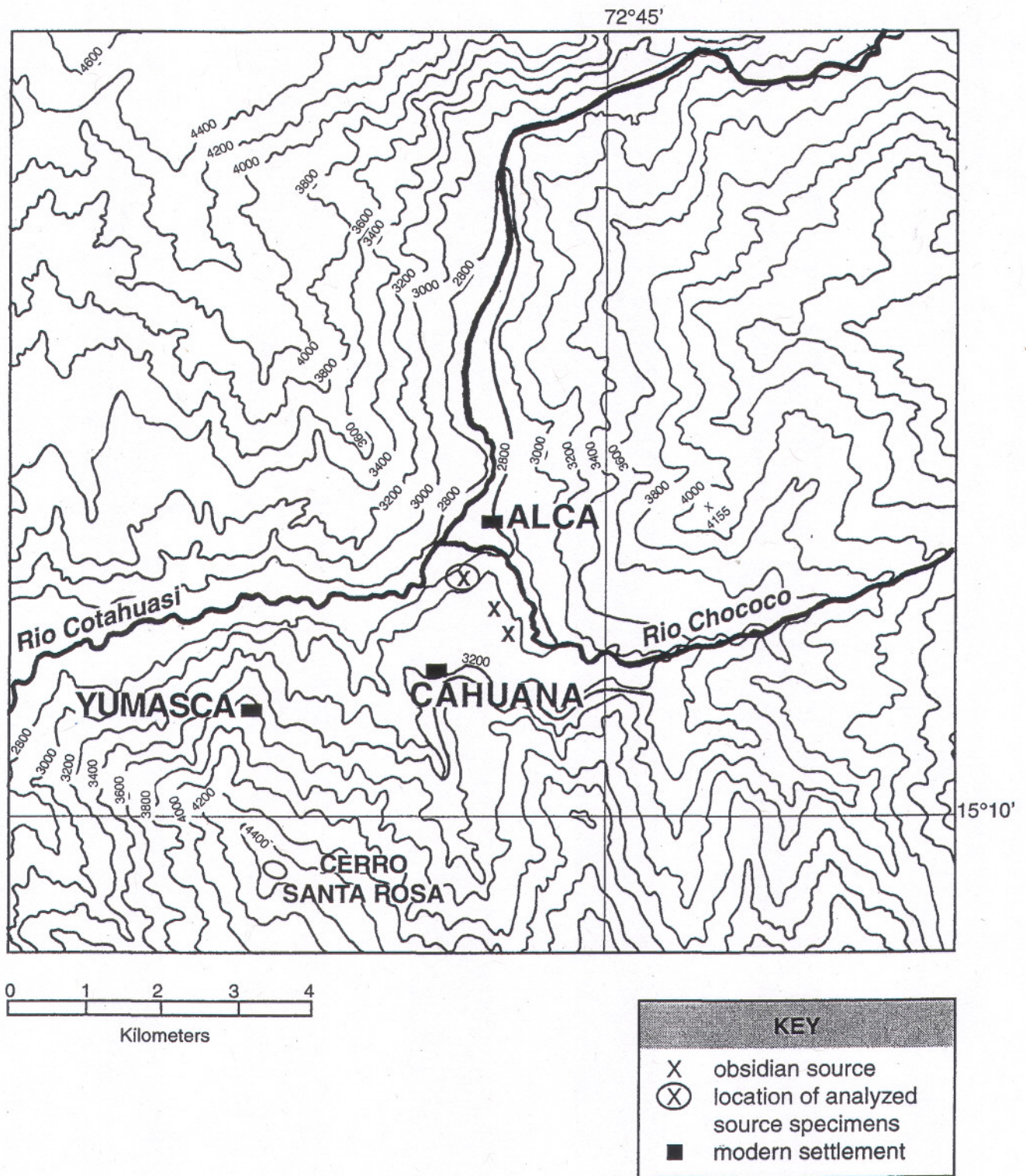**Figure 1.** Locations of various obsidian sources in southern Peru.

Figure 2. Detailed location of the Alca obsidian source in southern Peru