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Investigating Compositional Variation of Ceramic Materials during the Late Neolithic on the Great Hungarian Plain – Preliminary LA-ICP-MS Results

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Abstract: Investigations have been undertaken to assess the extent to which compositional analysis can be used to determine trade and interaction on the Great Hungarian Plain during the Late Neolithic. Ceramic and clay samples in the Körös and Berettyó River Basins were analyzed at the Elemental Analysis Facilities (EAF) at The Field Museum of Natural History in Chicago, IL, USA. With the use of laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS), the aim of the project was to ascertain if micro-regional or site-specific compositional signatures could be determined in a region that is typically characterized as highly geologically homogenous. Identifying site-specific signatures enables archaeologists to model prehistoric interactions and, in turn, determine the relationship between interaction and various socio-cultural changes. This paper focuses on the preliminary compositional results of materials analyzed from three different sites across the Plain and the methodological implications for future anthropological research in the region.

Keywords: Geochemical variation; Compositional analysis; Clay and ceramic materials; Eastern Europe; Prehistoric exchange

1 Introduction

Research on the Neolithic period of the Great Hungarian Plain has centered primarily on understanding how individual sites developed independently over time [see 1–8] and less on the impact that human interaction may have had on social developments in the region [e.g. 9–18]. In this article, we investigate the potential application of compositional analysis to identify chemical variation in clays and ceramics from Late Neolithic sites across the Great Hungarian Plain. By determining the source of materials and the places were produced and consumed, we can begin to model interactions – namely, those interactions involving exchange of ceramics – between people living on the Plain in the Late Neolithic period (ca. 5000–4500 BCE).

Towards the end of the Late Neolithic, three archaeologically distinct groups cohabited the Plain—the Tisza, Herpály, and Csőszhalom. Sites identified as Tisza are restricted to the southern portion of the Plain along the Tisza, Körös, and Maros Rivers; Herpály sites are located directly to the north along the Berettyó River; and Csőszhalom sites are distributed in the northernmost part of the Plain along the Tisza River (Figure 1) [17, 19–30]. Traditionally, these groups have been characterized by differences in ceramic decoration, domestic architectural style, site location, settlement layout, and subsistence practices. Sociocultural changes at the end of the Late Neolithic appear to have led to the homogenization of material culture over the Plain and the surrounding areas during the Early Copper Age (ca. 4500–4000 BCE) [31–39].

The decorations found on Tisza and Herpály ceramics traditionally have been used to reconstruct interactions between these archaeological groups, with Tisza ceramics characterized primarily by incisions and Herpály ceramics by painted motifs (Figure 2) [2]. However, this approach not only dismisses the possibility of diffusion, imitation, and independent social development of decorative styles, it also hinders an understanding of the interactions that occurred between peoples who used similar decorative styles.

To model interaction within and between Neolithic sites on the Great Hungarian Plain, geochemical analysis was implemented. Specifically, we used laser ablation-

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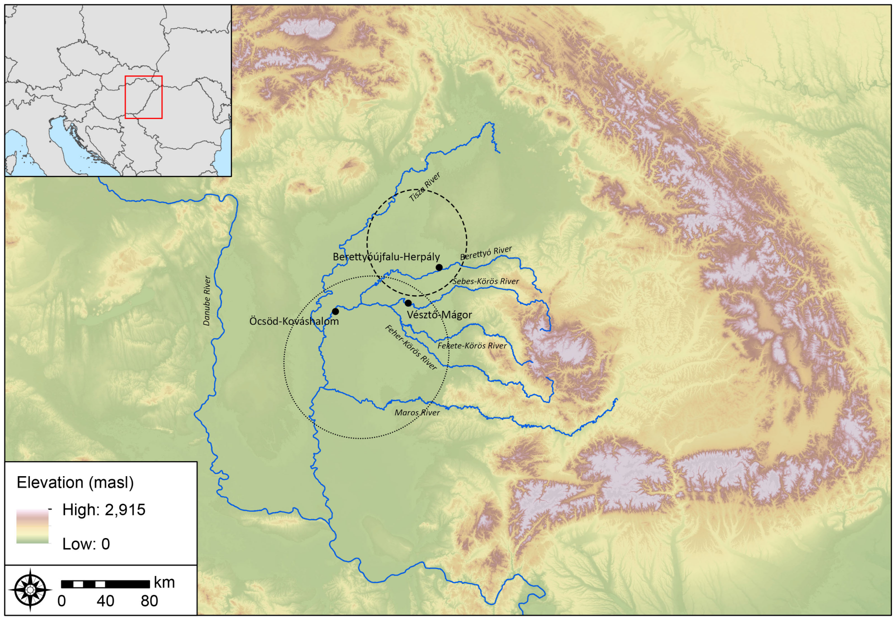

Figure 1: Map of the three sites included in this project. The rivers are reconstructed waterways for the Holocene period prior to the implementation of the Austro-Hungarian water regulation of the 19th century. The dashed line represents the presumed extent of the Herpály territory and the dotted line represents the presumed extent of the Tisza territory.

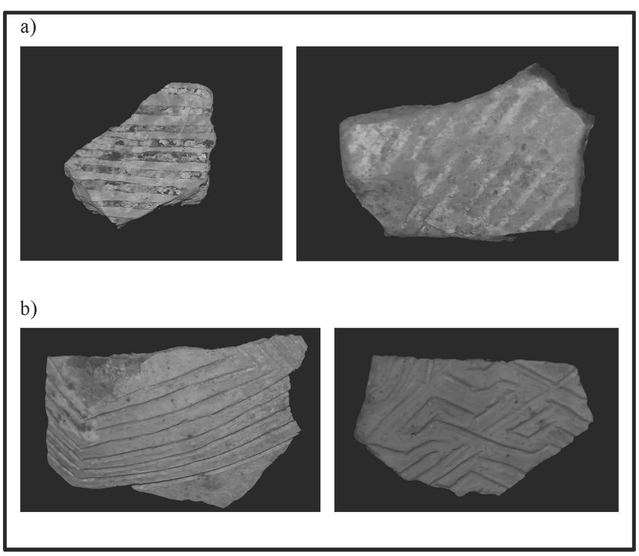

Figure 2: Images of ceramics with characteristics typically used to classify a) Herpály sites (both painted sherds (bh4 and bh3) from Berettyóújfalu-Herpály and b) Tisza sites [incised sherd (vm12) on the left is from Vésztő-Mágor; incised sherd (ok2) on the right is from Öcsöd-Kováshalom.

inductively coupled plasma-mass spectrometry (LA-ICP-MS) to analyze clays from Late Neolithic sites to identify the chemical signatures at various sites. These local elemental signatures were then compared to ceramic compositional results in order to distinguish locally-produced pottery versus imported wares. The tell sites (artificial hills created through the continual habitation at a single location over thousands of years and other anthropogenic processes) of Vésztő-Mágor [1, 40, 41] and Berettyóújfalu-Herpály [4, 5, 42], as well as the tell-like settlement of Öcsöd-Kováshalom [6, 7, 14] are included in this study (Figure 1). Previous research in the Körös region attempted to utilize petrographic analysis in order to examine trade in the region; however, the results indicated that petrographic analysis was not useful in identifying traded (vs. locally-made) materials due to the homogeneity of the ceramics [43, 44]. For the present study, it was therefore necessary to focus on other methods of analysis. The LA-ICP-MS equipment is capable of measuring a large number of elements and generating precise and accurate data [see 45], and therefore it is deemed a technique well-suited for assessing micro-regional geochemical variation in archaeological ceramic materials from the Great Hungarian Plain. This paper details the results of LA-ICP-MS analysis to identify site-specific signatures in an exploratory manner in order to model interaction during the Late Neolithic.

1.1 Previous Investigations

In 2006, Samuel Duwe conducted similar investigations that sought to model prehistoric trade via ceramic analysis of pedestaled vessels from six Early Copper Age Tiszapolgár (ca. 4500–4000 BCE) sites on the Plain [43, 44, 46].

During these investigations, Duwe incorporated both petrographic and geochemical analyses. According to Duwe *et al.*, "Petrographic analysis did not reveal any significant distinctions between ceramic samples taken from the four sites [Körösladány-14, Vésztő 20, Örménykút 13, and Vésztő-Mágor] in the study region, and [there is] little support for mineral and clay compositional variability across the region" [44]. Moreover, the authors go on to note that, "all of the petrographic samples fit within a certain, relatively narrow range of similar characteristics. The matrix is relatively fine and very homogenous, containing very little sand and only moderate amounts of silt. Based on these results, petrographic analysis does not provide direct, unambiguous evidence for the existence of an extensive pottery trade network..." [44]. The lack of information provided by the petrographic analysis encouraged Duwe to incorporate geochemical analysis as a way of distinguishing variation in ceramics and clays from sites on the Plain. Specifically, Duwe used time-of-flight (TOF) LA-ICP-MS at California State University, Long Beach, to analyze Early Copper Age ceramics from the sites of Endröd 108, Gyula 486, Körösladány 14, Vésztő 20, Örménykút 13, and Battonya-Vertán [see 47]. The distance between the sites varied, ranging from 60 meters to 80 kilometers. Although he was unable to identify site-specific compositional signatures, he did discern chemical variation between materials from Battonya-Vertán and all other sites. Duwe concluded that this distinction was due to the site's location on a different waterway, the Maros River, while the other sites are located on the Körös River or its tributaries [43, 44].

Building on Duwe's research, in spring 2011 Riebe reanalyzed a subsample of Tiszapolgár ceramics using LA-ICP-MS at The Field Museum's Elemental Analysis Facility (EAF). The analysis confirmed the pattern that Duwe had noted, but by concentrating on some of the trace elements not used in the TOF-LA-ICP-MS analysis, such as molybdenum (Mo), additional micro-regional differentiation was perceived. In total, Duwe's project included the concentrations of 42 elements measured by TOF-LA-ICP-MS [44]; for the present analysis, the concentrations of 58 elemental isotopes were determined using LA-ICP-MS, 49 of which were used in the statistical analysis for this study. Using trace elements–including hafnium (Hf), thorium (Th), nickel (Ni), lanthanum (La), sodium (Na), lithium (Li), beryllium (Be), boron (B), scandium (Sc), tungsten (W), and molybdenum (Mo)–and a high degree of precision and accuracy of the LA-ICP-MS equipment [see 45, 48–50] proved critical in determining geochemical variation in the ceramic and clay materials from across the Plain.

Current Project

Duwe's success in identifying compositional variation between sites on different river drainages set a precedent for studying the ceramic materials and clays from Late Neolithic sites on the Plain. To test Duwe's river hypothesis, the Late Neolithic study area was expanded north of the Körös River to include the Berettyó River (Figure 1). Importantly, the inclusion of the Berettyó River allowed for the analysis of material from sites traditionally classified as being culturally Herpály and Tisza. Specifically, ceramics and clays from three major Late Neolithic sites on the Plain were analyzed in order to assess the feasibility of isolating micro-regional, or site-specific, compositional signatures. The sites included in the study were two Tisza sites, Vésztő-Mágor and Öcsöd-Kováshalom, and the eponymous Herpály site, Berettyóújfalu-Herpály (Figure 1). The results generated from the project are preliminary, but the initial success encourages additional research using elemental analysis.

2 Materials

The ceramic samples from Vésztő-Mágor, Öcsöd-Kováshalom, and Berettyóújfalu-Herpály came from excavated collections stored at various county museums in Hungary, including the Mihály Munkácsy Museum (Békéscsaba), the János Damjanich Museum (Szolnok), and the Déri Museum (Debrecen). Ceramics were collected and prepared for shipment by Riebe and Drs. Zsuzsanna Siklósi (Eötvös Loránd Science University) and Attila Gyucha (Hungarian National Museum). A total of 59 ceramic samples were sent to The Field Museum for LA-ICP-MS analysis at the EAF. For each sample, a small fragment was removed from the body of the sherd with a pair of pliers, and the exposed paste on the freshly broken edge was targeted for spot ablations. This method minimizes potential error in compositional measurement due to surface contamination and post-depositional alterations.

In April 2011 and 2012, Riebe and Gyucha collected soil samples around the sites of Öcsöd-Kováshalom, Berettyóújfalu-Herpály, and Vésztő-Mágor. Soil samples were extracted with an Oakfield Soil Sampler from the plow zone, the cultural level, and the subsoil level at points located in the major cardinal directions at each site. However, only soil from the subsoil level was processed and analyzed since it was the material most likely available to prehistoric peoples for ceramic production. Moreover, the materials from this level are typically clay-

Table 1: Inventory of the Hungarian ceramics and clays analyzed using LA-ICP-MS from the sites of Öcsöd-Kováshalom, Vésztő-Mágor, and Berettyóújfalu-Herpály. Culture is based on classification of the sites published in *The Neolithic of the Tisza Region* [42].

Sample ID	Culture	Material	Sample ID	Culture	Material	Sample ID	Culture	Material	Sample	Culture	Material
Öcsöd-Kováshalom			*Berettyóújfalu-Herpály*			*Vésztő-Mágor*			*Vésztő-Mágor*		
ok1	Tisza	Ceramic	bh1	Herpály	Ceramic	vm1	Tisza	Ceramic	vm18	Tisza	Ceramic
ok2	Tisza	Ceramic	bh2	Herpály	Ceramic	vm2	Tisza	Ceramic	vm19	Tisza	Ceramic
ok3	Tisza	Ceramic	bh3	Herpály	Ceramic	vm3	Tisza	Ceramic	vm20	Tisza	Ceramic
ok4	Tisza	Ceramic	bh4	Herpály	Ceramic	vm4	Tisza	Ceramic	vm21	Tisza	Ceramic
ok5	Tisza	Ceramic	bh5	Herpály	Ceramic	vm5	Tisza	Ceramic	vm22	Tisza	Ceramic
ok6	Tisza	Ceramic	bh6	Herpály	Ceramic	vm6	Tisza	Ceramic	vm23	Tisza	Ceramic
ok7	Tisza	Ceramic	bh7	Herpály	Ceramic	vm7	Tisza	Ceramic	vm24	Tisza	Ceramic
ok8	Tisza	Ceramic	bh8	Herpály	Ceramic	vm8	Tisza	Ceramic	vm25	Tisza	Ceramic
ok9	Tisza	Ceramic	bh9	Herpály	Ceramic	vm9	Tisza	Ceramic	vm26	Tisza	Ceramic
ok10	Tisza	Ceramic	bh10	Herpály	Ceramic	vm10	Tisza	Ceramic	vm27	Tisza	Ceramic
ok11	Tisza	Ceramic	bh11	Herpály	Ceramic	vm11	Tisza	Ceramic	vm28	Tisza	Ceramic
ok12	Tisza	Ceramic	bh12	Herpály	Ceramic	vm12	Tisza	Ceramic	vm29	Tisza	Ceramic
ok13	Tisza	Ceramic	s_ bh1	-	Clay	vm13	Tisza	Ceramic	vm30	Tisza	Ceramic
ok14	Tisza	Ceramic	s_ bh2	-	Clay	vm14	Tisza	Ceramic	s_ vm1	-	Clay
ok15	Tisza	Ceramic	s_ bh3	-	Clay	vm15	Tisza	Ceramic	s_ vm2	-	Clay
ok16	Tisza	Ceramic	s_ bh4	-	Clay	vm16	Tisza	Ceramic	s_ vm3	-	Clay
ok17	Tisza	Ceramic				vm17	Tisza	Ceramic	s_ vm4	-	Clay
s_ ok1	-	Clay									
s_ ok2	-	Clay									
s_ ok3	-	Clay									
s_ ok4	-	Clay									

like in consistency (e.g., plasticity) and were presumably used in the local production of ceramics in prehistoric times, thus these samples will be referred to as "clay samples" throughout the duration of this paper. In the fall of 2011 and 2012, small briquettes were prepared from each collected sample. After drying the soil sample, the material was pulverized using an agate mortar and pestle and slowly mixed with deionized water until a thick paste was achieved. Small pellets, measuring approximately 1 cm in diameter and 3 mm in thickness, were hand formed. In total, 24 briquettes were created and fired for three hours at a temperature of 800 degrees Celsius. Only the 12 briquettes formed from subsoil samples were analyzed using LA-ICP-MS—four from Öcsöd-Kováshalom, four from Berettyóújfalu-Herpály, and four from Vésztő-Mágor. To minimize any potential surface contamination, the briquettes were broken prior to ablation, revealing a freshly fractured edge for the LA-ICP-MS analysis. Each ceramic and local clay sample was given a unique identifier or sample ID, which will be referenced throughout this report (Table 1).

3 Methods

Procedures followed were based on the standard protocol of the EAF laboratory (for more information see [45, 49, 51–53], all based on [54]). The ceramic and clay samples were analyzed using an ICP Bruker quadrupole mass spectrometer coupled with a New Wave UP213 system. Material was ablated from each sample using a 213 nm wavelength laser set at 70% energy (0.2 mJ) and a pulse frequency of 15 Hz. Clay material was removed from 10 locations on each sample using a laser spot size of 100 μm and a dwell time of 90 seconds. The ablated material was carried by helium gas from the laser chamber to the argon plasma, where the material was ionized and then delivered to the mass spectrometer.

When selecting the location for each ablation spot, visible temper was avoided as much as possible because it was the paste itself that we were most interested in analyzing in order to determine "local" vs. "non-local" elemental signatures. It is more likely that people in the past did not transport clays over long distances, whereas temper could be transported over greater distances (see [55, 56]). Assuming the composition of a piece of ceramic reflects the composition of the clay from which it was made (based on the Provenance Postulate [57, 58]), it was more important to target the paste component of each sample in order to ascertain an elemental profile most closely linked to its place of origin. From there, we were able to use the material object as a proxy for understanding the movement of goods and, subsequently, social interactions.

Standards

To calculate elemental concentrations and account for instrument drift over the course of analysis, standard reference materials (SRM), which have known ranges of elemental concentrations, were obtained from the National Institute of Standards of Technology (NIST) and Missouri University Research Reactor Center (MURR) and analyzed in conjunction with the samples. The glass standards used were NIST SRM 612 and NIST SRM 610 and the clay standards were NIST SRM 679 (brick clay) and New Ohio Red Clay (NORC) from MURR. Specifically NIST 612, 610, and 679 were used to calculate elemental composition, while NORC was used to correct for instrument drift over time. With all of the standards and the ceramic and clay samples, ablation of the material did not occur until the signal was stabilized as indicated by the chamber's blank recording a relative standard deviation (RSD) % level below 5% for silicon (^{29}Si). Standards were ablated 10 times each in different locations, avoiding visible temper in the case of the clay standards as much as possible. After running a complete series of standards, the first five ceramic or clay samples were placed into the chamber, the chamber was purged of residual ablated material, and each sample ablated. Following the ablation and removal of each set of samples, the standards NIST 610, NORC, and NIST679 were again placed in the chamber. After purging the chamber once again, the standards were ablated 10 times each. This pattern continued until all the samples were run.

Data Processing and Statistical Analysis

Methods for processing the raw data prior to statistical analysis of materials analyzed at the EAF are fully described by Dussubieux *et al.* [45], but the section below outlines the processing that occurred (for more in-depth descriptions of the processing, see also [49, 51]). During the ablation process, the instrument recorded nine replicates of the elemental data for each of the 10 spots targeted. During data processing, the first three replicates were removed from the final signal average to account for signal stabilization over time and to limit the introduction of values reflecting surface contamination into the data.

Using silicon (^{29}Si) as an internal standard, concentration values for the samples and standards were cal-

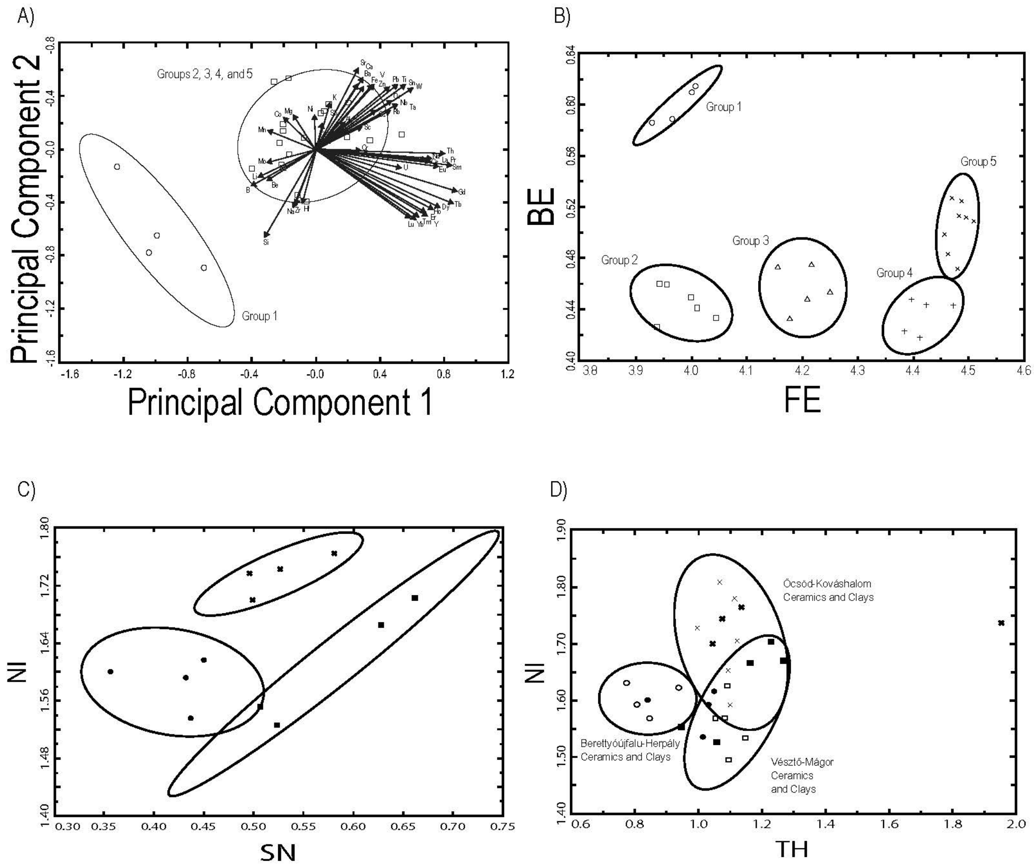

Figure 3: A) R-Q mode bivariate plot of principal component 1 (accounting for 28.30% of the variance) and principal component 2 (accounting for 15.37% of the variance) illustrating the compositional distinction between the Herpály ceramic group (Group 1, circles) and the remaining ceramics (Groups 2, 3, 4, and 5, squares). B) Bivariate plot of log base-10 concentrations of iron (Fe) and beryllium (Be) showing the compositional difference between the identified core ceramic groups: Group 1 (circles), Group 2 (squares), Group 3 (triangles), Group 4 (crosses), Group 5 (stars). C) Bivariate plot of log base-10 concentrations of nickel (Ni) and tin (Sn) depicting the clays from Berettyóújfalu-Herpály (solid circles), Vésztő-Mágor (solid squares), and Öcsöd-Kováshalom (solid stars). D) Bivariate plot of log base-10 concentrations of nickel (Ni) and thorium (Th) illustrating clays (solid shapes) and ceramics from Berettyóújfalu-Herpály (circles), Vésztő-Mágor (squares), and Öcsöd-Kováshalom (stars). Ellipses represent 90 % confidence intervals in all figures.

culated by subtracting the blank value and then dividing the result by the internal standard value. All values were then converted from counts-per-second to parts-per-million (ppm). Other elements [e.g., lead (Pb), chlorine (Cl), arsenic (As), silver (Ag), indium (In), bismuth (Bi), terbium (Tb), holmium (Ho), thulium (Tm), and lutetium (Lu)] were later removed because the values for these elements are often imprecise due to high background levels [59, 60].

Ceramics

Raw ceramic data was processed using Microsoft Excel. For each sample, no more than three outliers were removed for each recorded element. The outliers were identified as having measurements not consistent with a majority of the readings in a set, which could have occurred from the laser hitting temper or other contaminants during ablation, though steps were taken to minimize these incidents. Once this data processing was completed, the results of the ceramic analysis were imported into GAUSS, an Apetch Systems, Inc. program with routines developed by Hector Neff and Michael Glascock for examining compositional data at MURR. Using GAUSS, ppm concentrations were transformed to log base-10 values in order to minimize gross variations between major, minor, and trace elements [4, 61–63]. Principal components (PC) analysis was conducted on the logged data using an R-Q factor analysis based on the correlation matrix, and it was determined that there were 10 principal components with eigen values greater than one, often considered a cut-off point for determining which principal component values to use [64] (also see [49, 51–53]). These 10 principal components accounted for 84.12% of the compositional variance in the ceramics; however, due to the limited overall sample size and because some statistical procedures require there to be at least two more samples than variables (including Mahalanobis distance probability calculations), it was necessary to decrease the number of principal components used from 10 to eight.

Having completed this step, GAUSS was used to identify potential sample groupings in the compositional data, which can be accomplished using several methods. The first method employed generated a dendrogram [62, 63] based on the hierarchical cluster analysis using the first eight principal components (see also, [64–67]). The dendrogram used the Euclidean distance for the distance measure on the x-axis and the average linkage for the clustering algorithm for the y-axis, and it was used only as an exploratory method of analysis [68]. Principal component values also were used to generate bivariate plots illustrating the compositional values and potential groupings, which were useful in the first stages of analysis [61, 69].

Secondly, Mahalanobis distance probability calculations [63, 70] were carried out using the values of the first eight principal components to identify a core reference group and refine ceramic chemical groups [63, 64, 66, 71]. This process evaluates hypothetical group assignments [72] and shows the statistical likelihood of chemical group membership for each sample. A total of five outlier samples were removed from the original ceramic dataset because the probability that they belonged to the core reference group was less than 5%. Bivariate plots were used to graph the remaining 54 ceramic samples, and five potential ceramic groupings were identified. These results were mapped on a bivariate plot of PC1 and PC2, with PC1 accounting for 28.30% of the variance and PC2 for 15.37%. Within this bivariate plot (Figure 3), it was evident that one particular group of ceramics—Group 1 consisting of bh4, bh5, bh6, and bh7—was compositionally distinct from the other ceramic groups, which are more compositionally similar to each other than they are to Group 1. While the remaining four groups are broadly similar compositionally, they can still be differentiated from one another when graphed on bivariate plots with Group 1 removed.

Due to the homogenous nature of the clay on the Great Hungarian Plain, PC analysis and dendrograms were useful as exploratory tools, but differences identified through elemental bivariate analyses and mahalanobis distance measurements proved far more useful for discerning site-specific signatures. Therefore, to further refine the five groups, the 54 samples were re-projected using various elemental bivariate graphs. It was determined that an additional 27 samples were outliers and did not properly match the compositional profiles of any of the main groups identified through analysis. The remaining 27 samples could be projected using various elements to illustrate distinct core groups as reflected through iron (Fe) and beryllium (Be) (Figure 3). Moreover, when Mahalanobis distance calculations were performed on the remaining 27 ceramics, two major compositional groups were identified – Berettyóújfalu-Herpály and Tisza River materials (the results are recorded in Supplemental Table S1).

Clay Samples

Due to the small number of clay samples (n = 12), statistical analysis of the clay compositional data was limited. As with the ceramics, the raw data was processed and imported into GAUSS and then converted from ppm to log base-10 values. GAUSS was then used to construct elemental bivariate plots of the results. Based on these plots, the clays from Berettyóújfalu-Herpály, Vésztő-Mágor, and Öcsöd-Kováshalom were compositionally different from one another in their concentrations of elements such as nickel (Ni) and tin (Sn) (Figure 3). This is likely due to the sites being located on different waterways, the Berettyó River for the former site and the Körös River for the latter two sites. When the clay results are graphed with the ceramic compositional groups on an elemental bivariate plot, the groups representing locally-made wares from the sites of Berettyóújfalu-Herpály and Öcsöd-Kováshalom can be differentiated based on their chemical compositions (Figure 3).

4 Results

The analyzed ceramic samples can be separated into five geochemically distinct groups. As mentioned before, although principal components analysis was less helpful in identifying groups, selecting specific elements proved very useful in determining group membership (Figure 3). Elemental concentrations (including major elements and oxide %) for each sample are listed in Supplemental Table S2, while Table 2 displays a select number of elemental concentrations that were critical for group differentiation (discussed below).

Group 1 (n = 4) is represented by the samples bh4, bh5, bh6, and bh7, all from the site of Berettyóújfalu-Herpály. When compared to the clay samples in an elemental bivariate plot, they are found to be compositionally similar to the Berettyóújfalu-Herpály clays (Figure 3). Therefore,

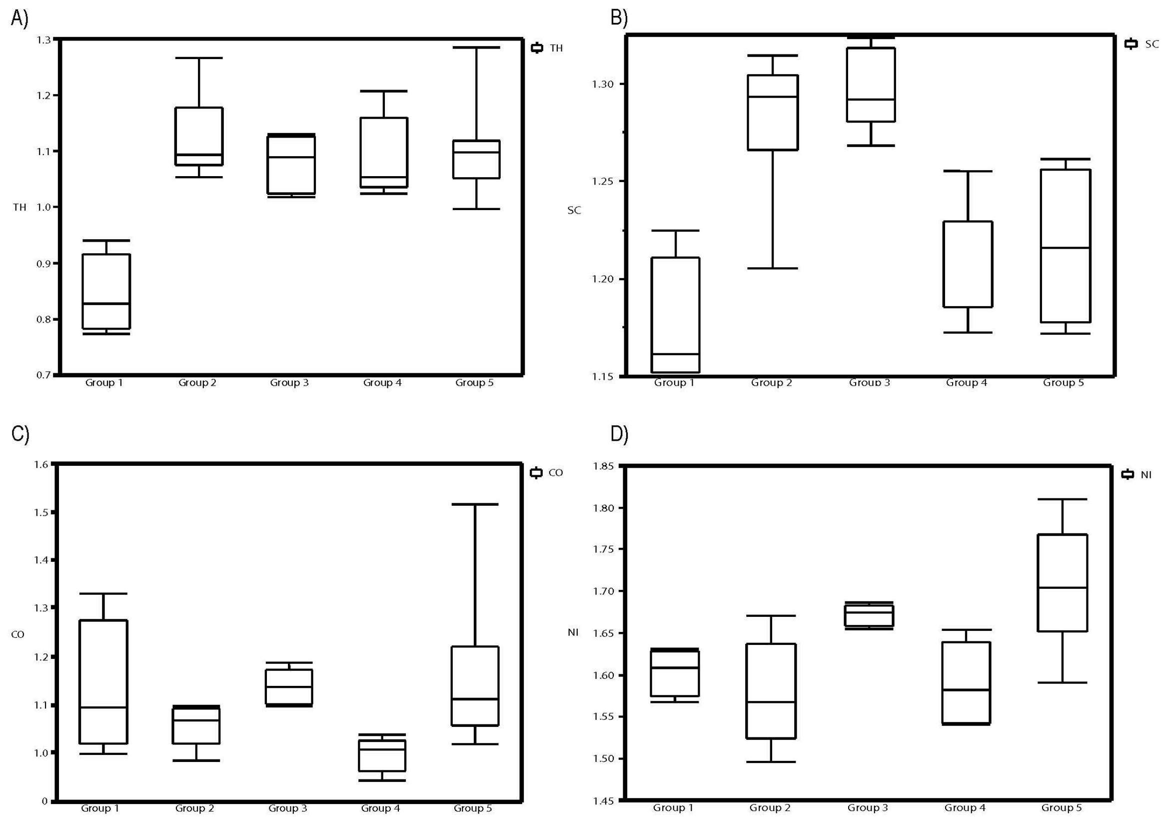

Figure 4: A) Box-and-whisker plot of log base-10 concentrations of thorium (Th) to highlight the variation in the ceramic groupings. Specifically, this element helps to distinguish Groups 1 from the remaining groups. B) Box-and-whisker plot of log base-10 concentrations of scandium (Sc) to highlight the variation in the ceramic groupings. Specifically, this element helps to distinguish Groups 2 and 3 from the other groups. C) Box-and-whisker plot of log base-10 concentrations of cobalt (Co) to highlight the variation in the ceramic groupings. Specifically, this element helps to distinguish Group 4 from the other groups. D) Box-and-whisker plot of log base-10 concentrations of nickel (Ni) to highlight the variation in the ceramic groupings. Specifically this element helps to distinguish Group 5 from the other groups.

these samples are presumed to represent pottery made at or near Berettyóújfalu-Herpály. Group 1 is characterized by lower concentrations of thorium (Th) and scandium (Sc) (Figure 4), iron (Fe), neodymium (Nd), and gadolinium (Gd), and higher concentrations of lithium (Li), beryllium (Be), boron (B), lanthanum (La), molybdenum (Mo), hafnium (Hf), and manganese (Mn) compared to the other groups.

Group 2 (n = 6) includes samples vm12, vm15, vm17, vm19, vm20, and vm21 from the site of Vésztő-Mágor (Table 2 and Figure 3). Though this group is compositionally more similar to Groups 3, 4, and 5 (which may be because these groups are all representative of material made at locations along the same river) than to Group 1, it appears more compositionally similar to Group 3 than to Groups 4 and 5. Compared to the other compositional groups, Group 2 can be distinguished by relatively higher concentrations of scandium (Sc) (Figure 4) and lower concentrations of lithium (Li), iron (Fe), and molybdenum (Mo). Based on the compositional analysis of the clays, it appears that the materials from Group 2 are representative of locally-produced ceramics from Vésztő-Mágor and this can be further illustrated in a bivariate plot of the clays and ceramics with nickel (Ni) and thorium (Th) (Figure 3).

Group 3 (n = 5) consists of vm22, vm23, vm26, vm29, and vm30 from the site of Vésztő-Mágor (Table 2 and Figure 3). This group is compositionally less similar to Groups 4 and 5 and shares similarities in distinguishing elements with Group 2, including scandium (Sc) (Figure 4), iron (Fe) molybdenum (Mo), and thorium (Th). However, Group 3 is distinctive from Group 2 due to higher concentrations of nickel (Ni) and cobalt (Co) (Figure 4). A clay match was not identified for this group.

Group 4 (n = 5) is comprised of ok1, ok4, ok7, ok11, and ok12 from the site of Öcsöd-Kováshalom (Table 2 and Figure 3). This group, while broadly compositionally similar to Groups 2, 3, 4, and 5, is most similar to Group 5. This patterning suggests that the location where Group 4 clay materials originated may be located near that of Group 5 (compositionally identified as Öcsöd-Kováshalom). Com-

Table 2: An abridged table of the oxide percent and parts-per-million (ppm) values of the elemental concentrations for ceramics. The main ceramic groupings identified within this study are shown and the elements used to identify the groupings are shaded in grey.

Groups	Sample ID	Mg	Li	Be	B	Sc	Mn	Fe	Ni	La	Ce	Pr	Mo	Nd	Sm	Gd	Hf	Th
1	bh4	7038.73	66.17	3.85	421.10	16.77	531.16	8496.91	41.95	24.58	64.18	6.73	1.29	23.92	5.41	4.86	14.97	8.67
1	bh5	10026.57	82.55	4.12	92.23	14.73	367.38	10169.70	42.76	21.60	50.96	5.53	0.99	18.45	3.68	2.99	2.00	5.94
1	bh6	7698.99	62.26	4.07	182.61	14.18	590.01	10011.05	39.16	22.19	48.52	5.76	3.37	20.61	4.47	4.13	13.28	6.40
1	bh7	7320.83	68.79	3.88	124.94	14.26	434.69	9238.76	37.00	24.64	54.23	6.46	1.60	22.50	5.08	4.00	15.47	7.05
2	vm12	7121.59	37.83	2.67	82.99	16.03	580.00	8687.36	36.97	25.97	51.34	6.57	0.45	23.87	5.33	5.67	17.01	11.31
2	vm15	6739.40	38.01	2.88	60.78	20.62	387.36	8771.98	31.28	28.75	58.42	7.15	0.48	24.67	5.09	4.39	16.93	12.41
2	vm17	6920.96	35.97	2.76	78.83	19.57	320.77	10243.79	34.20	35.82	74.21	9.01	0.76	31.29	6.32	5.37	4.47	14.04
2	vm19	7032.48	44.29	2.88	106.43	19.70	269.43	9031.77	42.30	27.45	57.08	7.09	0.78	24.40	5.17	4.54	9.66	12.30
2	vm20	7383.96	44.75	2.82	95.54	19.99	365.14	9982.57	37.06	29.02	56.79	7.18	0.60	24.70	5.00	4.53	11.48	12.08
2	vm21	7317.26	39.75	2.71	76.58	19.32	389.62	11062.70	46.83	50.32	104.03	12.66	0.79	43.48	8.69	7.53	3.01	18.46
3	vm22	7720.03	44.35	2.71	183.75	19.57	416.93	15045.87	48.48	22.16	45.48	5.63	0.53	19.39	4.30	4.02	20.51	10.44
3	vm23	7173.09	42.97	2.97	89.03	18.56	398.84	14319.87	45.86	22.73	47.51	6.01	0.60	21.28	4.70	4.17	8.66	10.63
3	vm26	7201.06	56.37	2.99	120.51	19.57	450.55	16445.27	47.27	33.62	63.98	8.11	0.96	28.01	5.84	5.09	5.50	12.26
3	vm29	7936.71	45.39	2.81	83.93	20.58	403.65	16183.32	47.89	39.49	74.56	9.49	0.71	32.96	6.74	6.01	23.71	13.25
3	vm30	8110.07	48.31	2.84	73.34	21.06	653.93	17781.39	45.22	30.99	60.85	7.57	0.81	26.67	5.71	5.31	8.23	13.53
4	ok1	6646.67	35.41	2.65	84.46	16.00	210.57	24258.32	34.73	44.56	90.06	10.43	0.57	37.64	7.10	5.06	4.15	16.15
4	ok4	7018.58	58.43	2.77	68.96	17.98	284.49	29668.47	45.13	27.98	54.37	7.03	0.61	25.71	5.65	6.49	14.75	11.17
4	ok7	7758.48	43.61	2.81	103.67	15.95	243.57	24975.76	41.94	34.22	77.47	9.20	0.70	33.27	7.26	6.05	3.02	12.93
4	ok11	7451.48	48.22	2.62	123.01	14.88	209.30	25848.66	38.12	32.60	70.06	8.49	0.56	30.76	6.40	5.12	3.75	10.56
4	ok12	6421.32	43.65	2.78	70.79	15.80	251.78	26482.68	34.96	33.11	69.99	8.36	0.52	29.78	5.84	4.94	9.33	11.33
5	bh12	9093.36	64.21	2.96	163.47	15.38	469.44	30145.34	53.50	26.99	52.56	6.73	1.49	23.71	5.27	5.66	13.51	9.94
5	ok10	8034.13	39.45	3.25	71.36	18.14	307.15	31282.19	39.08	31.92	71.70	8.30	1.10	29.63	6.15	4.99	4.92	12.62
5	ok14	9914.44	55.30	3.04	124.27	15.14	1287.65	28983.78	64.45	30.25	72.88	7.69	1.13	27.24	5.60	4.58	4.62	11.71
5	vm2	7653.48	47.94	3.26	106.49	15.02	324.67	30354.12	44.68	45.06	94.35	11.64	0.79	41.29	8.60	6.02	4.78	19.25
5	vm5	7941.14	45.34	3.23	158.85	17.74	536.15	32321.89	44.96	29.34	69.19	7.84	0.96	27.76	5.96	5.08	11.35	12.40
5	vm7	8889.85	53.85	3.35	101.81	18.26	330.19	30692.68	50.18	23.84	50.28	6.38	0.82	23.12	5.32	5.01	7.26	11.14
5	vm11	8628.47	56.84	3.36	95.89	17.55	1129.98	29485.94	60.26	27.66	62.48	7.16	1.57	25.74	5.36	4.71	3.09	13.06

pared with all the groups, Group 4 is characterized by higher concentrations of iron (Fe), cerium (Ce), samarium (Sm), and thorium (Th). It also has lower concentrations of cobalt (Co) (Figure 4), manganese (Mn), and molybdenum (Mo). A clay match was not identified for this group.

Group 5 (n = 7) is made up of samples bh12, vm2, vm5, vm7, vm11, vm26, ok10, and ok14 from the sites of Berettyóújfalu-Herpály, Vésztő-Mágor, and Öcsöd-Kováshalom (Table 2 and Figure 3). Based on the similarity of signatures between the clay collected from Öcsöd-Kováshalom and samples ok10 and ok14, the latter two sherds are representative of locally-produced materials, while the remaining "vm" and "bh" ceramics are presumed to have been produced at Öcsöd-Kováshalom and transported to Vésztő-Mágor and Berettyóújfalu-Herpály, where they were recovered during excavations. The materials from Group 5 are identified by higher concentrations of nickel (Ni) (Figure 4), magnesium (Mg), beryllium (Be), iron (Fe), molybdenum (Mo), and thorium (Th). Moreover, the geological clay data aids in identifying Group 5 as material from Öcsöd-Kováshalom (Figure 3).

5 Discussion

Based on the patterns identified in the preliminary ceramic elemental data thus far, we can offer a brief discussion regarding how this project can help researchers to infer trade and interaction on the Great Hungarian Plain during the Late Neolithic. Five main geochemical groupings were identified based on the ceramic materials. When the data from the ceramic analysis are plotted with the clay analysis data, Group 1 ceramics can be identified as material locally-produced at Berettyóújfalu-Herpály; Group 2 represents locally-made ceramics from Vésztő-Mágor; and Group 5 is representative of local ceramic material from Öcsöd-Kováshalom. The general similarity in compositional signatures between Groups 2 through 5 compared to Group 1 suggests that these ceramic materials are produced from clays found along the Körös River and its tributaries. The inclusion of additional clay samples from other Late Neolithic sites along the Körös Rivers would help to identify the places of production for materials from Groups 3 and 4.

Four of the seven samples that are compositionally representative of locally-made ceramics from Öcsöd-Kováshalom (Group 5) were recovered at Vésztő-Mágor, which may be indicative of some form of trade or exchange between Tisza sites in the period investigated. No ceramics from the Herpály compositional group have been identified in any of the Körös River basin groups. However, one ceramic collected from Berettyóújfalu-Herpály—bh12 (Group 5)—matches the local signature of materials (clay and ceramics) from the site of Öcsöd-Kováshalom, which suggests the occurrence of exchange between Tisza and Herpály sites during the Late Neolithic.

6 Conclusion

Based on the preliminary LA-ICP-MS analysis of ceramics and clays from three Late Neolithic sites, it appears possible to discern different elemental signatures for ceramics and clays from the Great Hungarian Plain on a micro-regional scale. While previous studies examined macro-regional variation, this study demonstrates that site-specific compositional signatures appear to be distinguishable across the Plain by focusing on the major, minor, and trace elements detected by LA-ICP-MS. One implication of these findings is that archaeologists should be able to begin reconstructing ancient exchange networks in the region and in turn, be able investigate interaction from an anthropological perspective. Specifically, a detailed model of Late Neolithic interactions can be created by increasing the ceramic sample size, including additional clay samples from the region, and adding more sites to the analysis. This method of analysis is not only applicable for materials from the Plain, but also can be adapted for research on ceramic materials and exchange around the world.

Furthermore, the results generated from this study also have implications for future geoscience research in Eastern Europe. Having identified a geochemical difference that appears to be related to different river ways, it is critical to expand this research to determine the source of the compositional variation. Investigations into the headwater sources for each of the rivers that traverse the Plain will help to elucidate the difference in elemental concentrations both at the source and across the Plain. In turn, this will generate a more nuanced understanding of the extent to which elemental concentrations change from the source to the Plain. Research of this nature is innovative, informative, and cross-disciplinary. As LA-ICP-MS becomes more affordable, the technique will increase in use and application for researchers in various disciplines around the world. In particular, this study has shown that by using LA-ICP-MS to analyze the compositional variation of ceramics and clays, researchers can begin to reconstruct prehistoric interaction – and thereby model the prehistoric human experience.

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Supplementary Materials

Table S1: Table listing geochemical group membership probabilities based on Mahalanobis distance calculations for the final core group of 27 ceramics using principal component 1 (accounting for 28.3% of the total variance) and principal component 2 (accounting for 15.37% of the total variance). Two main groups are noted, Herpály and Tisza, corresponding to the different waterways on which the sites are located.

Sample ID	Prob. in Groups 2, 3, 4, and 5	Prob. in Group 1
Samples in Geochemical Group 1 (Herpály)		
bh4	0.044	30.298
bh5	0.009	25.138
bh6	0.010	43.861
bh7	0.029	99.296
Samples in Geochemical Groups 2, 3, 4, and 5 (Tisza)		
bh12	13.748	4.482
ok1	48.739	4.179
ok10	55.441	1.810
ok11	91.081	2.248
ok12	75.507	2.026
ok14	7.574	2.091
ok4	23.714	1.640
ok7	48.036	1.655
vm11	5.261	2.395
vm12	8.325	4.284
vm15	46.560	4.192
vm17	96.285	2.260
vm19	62.707	3.589
vm2	89.447	2.272
vm20	71.802	3.516
vm21	2.234	1.292
vm22	14.703	6.154
vm23	60.035	2.979
vm26	96.603	2.723
vm29	60.994	1.901
vm30	38.378	1.561
vm5	70.995	1.951
vm7	66.418	3.143

Table S2: Table of oxide percent and parts-per-million (ppm) values for all elemental isotopes used in the analytical characterization of the ceramic and clay samples.

Field Museum ID	SiO_2	Na_2O	MgO	Al_2O_3	K_2O	CaO	Fe_2O_3	Oxides TiO	Li	Be	B	Na	Mg	Al
ok1	71.19%	0.97%	1.10%	17.30%	2.36%	1.25%	4.69%	0.65%	35.41	2.65	84.46	7218.79	6646.67	91578.50
ok2	72.84%	0.71%	1.11%	15.77%	2.10%	1.17%	5.01%	0.68%	37.50	2.33	75.23	5293.73	6676.60	83477.24
ok3	67.86%	0.83%	1.25%	16.94%	2.33%	2.12%	5.73%	0.84%	52.68	2.94	101.94	6137.87	7535.98	89664.59
ok4	66.88%	0.73%	1.16%	18.62%	2.09%	2.36%	5.74%	0.69%	58.43	2.77	68.96	5444.28	7018.58	98534.43
ok5	64.25%	0.65%	1.16%	18.45%	2.12%	2.59%	6.00%	0.92%	49.07	2.94	73.92	4810.93	6973.82	97626.77
ok6	67.87%	0.77%	1.24%	19.34%	2.51%	1.66%	5.36%	0.91%	35.83	2.49	60.29	5703.62	7459.86	102372.98
ok7	69.17%	0.93%	1.29%	18.47%	2.76%	1.32%	4.83%	0.78%	43.61	2.81	103.67	6888.44	7758.48	97757.17
ok8	66.09%	0.93%	1.48%	20.05%	2.67%	1.64%	5.63%	0.94%	46.52	2.80	76.62	6936.18	8898.10	106127.71
ok9	68.03%	1.02%	1.57%	18.53%	3.14%	1.19%	5.34%	0.73%	54.22	2.73	104.50	7593.97	9468.87	98080.12
ok10	67.00%	0.79%	1.33%	19.68%	2.40%	1.54%	6.05%	0.70%	39.45	3.25	71.36	5832.21	8034.13	104155.01
ok11	70.33%	1.00%	1.24%	17.19%	2.23%	1.89%	5.00%	0.66%	48.22	2.62	123.01	7449.37	7451.48	90957.18
ok12	69.32%	0.83%	1.06%	17.89%	2.16%	2.07%	5.12%	0.70%	43.65	2.78	70.79	6167.29	6421.32	94657.90
ok13	69.68%	0.80%	1.33%	18.18%	2.38%	1.00%	5.52%	0.61%	45.39	3.15	101.57	5934.11	8007.12	96208.95
ok14	69.35%	0.70%	1.64%	16.96%	2.48%	1.66%	5.61%	0.71%	55.30	3.04	124.27	5228.51	9914.44	89762.34
ok15	68.72%	1.35%	1.22%	19.12%	2.15%	1.09%	5.11%	0.89%	46.50	3.03	104.57	10022.29	7334.44	101195.43
ok16	67.92%	0.82%	1.78%	18.25%	2.35%	2.26%	5.41%	0.70%	53.16	3.49	54.48	6103.92	10712.25	96592.26
ok17	61.12%	0.74%	2.65%	16.29%	2.61%	10.06%	4.70%	0.77%	48.39	3.38	80.74	5519.50	15999.67	86228.02
bh1	73.74%	1.32%	1.16%	16.14%	1.73%	0.70%	4.26%	0.54%	56.15	3.49	67.51	9763.98	6974.31	85430.94
bh2	70.40%	0.67%	1.08%	19.53%	1.71%	0.92%	4.63%	0.65%	60.80	4.07	67.57	4981.14	6524.41	103352.24
bh3	73.13%	1.06%	1.09%	16.68%	2.08%	0.89%	3.93%	0.55%	42.84	4.17	71.72	7836.23	6571.69	88290.77
bh4	72.14%	1.30%	1.17%	18.51%	1.89%	0.60%	3.19%	0.73%	66.17	3.85	421.10	9624.95	7038.73	97984.32
bh5	71.27%	1.05%	1.66%	19.35%	1.54%	0.46%	3.81%	0.57%	82.55	4.12	92.23	7816.04	10026.57	102412.94
bh6	71.88%	1.16%	1.28%	17.75%	2.59%	0.73%	3.75%	0.41%	62.26	4.07	182.61	8592.61	7698.99	93949.57
bh7	71.87%	1.10%	1.21%	17.76%	1.94%	1.25%	3.47%	0.55%	68.79	3.88	124.94	8134.69	7320.83	94000.86
bh8	73.40%	1.04%	1.09%	16.36%	1.91%	0.94%	3.79%	0.77%	58.41	3.85	56.83	7702.36	6588.77	86573.81
bh9	71.37%	1.06%	1.54%	18.05%	1.94%	0.47%	4.58%	0.68%	50.03	2.69	156.19	7893.49	9311.08	95511.53
bh10	72.72%	0.85%	1.16%	14.59%	2.54%	0.93%	4.89%	0.77%	42.57	2.80	126.28	6297.72	7018.01	77212.19
bh11	72.06%	1.19%	1.28%	16.96%	2.10%	0.69%	4.45%	0.91%	45.19	3.37	87.41	8836.58	7742.16	89758.67
bh12	70.83%	0.92%	1.51%	17.14%	2.37%	0.70%	5.38%	0.70%	64.21	2.96	163.47	6845.78	9093.36	90716.16
vm1	64.59%	0.84%	1.30%	18.34%	2.16%	6.20%	5.15%	0.71%	36.56	2.91	101.59	6262.40	7825.83	97043.26
vm2	69.50%	0.93%	1.27%	17.44%	2.82%	0.99%	5.42%	0.67%	47.94	3.26	106.49	6891.79	7653.48	92296.21

Table S2: ... Continued

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Field Museum ID	SiO_2	Na_2O	MgO	Al_2O_3	K_2O	CaO	Fe_2O_3	Oxides TiO	Li	Be	B	Na	Mg	Al
vm3	69.41%	0.97%	1.41%	16.90%	2.06%	2.43%	5.03%	0.58%	44.51	2.82	90.57	7212.83	8510.64	89418.88
vm4	68.63%	1.07%	1.24%	18.81%	2.33%	1.58%	4.80%	0.89%	37.85	3.69	84.85	7925.66	7497.45	99576.82
vm5	66.62%	1.00%	1.32%	19.28%	2.80%	1.32%	5.77%	0.70%	45.34	3.23	158.85	7388.97	7941.14	102039.87
vm6	68.47%	0.85%	1.27%	19.39%	2.22%	1.54%	5.02%	0.77%	38.11	3.71	90.43	6337.01	7646.01	102633.43
vm7	67.38%	0.90%	1.47%	18.93%	2.45%	1.44%	5.85%	0.70%	53.85	3.35	101.81	6698.91	8889.85	100192.65
vm8	67.88%	0.87%	1.32%	18.20%	2.22%	2.42%	5.42%	0.58%	53.23	3.38	101.73	6423.39	7977.66	96330.61
vm9	68.80%	1.00%	1.21%	18.59%	1.93%	1.81%	5.08%	0.71%	43.78	3.95	73.13	7392.22	7315.84	98376.99
vm10	68.21%	0.83%	1.26%	19.77%	1.83%	1.61%	5.33%	0.67%	52.79	3.86	81.97	6181.55	7602.41	104636.45
vm11	66.84%	1.09%	1.43%	18.33%	2.64%	1.54%	5.62%	0.91%	56.84	3.36	95.89	8084.18	8628.47	97002.54
vm12	73.70%	0.73%	1.18%	16.02%	2.02%	1.15%	3.77%	0.82%	37.83	2.67	82.99	5387.65	7121.59	84791.77
vm13	71.77%	0.88%	1.33%	16.66%	2.27%	1.35%	3.89%	0.82%	51.17	2.76	81.51	6543.67	8037.37	88180.14
vm14	72.17%	0.79%	1.01%	17.78%	1.79%	1.22%	4.13%	0.52%	36.41	3.07	58.02	5868.15	6084.40	94098.14
vm15	71.37%	0.78%	1.12%	18.64%	1.88%	1.39%	3.81%	0.64%	38.01	2.88	60.78	5805.49	6739.40	98677.09
vm16	70.10%	0.91%	1.12%	18.01%	1.87%	1.56%	4.97%	0.71%	45.92	2.99	72.28	6765.55	6758.46	95344.63
vm17	69.22%	1.01%	1.15%	18.97%	2.24%	1.53%	4.44%	0.70%	35.97	2.76	78.83	7498.54	6920.96	100406.14
vm18	69.74%	0.94%	1.14%	18.70%	2.17%	2.01%	3.94%	0.74%	33.82	2.68	73.61	6953.20	6867.49	98984.77
vm19	69.58%	1.10%	1.17%	19.22%	2.56%	1.25%	3.92%	0.65%	44.29	2.88	106.43	8163.21	7032.48	101699.84
vm20	69.38%	1.02%	1.22%	19.20%	2.04%	1.72%	4.33%	0.59%	44.75	2.82	95.54	7553.28	7383.96	101594.07
vm21	68.19%	0.94%	1.21%	19.03%	2.45%	1.58%	4.80%	0.85%	39.75	2.71	76.58	6994.70	7317.26	100691.70
vm22	71.30%	0.86%	1.28%	17.41%	2.70%	1.07%	3.95%	0.70%	44.35	2.71	183.75	6352.87	7720.03	92125.16
vm23	69.60%	0.90%	1.19%	19.09%	2.69%	1.31%	3.76%	0.86%	42.97	2.97	89.03	6642.96	7173.09	101008.03
vm24	72.74%	0.78%	1.15%	17.35%	2.02%	1.41%	3.30%	0.74%	50.34	2.86	73.11	5753.56	6905.92	91843.73
vm25	71.30%	0.94%	1.32%	17.36%	2.08%	1.65%	3.89%	0.93%	40.40	2.53	63.64	6953.61	7941.85	91878.99
vm26	69.45%	0.98%	1.19%	18.60%	2.01%	1.92%	4.32%	0.73%	56.37	2.99	120.51	7290.46	7201.06	98424.37
vm27	69.44%	1.11%	1.13%	19.54%	2.04%	1.72%	3.79%	0.77%	45.74	2.73	61.29	8248.68	6839.20	103397.99
vm28	69.25%	0.94%	1.32%	19.41%	2.16%	1.69%	4.07%	0.69%	60.04	2.90	72.56	6973.38	7971.56	102705.75
vm29	67.94%	0.96%	1.32%	19.28%	2.95%	1.36%	4.25%	0.78%	45.39	2.81	83.93	7139.34	7936.71	102022.97
vm30	67.18%	0.88%	1.34%	19.46%	2.53%	1.81%	4.67%	1.01%	48.31	2.84	73.34	6529.06	8110.07	103004.40
s_ ok1	64.67%	0.89%	2.39%	16.29%	2.49%	5.93%	6.03%	0.87%	57.01	2.72	79.66	6603.71	14409.90	86208.41
s_ ok2	60.20%	0.74%	2.37%	16.00%	2.61%	9.92%	6.16%	0.87%	60.38	2.52	115.31	5511.31	14291.19	84674.52
s_ ok3	55.38%	1.22%	4.06%	15.39%	2.31%	15.11%	5.17%	0.80%	53.02	2.57	87.76	9064.93	24489.36	81435.37
s_ ok4	67.25%	0.94%	2.18%	17.76%	2.49%	1.26%	6.65%	1.07%	62.45	3.31	122.00	6993.66	13131.89	93998.94
s_ bh1	73.70%	1.08%	1.51%	12.70%	1.94%	3.24%	4.60%	0.82%	44.85	1.88	49.39	8038.50	9106.41	67198.54

Table S2: ... Continued

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Field								Oxides						
Museum ID	**SiO_2**	**Na_2O**	**MgO**	**Al_2O_3**	**K_2O**	**CaO**	**Fe_2O_3**	**TiO**	**Li**	**Be**	**B**	**Na**	**Mg**	**Al**
s_ bh2	73.15%	1.07%	1.48%	15.17%	1.95%	0.95%	4.91%	1.08%	43.12	2.25	72.72	7917.77	8916.80	80298.93
s_ bh3	72.12%	1.33%	1.62%	14.52%	2.43%	1.39%	4.54%	1.64%	44.46	2.37	119.36	9894.41	9743.44	76830.18
s_ bh4	72.89%	1.15%	1.55%	14.97%	2.27%	1.01%	5.00%	0.71%	48.60	2.19	72.17	8532.82	9357.22	79208.32
s_ vm1	68.64%	0.69%	1.58%	20.42%	2.31%	1.53%	3.75%	0.90%	54.27	3.28	60.34	5111.65	9537.43	108071.76
s_ vm2	73.44%	1.34%	1.26%	14.54%	2.05%	1.69%	3.51%	1.68%	37.14	2.41	44.46	9957.20	7578.27	76937.24
s_ vm3	75.09%	1.52%	1.11%	14.86%	1.66%	1.80%	3.04%	0.76%	41.87	3.56	48.94	11310.88	6683.96	78655.95
s_ vm4	70.61%	0.67%	1.61%	17.52%	2.62%	1.59%	3.99%	1.02%	50.97	3.09	103.14	4933.34	9712.11	92723.92
Parts-per-Million (ppm)														
Si	**K**	**Ca**	**Sc**	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Rb**	**Sr**
332757.59	19611.95	8954.47	16.00	2824.19	117.11	100.17	210.57	24258.32	8.78	34.73	30.31	109.89	130.87	117.06
340470.70	17439.32	8346.73	15.16	2938.72	117.76	95.18	269.66	25893.54	10.12	32.68	41.05	131.21	125.18	126.47
317227.24	19334.34	15179.02	15.34	3637.78	141.47	105.57	747.50	29620.08	11.56	45.74	68.59	138.20	115.81	209.58
312628.76	17338.14	16840.46	17.98	2990.79	149.53	115.01	284.49	29668.47	9.57	45.13	39.41	165.79	123.47	199.45
300346.32	17596.68	18489.50	16.87	3972.96	141.81	113.66	515.67	31028.64	15.36	53.11	46.63	140.17	112.25	310.31
317249.27	20826.74	11841.97	20.05	3928.38	152.08	125.96	239.26	27708.33	11.14	35.48	35.52	122.82	175.41	117.85
323334.38	22948.02	9412.15	15.95	3376.34	136.22	108.97	243.57	24975.76	10.36	41.94	44.13	175.75	157.76	112.57
308928.85	22151.69	11751.19	18.71	4076.42	145.54	116.03	392.64	29104.43	12.77	40.42	36.90	149.32	173.60	122.54
317995.48	26045.64	8535.35	15.86	3150.40	140.57	108.85	264.74	27632.49	11.18	45.96	49.02	158.98	160.66	113.49
313183.10	19895.60	11010.98	18.14	3041.27	148.18	154.47	307.15	31282.19	12.67	39.08	30.74	131.40	173.43	121.84
328750.79	18482.43	13482.42	14.88	2867.16	116.51	97.10	209.30	25848.66	10.17	38.12	40.66	117.50	133.68	151.93
324026.68	17900.45	14803.51	15.80	3032.25	133.53	103.89	251.78	26482.68	10.90	34.96	33.50	128.55	147.66	202.26
325703.14	19731.67	7168.43	14.85	2644.73	112.09	187.41	574.63	28563.15	12.90	50.75	44.36	148.64	133.68	121.23
324181.25	20561.39	11887.54	15.14	3051.98	138.17	104.07	1287.65	28983.78	16.57	64.45	45.96	141.75	139.19	180.23
321234.18	17811.50	7788.72	16.16	3850.15	122.08	105.66	258.60	26421.85	10.11	44.61	44.37	128.61	146.27	133.41
317483.62	19479.61	16137.90	20.52	2046.68	136.50	136.45	492.83	14428.05	18.80	66.52	34.78	137.86	164.37	123.32
285684.77	21689.00	71923.07	19.21	2266.18	150.46	114.54	3640.14	12542.79	49.01	90.94	30.78	165.46	139.86	261.69
344675.46	14370.08	5026.98	16.88	1581.99	123.29	100.40	572.49	11364.16	13.84	47.04	23.37	108.71	115.69	88.28
329076.66	14225.71	6565.56	20.06	1901.32	155.17	116.97	600.62	12352.68	17.61	53.88	24.58	116.03	152.93	95.72
341844.64	17301.04	6346.51	17.20	1623.17	134.00	97.92	492.21	10466.98	14.03	53.88	40.16	103.02	133.12	119.69
337199.01	15657.97	4270.81	16.77	2161.43	112.73	89.66	531.16	8496.91	21.38	41.95	20.34	86.80	98.57	76.90
333140.61	12786.64	3259.05	14.73	1669.78	126.06	116.34	367.38	10169.70	12.88	42.76	20.72	101.10	124.91	78.87
336008.99	21487.12	5245.66	14.18	1205.42	104.80	131.03	590.01	10011.05	11.98	39.16	16.72	89.91	110.97	93.32

Table S2: … Continued

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Parts-per-Million (ppm)														
Si	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Rb	Sr
335958.60	16105.05	8953.62	14.26	1606.58	112.81	82.73	434.69	9238.76	9.96	37.00	20.08	99.52	107.38	85.85
343121.54	15825.93	6745.96	13.54	2278.79	118.74	75.58	753.73	10096.14	12.45	40.83	18.96	96.48	106.04	80.19
333612.15	16106.85	3380.64	16.03	3009.93	133.07	144.01	295.53	25639.86	12.64	48.43	23.42	113.25	133.88	100.55
339941.88	21119.45	6615.11	13.88	3402.28	114.25	87.92	1319.12	27388.40	17.23	52.16	24.36	121.38	109.15	159.63
336838.23	17422.62	4908.63	14.79	4017.50	136.99	375.75	266.49	24928.80	9.10	41.11	87.09	107.33	130.88	95.08
331064.70	19656.68	5037.32	15.38	3084.90	135.04	103.89	469.44	30145.34	12.94	53.50	33.79	127.83	130.66	76.47
301940.99	17962.81	44303.47	17.15	3151.64	134.29	98.35	339.87	28847.91	12.74	42.45	65.76	136.68	141.87	146.10
324889.80	23435.36	7068.38	15.02	2962.28	116.82	138.22	324.67	30354.12	10.43	44.68	35.04	131.26	139.30	111.19
324473.24	17097.40	17382.05	15.12	2582.44	124.29	110.74	502.99	28165.90	17.79	36.28	25.43	157.89	125.83	144.39
320824.55	19370.33	11327.92	17.39	3931.38	127.37	106.17	505.74	26884.98	13.48	32.46	24.85	133.30	160.00	112.54
311427.95	23281.34	9443.15	17.74	3112.81	148.96	123.06	536.15	32321.89	16.72	44.96	43.70	155.82	145.85	130.25
320033.17	18422.01	11040.34	18.12	3427.05	135.15	99.87	398.41	28110.52	13.99	37.98	24.05	131.04	156.71	115.23
314966.04	20372.08	10305.96	18.26	3221.56	141.04	100.46	330.19	30692.68	11.04	50.18	34.19	137.90	130.55	119.03
317279.12	18456.13	17316.59	17.85	2689.50	126.24	102.26	526.52	28429.24	13.25	42.96	33.74	159.50	151.15	151.93
321593.68	16012.70	12954.94	18.19	3285.32	125.90	97.99	411.95	26630.87	10.76	34.77	22.99	123.48	153.69	129.22
318853.43	15214.53	11484.54	18.78	3088.13	136.22	115.66	296.92	27965.28	11.17	39.18	26.64	122.38	157.43	114.92
312425.53	21946.43	11021.76	17.55	4200.95	137.76	115.75	1129.98	29485.94	32.82	60.26	29.61	141.78	127.25	154.62
344523.92	16740.04	8212.75	16.03	2934.45	123.60	201.36	580.00	8687.36	9.63	36.97	21.89	121.98	134.50	102.91
335477.02	18845.24	9658.99	18.52	2926.47	133.99	96.80	233.31	8972.01	10.92	41.56	35.33	154.63	131.55	114.24
337365.40	14894.23	8752.56	16.28	1847.47	123.30	139.29	295.73	9520.20	11.01	32.86	29.51	127.04	130.42	105.71
333608.35	15585.75	9899.73	20.62	2271.72	127.68	105.77	387.36	8771.98	10.73	31.28	28.85	119.60	162.00	102.36
327690.39	15496.79	11146.51	17.53	2542.01	150.04	174.67	368.21	11456.20	12.75	46.08	23.85	157.37	129.81	120.88
323564.33	18636.63	10911.33	19.57	2495.24	147.04	111.50	320.77	10243.79	12.50	34.20	29.45	122.28	162.86	128.68
325976.63	18003.59	14391.84	19.98	2640.00	135.89	106.09	517.87	9079.39	13.60	37.11	21.54	126.73	166.86	126.38
325252.17	21270.50	8944.01	19.70	2326.76	147.09	110.16	269.43	9031.77	11.41	42.30	28.51	120.71	144.62	126.66
324322.64	16966.83	12264.14	19.99	2107.18	140.56	129.16	365.14	9982.57	11.89	37.06	27.01	120.94	165.37	128.12
318748.95	20341.23	11292.94	19.32	3051.38	143.80	116.39	389.62	11062.70	12.31	46.83	30.15	151.75	160.57	142.03
333295.91	22416.34	7676.82	19.57	2994.24	134.98	96.87	416.93	15045.87	14.43	48.48	28.36	171.44	130.25	122.92
325348.03	22335.45	9360.09	18.56	3690.84	141.44	128.24	398.84	14319.87	13.73	45.86	41.56	153.39	150.76	115.76
340031.96	16762.08	10074.23	17.21	3191.43	121.84	95.69	236.35	12567.05	9.95	39.98	24.68	120.37	164.15	116.87
333269.06	17291.04	11795.82	19.63	3997.45	136.43	98.24	840.82	14825.67	26.98	46.11	22.95	118.42	148.00	133.36
324655.80	16716.70	13707.67	19.57	3158.21	153.25	187.31	450.55	16445.27	12.57	47.27	33.60	138.95	157.45	138.36
324586.98	16897.12	12279.34	19.72	3334.43	141.48	108.30	403.35	14425.15	13.90	36.17	31.04	127.15	177.03	136.56

Table S2: ... Continued

Continued on the next page

Parts-per-Million (ppm)														
Si	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Rb	Sr
323709.35	17940.19	12085.23	23.17	2978.08	144.76	114.57	406.60	15512.72	12.64	51.60	37.90	121.41	166.34	118.66
317556.71	24459.73	9745.39	20.58	3375.50	155.30	110.51	403.65	16183.32	12.78	47.89	30.08	164.97	149.76	172.72
314019.67	20966.93	12949.99	21.06	4353.47	159.97	121.80	653.93	17781.39	15.39	45.22	30.16	132.29	157.77	173.62
302292.63	20708.78	42403.13	15.64	5004.10	129.82	94.08	691.69	37326.22	15.03	55.43	39.23	107.19	147.61	130.30
281386.23	21654.10	70893.04	16.23	4998.06	130.76	94.18	727.70	38079.32	14.73	54.60	44.51	151.19	151.88	197.54
258861.68	19186.94	108006.84	14.23	4590.77	119.59	86.37	745.62	31999.13	14.59	50.20	27.02	88.01	136.05	338.24
314366.38	20694.79	8999.79	15.79	6158.04	132.42	109.61	593.16	41140.24	13.90	58.22	37.98	120.89	154.69	103.01
344500.06	16070.58	23141.74	12.10	4751.70	95.14	203.87	471.72	28476.17	11.38	39.92	23.36	86.47	102.50	112.49
341912.47	16175.75	6800.85	15.21	6200.03	106.29	88.17	368.12	30354.64	13.13	41.40	25.33	100.17	120.07	82.72
337126.47	20171.22	9953.16	12.13	9456.95	105.67	130.02	743.06	28097.35	14.68	39.16	33.65	106.40	112.33	113.42
340740.39	18869.20	7197.35	13.53	4111.84	110.08	135.02	327.51	30938.68	8.34	34.35	27.74	91.14	124.48	89.92
320862.29	19196.21	10940.60	19.19	5253.33	136.49	123.89	180.75	6077.69	10.43	46.32	47.44	175.37	170.98	120.18
343302.10	17026.97	12047.99	14.19	9826.92	111.21	86.26	182.11	5701.86	10.24	35.68	25.61	105.56	115.97	120.15
350996.64	13739.74	12884.95	11.44	4462.93	85.77	65.73	238.46	4935.64	9.61	33.59	23.73	96.52	105.88	153.25
330054.78	21755.22	11342.04	17.94	5957.37	135.66	101.85	312.21	6475.92	15.70	50.48	59.22	221.53	183.66	115.67
Parts-per-Million (ppm)														
Y	**Zr**	**Nb**	**Sn**	**Sb**	**Cs**	**Ba**	**La**	**Ce**	**Pr**	**Nd**	**Sm**	**Eu**	**Gd**	**Tb**
21.90	147.81	16.88	2.83	0.59	5.94	452.89	44.56	90.06	10.43	37.64	7.10	1.38	5.06	0.67
74.56	266.40	18.34	3.25	0.81	6.24	406.56	62.75	137.44	16.61	61.17	12.48	1.83	10.21	1.68
21.17	100.54	22.59	3.23	0.79	5.84	886.95	27.43	56.33	6.96	25.56	5.31	1.16	4.13	0.61
49.45	467.58	20.89	3.46	0.70	6.29	1034.19	27.98	54.37	7.03	25.71	5.65	1.39	6.49	1.24
25.30	83.14	28.05	3.75	0.97	5.68	1685.06	30.52	62.36	7.98	30.10	6.23	1.35	5.31	0.78
31.42	142.74	27.60	3.34	0.81	8.93	482.15	55.62	106.93	13.68	50.30	9.79	1.77	7.68	1.02
32.38	100.58	20.96	3.50	0.89	7.91	490.48	34.22	77.47	9.20	33.27	7.26	1.39	6.05	0.92
68.19	404.58	21.75	7.18	0.84	8.89	603.31	34.62	77.75	9.15	33.71	7.37	1.69	7.54	1.31
17.28	120.10	20.24	3.70	0.72	8.20	525.18	27.56	60.64	7.09	24.75	4.95	1.10	3.81	0.54
24.55	162.66	20.10	3.68	0.86	9.32	517.38	31.92	71.70	8.30	29.63	6.15	1.43	4.99	0.78
30.91	109.85	20.14	3.88	0.97	7.40	600.62	32.60	70.06	8.49	30.76	6.40	1.34	5.12	0.78
21.80	301.73	19.13	3.61	0.94	7.28	912.27	33.11	69.99	8.36	29.78	5.84	1.33	4.94	0.72
26.34	357.39	16.81	3.55	0.78	7.55	598.56	33.43	76.61	9.05	31.91	6.50	1.36	5.44	0.84
20.25	148.61	20.05	3.84	1.01	8.08	673.17	30.25	72.88	7.69	27.24	5.60	1.24	4.58	0.67
264.96	260.15	23.35	4.11	0.75	7.88	647.47	43.27	95.42	10.59	37.38	8.65	2.33	17.65	4.43

Table S2: … Continued

Continued on the next page

Parts-per-Million (ppm)

Y	Zr	Nb	Sn	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb
33.06	87.30	22.77	3.43	2.58	10.03	447.51	44.75	98.23	11.45	40.21	7.96	1.67	6.43	0.96
31.15	284.38	30.48	3.06	1.31	8.28	959.63	36.05	76.25	9.19	32.58	6.57	1.48	5.69	0.90
29.27	410.42	16.63	2.69	0.91	6.89	415.22	26.34	53.31	6.78	24.15	5.34	1.21	4.94	0.82
34.95	87.13	21.43	3.30	0.95	10.18	570.67	35.40	80.77	9.21	33.73	7.07	1.63	6.75	1.03
21.97	412.99	18.56	2.73	0.75	7.08	501.73	36.06	81.47	9.52	32.67	6.59	1.34	4.95	0.68
36.82	570.62	18.17	2.12	0.66	4.99	443.83	24.58	64.18	6.73	23.92	5.41	1.17	4.86	0.80
14.11	75.23	17.34	2.41	0.74	6.91	348.32	21.60	50.96	5.53	18.45	3.68	0.77	2.99	0.41
29.80	544.57	12.87	1.99	1.04	5.89	427.68	22.19	48.52	5.76	20.61	4.47	0.94	4.13	0.70
22.66	778.69	15.64	2.22	0.87	5.33	380.13	24.64	54.23	6.46	22.50	5.08	0.87	4.00	0.61
19.30	155.94	59.00	2.51	0.70	5.09	365.75	21.82	51.59	5.93	20.94	4.37	0.97	3.52	0.51
22.15	165.06	18.94	3.11	1.65	7.69	444.58	25.84	55.65	6.58	22.58	4.91	1.02	4.39	0.66
16.70	120.17	21.56	2.78	0.72	5.11	644.25	27.78	65.79	7.71	27.09	5.65	1.21	4.23	0.56
29.68	75.98	21.83	2.77	0.66	6.12	531.17	121.43	255.21	29.48	101.97	19.99	3.67	14.74	1.66
48.31	289.26	19.96	2.98	0.95	6.32	469.67	26.99	52.56	6.73	23.71	5.27	1.12	5.66	1.03
20.52	115.56	18.58	3.78	0.90	7.86	621.79	28.16	60.80	7.21	25.27	5.37	1.23	4.66	0.68
23.82	145.50	20.89	3.13	0.87	7.10	492.18	45.06	94.35	11.64	41.29	8.60	1.48	6.02	0.78
19.59	84.85	15.87	2.88	0.70	7.11	434.80	20.57	45.03	5.27	18.77	3.99	0.93	3.63	0.55
197.57	111.97	30.38	3.81	0.93	8.32	471.97	166.43	357.34	41.10	141.44	28.59	4.78	28.11	4.54
26.22	448.17	19.10	3.73	1.28	8.68	475.18	29.34	69.19	7.84	27.76	5.96	1.28	5.08	0.78
26.81	499.60	21.28	3.23	0.74	8.84	478.24	31.60	68.14	8.02	28.59	5.84	1.20	5.22	0.81
29.25	267.34	17.04	3.14	1.04	6.95	528.48	23.84	50.28	6.38	23.12	5.32	1.21	5.01	0.79
82.40	243.25	16.77	2.85	0.95	8.32	480.67	27.99	58.43	7.57	27.30	6.57	1.72	9.85	1.89
21.29	101.27	20.77	3.55	1.22	8.50	469.67	25.07	59.66	6.44	24.26	5.32	1.14	4.40	0.66
32.86	113.97	19.51	3.58	0.93	9.16	497.36	56.71	114.78	14.66	52.88	10.64	1.43	8.79	1.20
19.50	104.92	21.18	3.17	0.92	6.73	545.46	27.66	62.48	7.16	25.74	5.36	1.08	4.71	0.66
38.95	617.95	23.70	3.13	0.76	6.20	434.74	25.97	51.34	6.57	23.87	5.33	1.33	5.67	0.99
41.31	411.54	34.00	2.77	0.74	6.52	397.44	25.30	50.52	6.35	22.08	4.53	1.07	4.81	0.90
28.19	115.95	18.72	2.70	0.68	7.21	399.19	32.76	63.65	8.09	27.98	5.74	1.22	5.24	0.86
25.22	633.43	21.09	3.09	0.73	8.52	419.22	28.75	58.42	7.15	24.67	5.09	1.12	4.39	0.67
37.61	107.95	19.43	3.13	0.93	7.42	475.69	81.18	164.87	20.33	70.37	14.18	2.89	12.61	1.67
25.58	140.49	19.48	3.42	0.91	8.93	473.34	35.82	74.21	9.01	31.29	6.32	1.35	5.37	0.82
339.77	403.56	19.44	3.19	0.81	8.47	496.24	36.25	78.51	9.34	34.52	13.16	2.62	31.26	7.75
23.34	332.25	17.95	3.29	0.82	7.88	452.84	27.45	57.08	7.09	24.40	5.17	1.15	4.54	0.70

Table S2: ... Continued

Continued on the next page

Parts-per-Million (ppm)														
Y	Zr	Nb	Sn	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb
26.02	390.52	16.52	3.24	0.87	9.40	463.58	29.02	56.79	7.18	24.70	5.00	1.21	4.53	0.71
39.30	103.83	22.73	3.24	0.82	8.66	553.31	50.32	104.03	12.66	43.48	8.69	1.34	7.53	1.19
28.50	704.28	16.10	2.79	0.74	6.12	468.55	22.16	45.48	5.63	19.39	4.30	1.00	4.02	0.69
27.43	346.97	19.88	3.15	0.79	8.05	448.63	22.73	47.51	6.01	21.28	4.70	1.07	4.17	0.69
27.14	100.93	22.27	3.31	0.78	8.24	430.22	32.82	65.28	8.19	28.62	5.87	1.23	4.97	0.77
45.95	999.74	20.31	2.92	1.22	7.21	491.99	94.06	279.84	38.05	142.58	28.33	5.00	15.54	1.72
27.81	222.15	18.33	3.17	0.96	8.29	493.01	33.62	63.98	8.11	28.01	5.84	1.31	5.09	0.79
72.67	119.36	19.87	3.26	0.85	8.99	506.61	36.09	78.63	9.21	32.34	7.50	1.72	8.93	1.73
33.51	2809.92	17.50	3.12	1.16	8.71	491.15	32.01	60.72	7.84	27.28	5.75	1.28	5.35	0.87
34.74	813.73	21.13	3.15	0.77	6.92	567.94	39.49	74.56	9.49	32.96	6.74	1.47	6.01	0.96
34.62	313.31	25.80	3.36	0.96	8.00	607.29	30.99	60.85	7.57	26.67	5.71	1.37	5.31	0.91
22.21	93.84	18.80	3.36	1.49	8.89	426.62	31.51	65.12	7.84	28.37	5.76	1.27	4.67	0.72
38.86	515.78	17.09	3.13	1.42	9.21	477.52	148.32	324.18	40.54	142.25	29.75	1.52	18.53	2.02
20.01	83.83	15.76	3.15	1.14	7.66	458.55	37.79	62.84	9.10	32.99	6.45	1.37	5.24	0.74
27.48	86.75	18.33	3.81	1.19	9.66	458.92	32.41	58.17	8.29	30.32	6.64	1.42	6.18	0.93
20.95	113.33	15.72	2.27	0.73	4.84	373.37	23.50	42.41	5.34	18.69	3.82	0.87	3.54	0.56
33.31	1871.92	21.25	2.82	0.86	6.09	427.77	28.70	57.04	7.10	26.11	5.61	1.23	5.00	0.84
16.66	111.05	24.54	2.71	0.66	5.69	399.06	23.38	50.70	6.03	21.23	4.57	1.08	3.77	0.56
23.10	98.71	16.99	2.73	0.83	6.42	388.43	25.33	50.25	6.63	24.57	5.42	1.16	4.89	0.76
77.78	124.27	21.54	4.24	1.10	10.65	488.28	41.71	82.71	10.58	33.25	7.59	1.85	9.86	2.00
34.48	284.23	31.32	3.21	1.16	6.51	440.91	49.05	101.60	12.71	40.60	8.14	1.73	6.63	1.04
25.17	218.54	17.47	3.34	1.29	6.48	355.89	27.05	57.39	6.99	22.20	4.53	1.14	4.00	0.71
30.65	96.99	21.71	4.59	1.32	10.53	522.66	97.78	198.40	26.03	84.22	16.05	2.38	10.32	1.35

Parts-per-Million (ppm)												
Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Mo	Pb	Th	U
3.78	0.75	2.01	0.29	2.08	0.32	4.15	1.16	1.71	0.57	21.08	16.15	2.12
12.03	2.76	6.90	0.95	7.20	0.98	8.11	1.24	2.01	0.84	23.25	21.91	6.65
3.77	0.72	2.07	0.29	2.01	0.30	3.03	1.95	1.99	0.79	25.04	10.50	2.34
8.27	1.77	5.09	0.75	5.34	0.83	14.75	1.41	2.32	0.61	25.03	11.17	3.98
4.77	0.95	2.55	0.34	2.44	0.34	2.59	1.97	3.75	1.34	37.55	11.93	2.79
6.03	1.14	2.89	0.41	2.65	0.39	4.02	1.56	3.50	0.62	27.87	20.76	4.25
5.71	1.20	3.42	0.47	3.29	0.46	3.02	1.46	2.41	0.70	31.66	12.93	2.85

Table S2: … Continued

Continued on the next page

9.86	2.36	7.04	1.06	7.15	1.05	12.64	1.59	2.60	0.91	29.29	12.32	4.72

Parts-per-Million (ppm)												
Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Mo	Pb	Th	U
3.23	0.64	1.82	0.28	2.07	0.31	3.86	1.52	2.22	1.24	25.39	8.91	2.07
4.70	0.92	2.56	0.37	2.69	0.39	4.92	1.40	2.32	1.10	31.36	12.62	3.08
4.89	1.06	3.17	0.51	3.48	0.54	3.75	1.90	2.24	0.56	28.16	10.56	3.94
4.47	0.90	2.61	0.40	2.88	0.44	9.33	1.39	2.30	0.52	30.79	11.33	3.29
5.35	1.07	3.10	0.44	3.18	0.49	9.11	1.33	2.06	0.55	27.47	13.22	3.91
4.23	0.84	2.34	0.34	2.33	0.37	4.62	1.49	2.37	1.13	31.03	11.71	2.79
37.19	9.39	28.10	3.93	25.68	3.38	8.73	1.87	3.01	0.46	32.99	23.63	3.68
6.05	1.23	3.61	0.49	3.58	0.55	3.05	1.84	2.65	0.54	30.43	17.90	4.04
5.42	1.12	3.08	0.44	3.34	0.50	9.83	2.90	4.90	8.30	39.37	14.16	5.68
5.29	1.08	3.12	0.47	3.50	0.56	13.53	1.54	1.98	1.01	31.81	11.81	3.39
6.84	1.31	3.46	0.50	3.52	0.50	3.17	1.88	2.52	1.87	37.25	13.59	4.06
4.03	0.82	2.54	0.43	3.46	0.58	14.04	1.51	2.28	1.06	27.25	12.45	6.38
5.47	1.18	3.58	0.56	4.18	0.66	14.97	1.04	1.47	1.29	17.51	8.67	3.47
2.52	0.50	1.39	0.21	1.42	0.21	2.00	1.02	1.66	0.99	16.89	5.94	1.41
4.61	1.00	2.83	0.43	2.94	0.42	13.28	0.73	1.37	3.37	17.27	6.40	2.25
3.91	0.80	2.38	0.36	2.65	0.38	15.47	0.95	1.29	1.60	13.79	7.05	1.91
3.32	0.66	1.81	0.27	1.84	0.28	3.81	3.10	1.95	2.09	16.08	5.66	1.52
4.17	0.78	2.29	0.33	2.13	0.35	5.08	1.34	2.09	0.75	19.32	9.79	2.99
3.24	0.61	1.71	0.25	1.63	0.27	3.62	1.32	2.88	3.96	20.93	9.64	2.90
7.08	1.15	2.99	0.43	2.83	0.40	2.07	1.60	3.14	0.89	17.04	44.39	6.60
7.89	1.65	5.13	0.78	5.20	0.73	13.51	1.62	1.81	1.49	19.99	9.94	3.72
4.00	0.81	2.15	0.31	2.10	0.32	3.58	1.30	2.12	0.49	30.99	11.47	3.18
4.35	0.87	2.42	0.35	2.70	0.38	4.78	1.46	2.11	0.79	27.89	19.25	2.92
3.51	0.69	2.07	0.29	1.97	0.29	2.39	1.06	1.84	0.33	22.02	8.76	2.80
31.54	6.98	21.18	3.26	24.61	3.67	2.96	2.82	2.56	0.39	28.39	44.91	9.60
4.88	1.02	2.90	0.44	3.06	0.51	11.35	1.30	2.52	0.96	30.66	12.40	5.02
4.82	0.97	2.76	0.43	3.00	0.49	15.30	1.40	2.21	0.40	26.69	13.38	5.06
5.16	1.07	3.02	0.40	2.92	0.42	7.26	1.26	1.91	0.82	24.45	11.14	3.42
14.25	2.94	8.57	1.24	8.07	1.11	6.56	1.19	2.08	1.09	26.18	12.77	4.62
3.92	0.82	2.33	0.31	2.33	0.33	2.98	1.37	2.04	0.54	39.04	11.66	3.26
6.53	1.26	3.37	0.46	3.03	0.45	3.54	1.42	2.31	0.46	29.37	28.05	5.09
4.00	0.77	2.13	0.28	2.07	0.32	3.09	1.48	2.67	1.57	26.99	13.06	5.35

Table S2: ... Continued

Continued on the next page

Parts-per-Million (ppm)

Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Mo	Pb	Th	U
6.47	1.40	4.05	0.60	4.25	0.65	17.01	1.74	2.19	0.45	17.29	11.31	4.22
6.25	1.47	4.46	0.70	4.66	0.70	10.80	2.20	1.75	0.44	19.79	10.39	3.89
5.08	1.02	2.70	0.38	2.60	0.39	3.19	1.23	1.58	0.64	30.56	12.42	3.07
4.23	0.88	2.50	0.39	3.02	0.51	16.93	1.26	1.99	0.48	23.40	12.41	4.58
7.98	1.38	3.48	0.47	3.14	0.45	3.01	1.24	2.11	0.99	31.73	34.13	4.01
4.75	0.95	2.52	0.37	2.55	0.39	4.47	1.27	2.28	0.76	26.62	14.04	4.07
57.86	11.29	29.18	4.37	23.65	3.20	12.92	1.15	2.35	0.61	28.31	16.21	5.50
4.18	0.86	2.39	0.36	2.55	0.42	9.66	1.25	2.07	0.78	30.41	12.30	3.84
4.46	0.93	2.67	0.41	3.12	0.53	11.48	1.06	2.24	0.60	27.25	12.08	4.55
7.27	1.52	3.95	0.57	3.84	0.56	3.01	1.86	2.22	0.79	26.96	18.46	4.21
4.53	1.02	3.12	0.53	3.74	0.64	20.51	1.14	1.75	0.53	19.93	10.44	4.84
4.68	0.98	2.71	0.44	2.72	0.43	8.66	1.39	1.98	0.60	24.25	10.63	3.22
4.73	0.97	2.56	0.37	2.38	0.35	2.86	1.30	2.59	0.52	26.99	12.36	2.69
8.49	1.60	4.33	0.66	4.61	0.77	23.19	1.40	1.89	0.47	22.58	16.74	3.97
4.81	1.00	2.73	0.41	2.82	0.43	5.50	1.23	1.87	0.96	24.40	12.26	3.20
11.78	2.58	6.81	0.93	5.57	0.79	3.33	1.46	2.39	0.47	29.11	13.32	4.04
5.48	1.17	3.51	0.62	4.98	0.93	77.74	1.32	1.94	0.91	30.48	12.66	11.65
5.87	1.22	3.34	0.49	3.18	0.50	23.71	1.34	1.95	0.71	24.16	13.25	4.27
5.73	1.22	3.39	0.51	3.32	0.51	8.23	1.95	2.22	0.81	28.24	13.53	3.52
4.38	0.91	2.48	0.35	2.46	0.36	3.03	1.37	2.34	0.95	24.98	11.89	2.46
9.22	1.58	4.20	0.60	4.34	0.68	19.80	1.25	2.18	0.78	28.68	89.96	12.24
4.34	0.83	2.20	0.31	2.16	0.32	2.78	1.17	1.98	1.44	22.91	11.08	2.75
6.03	1.13	3.03	0.42	2.86	0.43	3.05	1.41	2.34	0.85	25.26	13.67	2.62
3.65	0.76	2.21	0.31	2.05	0.29	3.24	1.22	1.29	0.83	16.83	6.94	1.28
5.35	1.21	3.93	0.67	5.39	0.93	39.05	1.28	1.90	0.68	22.84	11.25	2.56
3.38	0.66	1.79	0.25	1.77	0.27	3.22	2.45	1.80	1.63	23.14	10.80	1.70
4.66	0.89	2.46	0.35	2.32	0.34	3.34	1.48	2.21	0.81	22.10	10.38	1.77
12.72	2.75	7.34	1.06	6.59	0.92	3.71	1.47	2.53	0.51	32.31	14.57	3.69
5.71	1.18	3.08	0.45	2.93	0.45	7.57	1.71	2.72	0.38	22.69	8.83	2.67
4.04	0.91	2.46	0.40	2.66	0.46	7.32	1.41	2.36	0.59	32.12	11.45	3.34
6.10	1.12	2.77	0.41	2.61	0.38	3.07	1.48	2.78	1.07	37.05	16.93	2.99

Concluded