Instrumental Neutron Activation Analysis of Ceramics and Clays for the Palmitopamba Archaeology Project, Ecuador

Report Prepared by:
Robert J. Speakman and Michael D. Glascock
Archaeometry Laboratory
Missouri University Research Reactor
University of Missouri
Columbia, MO 65211

For:
Ronald D. Lippi
University of Wisconsin-Marathon County
518 S. 7th Avenue
Wausau, WI 54401

And

Tamara Bray
137 Manoogian Hall
Department of Anthropology
Wayne State University
Detroit, MI 48202

31-Jan-2003

Introduction

Instrumental neutron activation analysis (INAA) has been undertaken on a sample of 54 ceramic and 2 raw clay samples from the Palmitopamba site located in north central Ecuador. The analyses were conducted at the University of Missouri Research Reactor Center (MURR). Here, we describe sample preparation and analytical techniques used at MURR and report on the subgroup structure discovered in the chemical data.

Background

In 2002, Ronald Lippi and Tamara Bray submitted 54 ceramic and 2 clay samples to MURR for analysis by INAA. These ceramics were sampled from Pucara de Palmitopamba a prehistoric hilltop fortress located 45 km northwest of Quito. The site is of particular interest because of the discovery of Inca-style pottery at the site. An Inca presence at Palmitopamba is considered unusual since the Inca conquest of Peru and most other regions of the Andes was primarily a highland expansion and typically did not include tropical forest elevations at less than 1500 meters above sea level (Lippi and Bray 2002). The samples submitted for analysis include Inca-style pottery, Yumbo pottery which is presumably of local manufacture, and a sample of Cosanga (or Panzaleo) pottery which is hypothesized to be a "ritual" ceramic imported from the eastern lowlands.

Sample Preparation

The 54 ceramic samples from Palmitopamba were prepared for INAA using procedures standard at MURR. First, 1cm^2 fragments were removed from each sample and abraded using a silicon carbide burr in order to remove glaze, slip, paint, and adhering soil, thereby reducing the risk of contamination. Each sample was then washed in deionized water and allowed to dry in the laboratory. Once dry, each sherd was ground in an agate mortar to homogenize the sample. Archival samples were retained from each sherd (when possible) for future research. Clay samples were formed by hand into briquettes and fired to 700 degrees C. After firing, a portion from each clay sample was ground in an agate mortar to homogenize the sample. The powdered samples were oven-dried at 100 degrees C for 24 hours. Portions of approximately 150 mg were weighed into small polyvials used for short irradiations at MURR. At the same time, 200 mg of each sample was weighed into the high-purity quartz vials used for long irradiations. Along with the unknown samples, reference standards of SRM-1633a (coal fly ash) and SRM-688 (basalt rock) were similarly prepared, as were quality control samples (i.e., standards treated as unknowns) of SRM-278 (obsidian rock) and Ohio Red Clay.

Irradiation and Gamma-Ray Spectroscopy

Neutron activation analysis of ceramics at MURR, which consists of two irradiations and a total of three gamma counts, constitutes a superset of the procedures used at most other NAA laboratories (Glascock 1992; Neff 1992, 2000). As discussed in detail by Glascock (1992), a short irradiation is carried out through the pneumatic tube irradiation system. Samples in the polyvials are sequentially irradiated, two at a time, for five seconds by a neutron flux of 8 x 10^{13} n/cm^2/s. The 720-second count yields gamma spectra containing peaks for short-lived elements aluminum (Al), barium (Ba), calcium (Ca), dysprosium (Dy), potassium (K), manganese (Mn), sodium (Na), titanium (Ti), and vanadium (V). The samples encapsulated in quartz vials are subjected to a 24-hour irradiation at a neutron flux of 5 x 10^{13} n/cm^2/s. This long irradiation is analogous to the single irradiation utilized at most other laboratories. After the long irradiation, samples decay for seven days, then are counted for 2,000 seconds (the "middle count") on a high-resolution germanium detector coupled to an automatic sample changer. The middle count yields determinations of seven medium half-life elements, namely arsenic (As), lanthanum (La), lutetium (Lu), neodymium (Nd), samarium (Sm), uranium (U), and ytterbium (Yb). After an additional three- or four-week decay, a final count of 9,000 seconds is carried out on each sample. The latter measurement yields the following 17 long half-life elements: cerium (Ce), cobalt (Co), chromium (Cr), cesium (Cs), europium (Eu), iron (Fe), hafnium (Hf), nickel (Ni), rubidium (Rb), antimony (Sb), scandium (Sc), strontium (Sr), tantalum (Ta), terbium (Tb), thorium (Th), zinc (Zn), and zirconium (Zr).

Elemental concentration data from the two irradiations and three counts (a total of 33 elements) are assembled into a single tabulation and stored in a dBASE file along with descriptive information available for each sample. The diskette included with this report contains the complete database in two formats, Excel and dBASE/Foxpro.

Quantitative Analysis of the Chemical Data

The analyses at MURR described previously produced elemental concentration values for 32 or 33 elements in most of the analyzed samples. (Some elements, especially nickel, were found to be below detection in most samples.) Quantitative analysis was subsequently carried out on base-10 logarithms of concentrations for these data. Use of log concentrations instead of raw data compensates for differences in magnitude between the major elements, such as calcium, on one hand and trace elements, such as the rare earth or lanthanide elements (REEs), on the other hand. Transformation to base-10 logarithms also yields a more nearly normal distribution for many trace elements.

The goal of quantitative analysis of the chemical data is to recognize compositionally homogeneous groups within the analytical database. Based on the “provenance postulate” (Weigand, Harbottle, and Sayre 1977), such groups are assumed to represent geographically restricted sources or source zones. The location of sources or source zones may be inferred by comparing the unknown groups to knowns (source raw materials) or by indirect means. Such indirect means may include the “criterion of abundance” (Bishop, Rands, and Holley 1982) or arguments based on geological and sedimentological characteristics (e.g., Steponaitis, Blackman, and Neff 1996).

Initial hypotheses about source-related subgroups in the compositional data can be derived from non-compositional information (e.g., archaeological context, decorative attributes, etc.) or from application of pattern-recognition techniques to the chemical data. Principal components analysis (PCA) is one technique that can be used to recognize patterns (i.e., subgroups) in compositional data. PCA provides new reference axes that are arranged in decreasing order of variance subsumed. The data can be displayed on combinations of these new axes, just as they can be displayed relative to the original elemental concentration axes. PCA can be used in a pure pattern-recognition mode to search for subgroups in an undifferentiated data set or in a more evaluative mode to assess the coherence of hypothetical groups suggested by other criteria (archaeological context, decoration, etc.). Generally, compositional differences between specimens can be expected to be larger for specimens in different groups than for specimens in the same group, and this implies that groups should be detectable as distinct areas of high point density on plots of the first few components.

One strength of PCA, discussed by Baxter (1992) and Neff (1994), is that it can be applied as a simultaneous R- and Q-mode technique, with both variables (elements) and objects (individual analyzed samples) displayed on the same set of principal component reference axes. The two-dimensional plot of element coordinates on the first two principal components is the best possible two-dimensional representation of the correlation or variance-covariance structure in the data: Small angles between vectors from the origin to variable coordinates indicate strong positive correlation; angles close to 90^{o} indicate no correlation; and angles close to 180^{o} indicate negative correlation. Likewise, the plot of object coordinates is the best two-dimensional representation of Euclidean relations among the objects in log-concentration space (if the PCA was based on the variance-covariance matrix) or standardized log-concentration space (if the PCA was based on the correlation matrix). Displaying objects and variables on the same plots makes it possible to observe the contributions of specific elements to group separation and to the distinctive shapes of the various groups. Such a plot is called a "biplot" in reference to the simultaneous plotting of objects and variables. The variable interrelationships inferred from a biplot can be verified directly by inspection of bivariate elemental concentration plots (note that a bivariate plot of elemental concentrations is not a "biplot").

Whether a group is discriminated easily from other groups can be evaluated visually in two dimensions or statistically in multiple dimensions. A metric known as Mahalanobis distance (or generalized distance) makes it possible to describe the separation between groups or between individual points and groups on multiple dimensions. The Mahalanobis distance of a specimen from a group centroid (Bieber et al. 1976; Bishop and Neff 1989; Neff 2001; Harbottle 1976; Sayre 1975) is:

$$D^2_{y,X} = [y - \overline{X}]^t I_X [y - \overline{X}] \qquad (1)$$

where y is the 1 x m array of logged elemental concentrations for the individual point of interest, X is the n x m data matrix of logged concentrations for the group to which the point is being compared with $\overline{X}$ being its 1 x m centroid, and I_x being the inverse of the m x m variance-covariance matrix of group X. Because the Mahalanobis distance takes into account variances and covariances in the multivariate group it is analogous to expressing distance from a univariate mean in standard deviation units. Like standard deviation units, Mahalanobis distances can be converted into probabilities of group membership for individual specimens (e.g., Bieber et al.

1976; Bishop and Neff 1989; Harbottle 1976). For relatively small sample sizes, it is appropriate to base probabilities on Hotelling's T^2, which is the multivariate extension of the univariate Student's t.

With small groups, Mahalanobis distance-based probabilities of group membership may fluctuate dramatically depending on whether or not the specimen is assumed to be a member of the group to which it is being compared. Harbottle (1976) calls this phenomenon "stretchability" in reference to the tendency of an included specimen to stretch the group in the direction of its own location in the elemental concentration space. This problem can be circumvented by cross-validation (or "jackknifing"), that is, by removing the specimen from its presumed group before calculating its probability of membership in the group (Baxter 1994b; Leese and Main 1994). This is a conservative approach to group evaluation that may sometimes exclude true group members. All probabilities discussed below are cross-validated. Mahalanobis distance-based probabilities also require that there must be at least one more specimen in the group than there are variables/elements (n+1). When cross-validation is used, the group must contain two more specimens than there are variables (n+2). This presents a problem with small groups that may contain fewer specimens than variables, because it would require the analyst to remove variables (elements) in an adhoc fashion. It is possible to circumvent this problem by using PCA scores generated for the individual specimens. In the present situation, more than 90% of the cumulative variation is explained by the first nine principal components. All Mahalanobis distance-based probabilities discussed below were generated using principal components 1 through 5.

Results and Conclusion

The subgroup structure observed in the dataset is fairly easy to interpret and thus offer archaeologically-based conclusions. Two compositional groups exist within the Palmitopamba ceramic sample. The first compositional group, Cosanga, contains all but one of the 15 ceramics classified as Cosanga. The second compositional group (Palmitopamba core) contains 36 samples of pottery classified as Yumbo and Inca. Four ceramic and two clay samples are unassigned. Descriptive information and group assignments are listed in Table 1.

Figure 1 is a variance-covariance matrix biplot derived from PCA of the 56-specimen Palmitopamba data set. It shows that the major axis of variation in the data (principal component 1) expresses enrichment in rare earth elements and most transition metals. Principal component 2 expresses enrichment in calcium and sodium and dilution of barium and aluminum. The separation of these two groups is further illustrated by Figure 2, a bivariate plot of chromium and thorium base-10 logged concentrations.

Mahalanobis distance-based probabilities for group membership are presented in Table 2 and Table 3. Eigenvalues and percentage of variance based on PCA of the data set are listed in Table 4. Probabilities of membership for each group are generally high and none of the samples exceed 1% probability of membership in the other group. The four unassigned samples have less than 1% probability of membership in either the Cosanga or Palmitopamba core groups. Interestingly, RDL003 a ceramic sherd classified as Cosanga is unassigned and plots consistently near the Palmitopamba core group. If Cosanga is an import as Lippi suggests (personal communication to Speakman 2003), this would seem to imply that RDL003 was locally manufactured in the Cosanga *style* or is typologically misclassified. Re-examination of this sherd is warranted to verify the typological classification.

One of the more interesting findings of this study is that pottery in the presumably local Palmitopamba core group contains both Yumbo and Inca pottery. This may suggest that the Yumbo potters were imitating Inca ceramics. Since there is a possibility that RDL003 may be a local imitation of Cosanga pottery, it does not seem unlikely that Cosanga potters would have produced imitation of other wares as well. Alternatively, the apparent heterogeneity between Yumbo and Inca pottery may result from Inca pottery specialists (living at Palmitopamba) producing pottery from clays local to this region of Ecuador. Analysis of Inca style pottery from other Inca conquest sites may provide insight into whether there is a large-scale trade network in Inca pottery or whether each site was producing Inca style pottery for local consumption. A study of this scale would certainly contribute to the understanding Inca trade and economic systems. Consequently it may be worthwhile to use this information to purse funding for a larger-scale project.

RDL040 is an unassigned outlier that Lippi suggests may be of early Spanish manufacture or influence, given the white slip, unique paste, and rim form (Lippi and Bray 2002). A Euclidean distance search of the MURR INAA database (n=32,000+ samples) was conducted to determine if this sherd was a close match for any other sample previously analyzed at MURR. The technique is straightforward: Euclidean (straight-line) distances are calculated between a given individual specimen and all specimens in the composirtional databank, and the top 10 specimens are extracted for comparison. Actually, the distance measure for which minima are sought is the average Euclidean distance:

$$ED_{a,b} = \frac{\sqrt{\sum_{i=1}^{m}\left(a_i - b_i\right)^2}}{m}$$

where *a* and *b* are vectors containing *m* elemental concentrations for the two individual specimens being compared. The 10 closest matches for this specimen were for sherds from Northern Peru submitted by Izumi Shimada and Frances Hayashida in 1992–1993. Comparison of this sample with ceramics from Hayashida's and Shimada's projects did not yield a convincing match. Despite the negative results, the Euclidean search does suggest a southern origin for this sample.

Two clay samples, RDL001 and RDL002 were submitted for INAA. Both clays have less than 1% probability of membership in either of the two ceramic compositional groups. RDL001 a clay sample from Hacienda Palmira plots favorably with the Palmitopamba core group in most projections of the data. Given the close proximity of Hacienda Palmira to the Palmitopamba site, it is probable that clays from this area would have been exploited for ceramic production, however, a definite identification of the clay source(s) used to manufacture pottery assigned to the Palmitopamba core groups is impossible without a more comprehensive raw material survey of the region. Ideally this survey would include analysis of clays from multiple geographic locales throughout the region. Analysis of sands and other nonplastics from the area would facilitate understanding of the compositional effects of temper (elemental dilution and enrichment) on the raw clays.

Between 1991 and 2000, Maria Masucci (and Earl Lubensky) submitted approximately 340 samples (primarily from the Guyas region of coastal Ecuador) to MURR for INAA analysis. While samples within the two data sets originate from completely different temporal contexts, a comparison to them offers some insight into the compositional variability between coastal Ecuador and the Pichincha Province. Given that Masucci's data remain unpublished, she should be consulted before presenting or publishing any of the comparative material presented. Figure 3 and Figure 4 are variance-covariance matrix biplots derived from PCA of the combined Palmitopamba and Masucci data set. Figure 3 shows the separation of the Cosanga group from Masucci's other fine-ware groups (i.e., white-on-red and fine gray). The Palmitopamba group overlaps with Masucci's core group and Salango-2 but are differentiated in Figure 3 which projects the three groups against principal components 1 and 3. While Salango-2 and the Palmitopamba group overlap somewhat in Figure 3, this is probably due to the relatively small size of both groups and should not be interpreted as originating for a common source. Likewise, the Cosanga pottery does not match with any of Masucci's groups. While it is impossible to say for certain whether this group is local to Palmitopamba or the eastern lowlands of Ecuador without a larger raw material sample, it is probable that this chemical group is non-local to Palmitopamba given the tremendous chemical differences between this group and the Palmitopamba core group.

In summary, initial results from this project are fairly promising and begin to address several of the research question proposed by Lippi and Bray (2002). Additional sampling of pottery from Palmitopamba would help to refine the Palmitopamba core group but is not likely to lead to the identification of additional compositional groups. Future analyses should be directed towards analysis of Yumbo, Inca, and Cosanga pottery from other sites to get at underlying questions of trade and distribution of pottery. As the project is expanded, additional clay and temper samples should also be analyzed in order to better assess regional variability in raw materials from this region.

Acknowledgements

This project was funded in part by the National Science Foundation through its support of the MURR Archaeometry Lab (grant no. SBR-0102325). Nicole Little, Kyra Lienhop, and Robert McNulty carried out the laboratory work for this project.

References

Baxter, M. J.

1992 Archaeological uses of the biplot—a neglected technique? In *Computer Applications and Quantitative Methods in Archaeology, 1991*, edited by G. Lock and J. Moffett. BAR International Series S577, 141–148. Tempvs Reparatvm, Archaeological and Historical Associates, Oxford.

1994a *Exploratory Multivariate Analysis in Archaeology*. Edinburgh University Press, Edinburgh.

1994b Stepwise discriminant analysis in archaeometry: a critique. *Journal of Archaeological Science* 21:659–666.

Bieber, A. M. Jr., D. W. Brooks, G. Harbottle, and E. V. Sayre

1976 Application of multivariate techniques to analytical data on Aegean ceramics. *Archaeometry* 18:59–74.

Bishop, R. L. and H. Neff

1989 Compositional data analysis in archaeology. In *Archaeological Chemistry IV*, edited by R. O. Allen, pp. 576–586. Advances in Chemistry Series 220, American Chemical Society, Washington, D.C.

Bishop, R. L., R. L. Rands, and G. R. Holley

1982 Ceramic compositional analysis in archaeological perspective. In *Advances in Archaeological Method and Theory*, vol. 5, pp. 275–330. Academic Press, New York.

Glascock, M. D.

1992 Characterization of archaeological ceramics at MURR by neutron activation analysis and multivariate statistics. In *Chemical Characterization of Ceramic Pastes in Archaeology,* edited by H. Neff, pp. 11–26. Prehistory Press, Madison, WI.

Harbottle, G.

1976 Activation analysis in archaeology. *Radiochemistry* 3:33–72. The Chemical Society, London.

Loose, R. W.

1977 Petrographic notes on selected lithic and ceramic materials. In *Settlement and Subsistence Along the Lower Chaco River*, edited by C. Reher, pp. 567–571. University of New Mexico Press, Albuquerque.

Leese, M. N. and P. L. Main

1994 The efficient computation of unbiased Mahalanobis distances and their interpretation in archaeometry. *Archaeometry* 36:307–316.

Lippi, R. D., and T. Bray

2002 Pottery and Clay Sourcing for the Palmitopamba Archaeology Project. Request for support submitted to the MURR Archaeometry Laboratory.

Neff, H.

1992 Introduction. In *Chemical Characterization of Ceramic Pastes in Archaeology*, edited by H. Neff, pp. 1–10. Prehistory Press, Madison, WI.

1994 RQ-mode principal components analysis of ceramic compositional data. *Archaeometry* 36:115–130.

2000 Neutron activation analysis for provenance determination in archaeology. In *Modern Analytical Methods in Art and Archaeology*, edited by E. Ciliberto and G. Spoto, pp. 81–134. John Wiley and Sons, Inc., New York.

2002 Quantitative techniques for analyzing ceramic compositional data. In Ceramic *Source Determination in the Greater Southwest*, edited by D. M. Glowacki and H. Neff. Monograph 44, Costen Institute of Archaeology, UCLA, Los Angeles.

Rautman, M. L., B. Gomez, H. Neff, and M. D. Glascock

1993 Neutron Activation Analysis of Late Roman Ceramics from Kalavasos-Kopetra and the Environs of the Vasilikos Valley. In *Report of the Department of Antiquities, Cyprus 1993*. Pp. 233–265.

Sayre, E. V.

1975 Brookhaven Procedures for Statistical Analyses of Multivariate Archaeometric Data. Brookhaven National Laboratory Report BNL-23128. New York.

Steponaitis, V., M. J. Blackman, and H. Neff

1996 Large-scale compositional patterns in the chemical composition of Mississippian pottery. *American Antiquity* 61:555–572.

Weigand, P. C., G. Harbottle, and E. V. Sayre

1977 Turquoise sources and source analysis: Mesoamerica and the southwestern U.S.A. In *Exchange Systems in Prehistory*, edited by T. K. Earle and J. E. Ericson, pp. 15–34. Academic Press, New York.

Figure Captions

Figure 1. Variance-covariance matrix biplot of principal component 1 and 2 showing Cosanga, Palmitopamba, clay, and unassigned samples. Ellipses represent 90% confidence interval for group membership.

Figure 2. Bivariate plot of chromium and thorium log-concentrations showing Cosanga, Palmitopamba, clay, and unassigned samples. Ellipses represent 90% confidence interval for group membership.

Figure 3. Variance-covariance matrix biplot of principal component 1 and 2 showing Cosanga, Palmitopamba, and Masucci ceramic groups. Ellipses represent 90% confidence interval for group membership.

Figure 4. Variance-covariance matrix biplot of principal component 1 and 3 showing separation of Palmitopamba, Masucci core, and Salango-2 compositional groups. Ellipses represent 90% confidence interval for group membership..

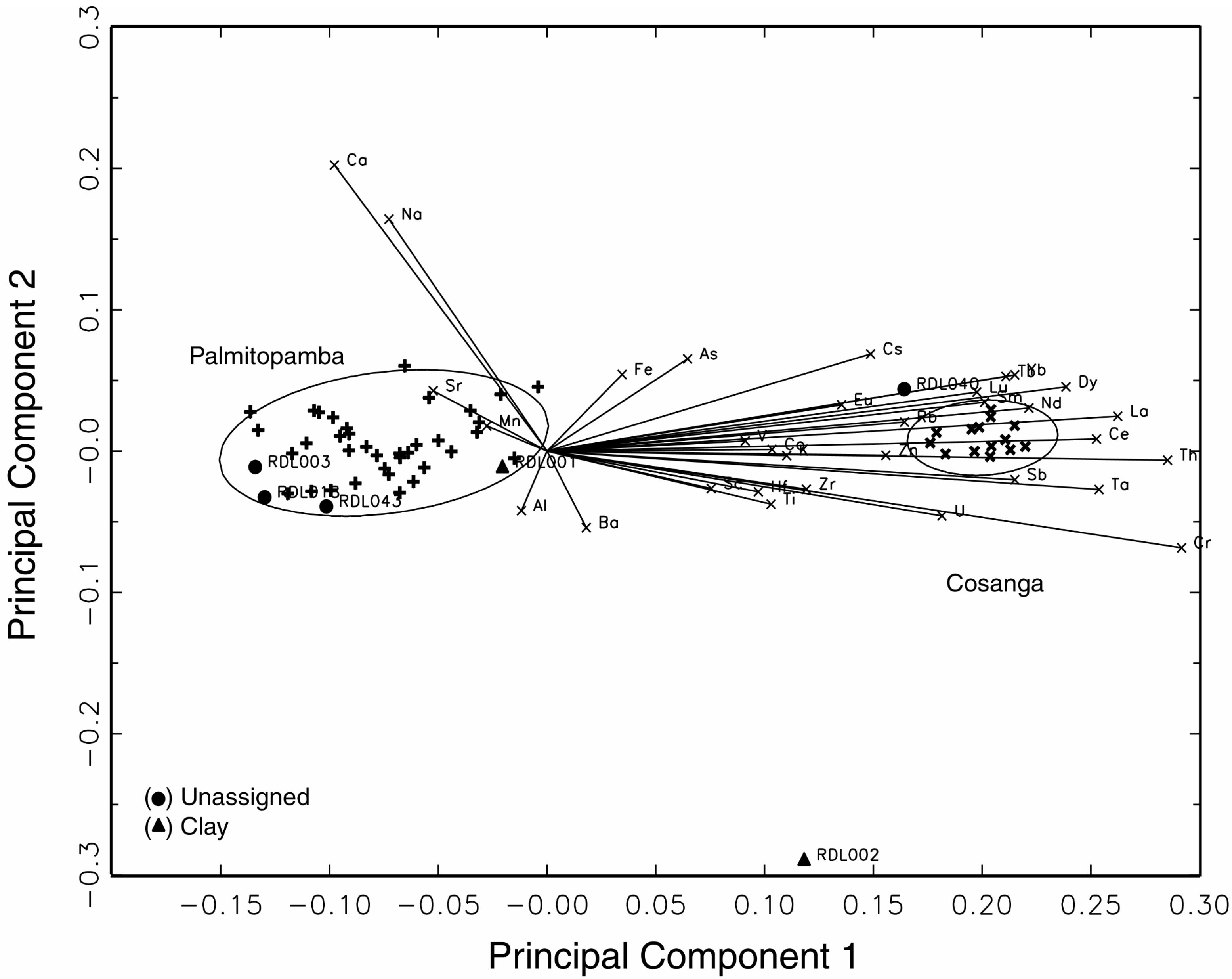

Principal Component 2
Principal Component 1
Palmitopamba
Cosanga
(●) Unassigned
(▲) Clay
RDL003
RDL043
RDL001
RDL002
RDL040
Ca
Na
Sr
Mn
Al
Ba
Fe
As
Cs
Eu
Dy
Nd
La
Ce
Th
Sb
Ta
Cr
U
Zr
Ti
Sc
Rb
Zn
V
Lu
Sm
0.3
0.2
0.1
−0.0
−0.1
−0.2
−0.3
−0.15
−0.10
−0.05
−0.00
0.05
0.10
0.15
0.20
0.25
0.30

Figure 1.

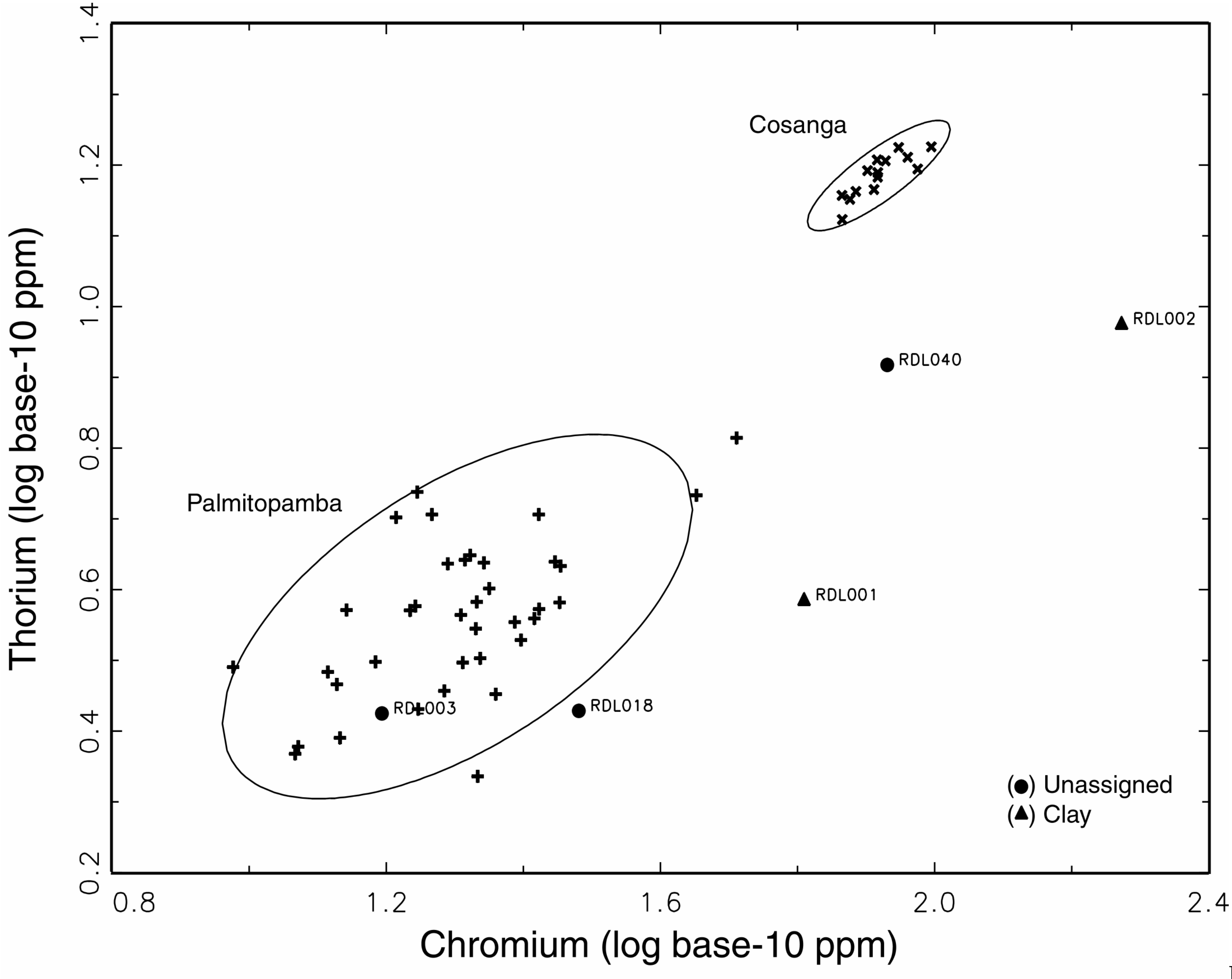

Cosanga
Palmitopamba
RDL002
RDL040
RDL001
RDL003
RDL018
(●) Unassigned
(▲) Clay
Thorium (log base-10 ppm)
Chromium (log base-10 ppm)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.8
1.2
1.6
2.0
2.4

Figure 2.

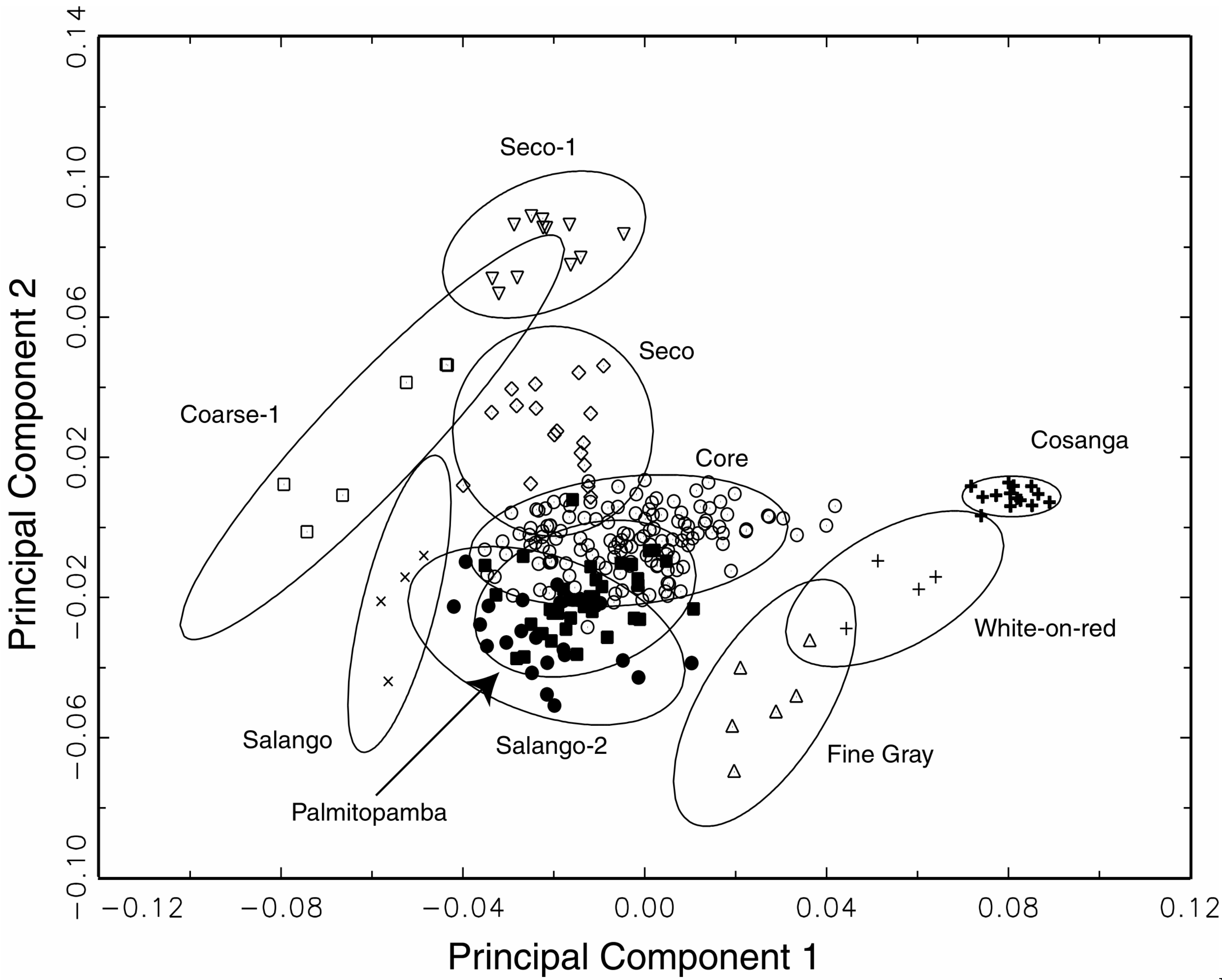
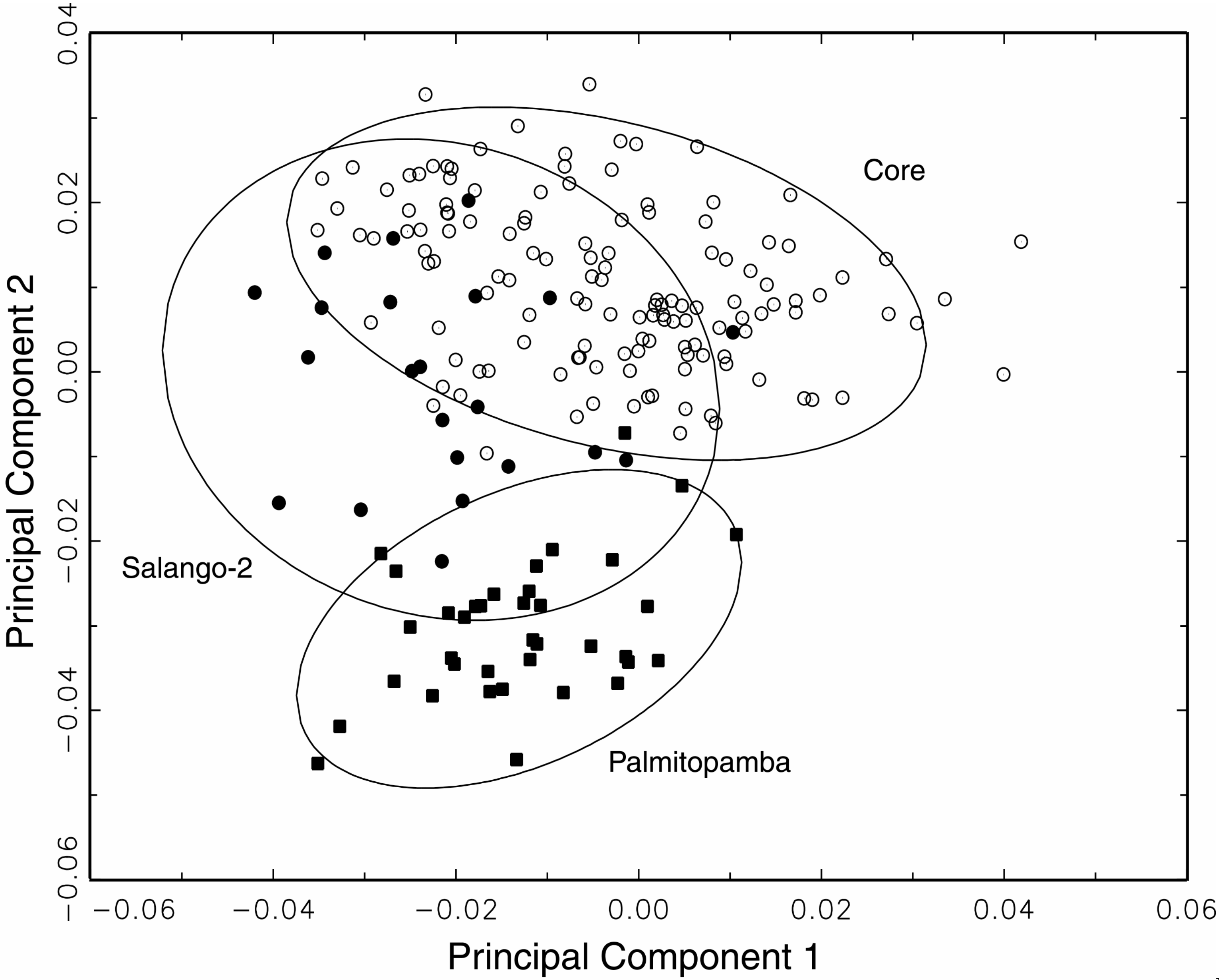

Seco-1
Seco
Coarse-1
Core
Cosanga
White-on-red
Salango
Salango-2
Fine Gray
Palmitopamba
Principal Component 2
Principal Component 1
0.14
0.10
0.06
0.02
−0.02
−0.06
−0.10
−0.12
−0.08
−0.04
0.00
0.04
0.08
0.12

Figure 3.



Core
Salango-2
Palmitopamba
Principal Component 1
Principal Component 2
−0.06
−0.04
−0.02
0.00
0.02
0.04
0.06

Figure 4.

Table 1. Descriptive information and compositional group assignements for the Palmitopamba pottery sample

ANID	CHEM03	SITE_NAME	SITE_NO	PROV	MATERIAL	TMPR	TYPE	FORM	DEC	PERIOD
RDL001	clay	Hacienda Palmira	P-QU-NI-20	Hacienda Palmira	clay	n/a	n/a	n/a	n/a	modern
RDL002	clay	Palmitopamba	P-QU-NI-20	Palmitopamba	clay	n/a	n/a	n/a	n/a	modern
RDL003	Unass.	Palmitopamba	P-QU-NI-20	Unit 2, Level 15	pottery	mica/sand	Cosanga		plain	
RDL004	Cosanga	Palmitopamba	P-QU-NI-20	Unit 4, Level 5	pottery	mica/sand	Cosanga		plain	
RDL005	Cosanga	Palmitopamba	P-QU-NI-20	Unit 6, Level 3	pottery	mica/sand	Cosanga		uncertain	
RDL006	Cosanga	Palmitopamba	P-QU-NI-20	Unit 11, Level 6	pottery	mica/sand	Cosanga		burnished	
RDL007	Cosanga	Palmitopamba	P-QU-NI-20	Unit 12, Level 6	pottery	mica/sand	Cosanga		plain	
RDL008	Cosanga	Palmitopamba	P-QU-NI-20	Unit 12, Level 6	pottery	mica/sand	Cosanga		plain	
RDL009	Cosanga	Palmitopamba	P-QU-NI-20	Unit 13, Level 3	pottery	mica/sand	Cosanga	bowl	plain	
RDL010	Cosanga	Palmitopamba	P-QU-NI-20	Unit 13, Level 6	pottery	mica/sand	Cosanga	bowl	plain	
RDL011	Cosanga	Palmitopamba	P-QU-NI-20	Unit 14, Levels 6-7	pottery	mica/sand	Cosanga	pedestal	plain	
RDL012	Cosanga	Palmitopamba	P-QU-NI-20	Unit 15, Level 2	pottery	mica/sand	Cosanga	bowl	plain	
RDL013	Cosanga	Palmitopamba	P-QU-NI-20	Unit 16, Level 6	pottery	mica/sand	Cosanga	bowl	plain	
RDL014	Cosanga	Palmitopamba	P-QU-NI-20	Unit 17, Level 1	pottery	mica/sand	Cosanga	bowl	punctate	
RDL015	Cosanga	Palmitopamba	P-QU-NI-20	Unit 17, Level 4	pottery	mica/sand	Cosanga		punctate	
RDL016	Cosanga	Palmitopamba	P-QU-NI-20	Unit 20, Level 2	pottery	mica/sand	Cosanga	bowl	plain	
RDL017	Cosanga	Palmitopamba	P-QU-NI-20	Unit 25, Level 5	pottery	mica/sand	Cosanga	olla	plain	
RDL018	Unass.	Palmitopamba	P-QU-NI-20	Unit 1, Level 12	pottery	grit/sand	Yumbo	olla	plain	
RDL019	Palm 1	Palmitopamba	P-QU-NI-20	Unit 1, Level 20	pottery	grit/sand	Yumbo		punctate	
RDL020	Palm 1	Palmitopamba	P-QU-NI-20	Unit 2, Level 23	pottery	grit/sand	Yumbo	flat base	plain	
RDL021	Palm 1	Palmitopamba	P-QU-NI-20	Unit 2, Level 25	pottery	grit/sand	Yumbo		burnished	
RDL022	Palm 1	Palmitopamba	P-QU-NI-20	Unit 5, Level 2	pottery	grit/sand	Yumbo	open bowl	plain	
RDL023	Palm 1	Palmitopamba	P-QU-NI-20	Unit 7, Level 3	pottery	grit/sand	Yumbo	restricted	plain	
RDL024	Palm 1	Palmitopamba	P-QU-NI-20	Unit 7B, Level 5	pottery	grit/sand	?		plain	
RDL025	Palm 1	Palmitopamba	P-QU-NI-20	Unit 8, Level 6	pottery	grit/sand	Yumbo	open bowl	plain	
RDL026	Palm 1	Palmitopamba	P-QU-NI-20	Unit 10, Level 13	pottery	grit/sand	Yumbo	open bowl	plain	
RDL027	Palm 1	Palmitopamba	P-QU-NI-20	Unit 12, Level 6	pottery	grit/sand	Yumbo	possible base	plain	
RDL028	Palm 1	Palmitopamba	P-QU-NI-20	Unit 15, Level 5	pottery	grit/sand	Yumbo	open bowl	plain	
RDL029	Palm 1	Palmitopamba	P-QU-NI-20	Unit 16, Level 5	pottery	grit/sand	Yumbo	open bowl	plain	
RDL030	Palm 1	Palmitopamba	P-QU-NI-20	Unit 17, Level 1	pottery	grit/sand	Yumbo	olla	red slip?	
RDL031	Palm 1	Palmitopamba	P-QU-NI-20	Unit 18, Level 4	pottery	mica/sand	?	open bowl	plain	

Table 1 (continued). Descriptive information and compositional group assignements for the Palmitopamba pottery sample

ANID	CHEM03	SITE_NAME	SITE_NO	PROV	MATERIAL	TMPR	TYPE	FORM	DEC	PERIOD
RDL032	Palm 1	Palmitopamba	P-QU-NI-20	Unit 18, Level 7	pottery	grit/sand	Yumbo	olla	plain	
RDL033	Palm 1	Palmitopamba	P-QU-NI-20	Unit 19, Level 8	pottery	mica/sand	?		plain	
RDL034	Palm 1	Palmitopamba	P-QU-NI-20	Unit 22, Level 6	pottery	mica/sand	?	olla	plain	
RDL035	Palm 1	Palmitopamba	P-QU-NI-20	Unit 27, Level 4	pottery	grit/sand	Yumbo	olla	plain	
RDL036	Palm 1	Palmitopamba	P-QU-NI-20	Shovel test 1G	pottery	grit/sand	Yumbo	olla	red slip	
RDL037	Palm 1	Palmitopamba	P-QU-NI-20	Shovel test 6B	pottery	grit/sand	Yumbo	open bowl	plain	
RDL038	Palm 1	Palmitopamba	P-QU-NI-20	Unit 7, Level 4	pottery	mica/sand	?	open bowl	whitish slip	very late?
RDL039	Palm 1	Palmitopamba	P-QU-NI-20	Unit 20, Level 2	pottery	grit/sand	?	olla	whitish slip	very late?
RDL040	Unass.	Palmitopamba	P-QU-NI-20	Units 7&7B Levels 5-	pottery	?	very unusual	olla	2 small loops	Colonial?
RDL041	Palm 1	Palmitopamba	P-QU-NI-20	Unit 12, Level 4	pottery	grit/sand	Inca	Inca form 10		Inca--1490+
RDL042	Palm 1	Palmitopamba	P-QU-NI-20	Unit 17, Level 1	pottery	grit/sand	Inca	Inca form 1		Inca--1490+
RDL043	Unass.	Palmitopamba	P-QU-NI-20	Unit 15, Level 4	pottery	grit/sand	Inca	Inca form 1	whitish slip	Inca--1490+
RDL044	Palm 1	Palmitopamba	P-QU-NI-20	Unit 9, Level 8	pottery	grit/sand	Inca	Inca form 1	whitish slip	Inca--1490+
RDL045	Palm 1	Palmitopamba	P-QU-NI-20	Unit 9, Level 6	pottery	grit/sand	Inca	Inca form 1		Inca--1490+
RDL046	Palm 1	Palmitopamba	P-QU-NI-20	Unit 18, Level 3	pottery	grit/sand	Inca	Inca form 1		Inca--1490+
RDL047	Palm 1	Palmitopamba	P-QU-NI-20	Unit 18, Level 3	pottery	grit/sand	Inca	Inca form 10		Inca--1490+
RDL048	Palm 1	Palmitopamba	P-QU-NI-20	Unit 12, Level 4	pottery	grit/sand	Inca	Inca form 1		Inca--1490+
RDL049	Palm 1	Palmitopamba	P-QU-NI-20	Unit 16, Level 5	pottery	grit/sand	Inca	Inca form 10		Inca--1490+
RDL050	Palm 1	Palmitopamba	P-QU-NI-20	Unit 12, Level 4	pottery	grit/sand	Inca	Inca form 10		Inca--1490+
RDL051	Palm 1	Palmitopamba	P-QU-NI-20	Unit 7B, Level 3	pottery	grit/sand	Inca	Inca form 10		Inca--1490+
RDL052	Palm 1	Palmitopamba	P-QU-NI-20	Unit 6, Level 2	pottery	grit/sand	Inca	Inca form 10		Inca--1490+
RDL053	Palm 1	Palmitopamba	P-QU-NI-20	Shovel test 2G	pottery	grit/sand	Inca	Inca form 1		Inca--1490+
RDL054	Palm 1	Palmitopamba	P-QU-NI-20	Unit 17, Level 7	pottery	grit/sand	Inca	Inca form 10		Inca--1490+
RDL055	Palm 1	Palmitopamba	P-QU-NI-20	Unit 13, Level 3	pottery	grit/sand	Inca	Inca form 10		Inca--1490+
RDL056	Palm 1	Palmitopamba	P-QU-NI-20	Unit 12, Level 4	pottery	grit/sand	Inca	Inca form 10?	whitish slip	Inca--1490+

Table 2. Mahalanobis Distance Calculation for Palm 1 and Cosanga Compositional Groups

Variables used are:PC01, PC02, PC03, PC04, PC05, PC06
Probabilities are jackknifed for specimens included in each group.

The following specimens are in the file **Palm 1**

Probabilities:

ID. NO.	Palm 1	Cosanga	From:	Into:
RDL019	32.395	0.000	1	1
RDL020	4.270	0.000	1	1
RDL021	76.019	0.000	1	1
RDL022	43.119	0.000	1	1
RDL023	85.958	0.000	1	1
RDL024	41.922	0.001	1	1
RDL025	73.176	0.000	1	1
RDL026	32.235	0.001	1	1
RDL027	40.472	0.001	1	1
RDL028	57.358	0.000	1	1
RDL029	80.649	0.001	1	1
RDL030	63.073	0.000	1	1
RDL031	60.287	0.001	1	1
RDL032	53.093	0.001	1	1
RDL033	60.286	0.000	1	1
RDL034	41.264	0.000	1	1
RDL035	50.014	0.001	1	1
RDL036	68.027	0.001	1	1
RDL037	18.045	0.002	1	1
RDL038	43.415	0.001	1	1
RDL039	77.940	0.002	1	1
RDL041	37.374	0.000	1	1
RDL042	63.174	0.000	1	1
RDL044	27.159	0.000	1	1
RDL045	86.600	0.000	1	1
RDL046	91.715	0.001	1	1
RDL047	9.617	0.001	1	1
RDL048	94.164	0.001	1	1
RDL049	95.516	0.000	1	1
RDL050	41.790	0.001	1	1
RDL051	51.892	0.000	1	1
RDL052	95.843	0.000	1	1
RDL053	93.466	0.001	1	1
RDL056	39.815	0.000	1	1
RDL054	5.230	0.000	1	1
RDL055	13.714	0.002	1	1

The following specimens are in the file **Cosanga**

Probabilities:

ID. NO.	Palm 1	Cosanga	From:	Into:
RDL004	0.000	64.275	2	2
RDL005	0.000	28.600	2	2
RDL006	0.000	15.182	2	2
RDL007	0.000	55.894	2	2
RDL008	0.000	74.690	2	2
RDL009	0.000	89.675	2	2
RDL010	0.000	8.440	2	2
RDL011	0.000	42.912	2	2
RDL012	0.000	31.319	2	2
RDL013	0.000	30.242	2	2
RDL014	0.000	90.544	2	2
RDL015	0.000	21.715	2	2
RDL016	0.000	97.872	2	2
RDL017	0.000	28.457	2	2

Table 3. Mahalanobis Distance Calculation for Unassigned Palmitopamba Pottery and Clay Samples

Variables used are:PC01, PC02, PC03, PC04, PC05

The following specimens are **unassigned**

ID. NO.	Probabilities: Palm 1	Cosanga
RDL003	0.150038	0.000031
RDL018	0.320158	0.000012
RDL040	0.000000	0.022816
RDL043	0.219629	0.000010

The following specimens are **Clay**

ID. NO.	Probabilities: Palm 1	Cosanga
RDL001	0.000074	0.000063
RDL002	0.000000	0.000001

Table 4. Principal Component scores for Palmitopamba Pottery Sample

Eigenvalue	%Variance	Cum. %Var.
0.9058	69.6720	69.6720
0.1120	8.6135	78.2855
0.0607	4.6653	82.9508
0.0568	4.3690	87.3198
0.0355	2.7340	90.0538
0.0242	1.8593	91.9131
0.0189	1.4527	93.3658
0.0162	1.2495	94.6153
0.0127	0.9775	95.5927
0.0093	0.7136	96.3063
0.0086	0.6589	96.9652
0.0071	0.5448	97.5100
0.0053	0.4102	97.9202
0.0044	0.3412	98.2614
0.0040	0.3039	98.5653
0.0029	0.2254	98.7908
0.0024	0.1882	98.9789
0.0022	0.1723	99.1512
0.0021	0.1614	99.3126
0.0017	0.1329	99.4455
0.0015	0.1176	99.5630
0.0012	0.0956	99.6586
0.0010	0.0735	99.7321
0.0008	0.0599	99.7920
0.0007	0.0534	99.8454
0.0005	0.0387	99.8841
0.0004	0.0314	99.9155
0.0004	0.0280	99.9434
0.0003	0.0210	99.9645
0.0002	0.0163	99.9808
0.0002	0.0120	99.9928
0.0001	0.0072	100.0000