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Characterization of pottery from Cerro de Las Ventanas, Zacatecas, México

By H. López-del-Río[1,]*, F. Mireles-García[1], R. Y. Méndez-Cardona[2], M. Nicolás-Caretta[3,4], R. J. Speakman[5] and M. D. Glascock[6]

[1] Unidad Académica de Estudios Nucleares, UAZ, Apdo. Postal 579C, 98068 Zacatecas, México
[2] Unidad Académica de Antropología, UAZ, Apdo Postal 555 Suc C, Zacatecas, México
[3] INAH Delegación Zacatecas, México
[4] Coordinación de Ciencias Sociales y Humanidades, UASLP, Av. Industrias 101-A, Fracc. Talleres 78494 SLP, México
[5] Museum Conservation Institute, Smithsonian Institution, Suitland, MD 20746, USA
[6] Research Reactor Center, University of Missouri, Columbia, MO 65211, USA

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Summary. With the aim of classifying prehispanic pottery from Cerro de Las Ventanas site, Juchipila, Zacatecas, México, instrumental neutron activation analysis (INAA) was used to analyze ceramic samples at the University of Missouri Research Reactor Center. Thirty-two chemical elements were measured: Al, As, Ba, Ca, Ce, Co, Cr, Cs, Dy, Eu, Fe, Hf, K, La, Lu, Mn, Na, Nd, Rb, Sb, Sc, Sm, Sr, Ta, Tb, Ti, Th, U, V, Yb, Zn, and Zr. Two multivariate statistical methods, cluster analysis and principal component analysis, were performed on the dataset to examine similarities between samples and to establish compositional groups. The statistical analyses of the dataset suggest that the pottery samples form a unique chemically homogeneous group, with the exception of one pottery sample. The compositional data were compared to an existing Mesoamerican ceramic database. It was found that the newly generated data fit best with data from a previous chemical analysis of pottery from the Malpaso Valley. However, despite the apparent similarity, pottery samples from the site of Cerro de Las Ventanas represent a new and unique chemical fingerprint in the region.

1. Introduction

Pottery is often the most common artifactual material recovered during archaeological field research. It can provide archaeologists with valuable information about the age of a culture, length of site occupation, social organization, technological phase, economic system, and cultural contact across a region [1]. In pottery analysis, archeologists are most commonly interested in stylistic variation through time and space, in the technological level involved in ceramic manufacture, and in the function and use of artifacts. With these purposes in mind, a classification is made on the basis of shared stylistic and functional attributes (*e.g.*, typologies) [2, 3]. However, visual examination of artifacts does not always provide definitive information with respect to the study of exchange networks or pottery provenance [4–6].

Chemical and mineralogical characterization of pottery provides valuable quantitative analytical data useful for inferring the location and techniques involved in its manufacture. Such studies include mineralogical composition, chemical composition, microstructure, and surface traits [1]. In particular, chemical analyses of pottery may be used to trace the source of raw material (provenance studies) by matching elemental abundances of wares with those of clays. Compositional analyses identify the chemical elements of the paste that represent a unique geochemical fingerprint [6]. According to the "provenance postulate" [7] the variation in chemical composition of the raw materials must be greater between two spatially separated regions than the variation within a particular region. Additionally, chemical analyses may be useful for investigating geographic displacements among spatially separated regions by comparing ceramic elemental patterns [8].

Compositional datasets typically are examined by applying pattern-recognition multivariate statistical methods in order to group ceramic samples according to their similarities. Thus, a new chemical-based classification of the pottery is obtained, and homogeneous groups are formed [9]. Compositional groups act as a new pseudo-typology that can be used to compare different ceramic types.

Currently, many analytical techniques can be applied to determine elemental composition of pottery: X-ray fluorescence (XRF) [10], instrumental neutron activation analysis (INAA) [11], proton induced X-ray emission (PIXE) [12], laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) [13], and electron probe microanalysis (EPMA) [14]. However, INAA has been and continues to be used by many researchers to study pottery. It allows simultaneous determination of a large number of elements with high accuracy, precision and sensitivity. It is sensitive enough to measure concentrations in the $\mu g\, g^{-1}$ range or below and sample preparation is relatively easy and fast.

In this work, we report the results obtained from chemical analysis of 15 ceramic potsherds from the Mexican ar-

*Author for correspondence (E-mail: hlopez@uaz.edu.mx).

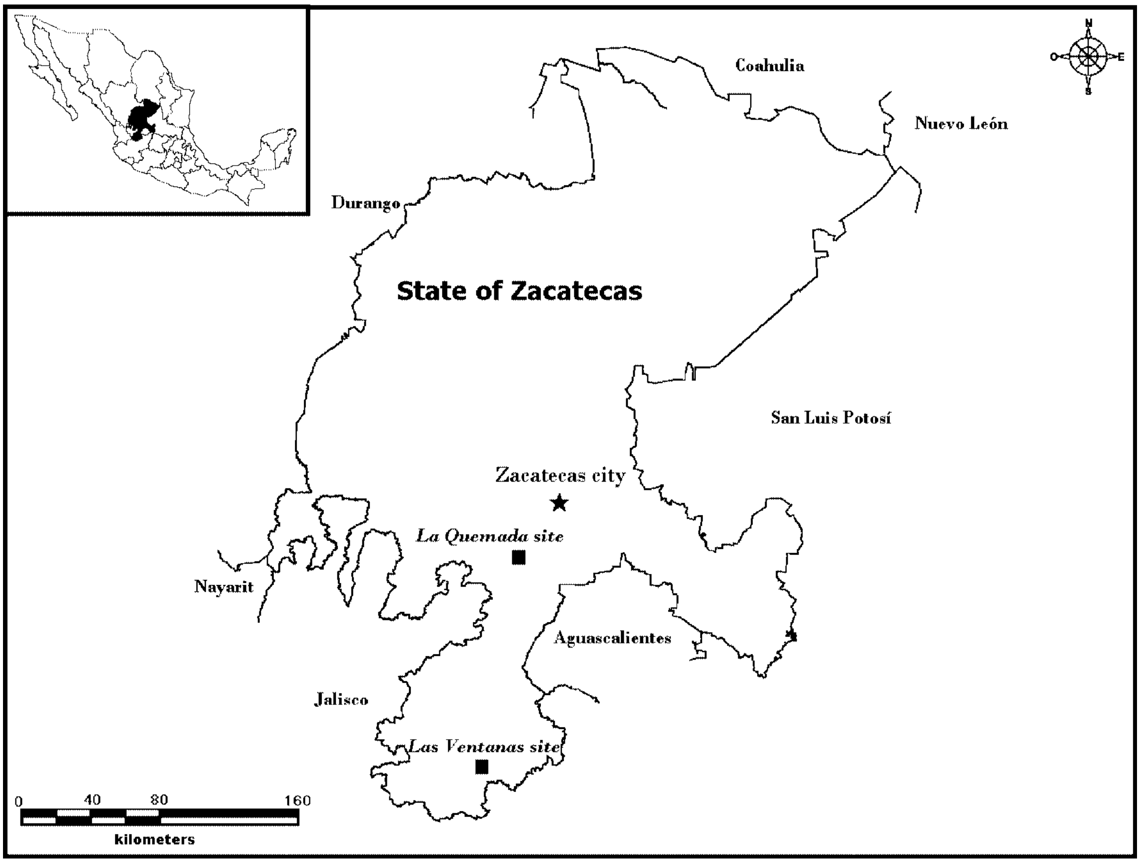

Fig. 1. Map showing the location of Cerro de Las Ventanas site.

chaeological site of Cerro de Las Ventanas. The site was an important Caxcan settlement, and archaeologists believe that it was included in a great exchange network extending from northern Zacatecas to Teotihuacan City in central México, during the Classic period [15]. The research performed at this site will allow archaeologists to attain a greater understanding of the interactions between prehispanic social groups in northwestern Mexico.

1.1 Archaeological background

The Cerro de Las Ventanas site is located in the southern part of the state of Zacatecas, México, in Juchipila town, covering an area of approximately 119 ha (Fig. 1). It is about 175 km away from the site of La Quemada, which is one of the most important prehispanic settlements of northwestern Mesoamerica. Cerro de Las Ventanas, along with La Quemada and other major settlements from Los Altos, Jalisco, and northern Guanajuato, were all connected to Teotihuacan through a large exchange network [15].

The most important archaeological structures are located on Las Ventanas hill (because of this it was called Cerro de Las Ventanas), but a portion of the site is encompassed by Cerro Chihuahua, Cerro Pico de Pecho, and Cerro Pico de Aguila. According to ^{14}C dating, there was a long period of occupation by the Caxcan culture from 20 ∼ 70 AD until 1400 AD [16]. The archaeological record consists of ceramics, lithics, and milling materials. The main monumental structures lie on Cerro de Las Ventanas, which encompass a pyramid-altar-square complex (*i.e.*, ceremonial center) and several residential houses including a cliff-house. Terraces and residential houses also are present on the piedmont and in the valley.

Although descriptions of the archaeological site have appeared in several documents from the early 20th century, the first academic research was carried out in the late 1980s and 1990s. Unfortunately, research at the site was interrupted for several years, but ultimately a more systematic INAH (Instituto Nacional de Antropologia e Historia) Project was initiated at Las Ventanas under the direction of Nicolás-Caretta and Jiménez in 2002. The materials analyzed for this paper were recovered during the excavation phase of this project in 2003.

2. Experimental

2.1 Pottery samples

Fifteen ceramic sherds were analyzed. The samples reported here were collected from Terrace No. 1 during Nicolás-Caretta and Jimenez-Bets's excavation [17], and they represent a ceramic occupation ranging from 30 to 280 cm in depth. One ceramic fragment (LVZ003) was collected on the surface. The specimens were selected based on the diagnostic quality they represented within the spectrum of material collected.

2.2 Sample preparation

Standard MURR procedures for pottery analysis were applied to samples [11]. An area of ∼ 1 cm^2 is removed from potsherd, and all surface layers were removed using a tungsten-carbide burring tool. Next, the sample was cleaned and washed with deionized water and allowed to dry for several hours. A fine powder was obtained by crushing the sample in an agate mortar. Finally, the powder was stored in clean glass vial and dried at 100 °C for at least 24 h.

2.3 Neutron activation analysis

Approximately 150 mg of ceramic powder was weighed into a clean polyethylene vial used for short irradiation. A second portion of about 200 mg powder was weighed into a high-purity quartz vial used for long irradiation. Both aliquots were weighed to the nearest 0.01 mg. Quality control samples and standards of Ohio Red Clay, SRM-1633a (coal fly ash), SRM-278 (obsidian rock), and SRM-688 (basalt rock) were similarly prepared.

Samples and standards in polyethylene vials were sequentially subjected to a short irradiation (5 s) in the pneumatic tube system with a neutron flux of 8×10^{13} n/(s cm^2). The samples were allowed to decay for 25 min and counted for 720 s using a high resolution, high-purity germanium detector (HPGe). The short irradiation yields data for nine short-lived elements: Al, Ba, Ca, Dy, K, Mn, Na, Ti, and V. A long irradiation of samples, standards, and quality control samples in quartz vials was carried out in the reactor pool using a neutron flux of 5×10^{13} n/(s cm^2) for a period of 24 h. The radioactive samples and standards were counted twice: a middle count of 1800 s after a 7-d decay and a final count for a period of 10 000 s after an additional 3- or 4-week decay. The first count measures seven medium-lived elements: As, La, Lu, Nd, Sm, U and Yb. The final count yields sixteen long-lived elements: Ce, Co, Cr, Cs, Eu, Fe, Hf, Rb, Sb, Sc, Sr, Ta, Tb, Th, Zn and Zr.

3. Results and discussion

Elemental concentration values for 32 elements were obtained from the analysis. A statistical summary of data is listed in Table 1. Missing values were replaced with values calculated from a Mahalanobis distance minimization routine to enable subsequent analysis. A series of GAUSS®-language based routines [18] were used to calculate missing values, to transform data, and to perform multivariate statistical analysis. Given that chemical characterization of pottery produces a dataset with high-concentration values (major elements) and low-concentration values (trace elements), elemental concentrations were converted to base-10 logarithms to compensate for differences in magnitude between the major elements and trace elements.

As a first approach to identifying compositionally homogenous groups within the matrix of data, a hierarchical cluster analysis was performed. Squared-mean Euclidean distances and average linkage were used for the clustering algorithm. From the resulting dendogram, shown in Fig. 2, partitioning of pottery samples into subgroups is possible, with two individual samples (3 and 7). Clearly, sample 3 is related to the archaeological context from which it was recovered making it the poorest match to any of the other samples.

Principal component analysis (PCA) was applied to confirm these assumptions. PCA, a pattern-recognition technique, is a multivariate statistical procedure used to identify patterns in data of high dimension through data compression and dimension reduction without a significant loss of information [19]. The data are transformed into a small number of linear combinations (principal components or scores) of the original variables and the eigenvectors based on a variance-covariance matrix. The first few principal component scores account for a maximal amount of variance in the data set. It was found that the first five principal components account for more than 90% of the total variance in the dataset (Table 2). A bivariate plot of principal components 1 and 2 (Fig. 3) with a 90% confidence ellipse used to establish group membership, suggests that the pottery samples form a unique chemically homogeneous group, with the exception of pottery sample 3. This is in agreement with the cluster analysis results.

Table 1. Statistical summary of compositional data for the Cerro de Las Ventanas pottery (in µg g^{-1}).

Element	Mean	S.D.	Minimum	Maximum
As	59.1	76.3	13.4	304.4
La	29.0	10.9	14.8	54.2
Lu	0.587	0.217	0.236	1.169
Nd	41.3	21.5	12.8	83.7
Sm	5.99	2.32	2.36	11.3
U	3.95	1.93	1.48	9.52
Yb	4.28	1.67	1.78	8.79
Ce	71.6	25.5	29.4	110.4
Co	5.69	3.27	1.18	12.1
Cr	26.0	24.0	10.5	100.3
Cs	12.92	9.78	2.31	31.0
Eu	0.755	0.410	0.235	1.728
Fe	27 256	6505	14 935	37 019
Hf	10.82	3.45	6.32	17.0
Rb	114	34	77	180
Sb	3.45	6.89	0.51	28.0
Sc	8.41	3.79	3.93	19.73
Sr	279	117	121	652
Ta	2.60	1.17	0.79	5.17
Tb	1.07	0.45	0.35	2.23
Th	14.8	3.30	7.78	20.9
Zn	90	21	50	120
Zr	241	73	124	367
Al	89 324	12 584	71 209	115 989
Ba	1209	1356	266	5843
Ca	9301	3312	5777	18 695
Dy	6.05	2.52	1.94	12.57
K	35 758	7056	26 505	51 599
Mn	346	182	96	589
Na	7887	1884	3703	10 707
Ti	2866	1114	1243	5944
V	54.9	30.9	17.9	151.8

Table 2. Eingenvalues and percentage of variance of Principal Components based on a variance-covariance matrix.

Principal component	Eigenvalue	% Total variance	% Cumulative variance
1	0.5696	38.28	38.28
2	0.4283	28.78	67.07
3	0.1498	10.06	77.14
4	0.1114	7.48	84.63
5	0.0760	5.12	93.15

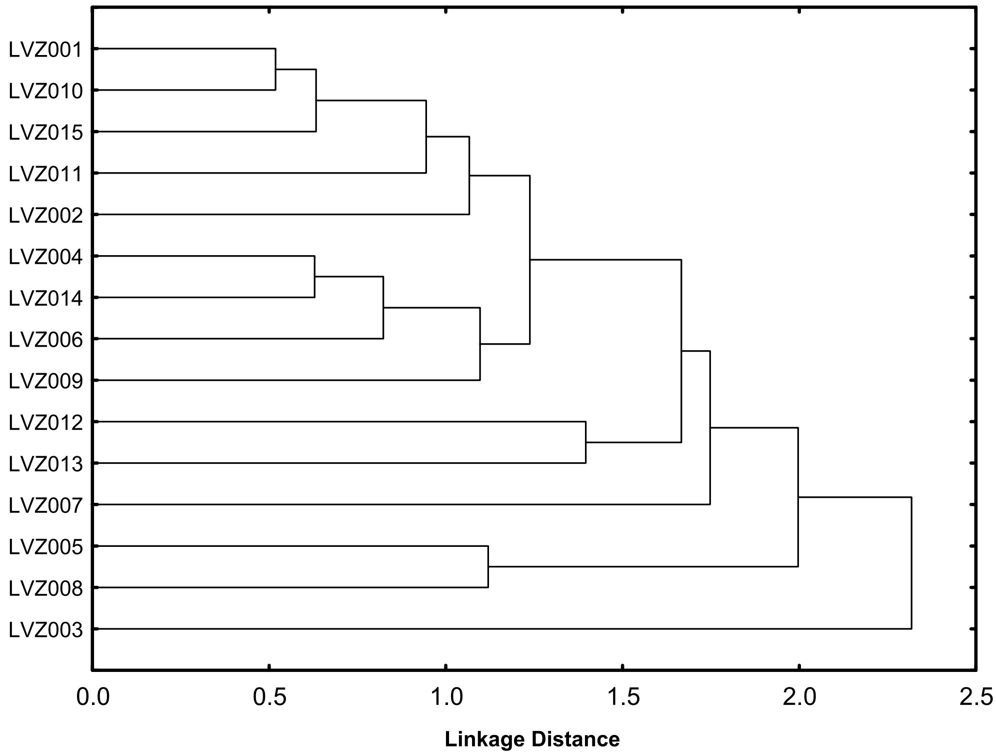

Fig. 2. Dendogram for 15 pottery samples from the site of Cerro de Las Ventanas.

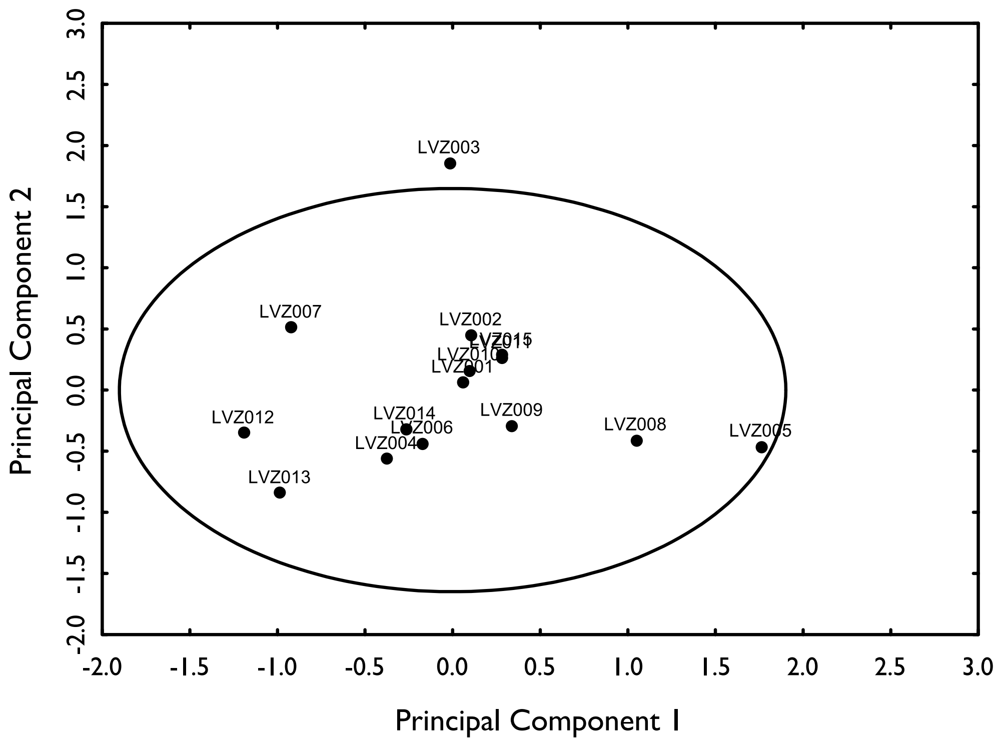

Fig. 3. Bivariate plot of principal components 1 and 2 for the Cerro de Las Ventanas pottery. The ellipse indicates the 90% confidence level for group membership.

Subsequently, the compositional data generated for samples from the Cerro de Las Ventanas site were compared to the database of Mesoamerican pottery at the MURR Archaeometric Laboratory consisting of more than 10,000 analyzed pottery samples, in order to match pottery samples with well-characterized regional pottery. We found that the compositional data for the Cerro de Las Ventanas pottery samples best matched the data generated for a previous chemical characterization research of pottery from the Malpaso Valley carried out by Strazicich [20]. The Malpaso Valley regional system, a geographical area located in the southern end of the State of Zacatecas, is located about 175 km from the site of Cerro de Las Ventanas site and is one of the northernmost and largest of the regional systems that form the Mesoamerican frontier [21]. The Malpaso Valley is dominated by the extensive center of La Quemada that was founded around 500 AD and abandoned by 900 AD [22]. Strazicich identified three chemical compositional groups

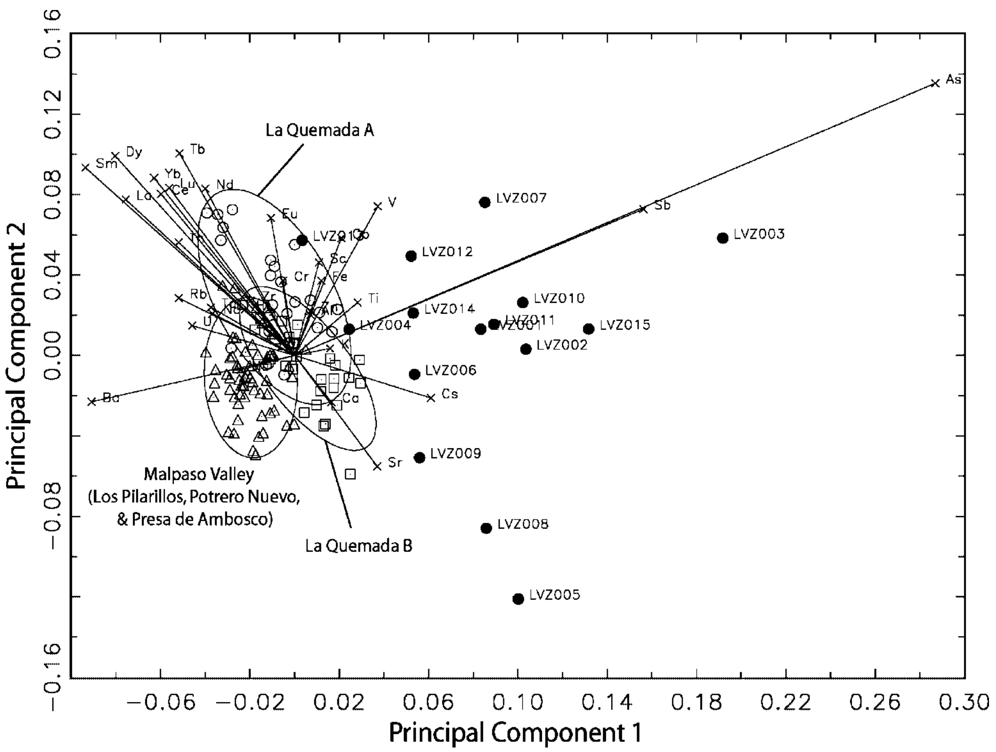

Fig. 4. Biplot of principal components 1 and 2 based on PCA of the Malpaso Valley, La Quemada, and Cerro de Las Ventanas data sets. The ellipses indicate the 90% confidence level for group membership.

for the region: La Quemada A, La Quemada B, and Malpaso Valley. The first two are assumed to represent ceramic production at the La Quemada site; the third includes pottery from several minor sites: Los Pilarillos, Puerto Nuevo, and Presa de Ambosco. Differences between the two data sets are illustrated in Fig. 4. Despite the apparent similarities, none of the Malpaso Valley samples chemically match the Cerro de Las Ventanas samples, which is supported by the calculated Mahalanobis distance probabilities.

4. Conclusions

Elemental compositions of fifteen ceramic fragments from the site of Cerro de Las Ventanas were obtained using INAA. At the 90% confidence level for group membership, one compositionally homogeneous group was identified by multivariate statistical analysis, and one individual sample. Analytical results were compared with previous data for regional pottery. We found that the samples from Cerro de Las Ventanas matched best with data generated for pottery from the Malpaso Valley located in the same general region of México. However, the pottery samples from Cerro de Las Ventanas represents a unique new chemical fingerprint for this region.

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