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Background

Of the major chemical types of obsidian utilized for tools by pre-Hispanic cultures in the Titicaca Basin of southern Peru and northern Bolivia, one chemical group overshadowed all others in frequency regardless of time period. In our initial study of the provenience of obsidian artifacts carried out at what is now called the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL) between 1974-1975, obsidian with this chemical signature was referred to as Titicaca Basin Type obsidian for ease of discussion (Burger and Asaro 1977, 1979). Obsidian from this unlocated obsidian source was used at major Peruvian sites in the Department of Puno such as Qaluyu and Sillustani and also at Bolivian sites on the other side of Lake Titicaca, such as Qallamarka and Tiahuanaco. Our subsequent research (1977-1978) confirmed this general pattern of pre-Hispanic obsidian distribution and, in addition, demonstrated that this type of obsidian was the predominant type present at six archaeological sites in southern Arequipa (Burger *et al.* n.d.). The abundance of this chemical type of obsidian at Preceramic sites such as Sumbay and the volcanic character of southern Arequipa led us to suggest that the source of this obsidian might be found in this region rather than in the Titicaca Basin (Burger and Asaro 1993:222-223, 230), but the absence of detailed geologic data on obsidian deposits hindered further progress.

In 1989, Rosalía Avalos de Matos provided Burger with a sample of non-artifactual obsidian from a mine in the Chivay area in the Colca Valley of Arequipa, and x-ray fluorescence (XRF) analysis of the sample at LBNL suggested a match with the Titicaca Basin Type obsidian artifacts. Unfortunately, information was not available concerning the exact location where the sample had been collected.

Subsequently, Sarah Brooks, a University of Wisconsin geographer working in the Colca Valley, encountered small obsidian pebbles at 3700-3800 meters above sea level (masl) on the flanks of Pampa Finaya, across the river and approximately 1.5 km west from the town of Chivay. Collaborative research with Brooks and Michael Glascock at the Missouri Research Reactor (MURR) demonstrated through instrumental neutron activation analysis (INAA) that a chemical match existed between these samples and the composition of Titicaca Basin Type obsidian artifacts (Brooks *et al.* 1993). However, the consistently small size of these pebbles precluded the possibility that Pampa Finaya was the source for the Titicaca Basin Type obsidian artifacts.

The Chivay Obsidian Source: Location And Geology (Figures 2, 3)

In an effort to locate more precisely the primary geologic source of this material, Burger suggested to one of his students, Eli Gould, that a reconnaissance visit to the Chivay area might be worthwhile, and in January of 1994, Gould successfully located quantities of obsidian above the Quebrada de los Molinos, roughly 4-6 km east of the modern town

of Chivay. Nodules of unworked obsidian were found at approximately 4900 masl on a level surface at the foot of the western slopes of Cerro Ancachita (5131 masl); the obsidian was mixed with deposits of what appeared to be volcanic tuff. Gould observed obsidian specimens up to 30 cm on a side. These were substantially bigger than those found at Pampa Finaya and sufficiently large to have served as source material for artifact production. According to a local farmer, a German resident of Bolivia had visited this obsidian deposit in order to collect obsidian for export to La Paz, where it was to be transformed into craft products. Three of the samples studied in this work, Chivay-1, -2, and -3, came from this location.

In his brief reconnaissance of the Chivay area, Gould noted that some obsidian is found in Chivay itself (including the town's bull-ring), but these specimens appear to have been redeposited by erosional or human forces. In contrast, the material from the slopes of Cerro Ancachita appeared to be in its original geological context. A June, 1998 survey of the glacial geology around Chivay by Harold W. Borns, Daniel H. Sandweiss, and Bernardino Ojeda determined that obsidian from Cerro Ancachita and vicinity was brought down Quebrada de los Molinos and a small adjacent quebrada by glacial activity. Small nodules of this obsidian are present in morrainal deposits under the town of Chivay as well as in the Quebrada itself (H. Borns, personal communication).

In July of 1995, Burger and Arequipa geologist Guido Salas traveled to the Chivay area to collect additional geological information and obsidian samples from the source area visited by Gould. During the walk up the Quebrada de los Molinos, Burger and Salas observed obsidian and other volcanic rocks eroding into the ravine from the volcanic deposits above. They also encountered a local farmer who had been collecting quantities of obsidian from these deposits for future sale. Field observations indicate that the obsidian deposit extends beyond the area on the western slopes of Cerro Ancachita documented by Gould. Large and small obsidian spherical nodules also occur to the east of Cerro Ancachita in the area known as Pampa Ichocollo (4500-4900 masl), roughly 7 km east of Chivay. Obsidian blocks were on the southern slopes of Cerro Ancachita, and they are remarkably free of flaws and impurities. Some of the obsidian recovered has the same distinctive purplish hue observed in obsidian artifacts of the Titicaca Basin Type. The obsidian pieces are variable in shape and, as would be expected, are covered with cortex or weathering rind; most show no evidence of having been worked. However, an obsidian core and obsidian flakes were observed in the Quebrada de los Molinos.

The full extent of the primary deposit of obsidian has not been determined but the information available suggests that it extends over several kilometers. No effort was made to locate ancient quarry areas or workshops, and such essential information can only be obtained by additional research in the field. Four of the samples studied in this work, Chivay-4, -5, -6, and -7, came from this area.

Sarah Brooks, who has been working independently in the Colca Valley, has recently reported locating a huge obsidian quarry and her work promises to shed light on obsidian procurement (Sarah Brooks, 1996, personal communication).[1]

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[1] Following the submission and acceptance of this article, Brooks *et al.* (1997) published a short article in the Scientific Correspondence section of *Nature* in which an obsidian quarry whose chemical signature matches the Titicaca Basin Type is discussed. This quarry, which is referred to as Cotallalli, is located in the Colca Valley but its relationship to the obsidian source described here is difficult to determine without further information. No information is provided in the Brooks *et al.* article which would allow the quarry to be located with precision, and the general map illustrating the article shows Cotallalli to be 50 km north of Sumbay, which would place it some 20 km northeast of the area described here. We were unable to locate a volcano or mountain named Cotallalli in the current maps of Peru's Instituto Geográfico Nacional or in the geological literature. This ambiguity will no doubt be resolved with the fuller publication of the work by Ms. Brooks and her colleagues.

In 1997, Salas returned to the Chivay area for two days in order to document better the context of the obsidian within the local geological formations. To the south of Cerro Ancachita, Salas identified a large rhyolitic dome, known as Cerro Hornillo (Figure 4). The dome extends for approximately 2.6 km (N-S) by 2.2 km (E-W). Along its edges are vitrified deposits (*i.e.*, obsidian), including nodules and large blocks of volcanic glass. The vitrification along the northern edge of the dome accounts for the obsidian encountered in the earlier visits to Cerro Ancachita, and a still larger concentration of obsidian blocks was encountered on the dome's western edge (Figure 5), some 5 km west of Chivay. A reading by Salas using the Global Positioning System, GPS, measured the location of the dome's obsidian deposits, and it yielded the following location (in Universal Transverse Mercator, UTM, coordinates): E 227,234 and N 8,268,421. The obsidian source has a general location of 15°31'13"-15°32'46" S latitude, 71°38'6" W longitude. We propose to refer to this obsidian deposit as the Chivay Source, because of its proximity to the well-known town of Chivay. Judging from a regional geologic study by Peru's INGEMMET (Instituto Geológico Minero y Metalúrgico) that included Chivay (Palacios *et al.* 1993), the volcanic deposits containing the obsidian belong to the Barroso Group, which, according to the INGEMMET study, includes andesitic lavas, trachytes, and tuffs (such as pumice). In the Chivay area, the Barroso Group consists primarily of andesitic lavas with concentrations of plagioclase crystals. The Barroso Group includes transversal flows that are responsible for ridges and crests, such as Cerro Saylluta and Cerro Ancachita, and the volcanic dome known as Cerro Hornillo. These Barroso Group deposits (Ts-Ba) directly overlie strata of the Tacaza Formation (Tm-Ta) which are deep (200 m) deposits of lavas and andesitic breccias that date to the Early/Middle Miocene. This superposition can be observed at the lower end of the Quebrada de los Molinos. In very rough chronological terms, the Barroso Group dates to the Late Miocene/Pliocene between 6 million years ago (Ma) and 1 Ma (Palacios *et al.* 1993:191). Salas observed that the obsidian

appears to occur where lavas have cooled rapidly when they came into contact with the contiguous deposits of the older Tacaza Group. Significantly, Pampa Finaya, like Cerro Ancachita and Pampa Ichocollo, corresponds to the Barroso Group. The intervening area between Pampa Finaya and Cerro Ancachita, including the land beneath the modern town of Chivay, consists of later fluvial conglomerates, lacustrine materials, and glacial morraines deposited during the Pleistocene.

Instrumental Neutron Activation Analysis

In the INAA process, there are measurement uncertainties concerned with counting gamma rays (called counting errors) which can be made smaller by counting for longer periods of time, irradiating larger amounts of sample, or irradiating for longer periods of time. As a practical matter there are other significant errors (which can overshadow small counting errors) which come from a multitude of sources and sometimes can be attacked only one at a time. In earlier studies a 1% precision in the abundance values was about the best that could be accomplished, although between 1% and 2% was more routine. The present measurements of element abundances by neutron activation analysis are considerably more precise than previous ones.

Sample preparation

As the details will be described in another publication, only a brief sketch will be given here. The obsidian nodules collected in the field were broken, and the pieces sent to LBNL. There, some of the pieces were crushed and coarsely powdered with an agate mortar and a pestle. Powder samples of about 100 mg were weighed with a precision better than 0.1 mg and encapsulated in a weighed amount of 99.9999% pure Al metal. Each capsule was completely wiped twice with a cotton swab wetted with ethyl alcohol in order to remove any loose Al flakes or sample powder. The cleaned capsules containing obsidian powder along with many other samples were placed in stacks of 38 in quartz tubes that had been sealed on the bottom. Each stack had an empty Al capsule at the top. One tube (out of

a total of 7) contained 16 standards distributed at the bottom, middle, and top of the tube. For calibrating most elements, the standards were 25, 50, and 100 mg of Standard Pottery (Perlman and Asaro 1969, 1971) at each of the three positions. For calibrating Ir and Zn, the standards were 25 and 50 mg samples of DINO-1 (Alvarez *et al.* 1982) at each of the three positions. One sample of $CaCO_3$ was also in the standard capsule to measure any impurities introduced in the sample preparation process. Four of the obsidian samples, Chivay-4, -5, -6, and -7, were in the same quartz tube as the standards. The other three obsidian samples, Chivay-1, -2, and -3, were in adjacent positions in another tube. After correcting for half-lifes, time of decay, sample weight, counting time, counting rate, and interferences, calibration coefficients were calculated for each element of interest for each standard. The calibration coefficients (abundance per 100 mg weight per count-per-minute corrected to the end of irradiation) for the various elements in Standard Pottery were respectively about 1.2% and 6.0% higher in the middle and top of the tube with the standards than at the bottom, and the exact values for each element were interpolated for each position in that tube. The same calibration coefficients had to be used for the obsidian in the other quartz tube containing obsidian as it contained no standards. As will be shown later, the abundances of samples Chivay-4, -5, and -7 from the tube with the standards and Chivay-1 and -2 from the other tube with obsidian agree very well. This indicates that fortuitously, the two tubes had not shifted significantly in the axial direction with respect to each other. In the future for very precise work, multiple standards of Standard Pottery will be included in all tubes. The open quartz tubes were heated to 190° C in an oven for several hours to drive off water and prevent the subsequently sealed tubes from cracking because of internal pressure during the irradiation. The quartz tubes were each individually tightly wrapped in kitchen foil to promote heat transfer during the irradiation and keep the temperature in the stacks below the melting point of Al, and the cluster of 7 tubes was loosely wrapped in kitchen foil for the same reason. The cluster of tubes was sent to the University of Missouri reactor in Columbia, Missouri and irradiated for 48 hours at a flux of 2.5×10^{13} neutrons per second per cm^2.

One month after the end of irradiation, the samples were sent back to LBNL, and subsequently the Al was unwrapped from the quartz tubes, and the tops of the latter were sawed off. As needed, samples were removed from the tubes and completely cleaned with cotton swabs wetted with ethyl alcohol about 4 times. Because small leakages of powder had occurred since the previous weighings, it was necessary to reweigh some of the obsidian samples after the irradiation and use those weights in the calculations.

Measurements

Measurements on the standards and obsidian samples were made with the Luis W. Alvarez Iridium Coincidence Spectrometer. This instrument had been designed and constructed specifically to measure instrumentally and with high sensitivity the abundance of iridium in deep sea sediments. It has been modified to measure many other elements simultaneously with Ir, and recent changes in the instrument permit significantly higher precision. The instrument can measure gamma rays with either of two Ge detectors or coincidences with both detectors. The measurements can be made with or without an anti-Compton shield, which reduces background from scattered gamma radiation. For obsidian studies, only the gamma ray detector with the best resolution was used for singles measurements of 9 elements and coincidences were used for Co, Hf, and Eu measurements. Selenium abundances were also very sensitively measured, but Se abundances are very sensitive to low-level laboratory contamination and are not included in this report.

Count rates of samples in each Ge detector can go as high as 150,000 per second and still give useful results, but 40,000 per second is optimal for coincidence measurements. The obsidian samples in the present work counted about 14,500 per second; the empty Al foils counted about 700 per second. The anti-coincidence shield normally counts about

500,000 counts per second, but was not used for the obsidian measurements.

The standards of Standard Pottery and DINO-1 were measured first, then the instrument background was determined and then the average impurity levels in or on the empty Al capsules. These levels for a 100 mg sample are shown in Table 1. It is seen that there is a very large Sc impurity in the Al foil, but it can be accurately subtracted from each sample because it is very homogeneous in the foil. Zinc, on the other hand, is also present as a large component in the Al foil, but it is not very homogeneous and therefore adds about 2% uncertainty to each Zn measurement. (Unwrapping the samples and counting the Al wrapping foils by themselves would remove this uncertainty.) The levels of background and Al impurities appropriate for each sample's weight are automatically removed from the abundances. One Al empty capsule had a large impurity of Co, over 0.1 parts-per-million (ppm). This value was considered a low-probability contamination fluke and was deleted from the subsequent calculations.

It is necessary to determine the Ge detector efficiency (which varies as a function of count rate) for each sample for both singles and coincidences measurements. A pulser alternately feeds pulses corresponding in amplitude to that of the ^{46}Sc 889 keV gamma ray to one detector and then pulses corresponding in amplitude to that of the ^{46}Sc 1121 keV gamma ray to the other detector. These pulses are treated by the electronic systems in the same fashion as gamma rays. The efficiency for singles measurements is the ratio of the pulser pulses passing through the detector to the input rate (raised to the power 1.02 to adjust for variations with count rate). The coincidence efficiency is the product of the efficiencies from both detectors (with one raised to a power of 0.427 or higher depending on the count rate in the Ge detector). The position of the sample along the central axis between the two detectors can vary by a few millimeters. The exact position is determined automatically by counting the ^{46}Sc 1121 keV gamma ray abundances in each detector and determining the position for each sample from the ratio. The geometry for the singles measurements is calculated from the sample position. No corrections are needed for geometry variations in the radial direction. No geometry corrections at all are needed for coincidences measurements as movement toward one detector is compensated by movement away from the other.

Errors

Known random errors in the present work come from three sources. One is the error associated with counting radioactivity and is random for all elements in each sample. Another is concerned with the error in the efficiency measurements. This is random for each sample, but every element measured by singles measurements for a given gamma ray count will have the same error. The errors in the coincidence measurements will be slightly larger, will also vary coherently among themselves, and in large part will vary coherently with the variations in the singles measurements. What one might then see is that all element abundances are larger or smaller in one sample compared to another by a nearly fixed amount. There is also a random error for the singles measurements due to uncertainties in the measurement of the ^{46}Sc gamma rays necessary to determine the exact position of the sample between the Ge detectors as it is being counted. This error, called the geometry error, will be the same for all elements determined by singles measurements and is somewhat smaller than the error due to the pulser efficiency.

There will be systematic errors in measurements of some gamma rays because they contain interferences from other radiations. We have studied these interferences in the past and corrected the data for them, but our studies have been at the 1% level of precision, not the 0.1% level which is desirable for 0.3% overall precision for the data taken over an extended period of time or by different laboratories. Where we had a choice of radiations or techniques we used that which had the least interferences or other problems.

Results

Five Chivay samples had a very similar chemical abundance pattern and their data are shown in Table 2. Also shown are the mean abundances for each element for the group of 5, their root-mean-square deviations and coefficients of variation (C. of V. = root-mean-square deviations divided by the mean values). For the 6 elements with counting errors better than 0.3% the average coefficient of variation was 0.26%. This value, which is an upper limit to the inhomogeneity in the measured samples, is slightly larger than expected (0.19%) from the average counting error (0.13%) and the errors in measurement of the gamma-ray efficiency (0.11%) and the gamma-ray geometry (0.08%).

Table 3 shows the data for samples Chivay-6 and Chivay-3. Chivay-6 differs from the main group by very close to +0.4% for all of the 6 best measured elements and the abundances of the other elements are all consistent with that value within their counting errors, except for that of Sb, which is low by about 6%. Except for Sb, an error of -0.4 mg in weight, -0.4% in the sample geometry or efficiency calculations, or an error of +3.5 mm in the sample position in the reactor irradiation could all give the same effect. Because the weight was checked after the irradiation and agreed to 0.06%, the difference is not due to a loss in weight. (This agreement is somewhat fortuitous because small amounts of water in the obsidian could be lost in the irradiation.) The sample was in the same capsule as the standards of Standard Pottery, and also in its proper position in the irradiation quartz tube with samples Chivay-4, -5 and -7, hence there was not a shift of 7 mm from its assigned position. Table 2 shows that the average coefficient of variation for the three runs for the 6 best measured elements is only 0.19%, consistent with the expected counting, geometry, and efficiency errors. So there was not a +0.4% error in the geometry or efficiency determination. We do not know the source of the +0.4% difference, but it may be due to the loss of water or one of the elements that we do not measure, *e.g.*, Si, Al, K, or O, in the geo-

chemical history of the sample, combined with a 6% loss in Sb.

Chivay-3 is somewhat similar to the abundance profile of the main Chivay group, but is easily distinguishable because its Ta abundance is over 1% lower and Hf, Fe, and Co abundances are higher by 4, 4, and 16%, respectively.

Table 4 compares the abundances of the main Chivay group with those of the Titicaca Basin Chemical Group of 21 artifacts measured by INAA at LBNL and published in 1977 and 1978. The old data readily fall into two precision groups: eight elements had a root-mean-square deviation (RMSD) of less than 4% and two elements had a RMSD of greater than 4%. The average deviation between the suites of data from the Main Chivay Source Group and the Titicaca Basin Chemical Group in the first group of elements is only 1.1% and the deviations in the second less precise group of elements are consistent with the uncertainties. This excellent agreement between the source samples and the previously analyzed artifacts confirms the assignment of the Titicaca Basin Chemical Group to the Chivay Source in Arequipa, and indicates that the old INAA data, while not as precise as the present work, gave group values precise at the 1% level. As the source loci studied in the present work have obsidian suitable for artifact production, one or more of them may have been the origin of at least some of the artifacts assigned to the Titicaca Basin Chemical group in 1977 and 1978, and the general volcanic deposit in Chivay from which the source samples were collected can be considered with a high degree of certainty as the origin of the obsidian used to produce artifacts of the so-called Titicaca Basin Chemical Group.

Archaeological Ramifications (Figure 1)

The location of the source of the Titicaca Basin Type obsidian above the town of Chivay in the Colca Valley has important implications for understanding the regional prehistory of southern Arequipa. It also provides crucial evidence for re-evaluating obsidian distribution patterns outside the Arequipa area.

The latter task has been undertaken as part of a long-term collaboration with Sergio Chávez and Karen Mohr Chávez (Burger *et al.* n.d.) and the current discussion will focus more narrowly on the Colca Valley and the immediately surrounding area.

With a few notable exceptions, the Colca Valley has been neglected by archaeologists until recently. Perhaps the most influential early study of Colca was the aerial photographic survey of the Shippee-Johnson Expedition in 1929 and 1931. Based on these efforts, dramatic oblique views of the extensive pre-Hispanic terracing in the Colca Valley were published (Johnson 1930; Shippee 1932, 1934). Many of these impressive agricultural systems were no longer in use and the Shippee-Johnson photographs became increasingly relevant as scholars became interested in the question of terrace and canal abandonment.

Pioneering archaeological studies of the Colca Valley were carried out by Máximo Neira (1961, 1990), and these were complemented by the investigations of Eloy Linares Málaga (1981, 1990) in the lower sections of the drainage (known as Majes and Camaná). Although these early studies were important contributions, the results stimulated little additional research.

Finally, between 1984 and 1986, The Río Colca Abandoned Terrace Project was carried out under the direction of geographer William Denevan. This project addressed the problem brought to the attention of scholars by the Shippee-Johnson Expedition, and involved the participation of a range of specialists to achieve this objective. From the perspective of this paper, it was particularly significant that several archaeologists (Pablo de la Vera Cruz, Michael Malpass, Daniel Shea) were included in the project. Their preliminary results were presented in 1985 at the 45th International Congress of Americanists in Bogotá (Denevan 1987). Nevertheless, even after this renewed archaeological activity, the Colca's prehistory remains poorly understood and it has been largely neglected in recent syntheses of Central Andean prehistory (*e.g.*, Bonavia 1991; Moseley 1992; Richardson 1994).

At the present time, little is known of Colca's prehistory before the Middle Horizon. However, it is likely that this is a function of the limited archaeological investigation carried out thus far, and a comprehensive program of survey and excavation, like that done in Moquegua, will probably produce a lengthier and more complex sequence. The procurement of raw obsidian from the Chivay source and its widespread distribution through what is now southern Peru and northern Bolivia indicates unambiguously that something significant was happening in Colca long before the Middle Horizon occupation detected in the valley.

Neira's excavations of preceramic occupations in the caves and rockshelters of Sumbay, located across the puna some 40 km to the south of Chivay, produced excellent evidence of hunting and gathering groups adapted to the puna environment (4127 masl). The third and fourth strata in the principal cave at Sumbay (Su-3) produced C-14 measurements of 3400±90 BC (BONN-1559) and 4210±120 BC (BONN-1558), respectively. These dates fit well with the typological study of the lithics (Neira 1990:50). Although retinite was the most popular lithic material used, obsidian artifacts were found in all strata at Su-3, including stratum 4 (*ibid.*:28-34). As reported in detail elsewhere (Burger *et al.* n.d.), twenty-five samples were analyzed at LBNL and all of them, including one sample from stratum 4 of Su-3, proved to be from the Chivay Source. Thus, the prehistoric inhabitants of southern Peru knew of the Chivay obsidian deposit by the Middle Preceramic Period and exploited it for the production of projectile points, scrapers, and unmodified flakes. During the Preceramic Period, as in later periods, the manner in which the obsidian source was exploited cannot yet be determined. Was it procured from the source by outsiders or by local residents of the Colca Valley? Whichever the case, such activities were likely to have produced contact between the pre-Hispanic peoples of Colca and the puna-dwelling consumers of the raw material.

There is no information on local cultural development in the Colca Valley for the next

three millennia, but artifacts made from Chivay Source obsidian appear at early agricultural sites such as Qaluyu in the northern Lake Titicaca Basin and Chiripa in the southern Lake Titicaca Basin. Obsidian from the Chivay deposit also appears in small quantities at Pikikallepata near Sicuani in the Upper Vilcanota and Marcavalle in the Cuzco Basin. This pattern of obsidian distribution appears during the Initial Period and continues during the Early Horizon and Early Intermediate Period (Burger and Asaro 1979, 1993; Burger *et al.* n.d.). After some significant changes during the Middle Horizon, it re-emerges during the Late Intermediate Period and Late Horizon (Burger and Asaro 1979). Large amounts of obsidian from the Chivay source are known in the northern Titicaca Basin during the Late Intermediate Period at sites such as Incatunuhuiri, Llalli, and Sillustani.

From the standpoint of Colca's prehistory, it is particularly significant that the main consumers of the Chivay Source obsidian were highland settlements in the Late Titicaca Basin. This is understandable given the location of the Chivay source and the surrounding topography. Natural routes lead up the valley from Chivay into the Colca's headwaters and across the puna and north into Llalli and Ayaviri and east towards Juliaca. Although still another route leads west towards Chumbivilcas and Cuzco, the Alca source of obsidian is significantly closer (approximately 130 km) to the Cuzco Valley. Llama caravans from Cuzco could have saved weeks of travel by acquiring obsidian from the Alca Source rather than from the Chivay Source.

By the Initial Period, domesticated camelids became widespread in the Cuzco Valley and the adjacent altiplano (Miller 1979; Miller and Burger 1995), and it is likely that the mining, transport, and exchange of obsidian from the Chivay Source would have reflected the role of llama caravans in the interzonal movements of bulky and heavy commodities such as obsidian (Browman 1974, 1975; Flores 1968). The appearance of artifacts made from Chivay Source obsidian at distant sites such as Chiripa and Tiahuanaco, suggests the degree to which obsidian became

integrated into these larger long-distance exchange systems. Given the radical changes in sociopolitical structure experienced on the altiplano between the Initial Period and the Late Horizon, it is likely that the exploitation and distribution of Chivay Source obsidian underwent significant transformations, but its continuation in whatever form would have maintained contact between the populations of the Colca and those of the altiplano. If the ethnohistoric and ethnographic cases can serve as a guide, these exchange relationships usually involve social linkages that reinforce the economic relationships.

Both archaeologists and ethnographers studying the Colca Valley have emphasized that its location makes it a natural point of contact between *quechua* zone farmers and puna herders (*e.g.,* Shea 1987:81-84). Even today, pastoralists descend from the puna to Coporaque in Colca to trade dried meat, wool, textiles, and pottery for maize (Vera Cruz 1987:96). In pre-Hispanic times, besides maize, fruit, and obsidian, the Colca was possibly a source of precious metals, copper, and textile dyes derived from the insects that breed on local cacti (*ibid.*:115-116).

Given the small amount of archaeological research conducted thus far, it should not be surprising that, except for the obsidian data considered here, evidence for these interzonal connections remains slight. Daniel Shea (1987) reports that his excavations of a late prehistoric site near Achoma in the Colca region uncovered storage facilities that contained camelid *charqui*, and he concludes that this find demonstrates a complex economy that included products acquired by trade with pastoralists. The structural links of the ancient inhabitants of the Colca region with the puna herders may have also been reinforced by the dependence of the valley agriculturalists on canal systems that use water from natural acquifers (springs, streams, lakes) situated in the puna. This is essential because the Colca Valley is so deeply entrenched that it is not feasible to raise water from the river level to the adjacent agricultural lands (Guillet 1987).

One of the most problematic and interesting interpretive problems presented by the location of the Chivay Source is the nature of obsidian procurement and distribution during the Middle Horizon. Traditionally, the Colca Valley has been viewed as being near the frontier between the Huari and Tiahuanaco states or spheres of influence. In Rowe's early formulation, this hypothetical frontier was placed between the Majes and Sihuas Valleys (1956; *cf*. Lumbreras 1974: figure 162). Subsequent work by Linares Málaga, Neira, and others confirmed the presence of Huari ceramics mainly dating to MH2 in the valleys of Caravelí, Ocoña, Majes (or Camaná) and Sihuas (Linares Málaga 1990; Neira 1990). Recent surveys have provided additional evidence of the Huari presence in Ocoña (Chávez Chávez and Salas Hinojoza 1990) and Majes (Manrique Valdivia and Cornejo Zegarra 1990; García Márquez and Bustamante Montoro 1990).

A detailed survey of the more southern Moquegua (or Osmore) drainage by the Programa Contisuyu yielded strong evidence for a Tiahuanaco-related occupation (Goldstein 1990). Significantly, scarce Huari-style materials in Moquegua were concentrated in the fortified Huari civic-ceremonial center of Cerro Baúl, and investigations at the site led archaeologists to conclude that the settlement was a short-lived intrusive political colony or outpost (Moseley *et al*. 1991; Goldstein 1990). The work in Moquegua reinforced the impression that the interaction along the Huari-Tiahuanco frontier was competitive and at times hostile (Goldstein 1990:101).

Recent research by Vera Cruz and Malpass has demonstrated a strong Huari presence in the middle section of the Colca Valley. Vera Cruz argues that a Huari center was established at Achachiwa (3131 masl), located 40 km downstream from Chivay, and Huari-related ceramics were excavated at Chijra near Coporaque, only 4 km below the modern town of Chivay. In fact, Vera Cruz and Malpass conclude that some of the terraces at Chijra and elsewhere in the Colca Valley may have been built while the Valley was under Huari control (Malpass 1987:62-64; Vera Cruz

1987:89). As noted earlier, Huari cultural materials also exist in the lower coastal sections of the drainage.

The foregoing review of the literature suggests that the obsidian deposit near Chivay was situated near the southern limit of Huari influence during the Middle Horizon. The procurement and distribution of raw obsidian during this period might be expected to reflect the special political realities of those troubled times. It could be suggested, for example, that obsidian from Chivay may have been distributed widely to Huari centers throughout the Central Andes, as has been observed for other types of obsidian from major deposits within the Huari sphere of influence (Burger and Asaro 1979). This, however, does not appear to be the case. With the exception of Cerro Baúl, obsidian artifacts made from Chivay source material have not been encountered thus far at Huari centers such as Huari, Jincamocco, or Pikillaqta.

Although the Chivay source was the closest obsidian deposit to the Huari center at Cerro Baúl, over 70 percent of the obsidian sampled (n=42) came from the more distant Alca source. Small quantities of Andahuaylas A Type obsidian were also documented at Cerro Baúl; its source is probably located in the Department of Apurímac. Analysis of Cerro Baúl lithics also showed the presence of Quispisisa obsidian. All three of these sources lie within the Huari heartland, and artifacts from them also occur at Huari itself (Burger and Asaro 1979). In contrast, only a single sample at Cerro Baúl (2% of the obsidian analyzed) came from the much closer Chivay Source.

The situation is complicated further by evidence from the site of Tiahuanaco. All of the sixteen obsidian samples from Tiahuanaco's surface tested at LBNL in our original study were of Titicaca Basin Type obsidian (Burger and Asaro 1979); this means that the raw material for all of the artifacts had been procured at the Chivay Source. This finding does not appear to be consistent with the frequent assumption that the frontier between the Huari and Tiahuanaco spheres of influence

impeded the movement of materials between the two zones. At the same time, it should not be forgotten that the samples tested from Tiahuanaco were all surface materials and consequently, they could all postdate the decline of Huari. If so, they would not be relevant to discussions of the impact of the Huari-Tiahuanaco frontier.

However, regardless of the dating of the Tiahuanaco obsidian, the patterning of obsidian procurement in the Cerro Baúl assemblage needs to be explained. Could the Chivay source have been under Tiahuanaco control despite the Huari presence in the middle and lower sections of the valley? Alternatively, could local residents of the Colca region have maintained a special relationship with the peoples of the altiplano during the Middle Horizon and consequently continued to supply these groups with raw material? A third alternative is the possibility of a decline or hiatus in obsidian procurement at the Chivay source during the crucial period of the Middle Horizon. Unfortunately, before trying to evaluate the relative merits of these (and other) alternatives, it would be necessary to have additional obsidian artifacts analyzed from contexts in southern Peru and northern Bolivia which could be situated within a unified Middle Horizon chronological framework.

Whatever the patterning of obsidian procurement and distribution during the Middle Horizon, it is clear that the Chivay Source continued to provide raw obsidian to the Peruvian altiplano in later pre-Hispanic times. In this light, it is interesting to recall discussions of the ethnic configuration of the Colca Valley described in the early Colonial documents and discussed at length by Neira (1961, 1990) and Pease (1977). Basically, the historical documents refer to two distinctive and contrasting ethnic groups: the Collaguas and the Cavana. The Collaguas are described as an Aymara-speaking group that dominated the upper portion of the Colca Valley, including Chivay and Coporaque. The Cavana are said to have been Quechua-speaking people who occupied the lower elevations in the Colca Valley including the area around Cabanaconde. Given the long-standing exchange links between the area

in which the Chivay source obsidian is located and the altiplano, it is intriguing to find that at the time of the Spanish conquest the Chivay area was dominated by an Aymara-speaking group linked to the puna habitat. Neira and others have argued that the Collaguas represent the original pre-Inca population of the Colca Valley (Neira 1990:178), despite the general scarcity of altiplano influence visible in the current archaeological sample from Colca (Vera Cruz 1987:121). Whatever the ultimate outcome of this and other debates, the presence of a major obsidian source near Chivay underlines the need to understand the Colca Valley's prehistory within a regional or even pan-regional framework, as well as in terms of local carrying-capacity and other narrow concerns.

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Table 1. Effective background abundances from contamination in the LWAICS and the 99.9999%-pure
Al encapsulating foil for 100 mg sample weight.[a]

Isotope and/or element	Energy of γ rays (keV)[b]	LWAICS bkg	Means and RMSD for 5 empty Al capsules (assume 100 mg)[c]	Means and RMSD for 5 empty Al capsules (true weight)[c]
^{46}Sc	889.25	$0.0017 \pm .0000$	$0.2079 \pm .0020$	$0.0812 \pm .0003$
^{233}Pa(Th)	312.01	$0.0011 \pm .0001$	$0.0061 \pm .0028$	$0.0024 \pm .0011$
^{134}Cs	795.87	$0.0044 \pm .0001$	$0.0017 \pm .0022$	$0.0007 \pm .0009$
^{59}Fe(%)	1099.25	$0.0005 \pm .0000$	$0.0012 \pm .0003$	$0.00045 \pm .00010$
^{182}Ta	67.75	$0.0002 \pm .0000$	$0.0001 \pm .0003$	$0.0000 \pm .0001$
^{141}Ce[d]	145.44	$0.0040 \pm .0006$	$0.011 \pm .010$	$0.004 \pm .004$
^{181}Hf	132.9-482.0	$0.0003 \pm .0000$	$0.0026 \pm .0006$	$0.0010 \pm .00025$
^{152}Eu	344.29-778.92	$0.004 \pm .000$	$0.0004 \pm .0004$	$0.00015 \pm .00014$
^{86}Rb	1076.69	$0.007 \pm .009$	$0.10 \pm .14$	$0.038 \pm .055$
^{60}Co	1173.2-1332.5	$0.0362 \pm .0005$	$0.014 \pm .006$	$0.0056 \pm .0023$
^{65}Zn	1115.52	$0.067 \pm .002$	$3.5 \pm .6$	$1.38 \pm .23$
^{124}Sb	1690.98	$0.0003 \pm .0002$	$0.043 \pm .005$	$0.0167 \pm .0018$
^{75}Se(ppb)	136.00-264.66	$1.75 \pm .08$	6.1 ± 2.2	2.4 ± 1.6
Weight for abund. calc. (mg)		100	100	
True weight (mg)				255.7 ± 2.2

[a]Abundances are given in parts-per-million (ppm) except for those of Fe, which are given in percent (%), and those of Se, which are given in parts-per-billion (ppb). LWAICS indicates measurements were made with the Luis W. Alvarez Iridium Coincidence Spectrometer.

[b]Where two gamma ray energies separated by a hyphen are given for an isotope, radiations of those energies were used in coincidence measurements.

[c]RMSD is the root-mean-square deviation.

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

Table 2. Comparison of diagnostic element abundances measured in samples from the Chivay obsidian source in Peru[a].

Element[b]	Chivay-1 Saylutta S16-104		Chivay-2 Saylutta S16-105		Chivay-4 S16-266		Chivay-5 S16-267		Chivay-7 S16-269		Mean & RMSD[c] for Chivay Main Group		C. of V. (%)[d]	M. S. E. (%)[e]
*Elements with sample counting errors of less than 0.3% (all are singles measurements)*
Sc	3.378	± .003	3.373	± .003	3.378	± .007	3.368	± .004	3.365	± .007	3.372	± .0059	0.18	0.06
Th	25.12	± .03	25.11	± .03	25.21	± .06	25.16	± .05	25.10	± .06	25.14	± .045	0.18	0.10
Cs	10.26	± .02	10.27	± .02	10.26	± .03	10.29	± .03	10.21	± .03	10.26	± .029	0.28	0.11
Fe(%)	0.509	± .001	0.507	± .002	0.507	± .002	0.506	± .001	0.509	± .002	0.508	± .0013	0.26	0.23
Ta	1.677	± .003	1.681	± .003	1.688	± .005	1.678	± .004	1.682	± .005	1.681	± .0043	0.26	0.12
Ce[f]	43.76	± .07	43.57	± .05	43.59	± .12	43.78	± .09	43.34	± .12	43.61	± .18	0.41	0.14

Average (%)	0.26	0.13
Average efficiency uncertainty (singles) (%)		0.11
Average geometry uncertainty (singles) (%)		0.08
Overall uncertainty (%)		0.19

Element[b]	Chivay-1 Saylutta S16-104		Chivay-2 Saylutta S16-105		Chivay-4 S16-266		Chivay-5 S16-267		Chivay-7 S16-269		Mean & RMSD[c] for Chivay Main Group		C. of V. (%)[d]	M. S. E. (%)[e]
*Elements with sample counting errors greater than 0.3%*
Hf[g]	3.934	± .017	3.873	± .014	3.882	± .027	3.878	± .020	3.860	± .027	3.885	± .028	0.7	0.5
Eu[g]	0.294	± .002	0.290	± .002	0.297	± .005	0.295	± .003	0.286	± .005	0.292	± .004	1.5	1.1
Rb	249.3	± 3.7	248.3	± 3.5	250.6	± 3.8	247.7	± 3.9	247.4	± 4.1	248.7	± 1.3	0.5	0.7
Co[g]	0.333	± .007	0.320	± .006	0.329	± .015	0.324	± .010	0.336	± .015	0.328	± .007	2.0	2.5
Zn	32.4	± .6	31.7	± .6	31.9	± .6	33.1	± .6	32.2	± .6	32.3	± .5	1.7	1.8
Sb	0.896	± .018	0.953	± .016	0.899	± .029	0.900	± .022	0.920	± .030	0.914	± .024	2.6	2.1

Average (%)	1.5	1.5

[a]Abundances are given in parts-per-million (ppm) except for those of Fe, which are given in percent (%). Errors for individual samples are usually the counting errors due to both the samples and the standards. The exceptions are the Zn values which include the uncertainties in the variable amount of Zn impurity in the Al capsules.

[b]Standard Pottery (Perlman and Asaro, 1969) was used to calibrate the abundances of all of the listed elements, except Zn. The abundances in the standard were taken from Perlman and Asaro, 1971. The Rb abundance in Standard Pottery, however, has since been revised to 64.5 ± 1.2 ppm. Zinc was calibrated versus the standard DINO-1 (Alvarez et al. 198.) 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 standards.

[c] RMSD is the root-mean-square deviation.

[d] C. of V. is the coefficient of variation, i.e. the root-mean-square deviation divided by the mean value.

[e]M. S. E. is the mean sample counting error (excluding the counting errors due to the standards).

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

[g] Best measurements are by coincidence techniques.

Table 3. Deviation of element abundances of Chivay-6 and Chivay-3 from those of the main Chivay source group[a]

Element[b]	Main Chivay Group Mean & (RMSD[c] or M.S.E.[e])	Chivay-6 3 counts of S16-268 Mean & RMSD[e]	C. of V. (%)[d]	M.S.E. (%)[e]	(Chivay-6 -Main Group) / Main Group (%)	Chivay-3 Saylutta S16-106	(Chivay-3 -Main Group) / Main Group (%)
Elements with sample counting errors of less than 0.3%							
Sc	3.372 ± .006	3.385 ± .007	0.19	0.06	0.39 ± .14	3.349 ± .003	-0.7 ± .1
Th	25.14 ± .05	25.20 ± .05	0.20	0.10	0.24 ± .15	25.14 ± .04	0.0 ± .2
Cs	10.26 ± .03	10.305 ± .031	0.30	0.11	0.44 ± .20	10.07 ± .03	-1.9 ± .3
Fe(%)	0.508 ± .001	0.5105 ± .0003	0.06	0.24	0.49 ± .18	0.528 ± .002	3.9 ± .4
Ta	1.681 ± .004	1.691 ± .003	0.19	0.11	0.59 ± .15	1.657 ± .004	-1.4 ± .3
Ce[f]	43.61 ± .18	43.77 ± .07	0.17	0.16	0.37 ± .21	43.54 ± .10	-0.2 ± .3
		Mean	0.19%	0.13%			
		Effic. and geo. uncertainties		0.15%			
		Best value			0.42 ± .07 %		
Elements with sample counting errors greater than 0.3%							
Hf[g]	3.885 ± .028	3.881 ± .025	0.6	0.6	-0.10 ± 0.5	4.025 ± .031	3.6 ± .9
Eu[g]	0.292 ± .004	0.295 ± .004	1.4	1.1	1.0 ± 1.0	0.300 ± .005	2.7 ± 1.8
Rb	248.7 ± 1.3	248.4 ± 2.1	0.8	0.9	-0.1 ± 0.6	244.2 ± 3.9	-1.8 ± 1.6
Co[g]	0.328 ± .007	0.326 ± .005	1.5	2.5	-0.6 ± 1.7	0.382 ± .010	16.5 ± 3.2
Zn	32.3 ± .5	32.9 ± .5	1.5	0.5	1.9 ± 1.1	32.5 ± .6	0.6 ± 2.0
Sb	0.914 ± .024	0.860 ± .023	2.7	2.3	-5.9 ± 1.8	0.920 ± .033	0.7 ± 3.8
		Mean	1.4%	1.3%			

[a,b,c,d,e,f,g]See footnotes in Table 2. Exceptions are: 1) errors for the Chivay-6 and Chivay-3 deviations from the main group presume without proof that the precision of the group averages can be expressed by the RMSD divided by the square root of the number of measurements; 2) "RMSD or M.S.E." is the larger of the root-mean-square deviation for the 5 samples or their mean counting error (excluding the counting errors due to the standards); 3) Effic. and geo. uncertainties = uncertainties in the singles measurements of gamma ray efficiency and geometry, respectively.

Table 4. Comparison of element abundances measured in samples
from the Chivay source in Peru with the Titicaca Basin
Chemical Group of Burger and Asaro, 1977[a]

El-ment[b]	Main Chivay Source Group (Mean & RMSD[c] for 5 samples)		Titicaca Basin Chemical Group (Mean & RMSD[c] for 21 samples)		Deviation (%)
Elements with RMSD better than 4% in the old LBNL INAA					
Sc	3.372	± .006	3.355	± .047	-0.5
Th	25.14	± .05	25.10	± .34	-0.2
Cs	10.26	± .03	10.21	± .37	-0.5
Fe(%)	0.508	± .001	0.498	± .017	-2.0
Eu	0.292	± .004	0.286	± .007	-2.1
Ce[f]	43.61	± .18	42.8	± 1.1	-1.9
Ta	1.681	± .004	1.681	± .031	0.0
Hf	3.885	± .028	3.82	± .12	-1.7

Average deviation (8) = 1.1%

Elements with RMSD poorer than 4% in the old LBNL INAA					
Co	0.328	± .007	0.31	± .08	
Rb	248.7	± 1.3	240	± 13[h]	

[a,b,c,f]See footnotes in Table 2. Deviation (%) = 100 x (Chemical group -
Source group) / Source group

[h]The abundance is the best value for the recalibrated Rb abundance that could be
deduced for 21 samples measured in 4 irradiation groups. The most realistic
RMSD comes from 3 of the groups with comparable error. As the value is
coincidentally small, 4 ppm, the average uncertainty of the 3 groups, 13 ppm,
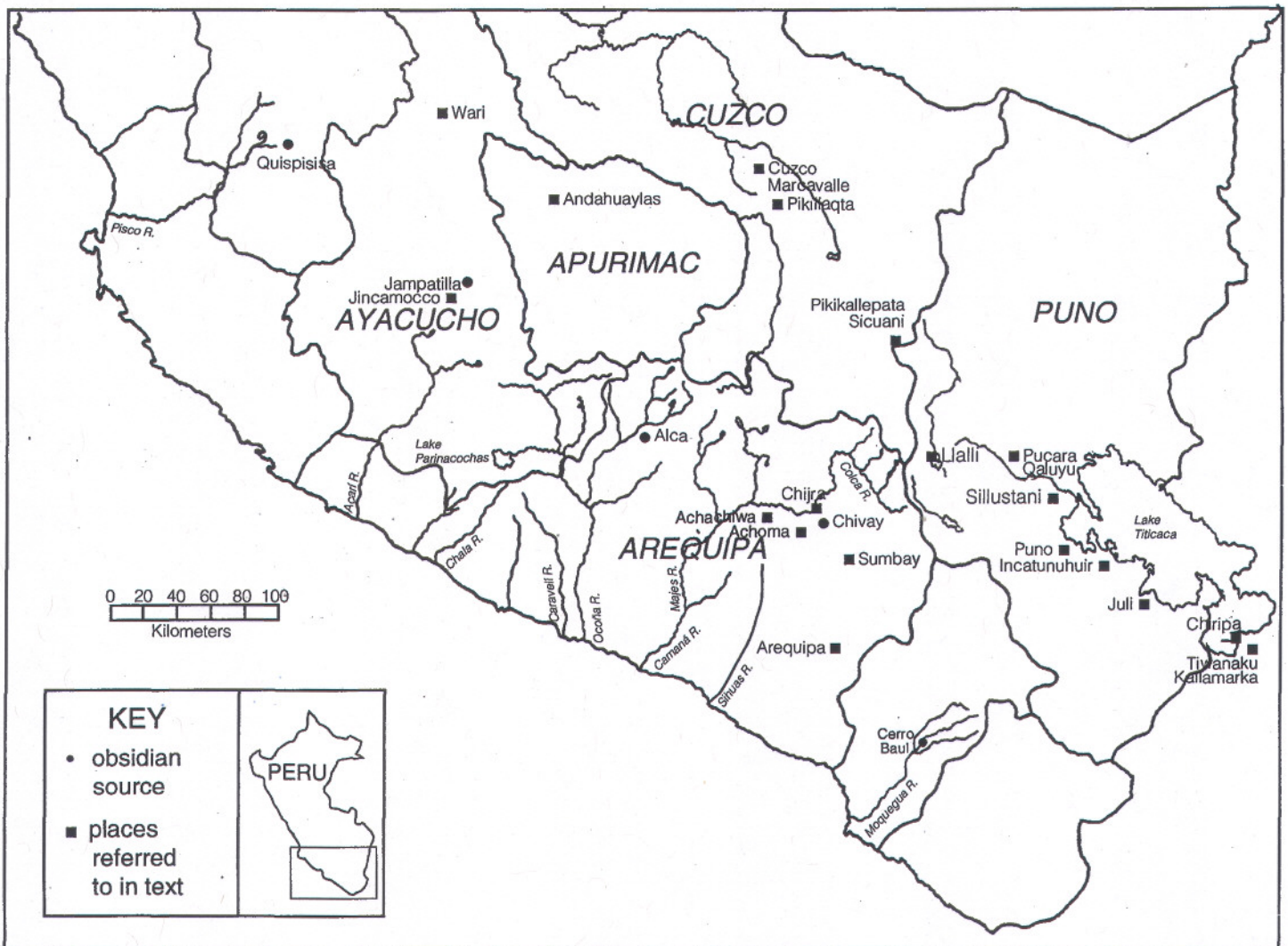is used.

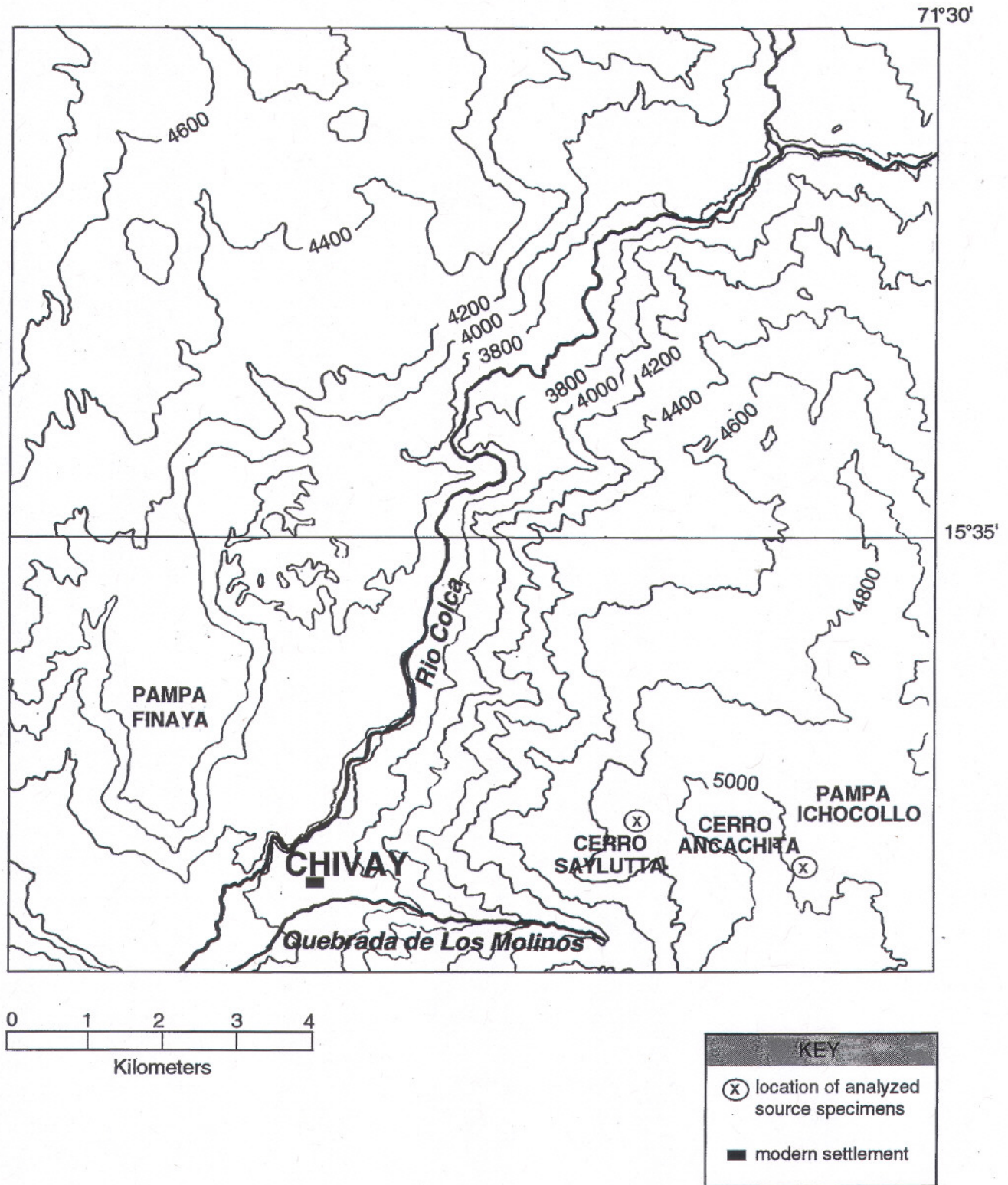**Figure 1**. Location of archaeological sites and other places mentioned in this article.

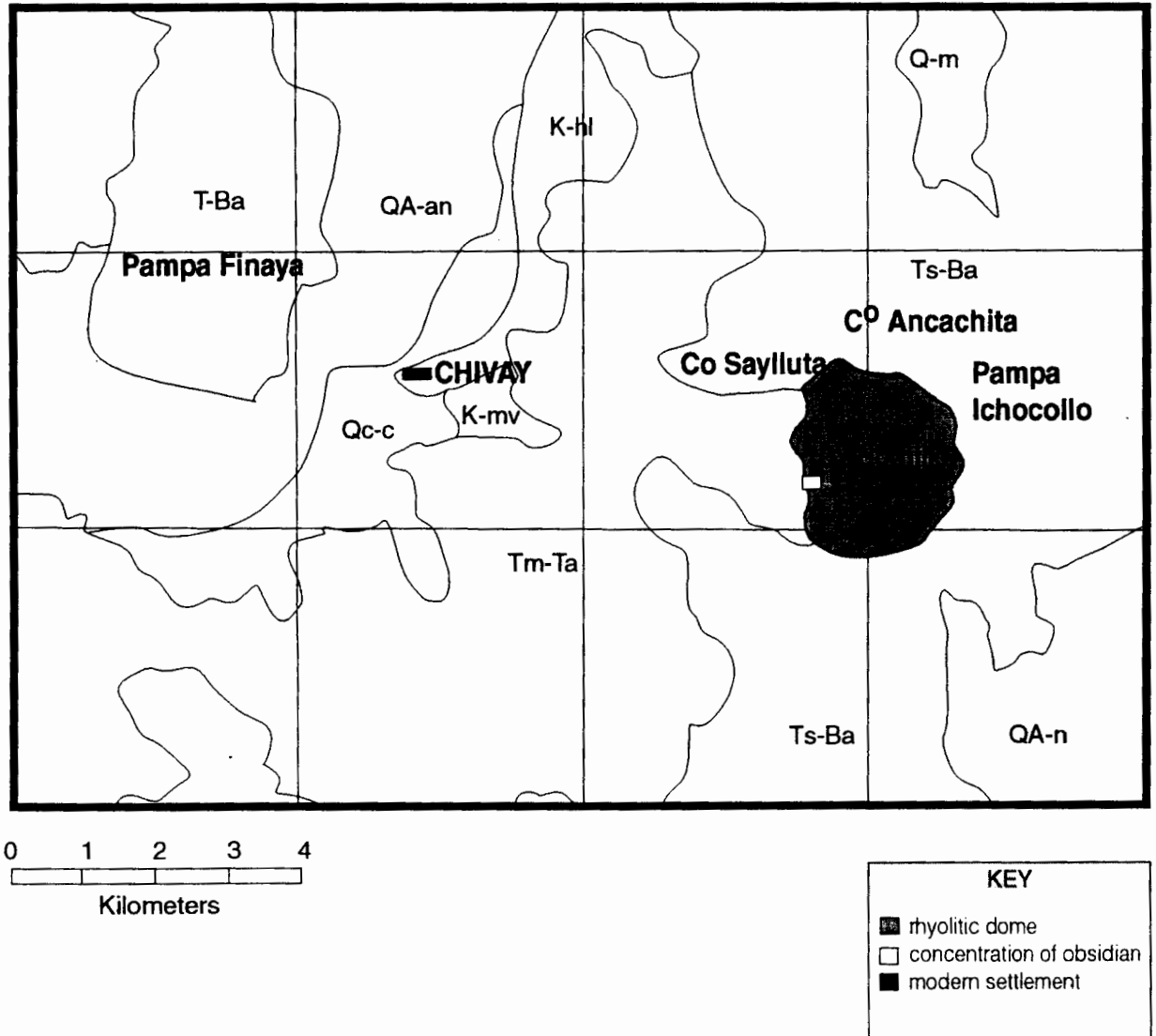**Figure 2**. Location of obsidian samples analyzed in this study.

Figure 3. Geology of the Chivay area, including the rhyolitic dome at Cerro Hornillo and the Chivay Source obsidian deposits associated with its perimeter (based on Palacios *et al.* 1993 and observations by Guido Salas).

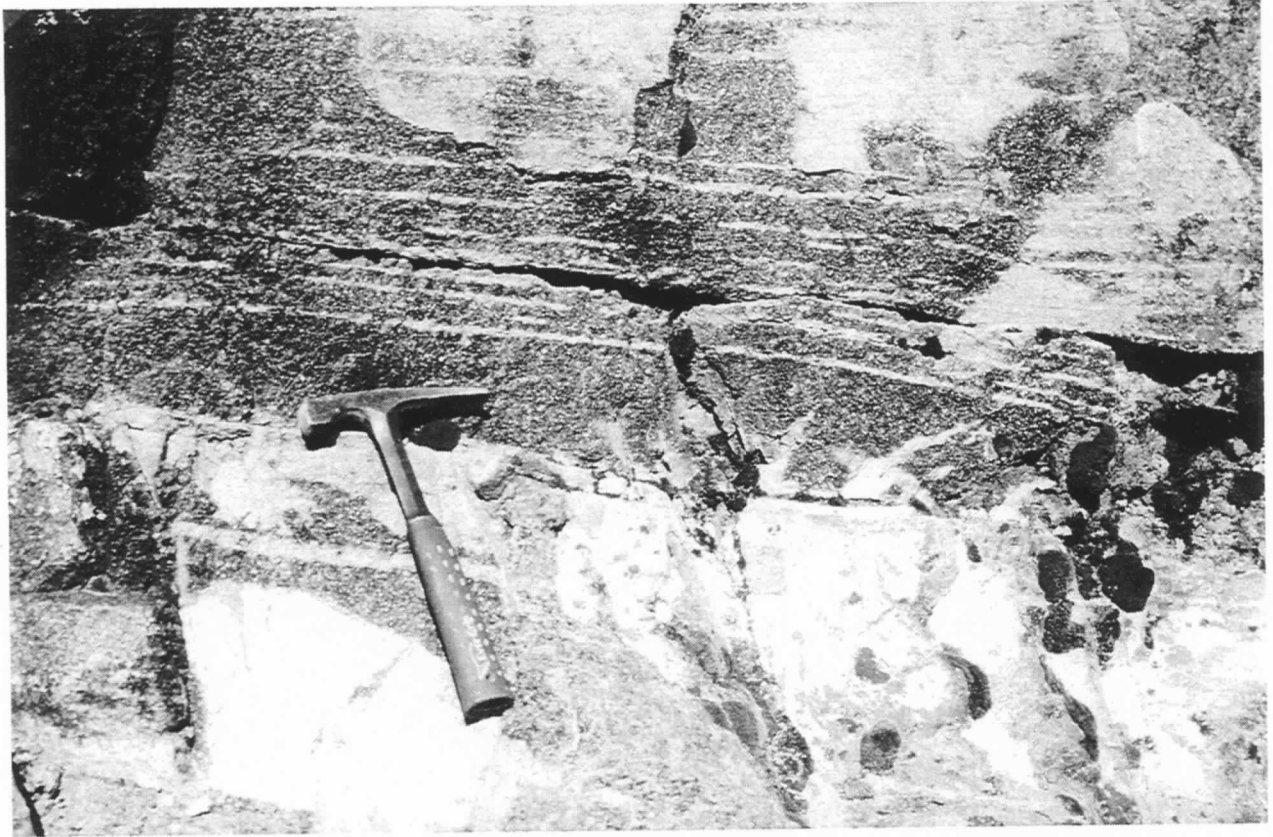**Figure 4**. Rhyolitic dome at Cerro Hornillo. Photograph by Guido Salas.

Figure 5. Obsidian layers on the western edge of Cerro Hornillo's rhyolitic dome (see Figure 4). Photograph by Guido Salas.