Instrumental Neutron Activation Analysis of Metavolcanic Rocks from the Vicinity of Fort Bragg, North Carolina

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Introduction

50 Metavolcanic rock specimens from Fort Bragg, North Carolina and surrounding area were analyzed by instrumental neutron activation analysis (INAA) at the University of Missouri Research Reactor Center (MURR). The samples were collected from seventeen discrete quarry locations in the region. Here, we describe sample preparation and analytical techniques used at MURR and report the subgroup structure identified through quantitative analysis of the ceramic compositional data set.

Background

As part of a multifaceted pilot project, the Archaeometry Laboratory at MURR was contracted to conduct INAA on metavolcanic rocks recovered from the Fort Bragg region of North Carolina. The purpose of this project was to provide a preliminary indication of the range of compositional variability within metavolcanic rocks in the region. The 50 rock samples originate from six counties surrounding Fort Bragg military installation (Figure 1). One generalized quarry location, Uwharries 1, was extensively sampled (n=21) in order to assess inter-group variability. Other quarry groups were sampled less intensively in order to maximize the number of quarries that could be sampled permitting compositional variability across a larger spatial area to be assessed.

Sample Preparation

The rock samples were powdered by Brent Miller at the University of North Carolina at Chapel Hill using an aluminum-oxide shatter box. The samples were then shipped to MURR in powder form. The powdered samples were oven-dried at 100 degrees C for 24 hours. Portions of approximately 150 mg were weighed and placed in small polyvials used for short irradiations. At the same time, 200 mg of each sample were weighed into 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 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 at a neutron flux of 8×10^{13} n/cm^2/s. The 720-second count yields gamma spectra containing peaks for the 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 5×10^{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 III 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. A few elements, especially arsenic, nickel, chromium, and vanadium were below detection in many of the samples. These four elements were therefore deleted from consideration in the analysis. 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 major elements, such as iron, 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 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 pattern (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, i.e., to search for subgroups in an undifferentiated data set, or in a more evaluative mode, i.e., 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:

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

where y is 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 $\bar{X}$ being its 1 x m centroid, and I_x is the inverse of the m x m variance-covariance matrix of group X. Because 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 each individual specimen (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 a 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 each 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 each specimen from its presumed group before calculating its own probability of membership (Baxter 1994; 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.

In the present case, several of the group sizes are smaller than the total number of variates, and this places a further constraint on use of Mahalanobis distance: with more variates than objects, the group variance-covariance matrix is singular thus rendering calculation of I_x (and D^2 itself) impossible. Dimensionality of the groups therefore must be reduced somehow. One approach to dimensionality reduction would be to eliminate elements considered irrelevant or redundant. The problem with this approach is that the investigator's preconceptions about which elements should best discriminate sources may not be valid; it also squanders one of the major strengths of INAA, namely its capability to determine a large number of elements simultaneously. An alternative approach to dimensionality reduction, used here, is to calculate Mahalanobis distances not with log concentrations but with scores on principal components extracted from the variance-covariance or correlation matrix of the complete data set. This approach entails only the assumption, entirely reasonable in light of the above discussion of PCA, that most group-separating differences should be visible on the largest several components. Unless a data set is highly complex, with numerous distinct groups, using enough components to subsume 90% of total variance in the data may be expected to yield Mahalanobis distances that approximate Mahalanobis distances in the full elemental concentration space.

Results and Conclusion

Based on the elemental data and spatial proximity between quarries, the analyzed Fort Bragg lithic subdivide into five clear compositional groups and three possible groups—Uwharrie 1, Uwharrie 2, Chatham 1, Chatham 2, Chatham 3, Cape Fear, Person, and Durham. There is also a tantalizing hint that several other possible groups may exist but this can only be proven through additional sampling. Figures 2 through 9 illustrate the basic data structure for the analyzed sample. Table 1 presents descriptive data and group assignments for the analyzed sample.

Figure 2 (and 3) shows the first two components derived from a PCA of the variance-covariance matrix for the 29 elements retained for quantitative analysis. Looking at the first biplot (Figure 2), the first component expresses enrichment of cobalt, calcium, strontium, and transition metals together with dilution of rare earth elements while the second component expresses an enrichment of cesium, barium, and antimony. Eigenvalues and eigenvectors for the PCA can be found at the end of this report.

Of the eight groups, Uwharrie 1 is statistically the most valid of the groups, a consequence of the number of samples having membership in this group. Additional analysis of source materials from this quarry probably will not affect the basic structure of this group. Mahalanobis Distance calculations (Table 2) indicates all samples assigned to this group have greater than 1% probability of membership.

Small group size prohibited the use of Mahalanobis Distance to test group membership in the other compositional groups. However all of the samples with the exception of a single Chatham 1 sample (FBL027) have less than 1% probability of membership in the Uwharrie 1 reference group (Table 3)

Uwharrie 2 consists of five samples from three discrete locations. It is possible that additional sampling may determine that one or more compositional subgroups exist for materials from these quarry areas.

Chatham 1 consists of four samples from a single location. This group in several projections of the data tends to be relatively heterogeneous. Additional sampling of material from this quarry may determine that multiple compositional subgroups exist. For example, two samples are laminated mudstone, one is felsic aphanite, and one is felsic metasandstone. Analysis of several more of the mudstones may demonstrate that the mudstones are chemically distinct from the felsic rocks.

Chatham 2 forms a relatively homogeneous compositional group. Additional sampling of material from this quarry will unlikely change the basic group structure.

Material categorized as Chatham 3 forms a relatively heterogeneous group. If sample FBL038 is excluded from the group, it is possible that the remaining three samples may form a single group (i.e., Figures 4 and 6). This may be a reflection of the occurrence of multiple composition subgroups in the sample that could be identified through additional analyses. Even though Chatham 3 is spatially close to Chatham 1 and Chatham 2, this group is distinct from these sources and as a whole has measurable concentrations of arsenic, chromium, and vanadium—something which cannot be said about the other compositional groups.

Like Chatham 3, there is the possibility that multiple subgroups exist in samples from the Cape Fear quarry. If data derived from sample FBL039 ignored, the remaining samples form a relatively compact group (i.e., Figures 3, 4, and 6). Descriptive information for the samples indicates that FBL039 is white, whereas, the remaining three samples are green indicating color may in part reflect some of the compositional variability in the samples from this area. Additional sampling of source material from this quarry should be attempted in order to refine this group(s).

Samples assigned to the Durham group form a relatively homogeneous group. It is unlikely that additional sampling will affect the basic group structure.

Samples from Person County tend to be fairly heterogeneous. Analyses of additional samples from this quarry are necessary.

As a whole, this pilot project has been successful. Analysis by INAA has resulted in the identification of several chemically distinct lithic sources. However, additional sampling of certain source material as discussed above is necessary to refine some of the possible groups. Additionally, it is preferable that all of the groups contain at a minimum six samples (though eight would be better) in order to better validate the group assignments using some of the statistical routines employed at MURR. We also recommend that in addition to the analysis of additional source samples, the next phase of this project include artifacts in order to provide the project with an archaeological component.

Acknowledgements

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Figure Captions

Figure 1: Map of the Fort Bragg vicinity showing quarry locations and compositional groups identified in the study.

Figure 2: Biplot derived from PCA of the variance-covariance matrix of the Fort Bragg lithic data. Vectors connect the origin with element coordinates. Ellipses represent 90% confidence level for membership in the groups.

Figure 3: Same PCA space shown in Figure 2 but without element coordinates and with ungrouped specimens plotted and labeled. Ellipses represent 90% confidence level for membership in the groups.

Figure 4: Bivariate plot of tantalum and thorium base-10 logged concentrations for the Fort Bragg lithic groups. Dashed lines indicate possible subgroups. Ellipses represent 90% confidence level for membership in the groups.

Figure 5: Same bivariate plot as Figure 4 except that samples not ellipsed are labeled.

Figure 6: Bivariate plot of tantalum and aluminum base-10 logged concentrations for the Fort Bragg lithic groups. Dashed lines indicate possible subgroups. Ellipses represent 90% confidence level for membership in the groups.

Figure 7: Same bivariate plot as Figure 4 except that samples not ellipsed are labeled.

Figure 8: Bivariate plot of dysprosium and lanthanum base-10 logged concentrations for the Fort Bragg lithic groups. Ellipses represent 90% confidence level for membership in the groups.

Figure 9: Same bivariate plot as Figure 4 except that samples not ellipsed are labeled.

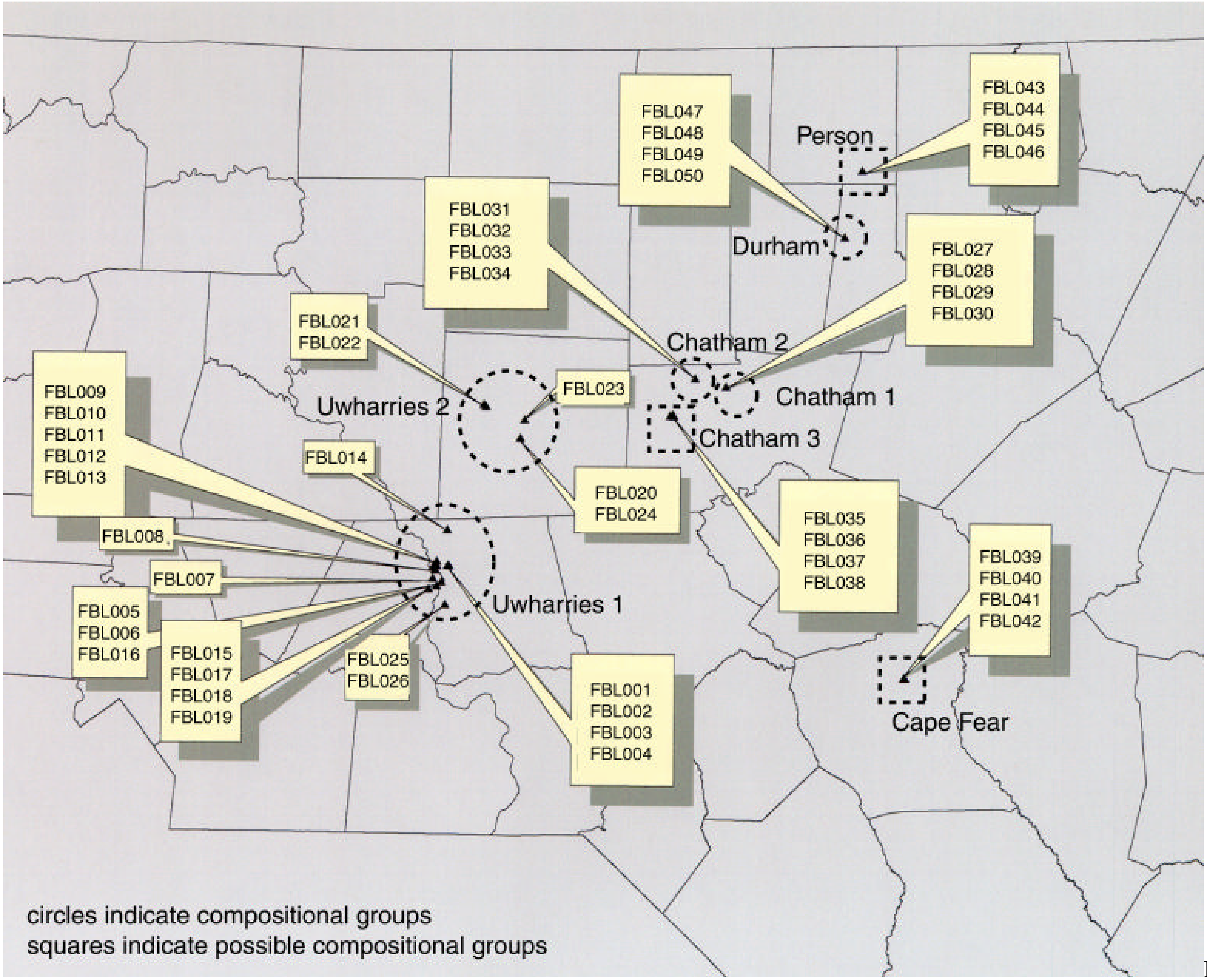
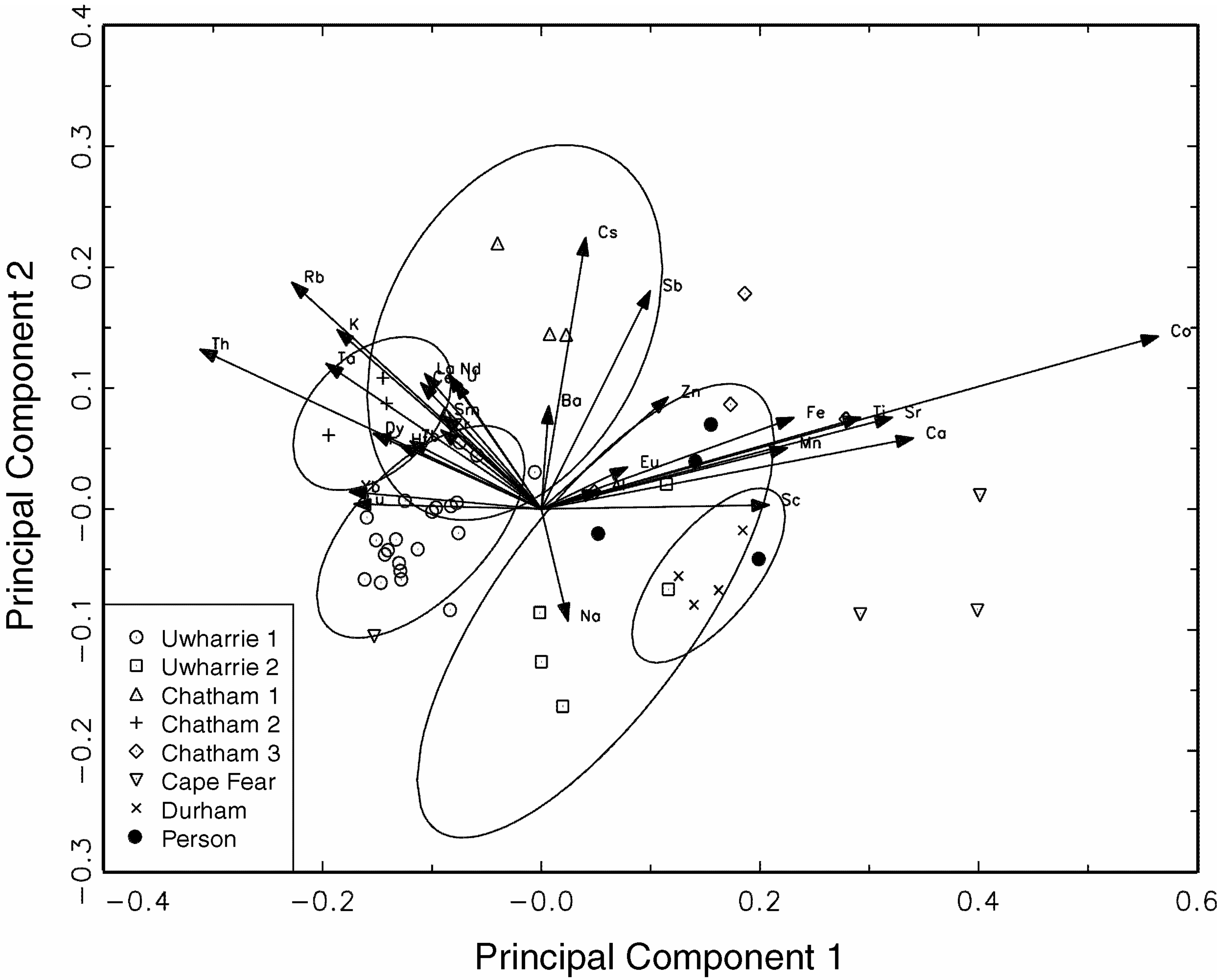
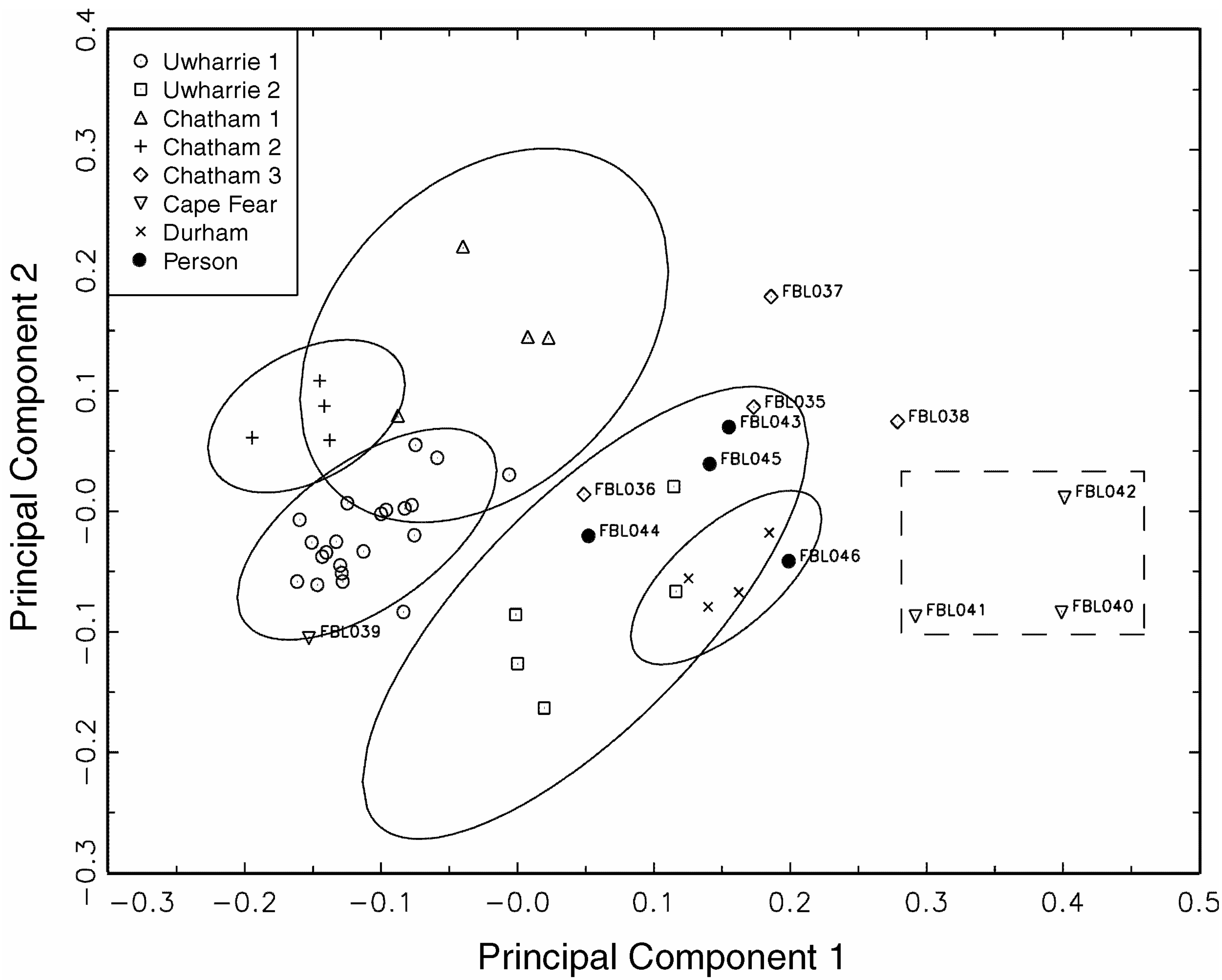

FBL047
FBL048
FBL049
FBL050
Person
FBL043
FBL044
FBL045
FBL046
FBL031
FBL032
FBL033
FBL034
Durham
FBL027
FBL028
FBL029
FBL030
FBL021
FBL022
Chatham 2
FBL023
Uwharries 2
Chatham 1
Chatham 3
FBL009
FBL010
FBL011
FBL012
FBL013
FBL014
FBL020
FBL024
FBL008
FBL035
FBL036
FBL037
FBL038
FBL007
FBL039
FBL040
FBL041
FBL042
Uwharries 1
FBL005
FBL006
FBL016
FBL015
FBL017
FBL018
FBL019
FBL025
FBL026
FBL001
FBL002
FBL003
FBL004
Cape Fear
circles indicate compositional groups
squares indicate possible compositional groups

Figure 1



Principal Component 2
Principal Component 1
Uwharrie 1
Uwharrie 2
Chatham 1
Chatham 2
Chatham 3
Cape Fear
Durham
Person
Cs
Sb
Rb
K
Th
Ta
La
Nd
Ce
U
Sm
Ba
Dy
Zn
Co
Fe
Ti
Sr
Ca
Mn
Eu
Sc
Na
Yb

Figure 2


Uwharrie 1
Uwharrie 2
Chatham 1
Chatham 2
Chatham 3
Cape Fear
Durham
Person
FBL037
FBL035
FBL043
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FBL045
FBL036
FBL042
FBL044
FBL046
FBL041
FBL040
FBL039
0.4
0.3
0.2
0.1
−0.0
−0.1
−0.2
−0.3
−0.3
−0.2
−0.1
−0.0
0.1
0.2
0.3
0.4
0.5
Principal Component 2
Principal Component 1

Figure 3

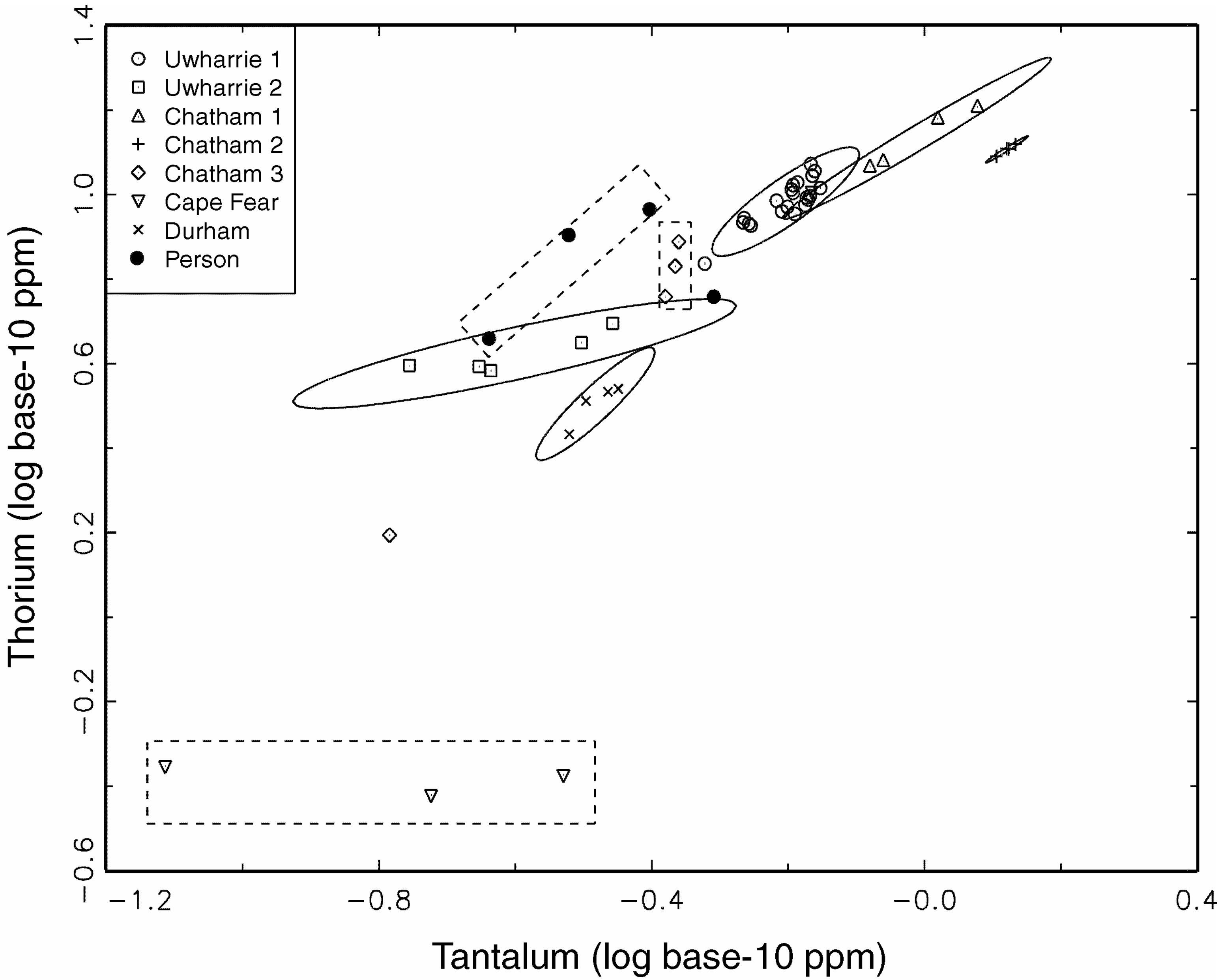

Uwharrie 1
Uwharrie 2
Chatham 1
Chatham 2
Chatham 3
Cape Fear
Durham
Person
Thorium (log base-10 ppm)
Tantalum (log base-10 ppm)
1.4
1.0
0.6
0.2
−0.2
−0.6
−1.2
−0.8
−0.4
−0.0
0.4

Figure 4

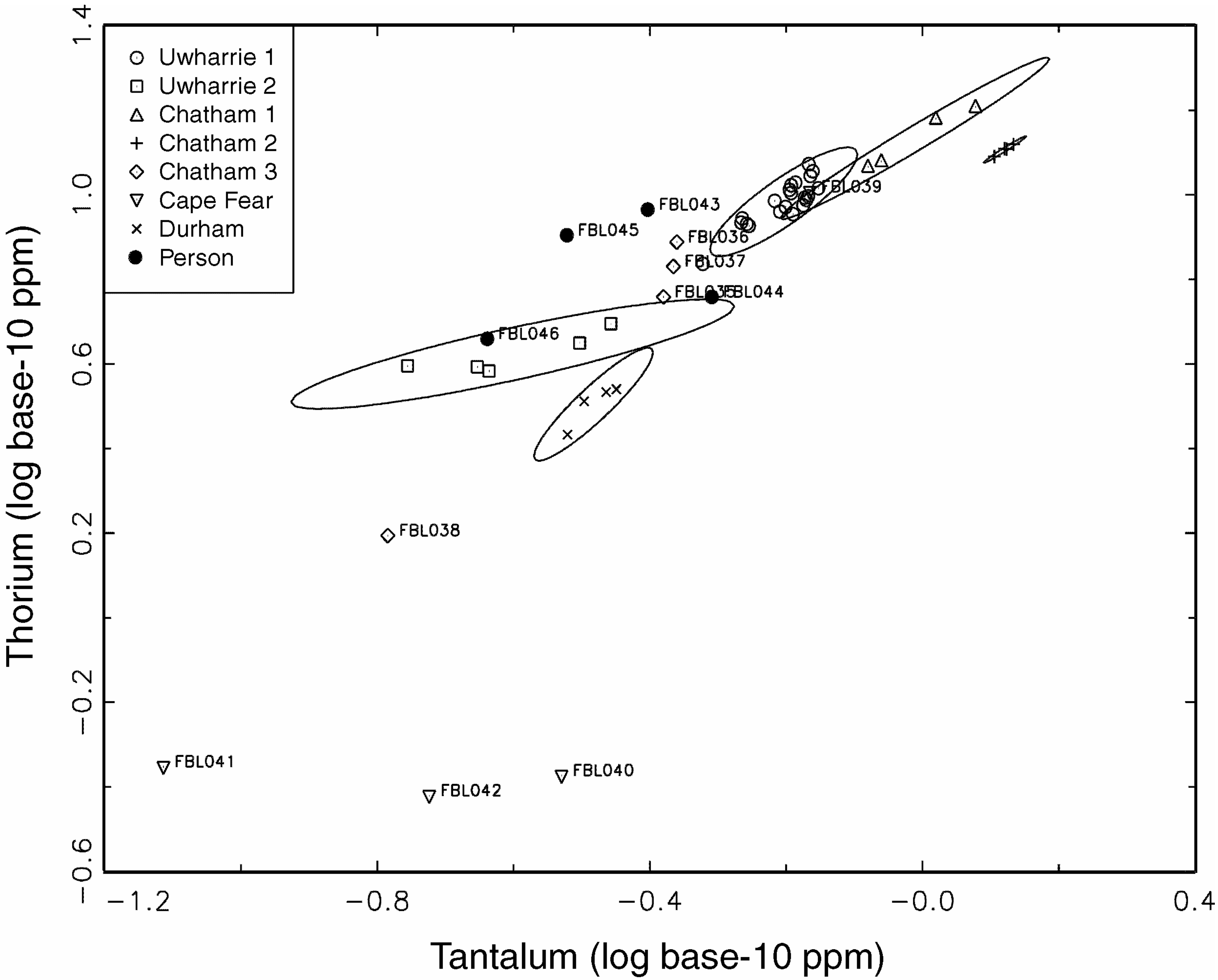

Uwharrie 1
Uwharrie 2
Chatham 1
Chatham 2
Chatham 3
Cape Fear
Durham
Person
FBL043
FBL045
FBL039
FBL036
FBL037
FBL035
FBL044
FBL046
FBL038
FBL041
FBL042
FBL040
Thorium (log base-10 ppm)
Tantalum (log base-10 ppm)
1.4
1.0
0.6
0.2
−0.2
−0.6
−1.2
−0.8
−0.4
−0.0
0.4

Figure 5

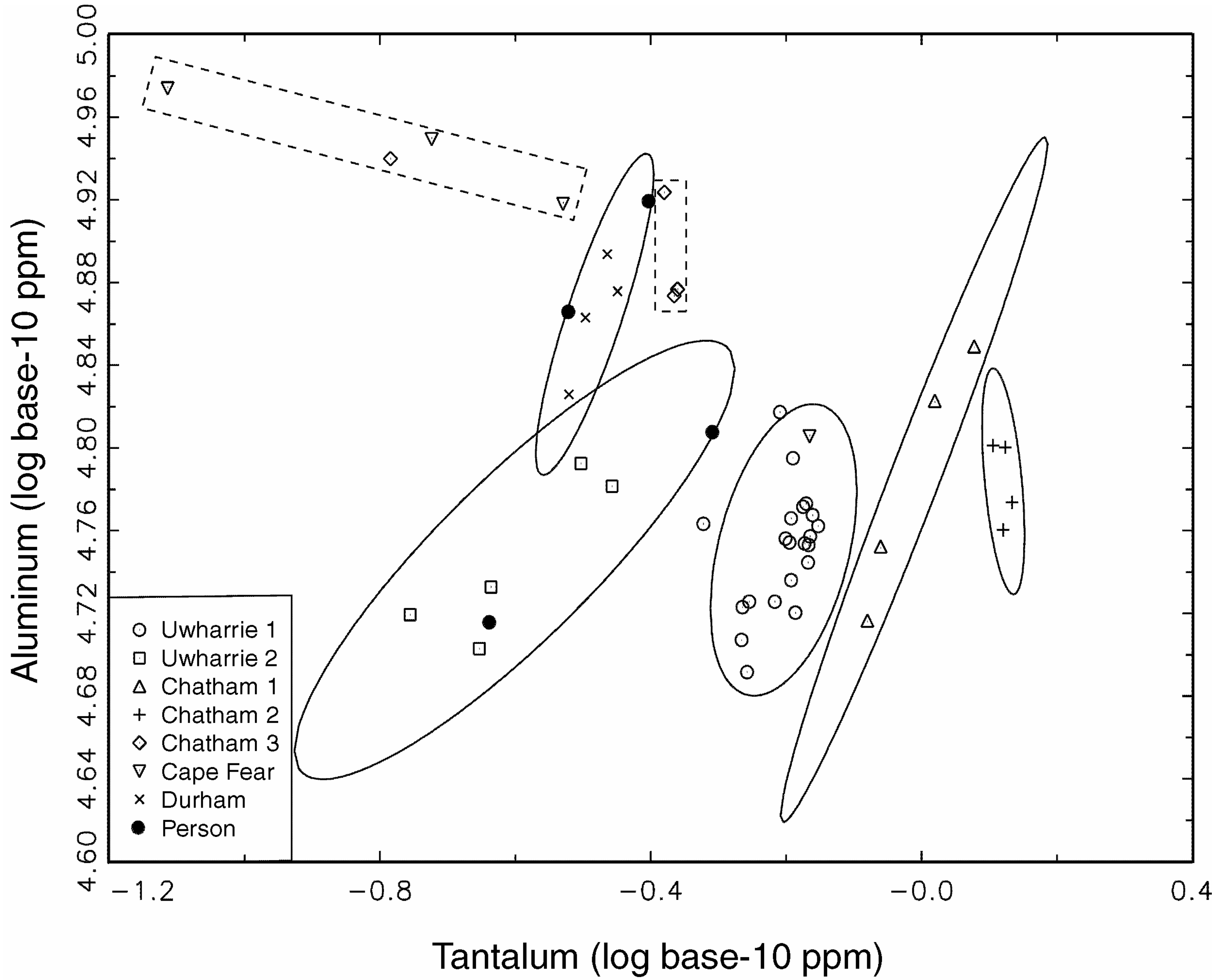
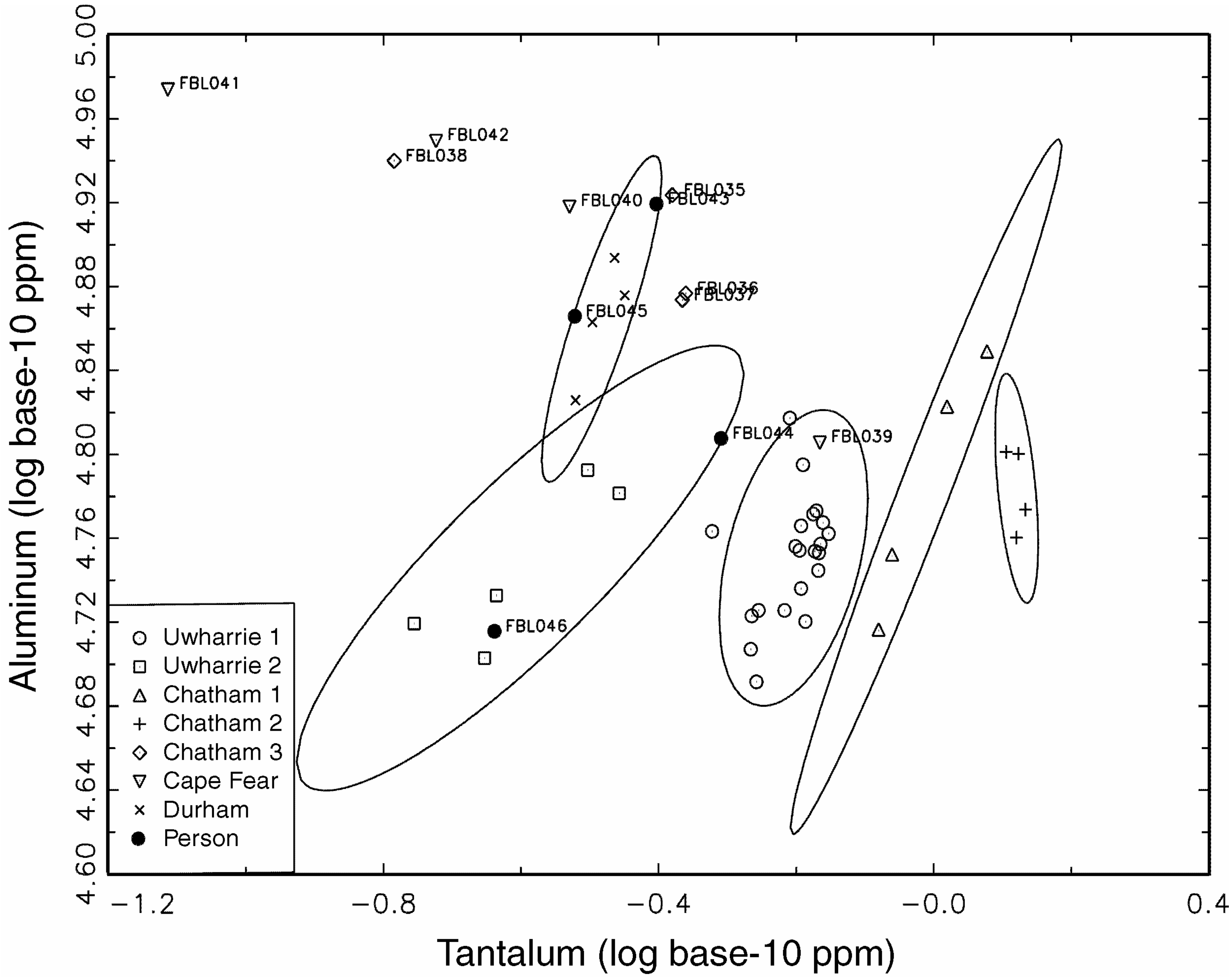

Aluminum (log base-10 ppm)
5.00
4.96
4.92
4.88
4.84
4.80
4.76
4.72
4.68
4.64
4.60
−1.2
−0.8
−0.4
−0.0
0.4
Tantalum (log base-10 ppm)
Uwharrie 1
Uwharrie 2
Chatham 1
Chatham 2
Chatham 3
Cape Fear
Durham
Person

Figure 6


FBL041
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FBL040
FBL036
FBL037
FBL045
FBL044
FBL039
FBL046
Uwharrie 1
Uwharrie 2
Chatham 1
Chatham 2
Chatham 3
Cape Fear
Durham
Person
Aluminum (log base-10 ppm)
Tantalum (log base-10 ppm)
4.60
4.64
4.68
4.72
4.76
4.80
4.84
4.88
4.92
4.96
5.00
−1.2
−0.8
−0.4
−0.0
0.4

Figure 7

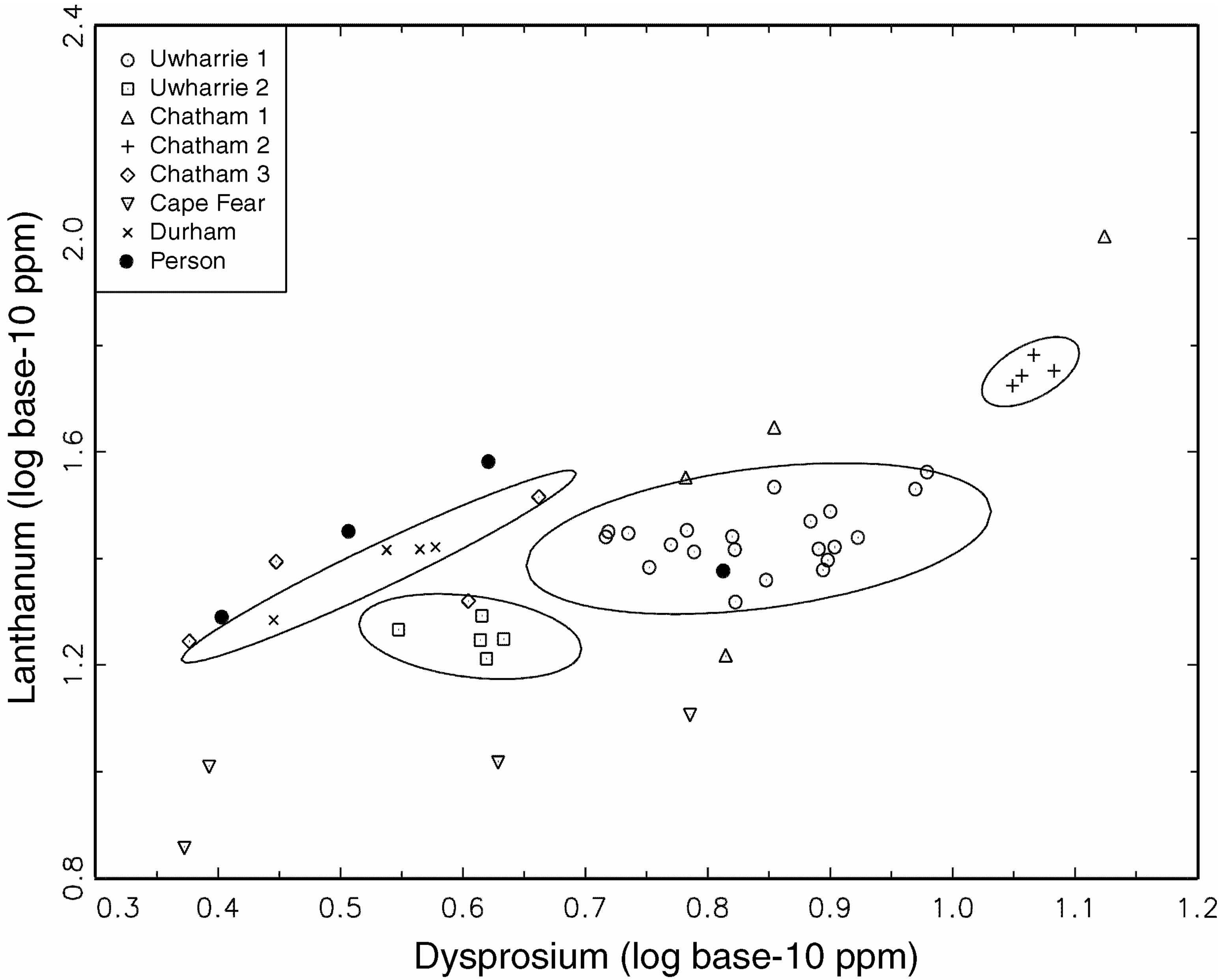
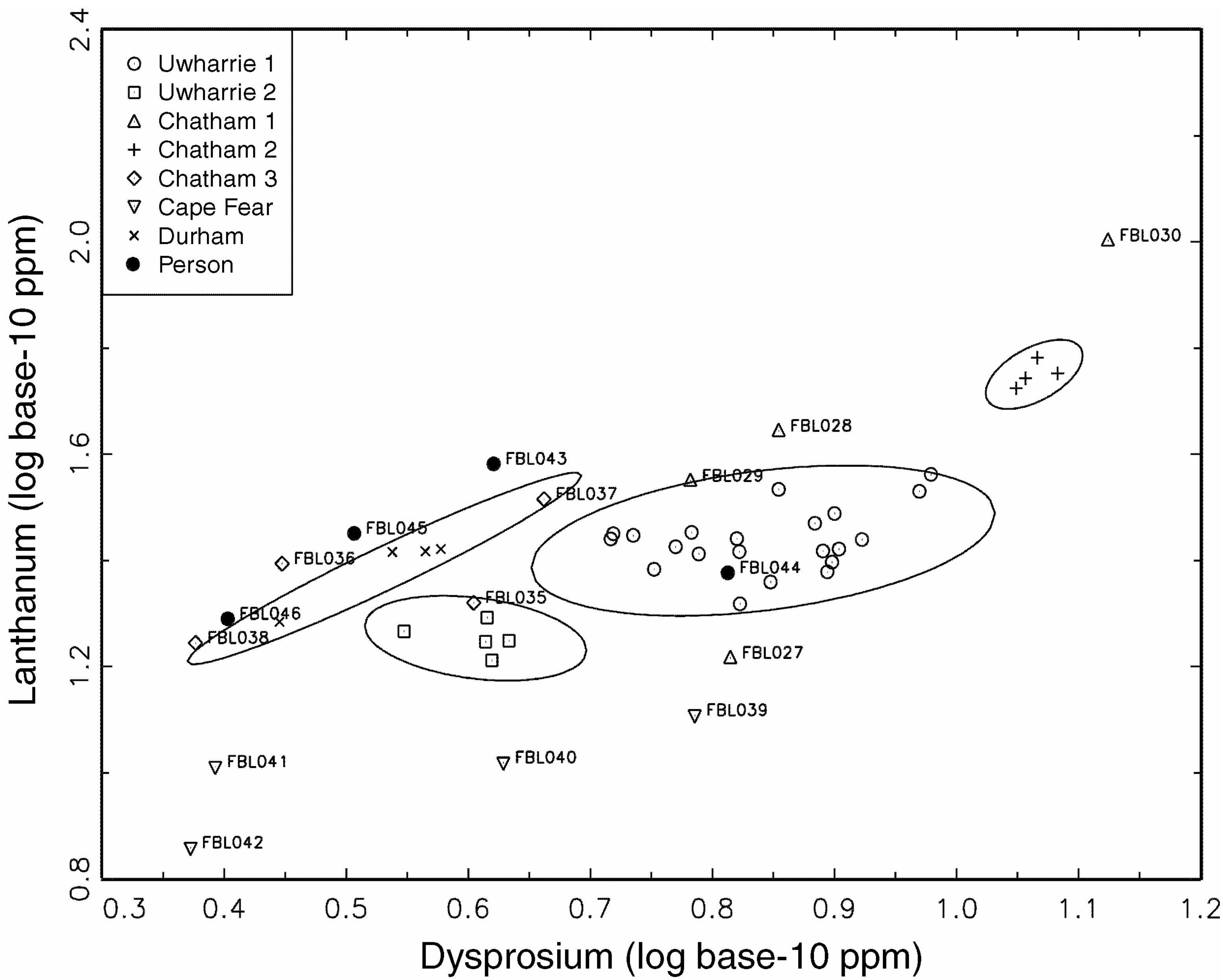

Uwharrie 1
Uwharrie 2
Chatham 1
Chatham 2
Chatham 3
Cape Fear
Durham
Person
Lanthanum (log base-10 ppm)
Dysprosium (log base-10 ppm)
0.8
1.2
1.6
2.0
2.4
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2

Figure 8



Uwharrie 1
Uwharrie 2
Chatham 1
Chatham 2
Chatham 3
Cape Fear
Durham
Person
FBL030
FBL028
FBL029
FBL043
FBL037
FBL045
FBL036
FBL044
FBL035
FBL046
FBL038
FBL027
FBL039
FBL041
FBL040
FBL042
Lanthanum (log base-10 ppm)
0.8
1.2
1.6
2.0
2.4
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Dysprosium (log base-10 ppm)

Figure 9

Table 1. Group assignments and descriptive data for Fort Bragg Lithics

anid	Group	Sample ID	Group	Site Name	Site Number	Northing	Easting	Description
FBL001	uwhar 1	rHD-18A	Uwharries Eastern	HD-18A	31MG554	3918069	587355	plag-qtz phyric rhyolite
FBL002	uwhar 1	rHD-18B	Uwharries Eastern	HD-18B	31MG554	3918158	586937	plag-qtz phyric rhyolite
FBL003	uwhar 1	HD-18A*	Uwharries Eastern	HD-18A	31MG554	3918069	587355	plag-qtz phyric rhyolite
FBL004	uwhar 1	HD-18B*	Uwharries Eastern	HD-18B	31MG554	3918158	586937	plag-qtz phyric rhyolite
FBL005	uwhar 1	rHD-19	Uwharries Eastern	HD-19	31ST68	3913174	584185	plag-qtz phyric rhyolite
FBL006	uwhar 1	rHD-21	Uwharries Eastern	HD-21	31ST66	3914094	585325	plag-qtz phyric rhyolite
FBL007	uwhar 1	rHD-22	Uwharries Eastern	HD-22	31ST67	3915034	583325	plag-qtz phyric rhyolite
FBL008	uwhar 1	rHD-4A	Uwharries Western	HD-4A	none	3916984	583805	plag-phyric rhyolite
FBL009	uwhar 1	rHD-8	Uwharries Western	HD-8	31MG639	3918064	584215	plag-phyric rhyolite
FBL010	uwhar 1	HD-9	Uwharries Western	HD-9	31MG639	3918154	584125	plag-phyric rhyolite
FBL011	uwhar 1	rHD-10	Uwharries Western	HD-10	31MG117	3919205	584222	plag-phyric rhyolite
FBL012	uwhar 1	HD-10*	Uwharries Western	HD-10	31MG117	3919205	584222	plag-phyric rhyolite
FBL013	uwhar 1	rHD-13	Uwharries Western	HD-13	31MG640	3917943	583375	plag-phyric rhyolite
FBL014	uwhar 1	rHD-31	Uwharries Western	HD-31	31MG641	3926914	586797	plag-phyric rhyolite
FBL015	uwhar 1	rHD-20	Uwharries Southern	HD-20	31RD18	3912457	582233	aphyric rhyolite
FBL016	uwhar 1	rHD-24	Uwharries Southern	HD-24	31ST64	3913131	584180	aphyric rhyolite
FBL017	uwhar 1	rHD-54	Uwharries Southern	HD-54	31ST18	3912457	582233	aphyric rhyolite
FBL018	uwhar 1	rHD-55	Uwharries Southern	HD-55	31ST18	3912457	582233	aphyric rhyolite
FBL019	uwhar 1	rHD-56	Uwharries Southern	HD-56	31ST18	3912457	582233	aphyric rhyolite
FBL020	uwhar 2	rHD-25B3	Uwharries Asheboro	HD-25B3	31RD37	3949435	604806	felsic tuff and breccia
FBL021	uwhar 2	rHD-33	Uwharries Asheboro	HD-33	31RD854/1201	3957254	596221	felsic tuff and breccia
FBL022	uwhar 2	rHD-34	Uwharries Asheboro	HD-34	31RD855/1202	3957764	595700	felsic tuff and breccia
FBL023	uwhar 2	rHD-38	Uwharries Asheboro	HD-38	none	3954018	605863	felsic tuff and breccia
FBL024	uwhar 2	rHD-66	Uwharries Asheboro	HD-66	31RD37	3949435	604806	felsic tuff and breccia
FBL025	uwhar 1	HT-A	Uwharries Southeast	Horse Trough Mountain	*31MG378,31MG379	3908577	586311	plag-qtz phyric felsite

Table 1 (continued). Group assignments and descriptive data for Fort Bragg Lithics

anid	Group	Sample ID	Group	Site Name	Site Number	Northing	Easting	Description
FBL026	uwhar 1	HT-B	Uwharries Southeast	Horse Trough Mountain	*31MG378,31MG379	3908577	586311	plag-phyric felsite
FBL027	Chatham 1	CH-729-A	Chatham County	Quarry 729/Pittsboro	31CH729	3962302	655654	felsic aphanite/mudstone
FBL028	Chatham 1	CH-729-B	Chatham County	Quarry 729/Pittsboro	31CH729	3962302	655654	laminated metamudstone
FBL029	Chatham 1	CH-729-C	Chatham County	Quarry 729/Pittsboro	31CH729	3962302	655654	laminated metamudstone
FBL030	Chatham 1	CH-729-D	Chatham County	Quarry 729/Pittsboro	31CH729	3962302	655654	felsic metasandstone
FBL031	Chatham 2	CH-741-A	Chatham County	Quarry 741/Silk Hope	31CH741	3964340	647964	purple spherulitic felsite
FBL032	Chatham 2	CH-741-B	Chatham County	Quarry 741/Silk Hope	31CH741	3964340	647964	purple felsic breccia
FBL033	Chatham 2	CH-741-C	Chatham County	Quarry 741/Silk Hope	31CH741	3964340	647964	dark gray aphanite
FBL034	Chatham 2	CH-741-E	Chatham County	Quarry 741/Silk Hope	31CH741	3964340	647964	dark purple/black breccia
FBL035	Chatham 3	CH-RR-F	Chatham County	Siler City/Rocky River	none	3955002	642790	dark gray lam. metamudst.
FBL036	Chatham 3	CH-RR-R	Chatham County	Siler City/Rocky River	none	3955233	642626	plag +/- qtz phyric dacite
FBL037	Chatham 3	CH427	Chatham County	Siler City/Rocky River	31CH427	3955164	641835	v fine metasandst/siltstone
FBL038	Chatham 3	CH-RR-T	Chatham County	Siler City/Rocky River	none	3955282	642442	fine green felsic tuff
FBL039	Cape Fear	400-1	Cape Fear	Fayetteville/Cape Fear 1	31CD400	3891155	700233	white musc + gar aplite
FBL040	Cape Fear	400-2	Cape Fear	Fayetteville/Cape Fear 1	31CD400	3891155	700233	dk green metass/hornfels
FBL041	Cape Fear	400-3	Cape Fear	Fayetteville/Cape Fear 1	31CD400	3891155	700233	greenstone or metasandstone
FBL042	Cape Fear	424-1	Cape Fear	Fayetteville/Cape Fear 2	31CD424	3891125	700463	v fine greenstone (?)
FBL043	Person	PCQA	Person County	Powerline Quarry	31PR115	4015567	688965	green metamudstone (?)
FBL044	Person	PCQB	Person County	Powerline Quarry	31PR115	4015567	688965	aphyric dark gray felsite
FBL045	Person	PCQC	Person County	Powerline Quarry	31PR115	4015567	688965	green felsite
FBL046	Person	PCQD	Person County	Powerline Quarry	31PR115	4015567	688965	metamudstone/metasiltstone
FBL047	Durham	DUR-A	Northwest Durham County	Cains Chapel Quarry	31DH703	3999181	684723	dk green fragmental rock
FBL048	Durham	DUR-B	Northwest Durham County	Cains Chapel Quarry	31DH703	3999181	684723	dk gray aphyric felsite
FBL049	Durham	QNWDC	Northwest Durham County	Cains Chapel Quarry	31DH703	3999181	684723	gray aphyric felsite
FBL050	Durham	QNWDD	Northwest Durham County	Cains Chapel Quarry	31DH703	3999181	684723	pale green felsite

Table 2. Mahalanobis Distance calculation for samples assigned to the Uwharrie 1 group.

Variables used are: PC01 PC02 PC03 PC04 PC05 PC06 PC07

Probabilities are jackknifed for specimens included in each group.

The following specimens are in the file PSW

	Probabilities:		
ID. NO.	PSW	From:	Into:
FBL001	67.098	1	1
FBL002	86.462	1	1
FBL003	13.731	1	1
FBL004	33.178	1	1
FBL005	35.944	1	1
FBL006	85.730	1	1
FBL007	71.708	1	1
FBL008	42.720	1	1
FBL009	6.377	1	1
FBL010	95.327	1	1
FBL011	88.971	1	1
FBL012	63.699	1	1
FBL013	1.028	1	1
FBL014	1.225	1	1
FBL015	89.890	1	1
FBL016	21.596	1	1
FBL017	95.849	1	1
FBL018	52.083	1	1
FBL019	55.575	1	1
FBL025	25.467	1	1
FBL026	54.282	1	1

Summary of Classification Success:

Classified Into Group:

	PSW	Total
From Group:		
PSW	21	21
Total	21	21

Table 2. Mahalanobis Distance calculation and posterior classification for Uwharrie 2, Chatham 1, Chatham 2, Chatham 3, Cape Fear, Person, and Durham.

The following specimens are in the file Uwharrie 2

ID. NO.	Probabilities: PSW	BEST GP.
FBL021	0.271732	1
FBL022	0.085673	1
FBL023	0.006314	1
FBL020	0.059781	1
FBL024	0.073068	1

The following specimens are in the file Chatham 1

ID. NO.	Probabilities: PSW	BEST GP.
FBL027	1.040695	1
FBL028	0.000054	1
FBL029	0.001769	1
FBL030	0.000210	1

The following specimens are in the file Chatham 2

ID. NO.	Probabilities: PSW	BEST GP.
FBL031	0.000007	1
FBL032	0.000001	1
FBL033	0.000001	1
FBL034	0.000001	1

The following specimens are in the file Chatham 3

ID. NO.	Probabilities: PSW	BEST GP.
FBL035	0.000012	1
FBL036	0.000002	1
FBL037	0.000007	1
FBL038	0.000001	1

The following specimens are in the file Cape Fear

ID. NO.	Probabilities: PSW	BEST GP.
FBL039	0.040495	1
FBL040	0.000002	1
FBL041	0.000002	1
FBL042	0.000001	1

The following specimens are in the file Person

ID. NO.	Probabilities: PSW	BEST GP.
FBL047	0.000074	1
FBL048	0.000139	1
FBL049	0.000115	1
FBL050	0.000065	1

The following specimens are in the file Durham

ID. NO.	Probabilities: PSW	BEST GP.
FBL043	0.000008	1
FBL044	0.140125	1
FBL045	0.000013	1
FBL046	0.000005	1

Principal Components Analysis Based All Lithic Samples

Simultaneous R-Q Factor Analysis Based on Variance-Covariance Matrix

Eigenvalues and Percentage of Variance Explained:

Eigenvalue	%Variance	Cum. %Var.
1.1995	53.7192	53.7192
0.3096	13.8634	67.5826
0.2492	11.1592	78.7419
0.1015	4.5472	83.2890
0.0752	3.3691	86.6582
0.0631	2.8241	89.4823
0.0505	2.2595	91.7418
0.0356	1.5938	93.3357
0.0318	1.4257	94.7613
0.0212	0.9514	95.7127
0.0169	0.7575	96.4702
0.0154	0.6895	97.1598
0.0149	0.6665	97.8263
0.0125	0.5578	98.3841
0.0101	0.4516	98.8357
0.0072	0.3230	99.1588
0.0052	0.2315	99.3902
0.0036	0.1626	99.5529
0.0026	0.1160	99.6688
0.0021	0.0929	99.7617
0.0014	0.0627	99.8244
0.0013	0.0595	99.8839
0.0009	0.0383	99.9223
0.0006	0.0290	99.9512
0.0005	0.0216	99.9729
0.0002	0.0098	99.9826
0.0002	0.0091	99.9917
0.0001	0.0044	99.9960
0.0001	0.0040	100.0000

Eigenvectors (largest to smallest):

```
La       -0.0976  0.2015 -0.1772  0.1504  0.1381  0.1365  0.0082 -0.1175
0.1695 -0.1293 -0.0300  0.0409 -0.1810  0.0582 -0.0013  0.1254  0.0612  0.1672
```

0.0523 -0.1107 -0.3305 0.1408 -0.6365 -0.1110 0.0555 0.2077 -0.2667
0.1648 -0.0812
Lu -0.1566 0.0071 -0.0976 0.1328 -0.1079 -0.1268 -0.0447 0.0647 -
0.0360 0.0932 -0.0517 0.1401 -0.0097 -0.1872 0.1906 -0.0398 0.2392 0.0930
-0.2581 0.0469 0.0367 0.3170 0.1425 -0.1995 -0.1073 0.3629 -0.0543
0.0074 0.6051
Nd -0.0779 0.2004 -0.2230 0.1253 0.0732 0.0915 -0.0467 -0.1437 -
0.0082 -0.0821 -0.0982 -0.2035 -0.1707 0.2364 0.1449 0.2274 -0.0138 0.1860
0.0999 -0.4732 0.0906 -0.0221 0.5072 -0.0244 0.2077 0.2070 0.0354 -
0.0614 -0.0998
Sm -0.0828 0.1401 -0.1442 0.1726 -0.0613 -0.0252 0.0263 -0.0267 -
0.0143 -0.0223 -0.0794 -0.0488 -0.1554 0.0660 0.1493 -0.0020 0.0697 -0.1521
0.0908 0.0172 -0.0176 -0.1591 -0.0006 0.2017 -0.2805 -0.1679 0.3956
0.6854 0.1446
U -0.0726 0.1905 -0.0860 -0.0265 -0.0265 0.1318 0.2902 0.2458
0.2018 0.4196 0.3901 -0.2634 -0.2221 -0.1184 -0.1905 -0.1896 0.0862 -0.2575
-0.1692 -0.1691 -0.2139 0.0434 0.1292 0.0842 0.0103 0.0048 -0.0988 -
0.0009 -0.0379
Yb -0.1605 0.0255 -0.0944 0.1407 -0.1094 -0.1346 -0.0512 0.1026 -
0.0416 0.0586 -0.0570 0.1157 -0.0153 -0.1413 0.1858 -0.0782 0.1210 0.0855
-0.2471 0.1156 0.0227 0.3488 0.0640 -0.1564 -0.0946 -0.0134 0.2191
0.0303 -0.7168
Ce -0.1008 0.1880 -0.1739 0.0959 0.0965 0.1013 0.0243 -0.0805
0.0811 -0.0722 -0.0427 -0.0239 -0.1049 0.1576 0.0530 0.0599 0.0424 0.0080
-0.0226 -0.0025 0.0134 0.1163 -0.0203 -0.0739 -0.5398 -0.5186 -0.0115 -
0.4810 0.1351
Co 0.5156 0.2571 0.0211 -0.0152 0.0678 0.1905 0.3152 0.1142 -
0.1234 -0.4268 -0.2476 -0.2312 -0.0074 -0.2540 0.0548 -0.0713 0.0841 -0.0975
-0.0139 0.1319 -0.0451 0.2781 0.0910 0.0659 0.0509 0.0178 -0.0028
0.0093 0.0113
Cs 0.0372 0.4038 0.3558 0.0771 -0.0225 -0.4388 0.1415 -0.3592 -
0.1911 -0.1886 0.2325 0.2873 -0.1178 0.0665 -0.2193 -0.1101 0.1669 -0.0259
-0.1173 -0.1346 -0.0331 -0.0571 0.0684 0.0166 -0.0119 -0.0122 -0.0524 -
0.0026 -0.0300
Eu 0.0722 0.0625 0.0579 0.3070 0.2201 -0.2437 0.0396 -0.0663
0.0256 0.1028 -0.0461 -0.1435 -0.0270 -0.0135 0.3512 -0.0127 -0.3563 -0.5513
-0.0266 0.0025 0.1633 -0.1128 -0.1343 -0.3298 0.0489 0.1032 -0.0599 -
0.0804 -0.0146
Fe 0.2112 0.1360 -0.0955 0.0643 -0.3132 0.1954 0.1788 0.0365
0.0392 0.0801 0.1486 0.0974 -0.0426 -0.1805 0.0619 0.0505 0.3101 0.1380
0.2194 0.0291 0.3868 -0.4403 -0.1238 -0.3360 -0.1074 0.1154 0.0120 -
0.0712 -0.0877
Hf -0.1189 0.0956 -0.2242 -0.0337 0.0626 0.1323 -0.0011 0.0228 -
0.1481 -0.0156 0.0478 0.2756 0.1388 -0.2227 0.1546 -0.1454 0.0039 -0.0714
-0.1208 -0.3379 0.3822 0.1023 -0.1493 0.1496 0.3664 -0.4132 -0.1767
0.1123 0.0720
Rb -0.2086 0.3373 0.3012 0.0536 -0.3535 0.0782 -0.2311 0.0228 -
0.1587 0.1461 0.0130 -0.2277 -0.0535 -0.0885 -0.0929 -0.0113 -0.2290 0.0231
0.4616 0.0699 0.1733 0.3656 -0.0817 -0.0018 0.0306 -0.0275 -0.0245
0.0049 0.0496
Sb 0.0912 0.3247 -0.2045 -0.6775 -0.0360 -0.3933 0.0326 0.0049
0.3053 0.1033 -0.0503 -0.0055 0.0634 0.1259 0.2624 -0.0150 -0.0288 0.0425

0.1112 0.0628 0.0534 0.0747 -0.0564 -0.0024 0.0217 0.0279 0.0265
0.0156 0.0110
Sc   0.1903 0.0059 0.1953 0.1612 0.0620 -0.2999 0.1377 0.3432
0.0614 0.1465 -0.0192 0.0596 0.0793 -0.3361 0.0906 0.3269 -0.2620 0.3739
0.0411 -0.3452 -0.1212 -0.0440 -0.0364 0.1069 -0.1771 -0.1196 0.0037
0.0227 0.0280
Sr   0.2933 0.1364 -0.2444 0.0914 0.3325 -0.0989 -0.3084 -0.2810 -
0.2065 0.3926 -0.0772 -0.2446 0.0307 -0.1811 -0.1956 -0.2795 0.0110 0.3035
-0.0560 0.1110 0.0286 -0.0843 -0.0359 -0.0042 -0.0173 -0.0329 0.0312
0.0263 0.0108
Ta   -0.1801 0.2164 -0.1179 0.0303 -0.0255 -0.0350 0.0951 0.3486 -
0.0148 -0.2812 0.0467 -0.1149 0.0964 0.1943 -0.2760 -0.1839 -0.3863 0.2738
-0.2822 0.1303 0.0982 -0.1654 0.0087 -0.3554 0.0813 -0.0576 0.0565
0.1296 0.0867
Tb   -0.1100 0.1010 -0.1134 0.1954 -0.1824 -0.1693 0.0057 0.0934 -
0.0442 -0.0059 -0.0768 -0.0258 -0.0660 -0.0818 0.1436 -0.0342 0.1445 0.0261
0.0935 0.1527 -0.3764 -0.2045 -0.1065 0.0790 0.5028 -0.1701 0.3655 -
0.3567 0.1318
Th   -0.2854 0.2376 -0.0667 -0.0013 0.4838 0.0041 0.0648 0.0785
0.0110 0.0013 0.1242 0.0722 0.2136 -0.1986 -0.2379 0.4868 0.1379 -0.1234
0.1115 0.3101 0.1614 0.0065 0.0672 0.0754 0.0600 0.1052 0.1393 -
0.0193 -0.0162
Zn   0.1062 0.1666 -0.0823 0.1510 -0.2315 0.0445 0.1505 -0.0301
0.1583 0.3314 -0.5987 0.3009 0.1957 0.1681 -0.3787 0.0933 -0.0543 -0.1812
-0.0712 -0.0366 -0.0104 0.0223 0.0461 0.0090 0.0534 0.0067 -0.0404
0.0026 -0.0159
Zr   -0.0840 0.1172 -0.2470 0.0051 0.0827 0.1092 0.0038 0.0749 -
0.1501 -0.0982 0.0753 0.3627 0.2526 -0.1236 0.0465 -0.3984 -0.2501 -0.0917
0.3689 -0.1155 -0.2674 -0.0809 0.1205 0.0797 -0.2487 0.2865 0.0492 -
0.1254 -0.0547
Al   0.0490 0.0275 -0.0020 -0.0201 -0.0198 0.0722 0.0315 0.0146
0.0028 -0.0158 0.0148 0.0269 -0.2236 0.0665 -0.0708 -0.0356 -0.1965 0.0218
-0.2673 -0.1048 0.3485 0.0376 -0.3308 0.4348 -0.0788 0.3582 0.4189 -
0.2725 0.0244
Ba   0.0062 0.1537 0.4481 0.1006 0.3849 0.2453 0.0406 0.2083
0.2032 0.2003 -0.0999 0.2311 -0.0973 0.2804 0.2740 -0.2967 0.1187 0.2229
0.0776 0.1437 0.0710 -0.0140 0.0735 0.0347 0.1075 -0.0192 0.0271
0.0257 0.0200
Ca   0.3111 0.1055 -0.0793 0.0401 0.0126 -0.0608 -0.6541 0.3952
0.1613 -0.1600 0.0811 0.2323 -0.2865 0.0042 -0.1713 0.0701 0.0772 -0.2252
0.0062 -0.0411 0.0038 -0.0092 0.0739 -0.0360 0.0217 -0.0269 -0.0357 -
0.0015 0.0013
Dy   -0.1407 0.1126 -0.1206 0.1593 -0.1391 -0.1492 -0.0162 0.1272 -
0.0738 -0.0452 -0.1108 -0.0742 -0.1033 0.0137 0.1669 0.0033 -0.0246 0.0631
-0.0854 0.3381 0.0934 -0.2620 0.0872 0.4862 -0.0816 0.0887 -0.5739 -
0.0388 -0.1124
K   -0.1708 0.2665 0.2611 -0.2854 -0.0626 0.3430 -0.2485 -0.1966
0.0441 -0.0100 -0.1830 0.0232 -0.0371 -0.3769 0.1478 0.1081 -0.1543 -0.0429
-0.3666 -0.0226 -0.2066 -0.3105 0.0682 -0.0727 -0.0649 0.0071 0.0322 -
0.0028 -0.0174
Mn   0.2056 0.0907 -0.0418 0.3068 -0.1827 0.1138 -0.0995 -0.2987
0.5187 -0.0826 0.3799 0.0259 0.3659 -0.0071 0.1088 0.0261 -0.1746 0.0920

-0.1016 0.1683 -0.0055 0.1181 0.1147 0.1567 0.0809 -0.0290 0.0441
0.0367 0.0318
Na   0.0222 -0.1667 -0.1550 -0.0509 0.0324 0.0196 0.2175 -0.2157
0.0924 0.0339 0.0170 0.3229 -0.5945 -0.2248 -0.0749 0.0412 -0.3740 0.1099
 0.1308 0.2749 0.0289 0.0929 0.1903 -0.0788 0.1222 -0.0958 -0.0139
0.0455 0.0387
Ti   0.2670 0.1361 -0.0850 -0.0704 -0.0845 0.1999 0.0200 0.0661 -
0.5271 0.2558 0.2787 0.1841 0.0352 0.3442 0.2125 0.3334 -0.1484 -0.0035
-0.1608 0.1594 -0.1812 0.0719 -0.0205 -0.0294 0.0295 -0.0125 -0.0016
0.0358 0.0218

Scaled Factor Loading Matrix (largest to smallest component):

La   -0.1069 0.1121 -0.0884 0.0479 0.0379 0.0343 0.0018 -0.0222
0.0302 -0.0188 -0.0039 0.0051 -0.0221 0.0065 -0.0001 0.0106 0.0044 0.0101
 0.0027 -0.0050 -0.0124 0.0051 -0.0186 -0.0028 0.0012 0.0031 -0.0038
0.0016 -0.0008
Lu   -0.1715 0.0039 -0.0487 0.0423 -0.0296 -0.0319 -0.0100 0.0122 -
0.0064 0.0136 -0.0067 0.0174 -0.0012 -0.0209 0.0191 -0.0034 0.0172 0.0056
-0.0131 0.0021 0.0014 0.0116 0.0042 -0.0051 -0.0024 0.0054 -0.0008
0.0001 0.0057
Nd   -0.0853 0.1115 -0.1113 0.0399 0.0201 0.0230 -0.0105 -0.0271 -
0.0015 -0.0120 -0.0128 -0.0253 -0.0208 0.0264 0.0145 0.0193 -0.0010 0.0112
 0.0051 -0.0215 0.0034 -0.0008 0.0148 -0.0006 0.0046 0.0031 0.0005 -
0.0006 -0.0009
Sm   -0.0907 0.0780 -0.0720 0.0550 -0.0168 -0.0063 0.0059 -0.0050 -
0.0025 -0.0032 -0.0103 -0.0061 -0.0190 0.0074 0.0150 -0.0002 0.0050 -0.0092
 0.0046 0.0008 -0.0007 -0.0058 -0.0000 0.0051 -0.0062 -0.0025 0.0056
0.0068 0.0014
U   -0.0795 0.1060 -0.0429 -0.0085 -0.0073 0.0331 0.0652 0.0464
0.0360 0.0612 0.0507 -0.0327 -0.0271 -0.0132 -0.0191 -0.0161 0.0062 -0.0155
-0.0086 -0.0077 -0.0080 0.0016 0.0038 0.0021 0.0002 0.0001 -0.0014 -
0.0000 -0.0004
Yb   -0.1758 0.0142 -0.0471 0.0448 -0.0300 -0.0338 -0.0115 0.0194 -
0.0074 0.0085 -0.0074 0.0144 -0.0019 -0.0158 0.0187 -0.0066 0.0087 0.0052
-0.0126 0.0053 0.0008 0.0127 0.0019 -0.0040 -0.0021 -0.0002 0.0031
0.0003 -0.0067
Ce   -0.1104 0.1046 -0.0868 0.0305 0.0265 0.0255 0.0055 -0.0152
0.0145 -0.0105 -0.0056 -0.0030 -0.0128 0.0176 0.0053 0.0051 0.0030 0.0005
-0.0012 -0.0001 0.0005 0.0042 -0.0006 -0.0019 -0.0119 -0.0077 -0.0002 -
0.0047 0.0013
Co   0.5647 0.1430 0.0105 -0.0049 0.0186 0.0478 0.0708 0.0215 -
0.0220 -0.0622 -0.0322 -0.0287 -0.0009 -0.0283 0.0055 -0.0061 0.0060 -0.0059
-0.0007 0.0060 -0.0017 0.0101 0.0027 0.0017 0.0011 0.0003 -0.0000
0.0001 0.0001
Cs   0.0407 0.2247 0.1776 0.0246 -0.0062 -0.1102 0.0318 -0.0678 -
0.0341 -0.0275 0.0302 0.0357 -0.0144 0.0074 -0.0220 -0.0094 0.0120 -0.0016
-0.0060 -0.0061 -0.0012 -0.0021 0.0020 0.0004 -0.0003 -0.0002 -0.0007 -
0.0000 -0.0003
Eu   0.0791 0.0348 0.0289 0.0978 0.0604 -0.0612 0.0089 -0.0125
0.0046 0.0150 -0.0060 -0.0178 -0.0033 -0.0015 0.0353 -0.0011 -0.0256 -0.0332

```
-0.0014  0.0001  0.0061 -0.0041 -0.0039 -0.0084  0.0011  0.0015 -0.0009 -
0.0008 -0.0001
Fe        0.2314  0.0757 -0.0477  0.0205 -0.0859  0.0491  0.0402  0.0069
0.0070  0.0117  0.0193  0.0121 -0.0052 -0.0201  0.0062  0.0043  0.0223  0.0083
 0.0112  0.0013  0.0145 -0.0160 -0.0036 -0.0085 -0.0024  0.0017  0.0002 -
0.0007 -0.0008
Hf       -0.1302  0.0532 -0.1119 -0.0107  0.0172  0.0332 -0.0003  0.0043 -
0.0264 -0.0023  0.0062  0.0342  0.0169 -0.0249  0.0155 -0.0123  0.0003 -0.0043
-0.0061 -0.0154  0.0143  0.0037 -0.0044  0.0038  0.0081 -0.0061 -0.0025
0.0011  0.0007
Rb       -0.2284  0.1876  0.1504  0.0171 -0.0970  0.0196 -0.0519  0.0043 -
0.0283  0.0213  0.0017 -0.0283 -0.0065 -0.0099 -0.0093 -0.0010 -0.0165  0.0014
 0.0235  0.0032  0.0065  0.0133 -0.0024 -0.0000  0.0007 -0.0004 -0.0003
0.0000  0.0005
Sb        0.0998  0.1807 -0.1021 -0.2159 -0.0099 -0.0988  0.0073  0.0009
0.0545  0.0151 -0.0065 -0.0007  0.0077  0.0141  0.0263 -0.0013 -0.0021  0.0026
 0.0057  0.0029  0.0020  0.0027 -0.0016 -0.0001  0.0005  0.0004  0.0004
0.0002  0.0001
Sc        0.2084  0.0033  0.0975  0.0514  0.0170 -0.0753  0.0309  0.0647
0.0110  0.0213 -0.0025  0.0074  0.0097 -0.0375  0.0091  0.0278 -0.0188  0.0225
 0.0021 -0.0157 -0.0045 -0.0016 -0.0011  0.0027 -0.0039 -0.0018  0.0001
0.0002  0.0003
Sr        0.3212  0.0759 -0.1220  0.0291  0.0912 -0.0248 -0.0693 -0.0530 -
0.0369  0.0572 -0.0100 -0.0304  0.0037 -0.0202 -0.0196 -0.0237  0.0008  0.0183
-0.0028  0.0051  0.0011 -0.0031 -0.0011 -0.0001 -0.0004 -0.0005  0.0004
0.0003  0.0001
Ta       -0.1973  0.1204 -0.0589  0.0097 -0.0070 -0.0088  0.0214  0.0658 -
0.0026 -0.0410  0.0061 -0.0143  0.0118  0.0217 -0.0277 -0.0156 -0.0278  0.0165
-0.0144  0.0059  0.0037 -0.0060  0.0003 -0.0090  0.0018 -0.0009  0.0008
0.0013  0.0008
Tb       -0.1205  0.0562 -0.0566  0.0623 -0.0500 -0.0425  0.0013  0.0176 -
0.0079 -0.0009 -0.0100 -0.0032 -0.0081 -0.0091  0.0144 -0.0029  0.0104  0.0016
 0.0048  0.0070 -0.0141 -0.0075 -0.0031  0.0020  0.0111 -0.0025  0.0052 -
0.0035  0.0012
Th       -0.3126  0.1322 -0.0333 -0.0004  0.1327  0.0010  0.0146  0.0148
0.0020  0.0002  0.0161  0.0090  0.0261 -0.0222 -0.0239  0.0413  0.0099 -0.0074
 0.0057  0.0141  0.0060  0.0002  0.0020  0.0019  0.0013  0.0016  0.0020 -
0.0002 -0.0002
Zn        0.1163  0.0927 -0.0411  0.0481 -0.0635  0.0112  0.0338 -0.0057
0.0282  0.0483 -0.0779  0.0373  0.0239  0.0188 -0.0380  0.0079 -0.0039 -0.0109
-0.0036 -0.0017 -0.0004  0.0008  0.0013  0.0002  0.0012  0.0001 -0.0006
0.0000 -0.0001
Zr       -0.0920  0.0652 -0.1233  0.0016  0.0227  0.0274  0.0008  0.0141 -
0.0268 -0.0143  0.0098  0.0450  0.0308 -0.0138  0.0047 -0.0338 -0.0180 -0.0055
 0.0188 -0.0053 -0.0100 -0.0029  0.0035  0.0020 -0.0055  0.0042  0.0007 -
0.0012 -0.0005
Al        0.0536  0.0153 -0.0010 -0.0064 -0.0054  0.0181  0.0071  0.0028
0.0005 -0.0023  0.0019  0.0033 -0.0273  0.0074 -0.0071 -0.0030 -0.0141  0.0013
-0.0136 -0.0048  0.0130  0.0014 -0.0097  0.0111 -0.0017  0.0053  0.0060 -
0.0027  0.0002
Ba        0.0068  0.0855  0.2237  0.0321  0.1056  0.0616  0.0091  0.0393
0.0363  0.0292 -0.0130  0.0287 -0.0119  0.0313  0.0275 -0.0252  0.0085  0.0134
```

0.0039 0.0065 0.0027 -0.0005 0.0021 0.0009 0.0024 -0.0003 0.0004
0.0003 0.0002
Ca   0.3407 0.0587 -0.0396 0.0128 0.0035 -0.0153 -0.1469 0.0746
0.0288 -0.0233 0.0106 0.0288 -0.0350 0.0005 -0.0172 0.0060 0.0056 -0.0136
0.0003 -0.0019 0.0001 -0.0003 0.0022 -0.0009 0.0005 -0.0004 -0.0005 -
0.0000 0.0000
Dy   -0.1541 0.0626 -0.0602 0.0508 -0.0381 -0.0375 -0.0036 0.0240 -
0.0132 -0.0066 -0.0144 -0.0092 -0.0126 0.0015 0.0168 0.0003 -0.0018 0.0038
-0.0043 0.0154 0.0035 -0.0095 0.0026 0.0124 -0.0018 0.0013 -0.0082 -
0.0004 -0.0011
K   -0.1870 0.1483 0.1303 -0.0909 -0.0172 0.0861 -0.0558 -0.0371
0.0079 -0.0015 -0.0238 0.0029 -0.0045 -0.0421 0.0148 0.0092 -0.0111 -0.0026
-0.0187 -0.0010 -0.0077 -0.0113 0.0020 -0.0018 -0.0014 0.0001 0.0005 -
0.0000 -0.0002
Mn   0.2252 0.0505 -0.0209 0.0977 -0.0501 0.0286 -0.0224 -0.0563
0.0925 -0.0120 0.0494 0.0032 0.0446 -0.0008 0.0109 0.0022 -0.0125 0.0055
-0.0052 0.0077 -0.0002 0.0043 0.0034 0.0040 0.0018 -0.0004 0.0006
0.0004 0.0003
Na   0.0243 -0.0928 -0.0774 -0.0162 0.0089 0.0049 0.0489 -0.0407
0.0165 0.0049 0.0022 0.0401 -0.0725 -0.0251 -0.0075 0.0035 -0.0269 0.0066
0.0067 0.0125 0.0011 0.0034 0.0056 -0.0020 0.0027 -0.0014 -0.0002
0.0004 0.0004
Ti   0.2925 0.0757 -0.0425 -0.0224 -0.0232 0.0502 0.0045 0.0125 -
0.0940 0.0373 0.0362 0.0228 0.0043 0.0384 0.0213 0.0283 -0.0107 -0.0002
-0.0082 0.0073 -0.0068 0.0026 -0.0006 -0.0007 0.0006 -0.0002 -0.0000
0.0004 0.0002