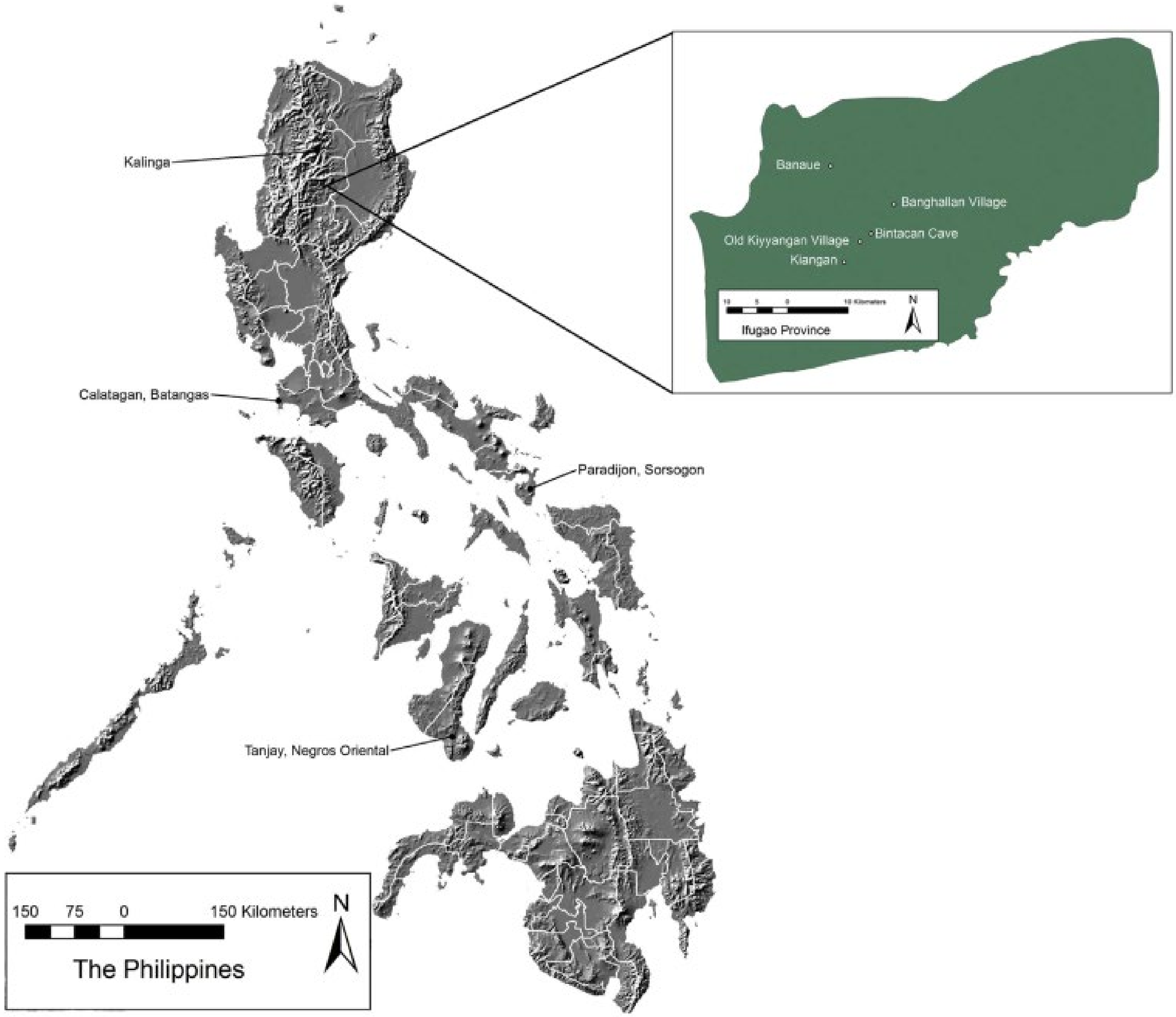
Ceramic Continuities: Analyses of pre-Spanish and colonial ceramic procurement and production in Old Kiyyangan Village, Ifugao, Philippines

Abstract: This paper compares pre-Spanish and colonial Ifugao ceramic procurement and production through physical (comparison of coefficient of variation value for sherd thickness) and chemical (principal component analysis of elemental abundances) analyses of sherds excavated from the Old Kiyyangan Village site. Contrary to previous research demonstrating a connection between socioeconomic change (agricultural intensification, centralized organization of labor) and pottery production and procurement standardization in the northern highland Philippines, analyses of the Old Kiyyangan Village sherds suggest continuities in pottery production and procurement even during times of dramatic socioeconomic transformations.

I. Introduction

Ceramic production (including the procurement of raw materials) and social, political, and economic changes share a mutually constitutive relationship, the nature of which has been the focus of archaeological study for decades (e.g. Berg 2004; Blackman et al. 1993; Earle 1981; Evans 1978; Longacre and Hermes 2015; Niziolek 2013b; Rice 1981; Wang and Marwick 2020). Archaeological examination of pottery standardization—largely via analysis of dimensions such as sherd thickness or chemical analysis to pinpoint the sources of raw materials—has emerged as a particularly valuable avenue of investigation; increases in pottery procurement or production standardization have been posited as signals of increasing social complexity and differentiation (Benco 1988; Clark 1995; Cobb 1996; Costin 2001; Longacre 1999). Scholars have compellingly demonstrated the correlation between increasing pottery standardization and social complexity across many difference contexts, including across multiple regions of the Philippines (Acabado et al. 2017; Barretto-Tesoro 2008; Earle 1981; Evans 1978; Longacre 1999; Junker 1999; Stark 1995). Despite this wealth of research, ceramics from the pre-Spanish and colonial Ifugao periods of the Philippine province of Ifugao have been relatively unstudied.

Figure 1 Map of the Philippines. Inset: Ifugao Province, with Ifugao Archaeological Project sites highlighted (adapted from Acabado et al. 2017).



My research investigates pottery excavated from Old Kiyyangan Village (Figure 1).The people of the Ifugao village (likely inhabited from the AD1050s into the AD1860s) embraced intensive wet-rice agriculture and drew in a growing population of indigenous refugees resisting the growing lowland Spanish colonial presence during the early modern period (Acabado 2018). Physical and chemical analyses compare pre-Spanish and colonial Ifugao ceramic procurement and production (Acabado 2018;). Methodologically, the combined analysis of both dimensional and chemical analyses is unique for northern Philippine pottery, wherein most previous work has focused on one or the other analytic method or on different areas within maritime Southeast Asia (Junker 1999; Longacre 1981; Niziolek 2010, 2013a, 2013b, 2015; Stark 1995; Stark et al. 2000). By combining both methods, my research simultaneously investigates possible changes in both pottery procurement and pottery production between the pre-Spanish and colonial periods in Ifugao. In doing so, the project aims to address the following questions:

1) Can we identify more standardized pottery production in Old Kiyyangan Village over time?
2) Can we detect changes in the raw material source used to produce ceramics found in Old Kiyyangan Village over time?

Its surprising results challenge previous works in the northern Philippine highlands and throughout the Philippine archipelago which argue that pottery production standardization correlates with increased socioeconomic complexity. Within the broader context of Southeast Asian archaeology, the paper is concerned with expanding the diachronic use of ceramic analysis, particularly in analyzing changes in objects produced before and during the colonialism of the Early Modern Period (AD1500s-AD1800s). In scholarship concerned with the Philippines, other regions of island Southeast Asia, and Southern China/mainland Southeast Asia, ceramic analysis has largely been focused on single time periods, often the contemporary (Barton 2012; Longacre and Stark 1994; Niziolek 2013a; Underhill 2003). Through its comparative scope, the analysis of both pre-Spanish and colonial Ifugao ceramics aims to elucidate indigenous peoples' navigations of new social and economic landscapes on the 'periphery' of a global empire (Acabado 2017; Beaule 2017).

II. Philippine Pottery Procurement & Production during Times of Change

Across various Philippine contexts, previous archaeological work has compellingly argued that rapid shifts to intensive wet-rice agriculture result in increasing social complexity and labor organization. In other Southeast Asian archaeological contexts, ceramic procurement and production practices—and the resulting variabilities in form and composition of ceramics—are sensitive to these cultural, economic, and environmental changes (Stark and Fehrenbach 2019). Standardization of pottery production can serve as evidence of the emergence of centralized, elite control of economic processes while diversity of pottery forms and techniques can serve as evidence of heterarchical organizations of power (Barretto-Tesoro 2008; Crumley 1995; Junker 1999; Stark 1995; Stark et al. 2000; White 1995).

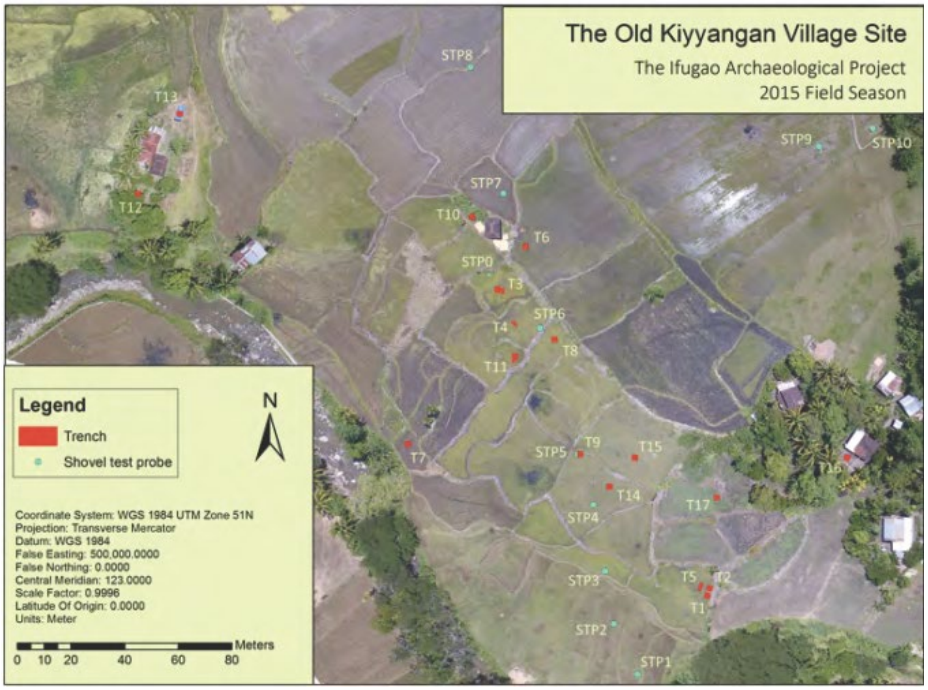
Previous archaeological work on the early modern Ifugao (AD1500s - AD1800s) again and again demonstrates innovative indigenous responses to the growing presence of Spanish colonizers, particularly the adoption of intensive wet-rice agricultural terracing (Acabado 2012, 2017, 2018; Acabado et al. 2019; Eusebio et al. 2015). Other work in the northern highland Philippines suggests that a shift to intensive wet-rice cultivation created economic pressure that stimulated the development of pottery production specialization as labor needs shift from crafts to agriculture (Stark 1995, Longacre 1981). Based on that work, this project investigates pottery recovered from Old Kiyyangan Village, an early modern large village where labor was organized around wet-rice cultivation and drew in a growing population of indigenous refugees resisting the growing lowland Spanish colonial presence (Acabado 2018).

III. The Old Kiyyangan Village Site & Excavated Pottery

Conventional wisdom—based largely on unsubstantiated hypothesizing by early 20th century American academics (Beyer 1955; Barton 1922)—has posited that the Ifugao Rice Terraces are millennia-old examples of an unconquered, pure indigenous culture (Acabado 2017). For over ten years, work done by scholars associated with the Ifugao Archaeological Project have questioned this narrative, compellingly arguing that the rice terraces were instead built by members of an Ifugao society that was densifying as people moved to higher elevations in response to a growing Spanish colonial presence in the northern Philippine lowlands (Acabado 2018).

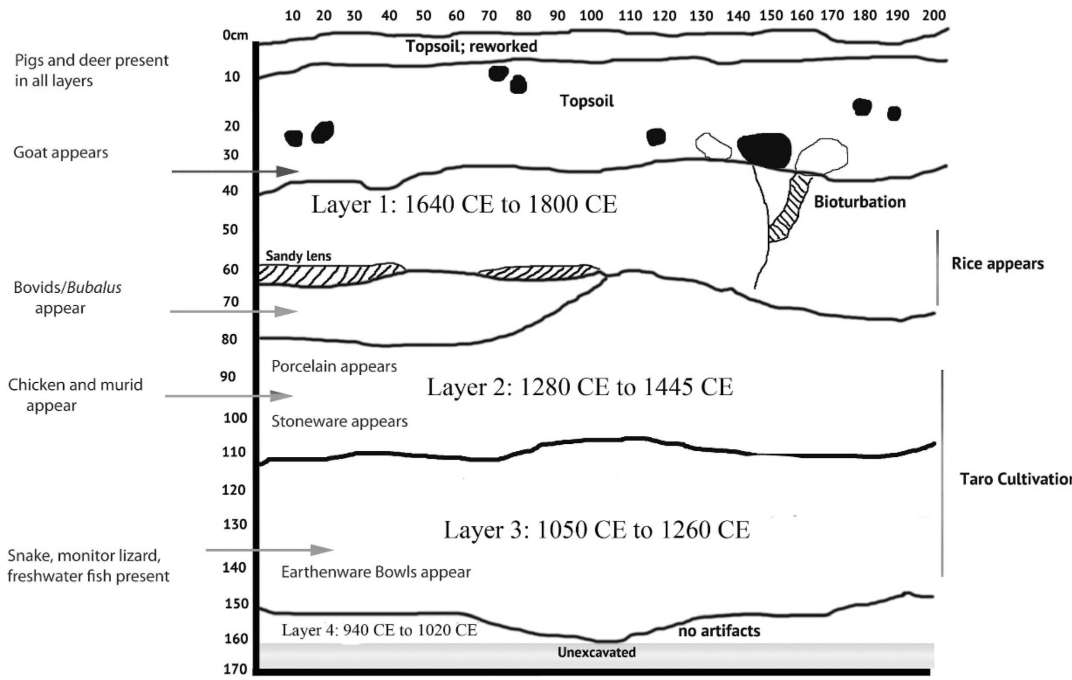
Old Kiyyangan Village is traditionally considered one of the origin locations of the Ifugao people and has been a major focus of study by the Ifugao Archaeological Project and the local community (Acabado 2018; Maher 1984; Figure 2). Scholars associated with the Ifugao Archaeological Project have compellingly argued that Ifugao resistance against the Spanish was fueled by elites centralizing landownership and successful due to the adoption of wet-rice agriculture and its attendant economic and political intensification geographically centered on Old Kiyyangan Village (Acabado 2017, 2018; Eusebio et al. 2015; Brosius 1988).

Figure 2 Aerial map of Old Kiyyangan Village Site at the end of the Ifugao Archaeological Project 2015 Field Season (adapted from Acabado 2015). Analyzed sherds were sampled from Trenches 3, 14, and 16.



Previous excavations of the Old Kiyyangan Village site have revealed three distinct archaeological layers through a suite of methods including radiocarbon dating, ethnohistorical research, and ethnographic work (Acabado 2012; Acabado et al. 2017). Based on these data, deposits in Layer 1 (between approximately 30cm and 80cm below the surface) date to between AD1640 to AD1800, and deposits in Layer 2 (between approximately 80cm and 120cm) date to between AD1280 to AD1445. Layer 1 contains excavation Levels 3-7, and Layer 2 contains excavation Levels 8-12 across all units (Figure 3). Deposits in Layer 3 (between approximately 120cm and 150cm below the surface) date to AD1050 to AD1260, but they have been excluded due to the relative dearth of sherds.

Figure 3 Profile of south wall of Trench 3 (adapted from Lapeña and Acabado 2017).



The Spanish colonial presence in the Philippines increased over decades beginning in the AD1520s and grew at variable rates in different regions of the Philippines, as a function of many factors including indigenous armed resistance, geography, and strategic relevance to the Spanish (Blair and Robertson 1903; de Zuñiga 1814). The lands of what is now Ifugao were particularly problematic for Spanish colonization due to their terrain and organized indigenous resistance. Part of this indigenous response included the shift from taro to wet-rice agriculture, which was likely stimulated by increasing population density fueled by indigenous lowlanders moving into the highlands to resist or avoid the growing Spanish colonial presence (Lapeña and Acabado 2017; Acabado 2012, 2018).

This relationship between layers is consistent across many units excavated in Old Kiyyangan Village, including Trenches 3, 14, and 16 (Acabado 2013; Acabado 2015). Bearing this information in mind, the nearly 200-year gap between the dating of Layers 1 and 2 becomes an incredibly useful analytic tool. For this project, Layer 2 represents a pre-Spanish period and

Layer 1 represents the early modern period wherein the Ifugao were implicated in global trade relationships due to European colonial expansion (Acabado 2017). Thus, analysis of sherds found in Layer 2 can provide insights into pre-Spanish Ifugao ceramic acquisition and production, and analysis of sherds found in Layer 1 can provide insights into early modern Ifugao ceramic procurement and production.

The overwhelming majority of artifacts excavated by the Ifugao Archaeological Project on the Old Kiyyangan Village site have been earthenware sherds (17236 out of 19329 accession numbers), with beads at a distant second (547 out of 19329 accession numbers). Most sherds likely came from globular pots with flaring rims that were used as water storage jars or cooking vessels. Previous ethnoarchaeological work and ceramic analysis suggests coiling, modeling, and paddle-and-anvil methods were used in production and red-slipping and burnishing were common decorative techniques (Acabado et al 2017).

IV. Analytic Approaches: Physical & Chemical Methods

Coefficient of variation analysis has been used by scholars studying the standardization of the production of highland Southeast Asian ceramics for decades; the analysis has been popular due to its relatively low technical/laboratory requirements and its ability to inform comparisons between pottery samples within and across regions. (Longacre 1981; Benco 1988; Stark 1991; Junker 1993; Junker 1994; Stark 1995; Longacre 1999; Underhill 2003; Longacre and Hermes 2015; Acabado et al. 2017; Wang and Marwick 2020). Previous research on Philippine Cordilleran ceramic production has compellingly used co-efficient of variation to examine pottery standardization (Longacre 1981; Acabado et al 2017), arguing that ≤0.06 signifies the emergence of specialized pottery production and that ≥0.12 signifies pottery production at the household level by non-specialists.

A growing body of research has chemically analyzed Southeast Asian and Pacific ceramics using Laser Ablated Inductively Couple Plasma-Mass Spectrometry (LA-ICP-MS) to examine the organization of raw material procurement and pottery production; less variation is argued to correlate with increased centralization of labor organization, but the quantification of variation varies between studies (Cochrane and Neff 2006; Niziolek 2013a, 2013b, 2015).

V. Physical & Chemical Characterization of Sherds

Sherds selected for analysis were from Trenches 3, 14, and 16 of the Ifugao Archaeological Project due to the trenches' spatial association with fetal/infant jar burials which indicate house platforms in Old Kiyyangan Village (Lauer and Acabado 2015). Trench 3 was excavated during the 2012 field season, and its location was chosen based on local informants' knowledge of a previous settlement (Amano et al. 2012). Besides earthenware sherds, excavators uncovered faunal remains, an adult human molar, beads (bone and glass), gold foil, Chinese porcelain/tradeware, and charcoal (Amano et al. 2012). Trench 14 was excavated during the 2015 field season, and its location was chosen based on proximity to productive trenches from the 2013 field season (Acabado 2015). Trench 14 included many pots, including some associated with human bones and likely included the foundations of two house structures (Acabado 2015). Trench 16 was excavated during the 2015 field season in the front yard of Marta Tuguinayo's household and produced relatively small amounts of artifacts (Acabado 2015).

Individual sherds were organized by excavation level to investigate potential changes over time; sherds' accession numbers per level were then randomly selected for physical and chemical analyses via RANDOM.org's true random number via atmospheric noise service (Haahr 2021). 114 sherds were ultimately selected for destructive analysis due to budgetary limits and policies of the National Museum of the Philippines.

Visual analysis of sherds was used to determine vessel function, charring, and vessel part. The overwhelming majority of excavated pottery in Old Kiyyangan Village are utilitarian earthenware ceramics, the majority of which were used as water jars or cooking vessels. Certain traits (such as lumpy interiors, exterior red-slipping, interior red-slipping, black-slipping and burnishing) have been previously correlated with water jars or cooking vessels and were used as diagnostic criteria (Acabado et al. 2017). The presence of interior and/or exterior carbon deposits was noted, and sherds were identified as rims, bases, and lids/handles based on shape and comparison to previously excavated pots. All others were identified as body sherds.

Thickness of the selected sherds was measured using NEIKO 01407A digital calipers (0-150 mm range, 0.01 mm resolution, ±0.02 mm accuracy). Three measurements at the center of sherds' largest faces were taken per sherd and averaged to account for inconsistent thickness common in early modern Philippine highland ceramics. Although other analyses of highland Philippine ceramics have incorporated pot lip thickness and rim diameter, the available samples were measured solely for thickness due to the lack of reliably identifiable lip and rim sherds (Longacre 1991, 1995). Sherd thicknesses were then used to calculate descriptive statistics, particularly coefficient of variation (CV) values (Tables 2-5).

The 114 sherds were sent to the Elemental Analysis Facility (EAF) of the Field Museum to undergo Laser Ablated Inductively Couple Plasma-Mass Spectrometry (LA-ICP-MS) analysis using a Thermo Fisher ICAP Q quadruple ICP-MS with a 230nm laser. LA-ICP-MS testing was run 116 times to correct for 2 failed tests. During analysis, samples were tested to measure: 1) the abundance of 50 elements measured in parts per million and 2) the concentration of 18 mineral oxides.

Though previous scholars have emphasized the importance of the relative abundances of elements in differentiating the geological sources of archaeological materials, certain elements were excluded from analyses due to consistently low concentrations (Gliozzo et al., 2014; Roll et al., 2005; Speer 2014a; Speer 2014b). The base-10 logarithm of the abundance of elements was used for analyses to account for sometimes large variations in the range and concentrations across elements. Following other LA-ICP-MS analyses based on archaeological materials done by the EAF, elements whose mean of the base-10 logarithm of abundance values was below the limits of detection (<0.50) were excluded (Niziolek 2013a, 2013b; Sharratt et al. 2009). All mineral oxides were excluded from analysis: all means of the base-10 logarithm of concentration values fell below the limits of detection.

Table 1 Elements and their means of base-10 logarithm abundance values. Bolded elements were included in analyses.

Element	**Mean of base-10 logarithm of element abundance values**	**Element**	**Mean of base-10 logarithm of element abundance values**
Li	1.17	**Ba**	2.93
Be	0.13	**La**	0.99
B	0.91	**Ce**	1.29
P	3.97	Pr	0.48
Cl	2.41	Ta	0.01
Sc	1.28	Au	0.03
Ti	3.56	**Y**	1.18
V	2.12	**Pb**	1.03
Cr	1.65	Bi	0.01
Mn	2.87	U	0.14
Fe	4.53	W	0.01
Ni	1.41	Mo	0.02
Co	1.13	**Nd**	1.08
Cu	1.70	Sm	0.48
Zn	2.30	Eu	0.06
As	0.59	Gd	0.47
Rb	1.81	Tb	0.02
Sr	2.92	Dy	0.46
Zr	1.86	Ho	0.02
Nb	0.48	Er	0.23

Ag	0.02	Tm	0.01
In	0.01	Yb	0.24
Sn	0.02	Lu	0.01
Sb	0.01	Hf	0.40
Cs	0.10	Th	0.42

Based upon these findings and other chemical analyses of southeast Asian ceramics, exploratory biplots comparing pairs of elements were created to identify possible groupings (Niziolek 2013a, 2013b). Element pairs were chosen based upon highest: mean log base-10 concentration (Phosphorus and Iron); standard deviation of log base-10 concentration (Phosphorus and Boron); and coefficient of variation of log base-10 concentration (Arsenic and Cobalt).

Due to the multivariate nature of the resultant LA-ICP-MS data, principal component analysis (PCA) was done to reduce the data's high dimensionality (Metsalu and Vilo 2015). PCA on LA-ICP-MS data has been successfully used in many contexts, including on Philippine and other Pacific Island ceramics (Niziolek 2013a, 2013b; Cochrane and Neff 2006). As stated previously, the base-10 logarithms of mineral abundance values were calculated and analyzed to account for scaling differences across elements, and all mineral oxides and many elements were excluded from PCA due to their consistently low values (Sharrat et al. 2009).

The elements used for statistical analyses were: Li, B, P, Cl, Sc, Ti, V, Cr, Mn, Fe, Ni, Co, Cu, Zn, As, Rb, Sr, Zr, Ba, La, Ce, Y, Pb, Nd. Using the DATAtab statistics webtool, K-means clustering was used on the data, with varying k values (Jesussek and Volk-Jesussek 2021). Using the ClustVis PCA and visualization webtool, standard singular value decomposition (SVD) analysis with imputation was conducted on the element abundance data to calculate principal components (Metsalu and Vilo 2015).

VI. Results

Due to the lack of information concerning the geological origin of available sherds and the small amount of previous work done on Early Modern Ifugao ceramics, multiple categorization schemes (trench, vessel function, charring, sherd type, k-means cluster of elemental concentrations, and layer) were used to organize sherds to help elucidate any possible patterns of thickness variation. Ultimately, categorization by layer proved to be the most useful, due to issues of sample size in the categorization schemes.

Table 2 Coefficient of variation values of sherd thickness by trench (measurements all in mm).

Trench 3 sherd thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	22	7.98	4.66	18.12	2.975	0.3729
Layer 2 (Levels 8-12)	26	8.18	4.31	16.37	2.865	0.3502
Trench 14 sherd thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	35	8.85	3.59	28.34	4.467	0.5049
Layer 2 (Levels 8-12)	16	8.44	4.71	14.34	2.366	0.2804
Trench 16 sherd thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	13	8.45	4.71	12.93	2.518	0.2981
Layer 2 (Levels 8-12)	5	7.78	6.56	8.44	0.8156	0.1048
All sherd thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	70	8.49	3.59	28.34	3.712	0.4367
Layer 2 (Levels 8-12)	47	8.22	4.31	16.37	2.256	0.3071

Table 2 shows higher coefficient of variation values in Layer 1 (AD1640 to AD1800) than in Layer 2 (AD1280 to AD1445) for all three trenches. However, previous research strongly suggests that at least 30 samples per class should be used to draw conclusions based upon coefficient of variation analysis (Longacre et al. 1988, Rice 1989). Bearing this in mind, the basis of the coefficient of variation values from both Layers in Trench 3, Layer 2 in Trench, and both Layers in Trench 16 can be considered insufficient (Table 2). Despite this limitation, other research has instead emphasized the usefulness of 'insufficient' data, with context, in proposing general trends (Acabado et al. 2017). In either case, the coefficient of variation values from Trench 16 are best disregarded. While the coefficient of variation values in Trench 3 increased by a mere .02 (from 0.35 to 0.37) from Layers 2 and 1, the same values increased by 0.23 (from 0.28 to 0.51) in Trench 14.

Following trends from previous research, the expected result would demonstrate a decrease in coefficient of variation values over time, in alignment with increasing population density and the centralized organization of labor occurring in Old Kiyyangan Village between the pre-Spanish and colonial periods (Longacre 1999; Acabado 2017, 2018). Despite the trend toward higher coefficient of variation values over time, it is important to note that all datapoints are far above the ≤0.06 expected for standardized manufacture by specialists in the Northern Philippine region. Further, all coefficient of variation values also exceed the expected value of between 0.06 to 0.12 that signifies non-standard, part-time household manufacture in the region (Longacre 1999).

Table 3 Coefficient of variation values of sherd thickness by vessel function (measurements all in mm).

Water jar sherds thickness	***N***	***Mean***	***Minimum***	***Maximum***	***SD***	***CV***
Layer 1 (Levels 1-7)	33	10.53	6.26	28.34	4.299	0.4082
Layer 2 (Levels 8-12)	26	9.44	4.88	16.37	2.626	0.2781
Cooking vessel sherds thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	37	6.69	3.59	13.19	1.681	0.4082
Layer 2 (Levels 8-12)	21	6.72	4.31	8.64	1.318	0.1963
All sherds thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	70	8.49	3.59	28.34	3.712	0.4367
Layer 2 (Levels 8-12)	47	8.22	4.31	16.37	2.256	0.3071

The data in Table 3, concerning vessel function, show an increase in coefficient of variation values over time and are also far higher than the coefficient of variation values expected of specialist (≤0.06) or household (between 0.06 and 0.12) manufacture (Longacre 1999).

Table 4 Coefficient of variation values of sherd thickness by charring (measurements all in mm).

Sherd with no char thickness	**N**	**Mean**	**Min**	**Max**	**SD**	**CV**
Layer 1 (Levels 1-7)	30	9.63	5.09	28.34	4.646	0.4827
Layer 2 (Levels 8-12)	13	8.1	5.13	16.37	3.064	0.3783
Sherd with interior char thickness	**N**	**Mean**	**Min**	**Max**	**SD**	**CV**
Layer 1 (Levels 1-7)	9	7.61	3.59	10.73	2.496	0.3281
Layer 2 (Levels 8-12)	8	9.17	6.56	12.94	2.252	0.2457
Sherd with exterior char thickness	**N**	**Mean**	**Min**	**Max**	**SD**	**CV**
Layer 1 (Levels 1-7)	26	7.66	4.66	18.12	2.866	0.3742
Layer 2 (Levels 8-12)	19	7.58	4.31	13.09	2.083	0.2747
Sherd with int & ext char thickness	**N**	**Mean**	**Min**	**Max**	**SD**	**CV**
Layer 1 (Levels 1-7)	5	7.71	7.1	9.01	0.806	0.1076
Layer 2 (Levels 8-12)	7	9.12	5.34	14.34	2.783	0.3051
All sherd thickness	**N**	**Mean**	**Min**	**Max**	**SD**	**CV**
Layer 1 (Levels 1-7)	70	8.49	3.59	28.34	3.712	0.4367
Layer 2 (Levels 8-12)	47	8.22	4.31	16.37	2.256	0.3071

Sherds were also grouped and examined by evidence of charring. Sample sizes of the different groupings of sherds are too small, so any observed trends are best disregarded (Table 4). Like the data examining differences between coefficient of variation values by trench and vessel function, the data concerning coefficient of variation values organized by evidence of charring are much higher than the coefficient of variation values expected of specialist (≤0.06) or household (between 0.06 and 0.12) manufacture (Longacre 1999). There is one exception: the coefficient of variation value of sherds exhibiting interior and exterior charring in Layer 1 does fall within values associated with household manufacture (Table 4). However, any conclusions or inferences drawn from this are questionable because of its extremely small sample size that is one sixth the recommend size (Rice 1981).

Table 5 Coefficient of variation of sherd thickness by sherd type (measurements all in mm).

Body sherd thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	28	6.89	3.59	11.75	1.846	0.268
Layer 2 (Levels 8-12)	30	8.03	4.31	14.34	2.575	0.3205
Rim sherd thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	37	8.57	5.28	14.02	2.292	0.2676
Layer 2 (Levels 8-12)	16	8.63	5.34	16.37	2.544	0.295
Base sherd thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	1	8.85	8.85	8.85	-	-
Layer 2 (Levels 8-12)	1	7.57	7.57	7.57	-	-
Lid sherd thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	4	19.07	11.17	28.34	7.057	0.37
Layer 2 (Levels 8-12)	0	-	-	-	-	-
All sherd thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	70	8.49	3.59	28.34	3.712	0.4367
Layer 2 (Levels 8-12)	47	8.22	4.31	16.37	2.256	0.3071

Sherds were also grouped and examined by sherd type. It is important to note the variation in sample sizes: very few sherds were identified as base sherds or lid sherds (Table 5). Because of this, results concerning base sherds and lid sherds are best disregarded. Table 5 shows a trend of very slight decrease for the coefficient of variation values from Layer 2 to Layer 1 based on sherd type. The coefficient of variation values for body sherds decreased by 0.05 (from 0.32 to 0.27) from Layers 2 and 1, the same values decreased by 0.03 (from 0.30 to 0.27) for rim sherds.

Unlike coefficient of variation value analysis organized around trench, vessel function, or evidence of charring, analysis based on sherd type demonstrates a slight decrease of coefficient of variation value over time. The small size of the value decrease also does not support the idea of increased pottery production standardization over time.

Table 6 Coefficient of variation of sherd thickness by k-means clusters (measurements all in mm).

Cluster 1 sherds thickness	***N***	***Mean***	***Minimum***	***Maximum***	***SD***	***CV***
Layer 1 (Levels 1-7)	40	8.53	4.71	28.34	4.067	0.4766
Layer 2 (Levels 8-12)	36	8.64	4.71	16.37	2.624	0.3039
Cluster 2 sherds thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	30	8.49	3.59	18.65	3.295	0.3880
Layer 2 (Levels 8-12)	11	6.95	4.31	10.10	1.688	0.243
All sherds thickness	**N**	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Layer 1 (Levels 1-7)	70	8.49	3.59	28.34	3.712	0.4367
Layer 2 (Levels 8-12)	47	8.22	4.31	16.37	2.256	0.3071

The coefficient of variation values for cluster 1 sherds increased by 0.18 (from 0.30 to 0.48) from Layer 2 to Layer 1, and the same values increased by 0.14 (from 0.24 to 0.38) for cluster 2 sherds, which in all cases is much higher than the expected values for specialized or household pottery production (Table 6).

Because of sample size issues, the most useful analysis examines the total number of sherds by layer (Tables 2-6). The coefficient of variation values for all sherds increased by nearly 0.13 (from 0.31 to 0.44) from Layers 2 and 1. The significance of the difference between these coefficients of variation for Layers 2 and 1 was found via asymptotically chi-square k-sample test statistics using the R package cvequality (Version 0.1.3) (Marwick and Krishnamoorthy 2019; Miller 1990). This difference suggests that pottery found in Layer 1 is significantly more variable in thickness than pottery found in Layer 2, x^2 (1, N = 114) = 74.7, p < .05.

In almost all cases, the coefficient of variations for the Old Kiyyangan Village sherds were much larger than either the ≤0.06 expected for standardized manufacture by specialists in the region or the expected value of between 0.06 to 0.12 that signifies non-standard, part-time household manufacture in the region (Longacre 1999). This may be a function of the small sample size, differences in measurement protocols to previous work, or more heterogeneity in ceramic production practices throughout the northern Philippines than previously thought (Rice 1981; Longacre 1999; Longacre and Hermes 2015). Regardless, further investigation into ceramics from Ifugao contexts would be valuable and may reveal patterns of household production that do not change dramatically over time.

Like many of the categorization schemes for sherd thickness, the exploratory biplots based upon highest concentration elements did not elucidate any clear groupings (Figures 4-6). Exploratory biplots have proven useful for determining elements that may be helpful in determining raw material sources in other Southeast Asian contexts, and further study is needed to explore its applications for Ifugao contexts (Niziolek 2013a, 2013b; Carter and Dussubieux 2016). The size and complexity of the data calls for multivariate analysis, such as the clustering and principal component analyses below.

Figure 4 Exploratory biplot of highest mean log base-10 concentrations (Phosphorus and Iron)

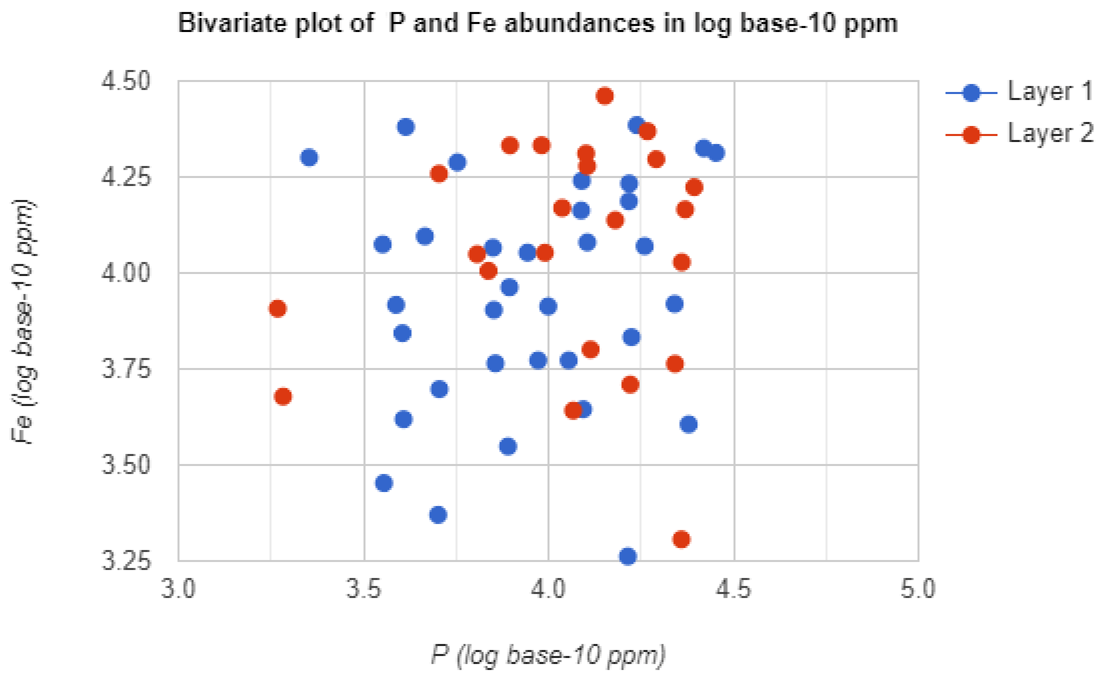


Figure 5 Exploratory biplot of highest standard deviation of log base-10 concentration (Phosphorus and Boron)

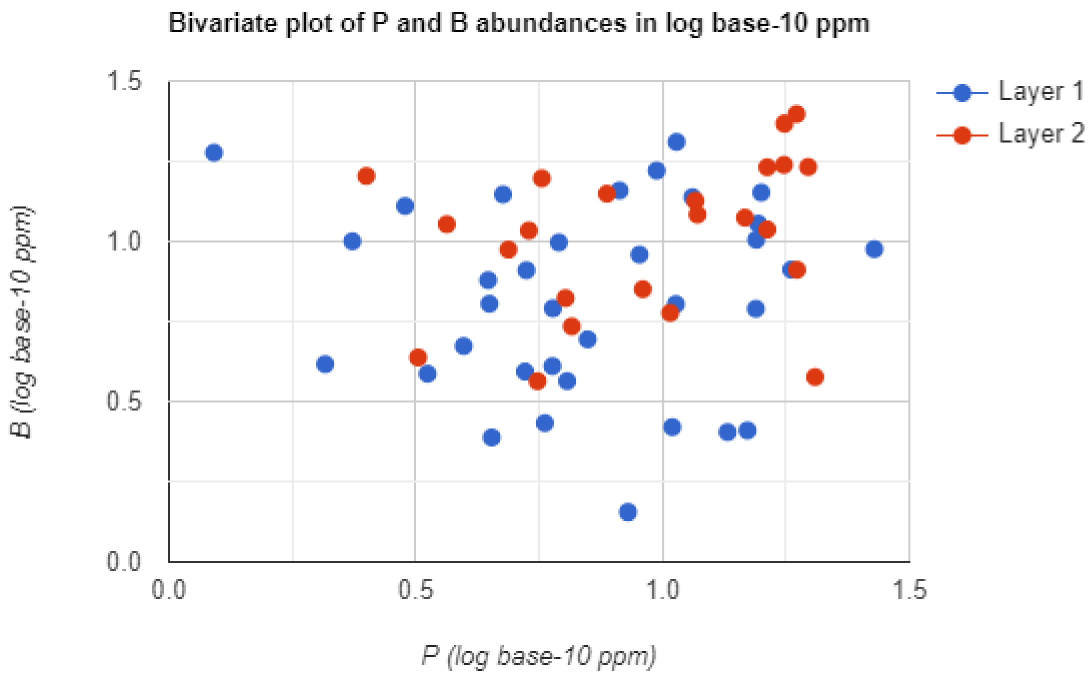
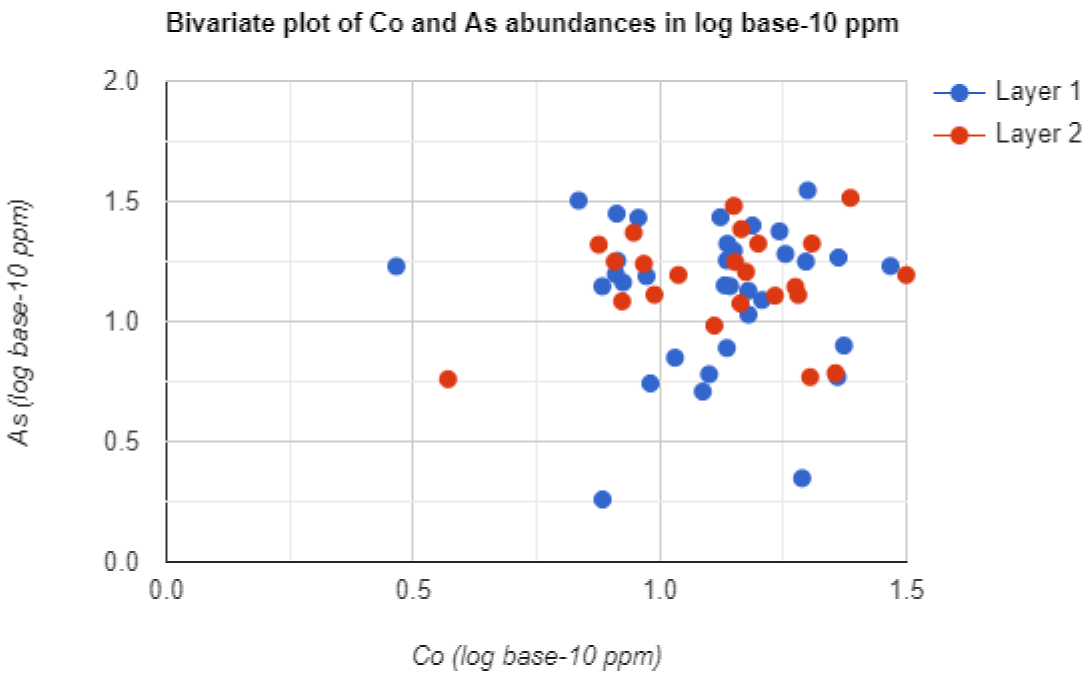


Figure 6 Exploratory biplot of highest coefficient of variation of log base-10 concentration (Arsenic and Cobalt)



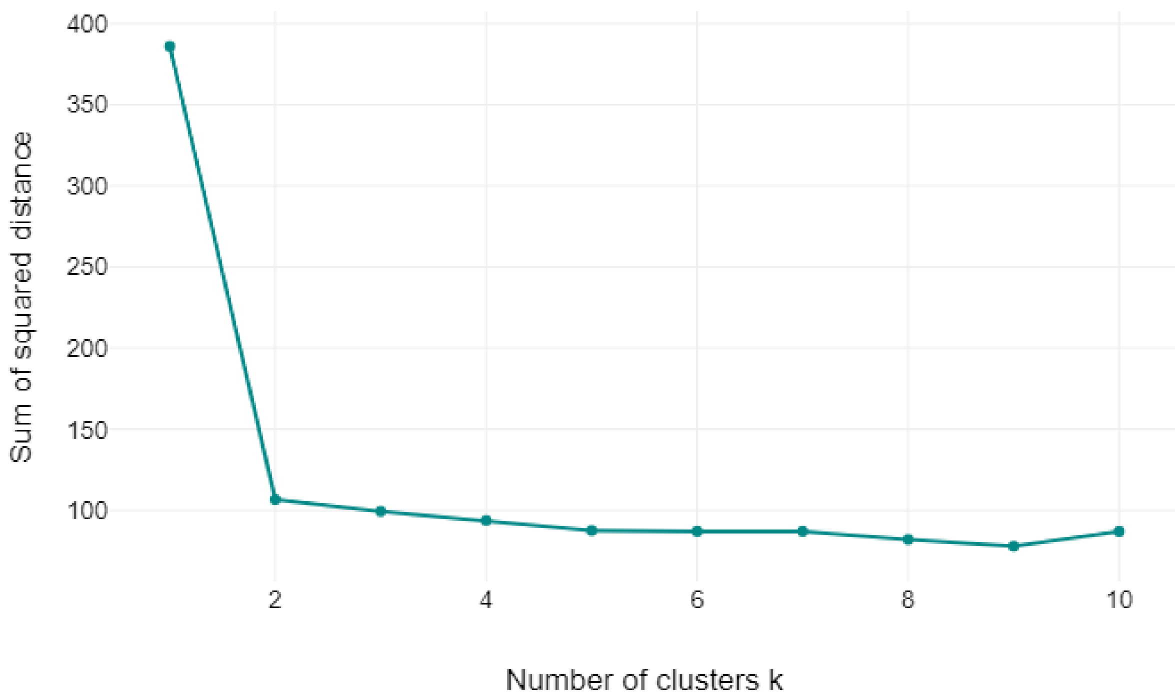
Data derived from LA-ICP-MS analysis underwent K-means clustering analysis. Using the DATAtab K-means clustering webtool, multiple k-means clustering analyses were run using k-values from 2 to 5 (Jesussek and Volk Jesussek 2021). Each k-value, except 2, resulted in at least one cluster containing 1 sherd; five sherds appeared in one of these clusters and were excluded from further analyses due to their likely status as chemical outliers (Table 7).

Table 7 Number of sherds per cluster in k-means clustering

Number of Sherds					
	Cluster				
K-value	1	2	3	4	5
2	75	39	-	-	-
3	92	1	21	-	-
4	74	1	38	1	-
5	17	1	50	45	1
Sherds excluded from further analysis: 1898, 3059, 15400, 15413.1, and 16991					

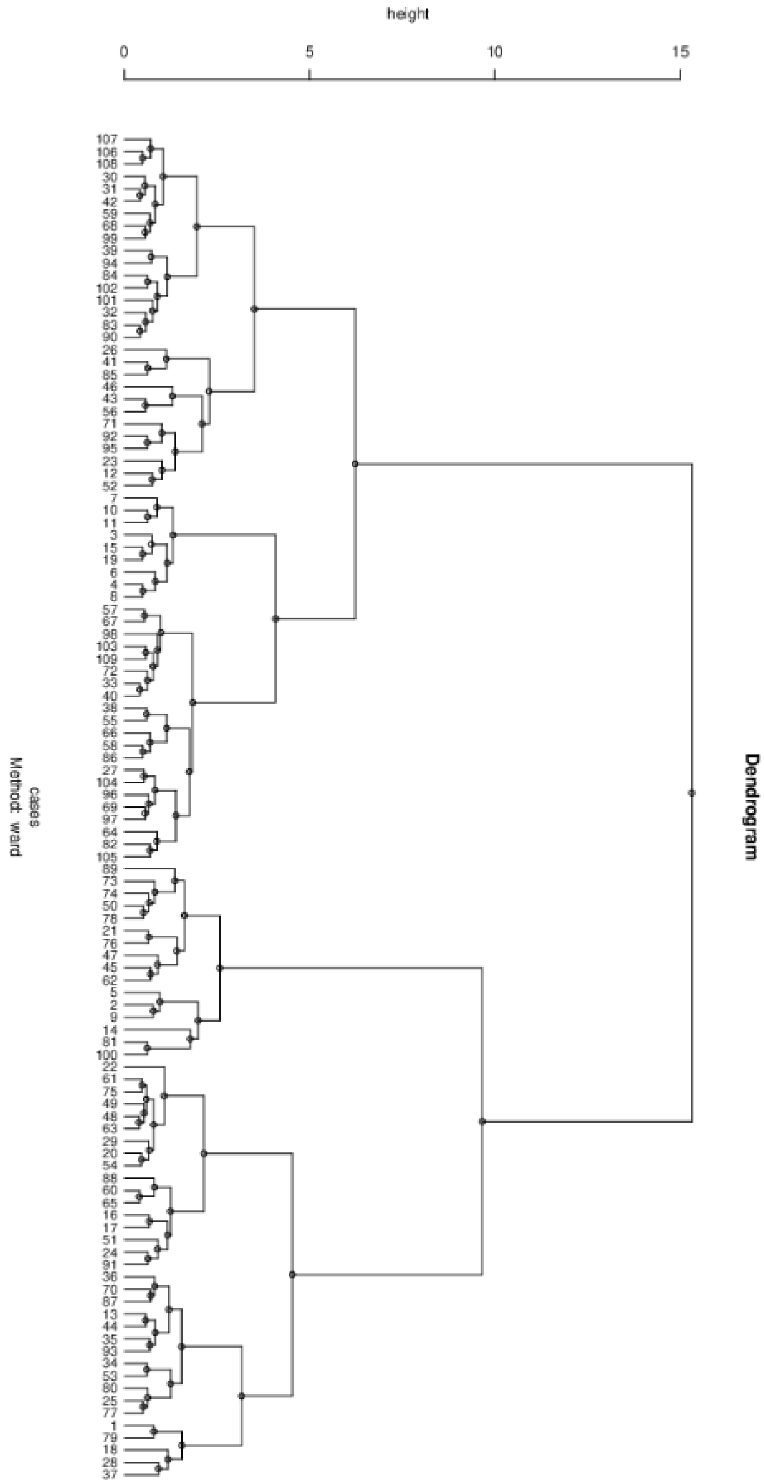
DATAtab was also used to create a graph examining within-cluster-sum of squared distance (Figure 7). Using the elbow method heuristic, Figure 7 suggests that a k-value of 2 would be the most useful for further analysis (Yuan and Yang 2019).

Figure 7 Number of clusters (k-value) versus sum of squared distance of standardized data (n = 109)



To further examine possible groupings, the Hierarchical Clustering v1.0.5 webtool was used to create a dendrogram using the standardized data with k-means analysis outliers removed (Wessa 2017; Figure 8). Ward method hierarchical cluster analysis was selected to minimize variance (Wessa 2017).

Figure 8 Dendrogram of Ward method hierarchical cluster analysis on standardized data (n = 109)



The results of the hierarchical cluster analysis suggest 2 clusters, one containing 59 sherds and the other containing 50 sherds while k-means clustering resulted in two clusters containing 73 and 36 sherds (Table 8). Cluster membership is not identical across the cluster analyses, but 87 of the 109 sherds (79.8%) were sorted into matching clusters for both K-means and hierarchical analyses.

Table 8 Size of clusters by clustering type

	Clustering Type		
Cluster	K-means (n = 109)	Hierarchical (n = 109)	K-means and Hierarchical overlap (n = 87)
1	73	59	55
2	36	50	32

Though the sample size is small, 16 of the 22 sherds (72.7%) that did not overlap across the clustering analyses were from Layer 1 (Table 9). This may suggest that mixing of materials and/or chemically unique pottery was more common in AD1600s – AD1800s than in the AD1280s – AD1440s in Old Kiyyangan Village. This was likely due to the population (and therefore material culture) influx catalyzed by Spanish colonial presence in the lowlands (Acabado 2018).

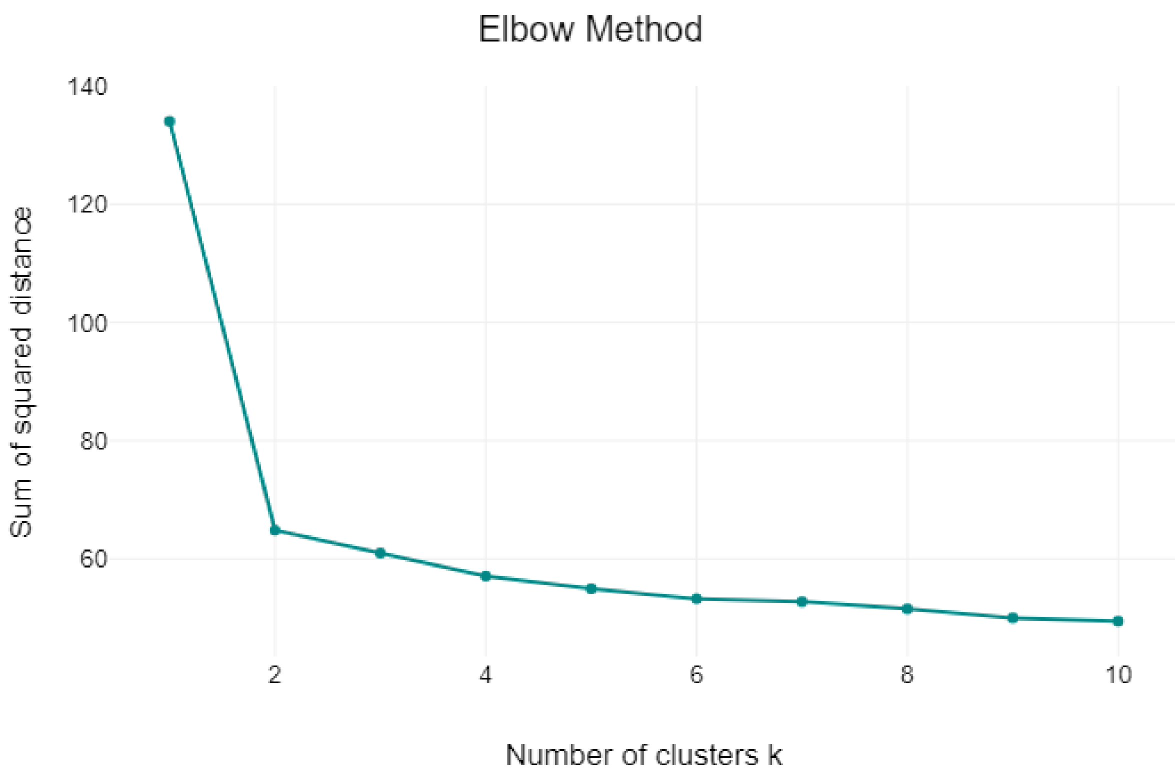
Table 9 Traits of Excluded Sherds (n = 22)

Sherd Trait						
Layer		***Trench***			***Function***	
1	**2**	**3**	**14**	**16**	**Cooking**	**Water**
16	6	8	8	6	10	12

Sherd Trait							
Charring				***Sherd Type***			
Int	**Ext**	**Int + Ext**	**None**	**Base**	**Body**	**Lid**	**Rim**
7	2	3	10	1	9	2	10

The DATAtab K-means clustering webtool was then used to analyze only the 87 sherds whose clusters overlapped in the previous K-means and hierarchical analyses (Jesussek and Volk Jesussek 2021; Table 8). The elbow method heuristic again suggested that a k-value of 2 would be the most useful for further analysis (Yuan and Yang 2019; Figure 9).

Figure 9 Number of clusters (k-value) versus sum of squared distance of standardized data, sherds with K-means and Hierarchical Cluster overlap (n = 87)



K-means clustering with a k-value of 2 was used in all PCA visualizations, and hierarchical clustering was used in conjunction with K-means clustering for one PCA visualization (Figures 10 and 11). The two clusters may represent two types of pottery created due to differences in procurement and/or production practices. 5 sherds were again excluded from all analyses due to their categorization into single-sherd clusters in different k-value tests (Table 7). PCA visualizations were created for both the overall 109 sherd population (Figure 10) and the 87-sherd population of overlapping K-means and Hierarchical clustering (Figure 11).

Data visualizations for principal component analysis omitted row scaling and included prediction ellipses with 0.95 confidence levels such that new concentration data from the same population would yield results within these ellipses with a probability of 95%. The lack of row scaling allows for some comparison between data visualizations, and the inclusion of predictive ellipses allows for easier comparisons between different datasets within a single data visualization.

The categorization schemes from the above coefficient of variation analyses (trench, vessel function, charring, sherd type, and layer) were analyzed for the 87 sherds with K-means and Hierarchical clustering overlap. Though they are a relatively small sample size, the categorization schemes may serve as directions for future research, with a foci on particular areas of Old Kiyyangan Village (northern), types of vessels (water jars), or sherd types (body sherds) to investigate possible contributing factors to the relative unequal representation within Layers 1 and 2 of sherds with particular traits.

Table 10 Traits of Sherds with K-Means and Hierarchical Cluster overlap (n = 87)

	Cluster	
Layer	1 *(n = 55)*	2 *(n = 32)*
1	27	22
2	28	10
Trench	1 *(n = 55)*	2 *(n = 32)*
3	29	9
14	18	19
16	8	4
Vessel Function	1 *(n = 55)*	2 *(n = 32)*
Cooking Vessel	25	18
Water Jar	30	14
Charring	1 *(n = 55)*	2 *(n = 32)*
Exterior	21	15
Interior	12	3
Int + Ext	6	2
None	16	12

Sherd Type	1 *(n = 55)*	2 *(n = 32)*
Base	1	0
Body	37	10
Lid	0	2
Rim	17	20

With diachronic analysis in mind, the relationship between clusters and layers is the most interesting and illuminating. Principal component analyses thus focused on these relationships. Two visualizations were created, one examining all 109 sherds (Figure 10) and the other examining the 87 sherds with K-means and Hierarchical cluster overlap (Figure 11).

Figure 10 PCA for Element Abundance (PPM) by k-means Cluster (k = 2) and Layer (n = 109) No scaling is applied to rows; SVD with imputation is used to calculate principal components. X and Y axis show principal component 1 and principal component 2 that explain 34.8% and 15.0% of the total variance, respectively. Prediction ellipses are such that with probability 0.95, a new observation from the same group will fall inside the ellipse. N = 109 data points.

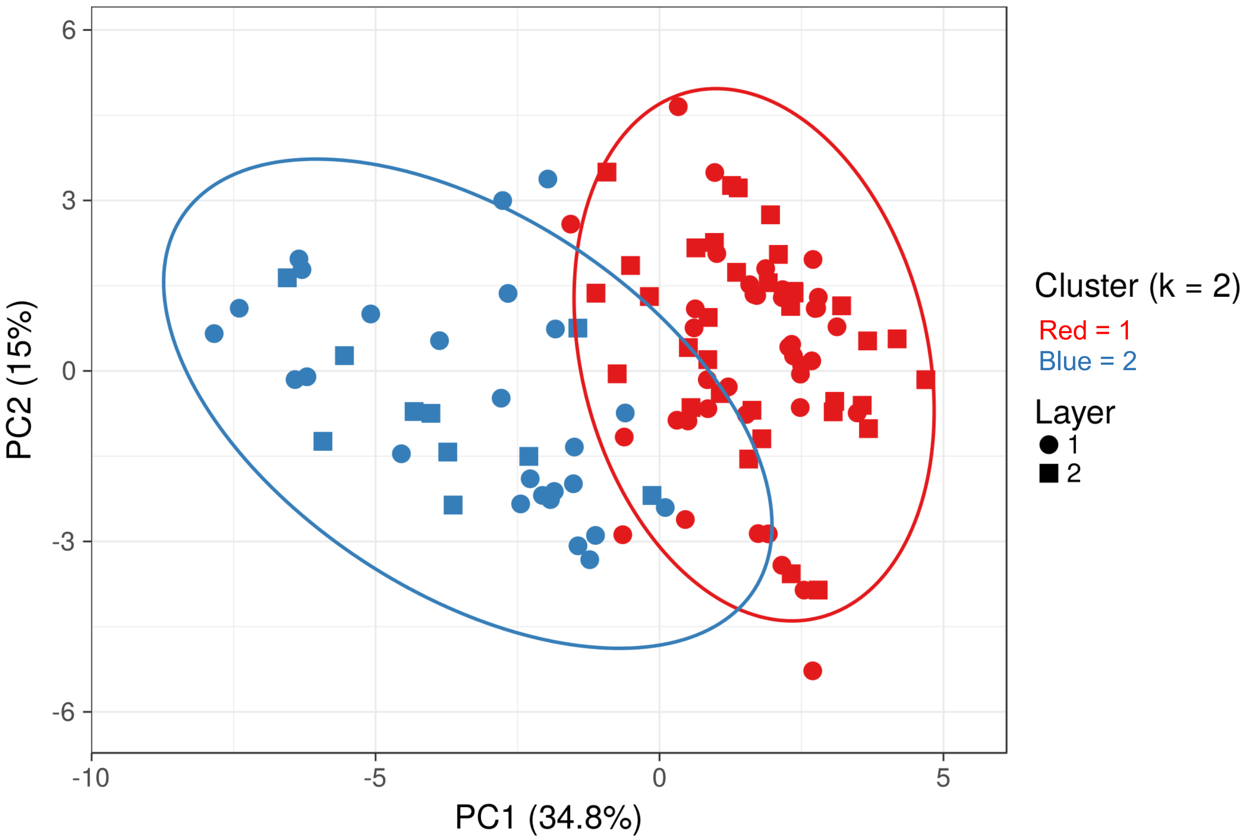


Table 11 Number of sherds by k-means cluster and layer (n = 109)

	Cluster	
Layer	1 *(n = 73)*	2 *(n = 36)*
1	39	26
2	34	10

Figure 10 demonstrates that Cluster 1 sherds vary less than Cluster 2 sherds in relation to PC1. Further, nearly 75% of Cluster 2 sherds appear in Layer 1, while Cluster 1 sherds appear in roughly equal frequency in Layers 1 and 2 (Table 10). Together, these data may suggest a variety of transitions, including transitions to procurement/production practices that skewed toward the production of more chemically heterogenous pottery over time. These data may contradict trends from previous research: expected results would include increased homogeneity in accordance with economic, social, and cultural change(s) toward more centralized craft production (Stark et al. 2000; Acabado et al. 2017).

Figure 11 PCA for Element Abundance (PPM) by k-means and Hierarchical Cluster (k = 2) and Layer, sherds with k-means and hierarchical cluster overlap (n = 87)
No scaling is applied to rows; SVD with imputation is used to calculate principal components. X and Y axis show principal component 1 and principal component 2 that explain 34.8% and 15.0% of the total variance, respectively. Prediction ellipses are such that with probability 0.95, a new observation from the same group will fall inside the ellipse. N = 87 data points.

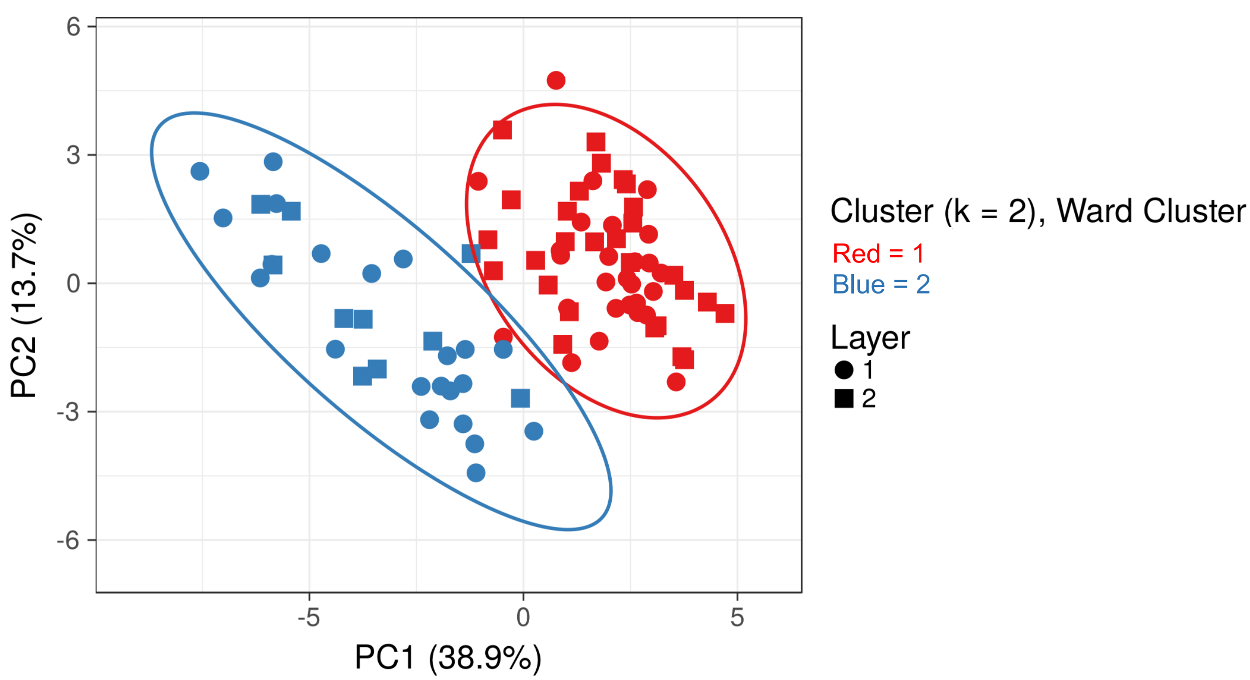


Table 12 Number of sherds by k-means and hierarchical cluster overlap and layer, (n = 87)

	Cluster	
Layer	1 *(n = 55)*	2 *(n = 32)*
1	27	22
2	28	10

Figure 11 demonstrates that the chemical makeup of Cluster 1 sherds varies less than that of Cluster 2 sherds in relation to PC1. 22 of 32 (68.8%) of the Cluster 2 sherds appear in Layer 1, while Cluster 1 sherds appear in roughly equal frequency in Layers 1 and 2 (Table 12). Like the principal component analysis examining all sherds, these data may also suggest a variety of transitions, including transitions to procurement/production practices that skewed toward the production of more chemically heterogenous pottery when comparing the centuries before and after the Spanish arrival in the northern Philippine highlands.

These data also contradict trends from previous research on northern Philippine pottery: expected results would include increased homogeneity following economic, social, and cultural change(s) toward more centralized economic activities, including craft production (Stark et al. 2000; Acabado et al. 2017).

Despite a relatively small sample size, the above analyses suggest some sort of shift in pottery procurement and production that resulted in more chemically heterogeneous ceramics in Old Kiyyangan Village during the Spanish colonial period than in the centuries before.

VII. Discussion & Conclusion

Though little research has been done on production standardization of specifically pre-Spanish and/or early modern Ifugao ceramics, previous ethnoarchaeological work has demonstrated a relationship between intensifying agricultural production, centralization of labor organization, and ceramic specialization in the northern highland Philippines (Longacre 1999;

Stark et al. 2000). Despite this trend in the region, coefficient of variation value analysis for the sampled Old Kiyyangan Village sherds shows no clear trend of increased standardization from the pre-Spanish to the early modern periods.

Bearing in mind a very small sample size, some data seem to suggest an increase in pottery thickness variation over time, in line with conclusions drawn from the analyses of another sample of Old Kiyyangan Village ceramics (Acabado et al. 2017). The trend toward increasing variation may suggest several phenomena, such as a decentralization of pottery production during a period of increased agricultural intensification or an increase in the number of pottery producers brought on by population growth/immigration from the lowlands catalyzed by the Spanish colonial presence (Acabado 2018). Possible contributing factors to this divergence may include: the role of the Ifugao rice terrace systems in the organization of labor; the role of lowland immigrants as a new labor source; or the relative stability of ceramic manufacture technology of the Ifugao since the AD900s (Acabado et al. 2017).

Future research—particularly analyses of a larger sample size of Old Kiyyangan Village ceramics or comparative energetics studies of other highland Philippine wet-rice agricultural systems—may provide useful evidence for discerning the most important contributing factors to the relationship between agricultural intensification and possible changes in craft production in the early modern Ifugao context.

Though this project is one of the first to apply insights of LA-ICP-MS analysis to the procurement/production of pre-Spanish and/or early modern Ifugao ceramics, previous research has demonstrated that other highland Philippine groups' ceramic procurement practices are very responsive to economic and cultural factors and skew toward homogeneity over time (Stark 1995; Stark et al. 2000). Initial results from principal component analysis of element abundances found in the fabric of sherds excavated from Old Kiyyangan Village complicate this trend: sherds' chemical heterogeneity increased over time. This may be a function of changes in sourcing (such as new geological sources) or production (such as more numerous and diverse potters resulting from population growth over time).

Unlike the continuities in Ifugao ceramic production discussed via coefficient of variation above, these changes in chemical makeup may indicate a reactivity of crafting practices within contexts of dramatic social change. However, geological reference materials may be useful for the further examination of Ifugao ceramic procurement practices because the geology of a region determines the possible resolution of analysis of resource procurement zones (Triadan 2018). For example, if ceramic sources are largely homogenous across Ifugao province, then the amount of LA-ICP-MS data (from both natural and archaeological sources) needed to discern significant differences in element abundances would increase dramatically. Unfortunately, due to the COVID-19 pandemic, geological reference materials have been impossible to find or access outside of the Philippines. Despite these limitations, the LA-ICP-MS data point to several elements as potential areas of further research because of their very low (in the cases of arsenic, boron, and lanthanum) or very high (in the cases of titanium, phosphorus, and iron) mean concentrations (Table 1).

Further study of pre-Spanish and colonial Ifugao procurement of raw materials for pottery and pottery production would benefit greatly from larger sample sizes, ideally reaching the minimum threshold of at least 30 sherds per class being analyzed (Longacre et al. 1988; Rice 1989). Despite sample size limitations, this project provides a fascinating window into the tension between continuities and transitions in Ifugao ceramic procurement and production that persisted through centuries of dramatic social and economic transformations.

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