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Geochemical soil analysis of sequential ritual and residential floors from the Maya site of Holtun

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ABSTRACT

This research elucidates the changing function of some of the earliest types of monumental architecture in the Maya world, the E-Group, using ICP-MS soil chemistry analysis of associated floor surfaces at the site of Holtun, Guatemala. E-groups are architectural assemblages first appearing during the Middle Preclassic period that are associated with public, ritual activities, such as marking important celestial and agricultural events. Our methodology targeted sequential, stratigraphic plaza floors in the E-Group compound at Holtun to examine changing activities through time. Residential patio surfaces were also sampled as a comparison to public, ritual activity. Our results suggest that activities related to food production and consumption are visible in sequential plaza floors of the E-Group, and the locations of some of these activities changed over time. Moreover, activities and locations revealed through soil chemical analysis also differed somewhat from those in residential patios, suggesting different patterns of use in public versus private spaces.

1. Introduction

An exploratory soil sampling and analysis program was carried out on exterior floor surfaces at the Maya site of Holtun, Guatemala in 2014. The goal of this program was to examine the feasibility of performing rapid, large-scale soil chemistry sampling and analyses from samples obtained directly from sequential plaster plaza (associated with public architecture) and patio (associated with residential architecture) floors at the site. To accomplish this, 38 test units were excavated alongside 46 auger probes over seven perpendicular transects in one plaza and two patios over the course of two weeks, for a total sampled area of 1541 m^2. In contrast to similar soil geochemistry studies carried out in the region, which have tended to focus on intensive sampling of a single plaza or domestic surface (i.e., Cook et al., 2006; Fulton et al., 2017; Kovacevich et al., 2004; Wells, 2004), our study instead aimed to obtain a broad perspective of a number of surfaces spread both horizontally and vertically at the site in order to identify changes over time and across space on a large scale and within a limited timeframe (see also LeCount et al., 2016; Simova et al., 2018). A total of 269 soil samples were collected from seven plaster floor surfaces (some consecutive stratigraphic floors), allowing us to conduct a rapid examination of how the inhabitants of Holtun utilized multiple living surfaces over time.

Similar studies in the Maya area have been able to detect differences in ritual vs. elite domestic activities in plazas (Wells, 2004; Wells et al., 2007), craft production (Cook et al., 2006; Kovacevich et al., 2004; Wells et al., 2000); building paint (Lamoureux-St-Hilaire et al., 2019; Wells et al., 2000), and feasting (Wells and Urban, 2006; Wells, 2004). Others have focused on open spaces between domestic structures and found that these spaces were used as well as domestic patios for everyday activities (Fulton, 2019). LeCount and colleagues (2016) found spatially discrete activities in an elite administrative structure at Actuncan, Belize. Some studies have been able to link midden contexts

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with on-floor activities in plazas and domestic structures (Wells, 2004; Wells et al., 2000). Lamoureux-St-Hilaire et al. (2019), for instance, found activities related to food and craft production, distinct pathways kept clean of activity and debris, as well as probable locations of nighttime illumination in a regal palace at La Corona, Guatemala. Studies have even been able to detect chemical signatures of ancient activities in submerged salt works (Sills et al., 2016). This study will add to this body of research by examining chemical signatures in sequential exterior floors in both public and private spaces, with a focus on the function of some of the earliest monumental architecture at sites in the Maya region.

2. Site background and research questions

Since 2010, Brigitte Kovacevich and Michael Callaghan with Patricia Castillo and later Karla Cardona as co-director and Rodrigo Guzmán as cartographer have been conducting fieldwork at the Maya site of Holtun, Guatemala (Fig. 1; Cardona et al., 2016, 2017; Kovacevich and Cardona, 2015; Kovacevich et al., 2010,2011,2014) in an effort to investigate the development of social inequality during the Middle Preclassic period (900–150 BCE). Our central hypothesis has been that social inequality developed with the use of both inclusive and exclusive political strategies by emergent elites. In this study, we present evidence from recent work at Holtun in support of testing our hypothesis, specifically focusing on analysis of chemical residues in soils associated with sequential floors within plazas and patios surrounded by both residential and monumental architecture. Holtun was founded circa 800 BCE with a focus on communal ritual activity that was, at least in part, the pathway for incipient social divisions during the Middle Preclassic period and could be partially determined by analysis of chemical residues in associated plaza floors that may contain evidence of feasting and other rituals.

The archaeological site of Holtun, Guatemala is appropriate for studying the development of social complexity and its relation to communal ritual as it was heavily occupied during the Preclassic period (800 BCE-AD 300 for Holtun specifically), with subsequent occupation in the Late and Terminal Classic (AD 550–900) after a probable depopulation during the Early Classic (AD 300–550). Preclassic period plaza floor contexts are well preserved and relatively easily accessible. The site is situated approximately 35 km southwest of Tikal and 12.3 km to the south of Yaxha and was eclipsed by its growing neighbors by the Classic period. The formal site consists of a monumental epicenter built atop a karstic hill positioned along a northeast-southwest axis. According to the most recent mapping at the site, the epicenter consists of 14 architectural groups and 86 structures all showing evidence of stone construction. Major monumental architecture consists of a Middle Preclassic E-Group (often interpreted as celestial observatories; see below and Doyle, 2012), Late Preclassic Triadic Group (a type of monumental ritual pyramid), ballcourt, wall-lined causeway, and various elite residential patio groups with masonry architecture.

A major focus of exploration in Holtun Archaeological Project (HAP) field seasons was an architectural assemblage called an “E-Group” by Mayanists (see for example Chase et al., 2017). Excavations at Preclassic Maya sites in Guatemala, Mexico, and Belize have consistently shown the ritual importance of these compounds. An E-Group consists of a public plaza created by the construction of a radial or square-shaped structure on its west side and a long, low range structure on its east side (Fig. 2). These architectural groups owe their name to the first of these compounds mapped and excavated in the 1920s at the site of Uaxactun, Guatemala, which was located in Group E of the site and was named for its location (Ricketson and Ricketson, 1937). E-Groups are among the earliest type of monumental architecture constructed at lowland Maya sites and date as early as the Early Middle Preclassic

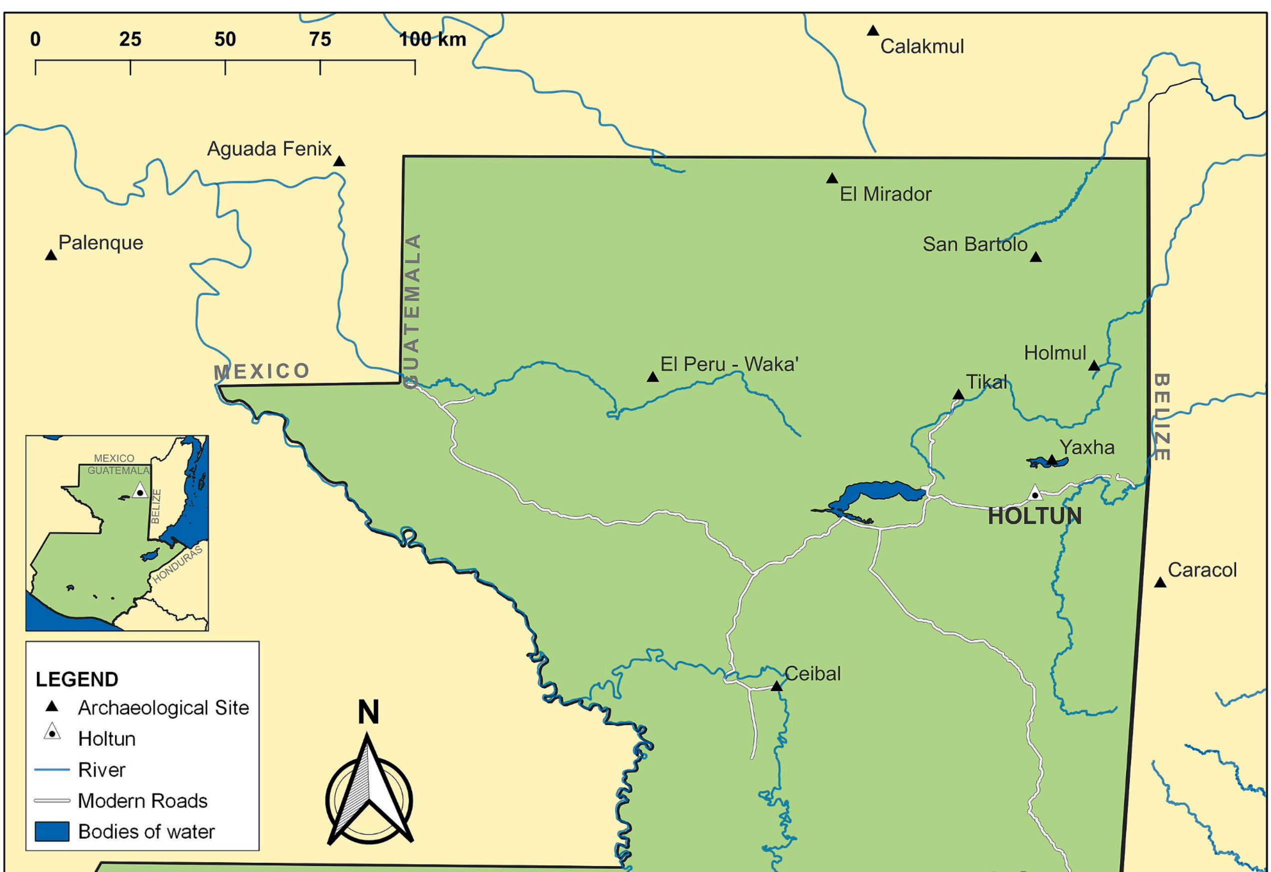

Fig. 1. Map showing the location of Holtun (map created by Rodrigo Guzmán).

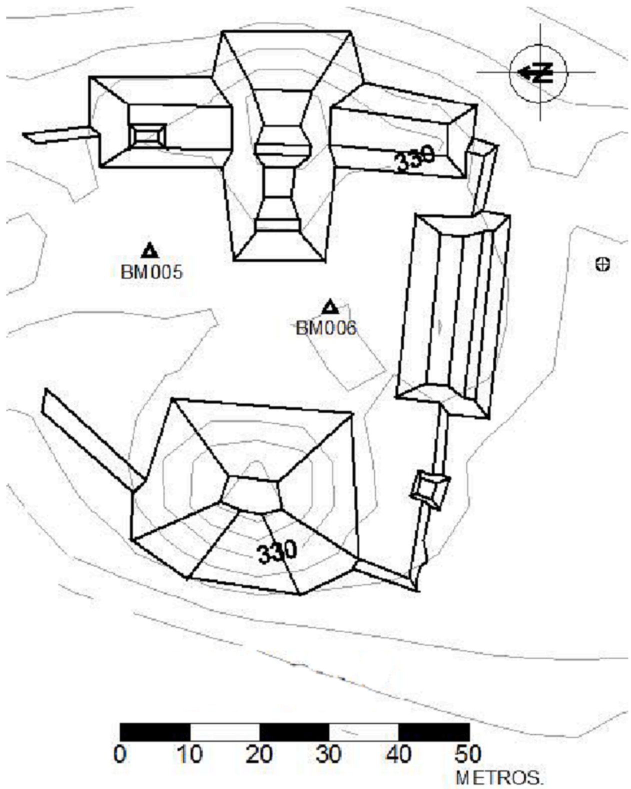

Fig. 2. "E-Group" architectural complex at Holtun with eastern range structure and western observational structure (map by Rodrigo Guzmán).

period at ca. 1000 BCE (Inomata et al., 2013). They appear to have been a center for ritual activity, evidenced in the archaeological record by the burial of individuals and objects in the form of caches and offerings in their plazas and structures. These objects include finely crafted goods made from exotic materials such as jade, shell, and ash-tempered ceramics. They sometimes include the placement of these objects in sacred cross-shaped "cosmograms," or perceived maps of the Maya universe as seen at the sites of Seibal (Smith, 1982; Inomata et al., 2013) and Cival (Bauer, 2005; Estrada-Belli, 2006, 2010) in Guatemala, as well as at Holtun (Callaghan et al., 2017).

At first thought to be related primarily to solstice observation and seasonal equinoxes with an observational structure in the west and a range structure in the east where the sun can be seen to rise (Blom, 1924; Ricketson, 1928a,1928b), more recent investigations of E-Group compounds trace a pattern of changing functions beginning in the Middle Preclassic period as celestial observatories (Aveni, 2003; Aveni and Hartung, 1989; Aimers, 1993; Aimers and Rice, 2006, and cf. Šprajc, 2021; Šprajc et al., 2023), but transforming through time into places of calendrical (Aimers and Rice, 2006) and agricultural commemoration (Aimers and Rice, 2006; Cohodas, 1980), ancestor veneration (Chase and Chase, 1995; Laporte and Fialko, 1995), and loci of regional political power (Laporte, 1993). As Ashmore (2015:318) points out "astronomic measurement and cultural contingency can and do enrich our understanding of the celestial landscape of the ancient Maya," despite possible changes in function through time and regional differences. These studies reveal a pattern in E-Group function beginning in the Late Middle Preclassic period in which a place of public ritual was rapidly transformed into a space of hierarchically organized, yet community focused ritual power, and transforming once again in the Terminal Preclassic period into a place for worship of specific elite lineages, which may have given rise to the dynastically organized political landscape of the Classic period (AD 300–830). It is this pattern of transformation from communal public ritual to specific ancestral lineages that we wished to test through investigation of the E-Group plaza and adjacent residential groups at Holtun.

A gap in our understanding exists in the area of the actual activities that transpired in the open plazas associated with E-Groups. It has been argued that their purpose and function changed over time (Aimers and Rice, 2006; see also Chase et al., 2017), but did this also correspond to activities carried out in plazas? Were activities in these plazas restricted to elites or did they include larger segments of the population? Soil chemistry analysis is uniquely suited to address some of these questions as excavations of the structures alone often provide only a window to elite activity, whereas a plaza may include remnants of the participation of larger groups and can record change through time with sequential stratigraphic floors.

Excavations in the Holtun epicenter suggest household settlement and ritual activity was focused around the E-Group during the Middle Preclassic period and this was the first monumental construction and elite residential area at the site at ca. 800 BCE. Group F (the location of the E-Group) appears to be the result of the oldest and largest construction activities at Holtun (Fig. 3). Patio A served as a platform for Middle Preclassic period elite households located adjacent to the E-Group compound in Group F Patio B. This is what is frequently labeled the "acropolis" when associated with E-Groups (see also Clark and Hansen, 2001; Laporte, 2001). E-Group ritual structures frequently, but not always, have these residential groups directly adjacent to the ritual structures located to the north. These have been interpreted as a residence for ritual specialists and/or emergent elites (Clark and Hansen, 2001). Radiocarbon and stratigraphic analysis from HTN 1–1 (a 2 × 2 m test pit) excavated into Group F Patio A revealed a sequence of Middle Preclassic period plaster floors and deep construction fill of more than 4 m dating between 600 and 400 BCE (2489, 2469, 2504, and 2500 uncalibrated BP from HTN 1–1-12, 13, 14, and 15 respectively; see Kovacevich et al., 2011). The residential structures and patio were built up during the Middle Preclassic period to reach the level of the E-Group, which was the highest point of possible settlement at the site. We aimed to sample the sequential patio floors of this residential group in order to compare and contrast elemental concentrations and patterns with the more public E-Group plaza.

The patio floors of Group D, another elite residential group, were also targeted for sampling. This is a residential group located outside of the E-Group and the Middle Preclassic ceremonial core but does have evidence of elite lineage and ritual activity (Kovacevich et al., 2011). Here, we wished to compare the chemical signatures both with that of the E-Group and its adjacent residential group to see if activities were different and/or were possibly more or less restricted.

Our aim was to see if we could determine change through time in activity and use of these patio (domestic) and plaza (public) floors. We expected to find that communal ritual was important in the early stages of the development of social hierarchy. Similar studies have been able to detect differences in ritual vs. elite domestic activities in plazas (Wells, 2004; Wells et al., 2007). Our results are somewhat exploratory in nature but are some of the first to address change through time (see also Simova et al., 2018) and the first to investigate plaza and patio activities through soil geochemistry of E-Groups and associated residential structures. We used an experimental sampling strategy of perpendicular transects to sample a large number of floors that would also reduce the amount of processing time and still yield empirical results. This methodology of sampling sequential floor surfaces could be utilized in the Maya region and beyond.

3. Materials and methods

Methods used to collect soils included direct collections from excavation units and the use of an auger probe and a soil corer. All instruments used to collect soils were made of stainless steel. An AMS telescoping auger probe consisted of a 2.25 in-wide bucket that extracted roughly 10 cm of soil with each probe. An Oakfield soil sampler was

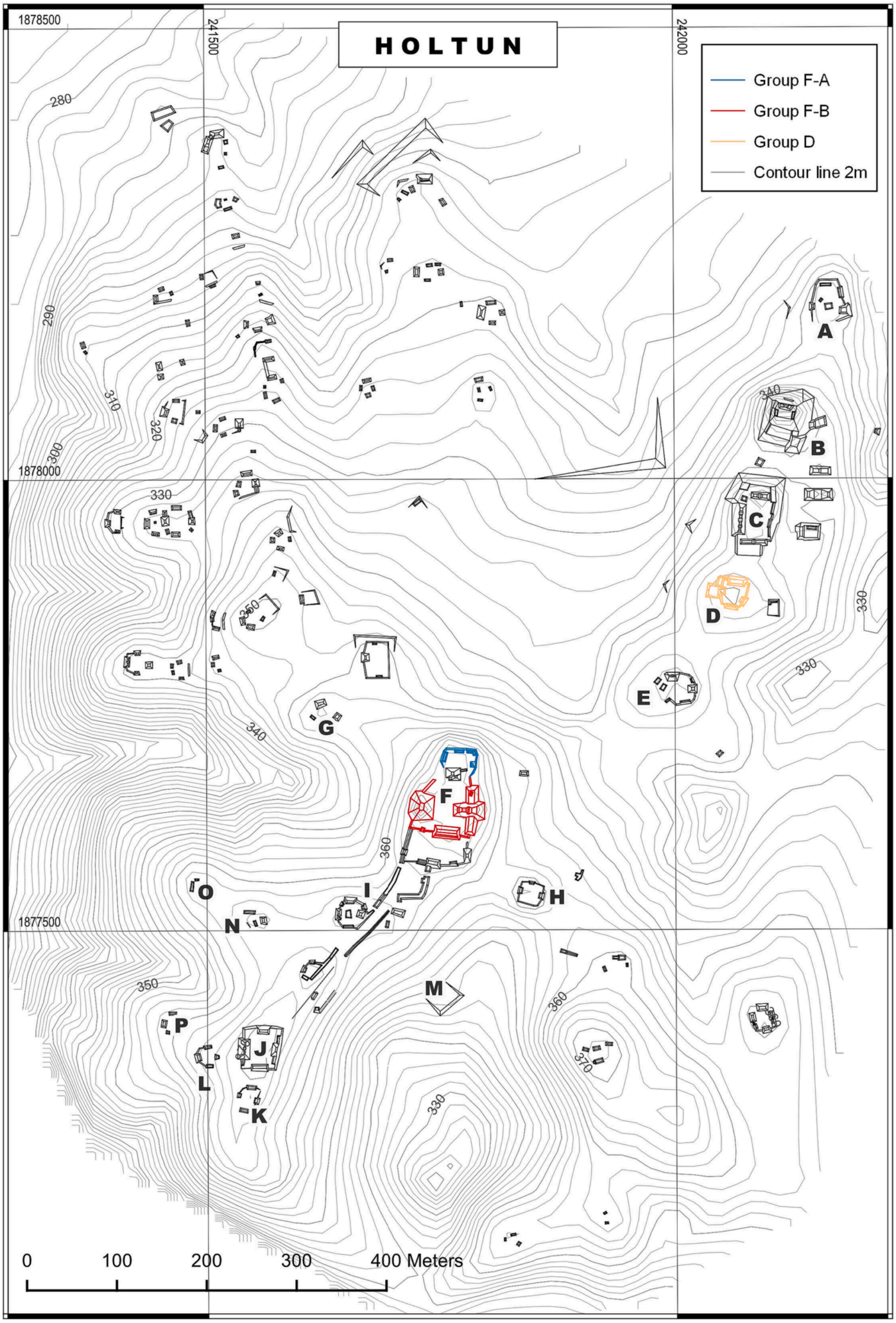

Fig. 3. Map showing the epicenter of Holtun with the sampled plazas and patios highlighted. The "E-Group" Plaza (FB) is in blue, the associated "acropolis" residential patio (FA) is in red and the residential patio of Group D is in yellow (map by Rodrigo Guzmán). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

used to collect samples from excavation unit walls and was 0.875 in wide and 21 in (53.34 cm) long. Roughly 50 g or 2 oz of soil was collected for each sampled location. Samples were placed directly into sterile polyethylene bags.

Exterior floors sampled included those of Group D, Group F-B, and Group F-A (Fig. 3). These plazas and patios were selected to test the various methods of collection across varied settings. Elite, domestic and ritual activities are expected to be represented in these contexts. Preclassic and Classic periods are both represented. Multiple plaster surfaces were identified and sampled, with four floors identified in Patio F-A (FA1 – FA4), three in Plaza F-B (FB1 – FB3), and one floor in Patio D. The lime plaster floors sampled as part of this study consist of three major components: binders such as clay or lime, aggregates like sand and crushed rock, and ash (see LeCount et al, 2016: 455 for a detailed explanation of these). The creation of lime plaster requires substantial amounts of plant or volcanic ash, which is added to calcinated limestone to produce a mixture that when hydrated solidifies into a stable surface. We observed no visible macroscopic differences in the color or composition of the plaster floors across the three sampled plazas. Most of the pH values for plaster floors range from 8 to 8.5, while those of samples obtained from other contexts have much lower values of 6.5–7.7.

A total of 261 soils samples was collected. Of those, 116 were from excavation, 65 from auger probes, 67 from soil coring in profiles, 5 from special contexts associated with a primary burial. Additionally, we collected 8 control (background) samples from locations within the site boundary but believed to not have been occupied in the past. These samples were chosen to represent the signatures of culturally sterile soil in adjacent areas and were generally characterized by clayey soils. A total of 38 units were excavated and sampled. A total of 46 auger probes were completed, including controls.

Instead of collecting samples along a grid pattern at regular intervals (Wells, 2004, 2010), we attempted to collect samples in parallel transects across the east–west and north–south axes of each plaza at intervals of 1 m. This was done to cut down on the amount of time and excavation required in the field as well as the amount of processing time in the lab. The E-Group plaza alone is quite large at more than 1700 m^2 and would require extensive sampling and excavation to fully sample along a grid, much less adding other residential patios to the sample. We hoped to determine if this type of sampling strategy could still produce meaningful preliminary results and serve as a guide for future investigations.

Sample extractants were analyzed for major elemental chemistry at the SMU Aqueous and Soil Chemistry Research Laboratory. Briefly, samples were diluted with 5% v/v trace metal grade HNO_3 and 18MΩ DDI water to within the range of calibrant standards. All samples, extraction blanks, instrumental blanks, and quality control samples were measured in triplicate on a Thermo-Fisher XSERIES 2 inductively coupled-plasma mass spectrometer. A total of 28 elements were characterized by ICP-MS as part of this study: Na, Mg, Al, P, K, Ca, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Kr, Rb, Sr, Mo, Ag, Cd, Au, Ti, Pb, Th, and U. Elements of atomic weight ≤K were run in standard mode while elements of higher atomic weights were run in CCT-KED (collision cell technology with kinetic energy discrimination) mode. Averages of raw measurements (counts per second) were converted to concentrations (parts per million) using a calibration curve of in-house multi-element standards produced from a certified stock solution.

4. Results

Elements were removed from consideration if extraction blank values fell within the sample measurement range. We removed calcium from our analyses because it is a primary component of the limestone bedrock for the area and its variation is environmental rather than cultural. Additionally, we chose the elements that exhibited variation beyond one standard deviation, since these would contribute to the creation of distinct principal components. Elements with little to no significant variation would likely all load onto a separate principal component that can only be interpreted as consisting of elements whose variation is non-significant (i.e., without any environmental or cultural interpretation). Summary statistics of the geochemical data for the elements of interest for this study across all identified floor surfaces are presented in Table 1 in parts-per-million (ppm). Summary statistics of the geochemical data obtained from the control samples are similarly presented in Table 2. In order to better compare the distribution of the archaeological samples data across space and time we converted ppm values to base-10 logarithms and plotted these values in a boxplot (see Fig. 4). Values across all of these elements are heterogeneous and characterized by outliers and extreme outliers, which is often indicative of meaningful patterning due to anthropogenic inputs into the soil matrix (see Wells et al., 2007). Importantly, the element concentrations obtained from the archaeological samples far exceed the values obtained from the control samples in our study, with few exceptions (i.e., Fe).

Table 1
Summary statistics for geochemical data of the archaeological samples. Coefficient of variation (CV) = St. Dev./Mean.

	Min	Max	Mean	SD	CV
pH	7.1	8.5	7.9	0.3	0.0
Na	0.00	1221.86	13.67	121.46	8.89
Mg	0.00	156.48	23.16	23.64	1.02
Al	0.00	377.47	7.16	46.90	6.55
P	0.00	73.51	3.81	10.55	2.77
K	0.00	87.61	2.04	10.44	5.11
Mn	0.84	41.19	3.86	4.62	1.20
Fe	0.00	16.23	1.56	2.12	1.36
Zn	0.00	4.82	0.38	0.63	1.68
Sr	1.34	30.81	2.47	2.93	1.19
Ti	0.00	0.06	0.05	0.01	0.15

Table 2
Summary statistics for geochemical data of the control (background) samples. Coefficient of variation (CV) = St. Dev./Mean.

	Min	Max	Mean	SD	CV
pH	6.6	8.2	7.4	0.6	0.1
Na	0.00	0.00	0.00	0.00	N/A
Mg	0.00	39.77	10.24	15.70	1.53
Al	0.00	0.00	0.00	0.00	N/A
P	0.00	0.00	0.00	0.00	N/A
K	0.00	0.00	0.00	0.00	N/A
Mn	0.77	37.16	11.55	11.47	0.99
Fe	0.30	18.08	5.21	6.07	1.17
Zn	0.00	4.60	0.50	1.36	2.71
Sr	1.69	4.99	3.16	0.83	0.26
Ti	0.05	0.06	0.06	0.00	0.05

Following previous studies in Mesoamerica and elsewhere (for recent examples see Fulton, 2015; Fulton et al., 2017; Lamoureux-St-Hilaire et al., 2019; LeCount et al., 2016; Middleton et al., 2010; Mixter, 2016; Simova et al., 2018; Wells et al., 2017), the Log10 standardized geochemical data were analyzed with principal components analysis (PCA) using a covariance matrix in the SPSS 27 software package. The component loadings were rotated using Varimax rotation with Kaiser normalization in order to present clearer associations between elements and components. The factor scores calculated by the PCA for each sample were imported into ArcGIS Pro 2.4.2 where they were spatially referenced and projected onto the map of Holtun using graduated colors via the Jenks Natural Breaks method and by taking into account the full range of values present within each component in order to facilitate the visual comparison of values within each identified floor. This particular method of analysis and presentation of results is best for addressing the complex geochemical signatures of human behavior (LeCount et al., 2016), particularly the associations of various element concentrations with particular human activities (Barba, 2007; Barba et al., 1996; Fulton, 2019; Fulton et al., 2017; Lamoureux-St-Hilaire et al., 2019; LeCount et al., 2016; Middleton et al., 2010; Mixter, 2016; Murakami et al., 2018; Wells et al., 2007). In addition, and given the preliminary nature of our data, this method allows us to make broad interpretations on a limited yet spatially and chronologically complex geochemical dataset.

The PCA identified four components accounting for approximately 76% of the variance of the elements obtained through ICP-MS (Table 3). Component loadings with correlations greater than 0.300 were considered as contributing substantially to the variance of a particular component (Table 4).

Component 1 of the PCA is correlated strongly with three elements (Al, K, and Mg). Ethnoarchaeological and archaeological studies have shown elevated concentrations of K and Mg are associated with the

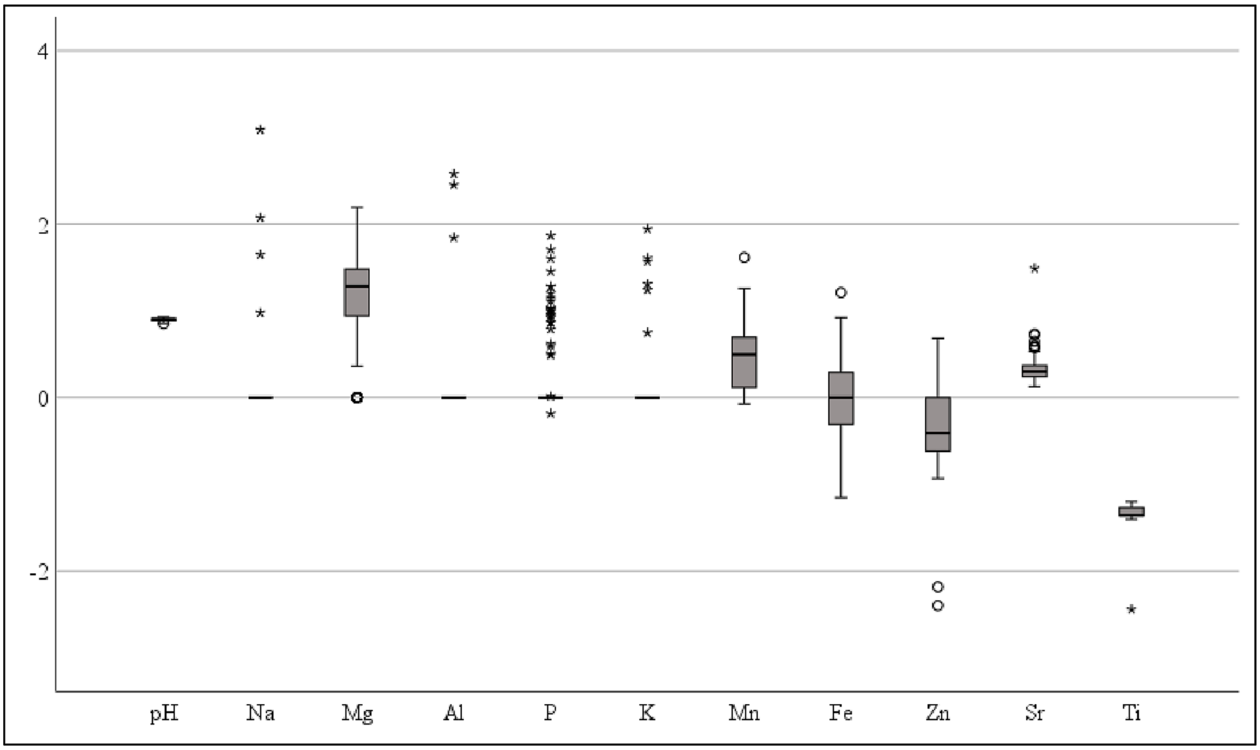

Fig. 4. Boxplot comparing the standardized (Log10) concentrations of 10 elements obtained from the archaeological samples. Open circles indicate outliers (values 1.5–3.0 × midspread) and asterisks indicate extreme values (greater than3.0 × midspread).

Table 3
Total variance of the PCA explained for the geochemical data from Holtun.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	0.451	28.296	28.296	0.451	28.296	28.296
2	0.296	18.549	46.845	0.296	18.549	46.845
3	0.257	16.129	62.974	0.257	16.129	62.974
4	0.203	12.715	75.69	0.203	12.715	75.69

Table 4
Rotated component matrix generated by the PCA of Holtun geochemical data.

Element	Rescaled Component			
	1	2	3	4
Al	0.886			
K	0.861			
Mg	0.432			
Zn		0.669		
Ti		0.381		
Sr		0.371		
Mn		0.344		
P			0.863	
Na			0.712	
Fe				0.962

deposition of wood ash and charcoal (Fernández et al., 2002; Middleton, 1998; Middleton and Price, 1996; Wells et al., 2007). Elevated Al concentrations may be the result of *in situ* burning, which thermally alters the clays present in the soil matrix (see Middleton et al., 2010: 186). Elevated Al levels are only present in three samples (in plaza floors D1, FB2 and FB3). It appears that this component is related to the deposition of wood ash, which can be indicative of fires used to prepare food (Middleton et al., 2010), though these could also have been used to create heat and light (see Gonlin and Dixon, 2018). Alternatively, this component might be related to the composition of the plaster floors themselves, whose creation requires large quantities of ash and charcoal.

The second component of the PCA is strongly positively correlated with a single element (Zn). High concentrations of zinc have been found associated with areas of human waste disposal, such as latrines (Middleton et al., 2010). This same component is moderately positively correlated to two elements (Sr, Mn) whose increased concentrations have been found to be associated with food preparation areas, which is a more likely activity to have taken place within an open plaza (Middleton et al., 2010). The third component of the PCA is positively correlated with P and Na, both of which are strongly associated with the deposition of organic byproducts, either as the result of food production or consumption activities (e.g., Barba, 2007; Barba and Ortiz, 1992; Fernández et al., 2002; Lamoureux-St-Hilaire et al., 2019; LeCount et al., 2016; Wells, 2004; Wells et al., 2007). Sodium has also been found to be associated with the deposition of wood ash (Fernández et al., 2002; Middleton et al., 2010; Wells et al., 2007). The fourth and final component derived from the PCA is strongly positively correlated with Fe, which is often associated with mineral-based pigments used for craft production or for ritual purposes (LeCount et al., 2016; Wells et al., 2000).

4.1. Plaza F-B, Floor FB1

Plaza F-B is the largest at Holtun and is the floor surface ringed by the site's E-Group. This plaza was chosen for sampling as it was a probable location for crowds to gather for communal ritual and to witness celestial events associated with the observational architecture. We hoped to gain knowledge of how these activities might have changed over time. Given the size of this plaza, we sampled it using one north–south transect and two east–west transects, for a total of 8 north–south and 10 east–west excavation units and 11 north–south and 11 east–west auger probes. A total of three plaster floors were identified in Plaza F-B. These floors likely date to the Middle Preclassic (600–300 BCE), Late Preclassic (300 BCE-AD 300) and Late Classic (AD 550–830).

The most recent plaster floor identified in Plaza F-B, FB1, dates to the Late Classic and is represented by a total of 35 soil samples (Fig. 5). Dating was determined by type:variety classification of pottery sherds above and below the floor. Elements associated with Component 1 have moderate concentrations throughout this plaza, particularly towards the central areas and away from the structures that ring it. Elements associated with Component 2 have high values near the northwestern corner of the plaza and overall low values elsewhere. Elements associated with Component 3 have high concentrations towards the central open area of the plaza, with low concentrations near the structures, particularly near and around the eastern structure. Factor 4 element concentrations in this plaza are among the highest in our dataset and are concentrated near the front of structures to the west and particularly the east side of the plaza.

4.2. Plaza F-B, Floor FB2

The second floor identified in Plaza F-B, FB2, dates to the Late Preclassic and is represented by a total of 20 soil samples (Fig. 6). Dating was determined by type:variety classification of pottery sherds above and below the floor. Component 1 element concentrations in this floor are highest near the western structure and in front of the southern structure, perhaps indicating the deposition of ash and charcoal in these areas. This distribution is different from that present in Floor FB1 in that these high values are localized instead of spread throughout a wider area. High values in the elements associated with Component 2 appear localized near the center of the plaza, as do Component 3 values. Similar to FB1, Component 3 values are low nearest the structures, indicating these areas were kept clean of the deposition of organic refuse. Component 4 values are also localized in this plaza floor and are highest near each of the structures ringing the plaza, indicating the deposition of iron-rich materials near the front each of these constructions.

4.3. Plaza F-B, Floor FB3

The third floor identified in Plaza F-B, FB3, likely dates to the Middle Preclassic and is represented by a total of 8 soil samples (Fig. 7). Dating was determined by type:variety classification of pottery sherds above and below the floor. All soil samples come from auger probes spread widely across the plaza. However, though dispersed, the geochemical data show high concentrations of elements associated with Component 1 adjacent to the western structure and very low concentrations of elements associated with Components 2 and 3 throughout the plaza. Elements associated with Component 4 have two localized high

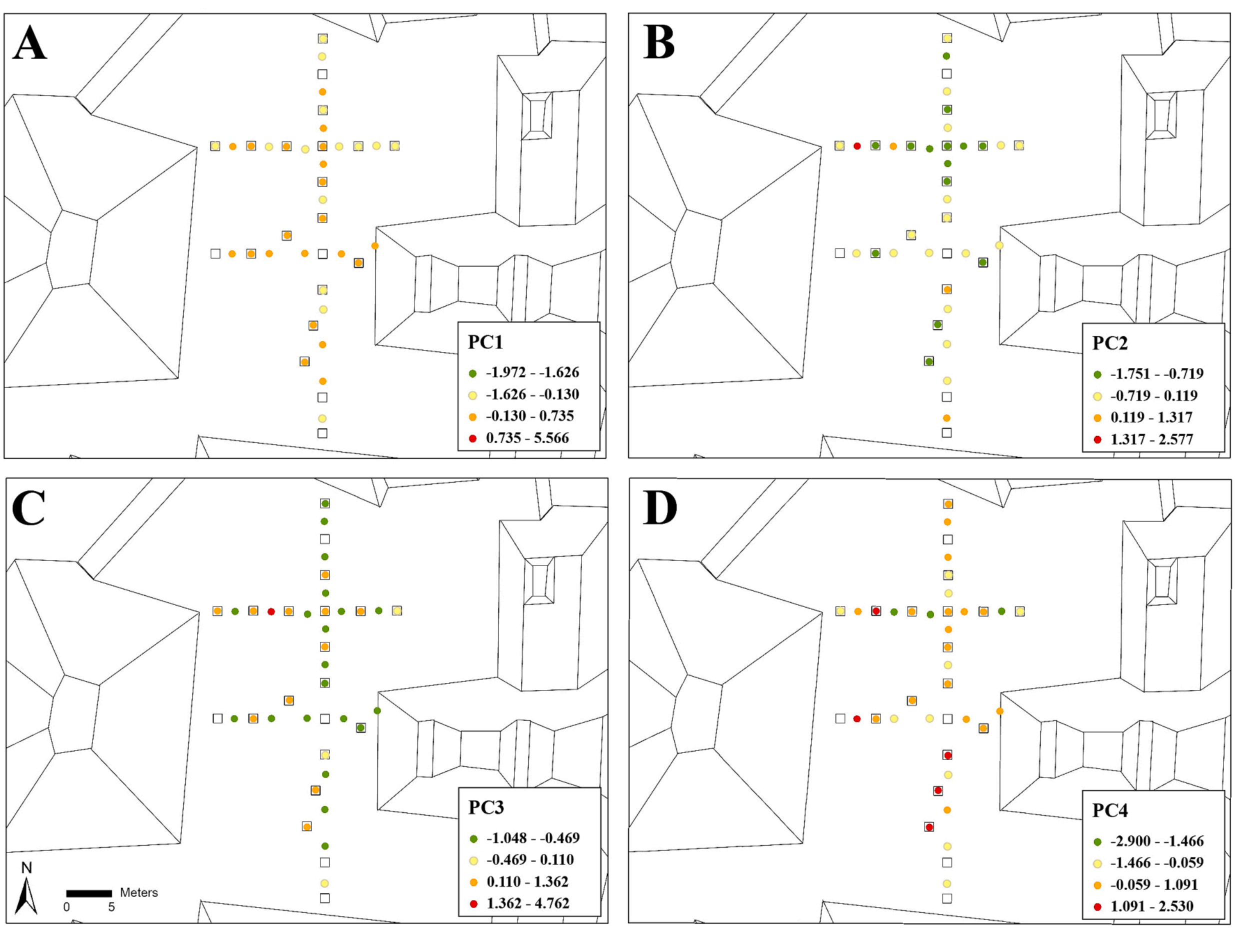

Fig. 5. a–d. Maps of the distribution of PC scores across Floor FB1 in Plaza F-B. Scores represent the presence above and below the mean for PC 1–4 throughout the site. Blank spaces indicate samples that were contaminated or not viable (Maps by Alejandro Figueroa and Rodrigo Guzmán).

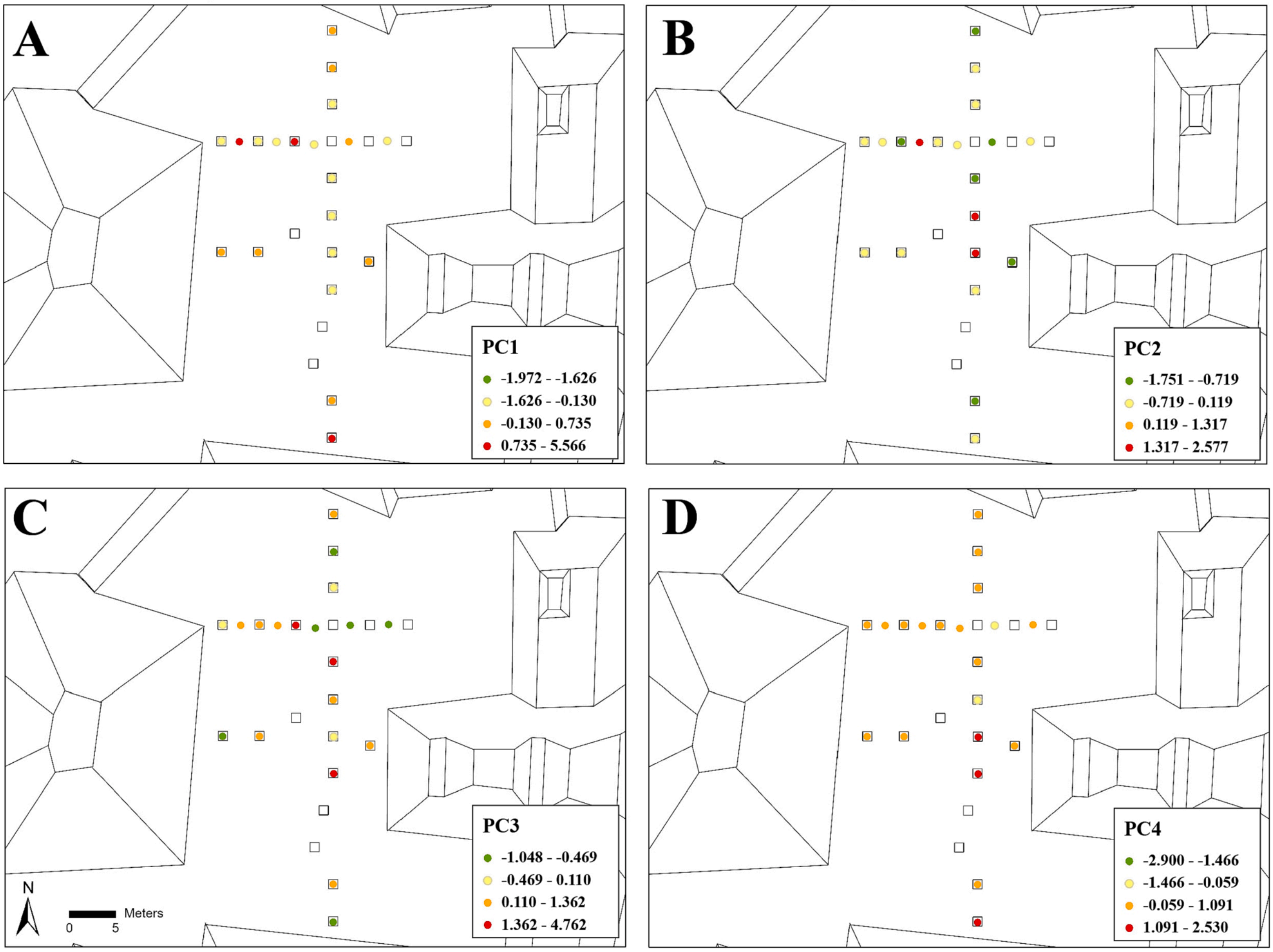

Fig. 6. a–d. Map of the distribution of PC scores across Floor FB2 in Plaza F-B. Scores represent the presence above and below the mean for PC 1–4 throughout the site. Blank spaces indicate samples that were contaminated or not viable (Maps by Alejandro Figueroa and Rodrigo Guzmán).

concentrations, one near the center of the plaza and the other near the western structure. Additional excavations are required to expand our understanding of these patterns.

4.4. Discussion Plaza F-B

The spatial distribution of our geochemical data in the E-Group plaza at Holtun suggests the localized deposition of wood charcoal and ash during the Middle and Late Preclassic and a more dispersed spatial deposition of this during the Late Classic. The deposition of organic byproducts, likely the result of food preparation and/or consumption activities, does not appear to have taken place during the Middle Preclassic, though this changed during the Late Preclassic, when these kinds of activities appear to have taken place near the center and western edges of the plaza—a pattern that continued into the Late Classic. These results contrast with those of Simova and colleagues (2018) who found higher levels of phosphorus (an indicator of generalized human activity) in earlier floors, decreasing through time, but did not find evidence of other elements associated with food consumption or preparation in the E-Group Plaza at Actuncan, Belize. Finally, the deposition of iron-rich materials, possibly pigments and other objects related to ritual, occurred throughout the occupation and use of this plaza near the structures that surrounded it, particularly the structures to the east and west. These results are interesting because it has been proposed that functions of E-Groups may have changed over time, which we see in some instances but not in others at Holtun. Central spaces during the Late Preclassic and Late Classic show lower elemental concentrations indicative of human activity, suggesting that this central area was either free of these activities, was such a high traffic area that chemical signatures were erased, or the spaces were cleaned at the conclusion of use (Wells et al., 2000). Either of these possibilities suggest that the central part of the plaza was a gathering area and/or a place that involved food preparation or consumption and was observed from the structures, where possibly more ritual activities were instead taking place. These results support those of earlier research (see Inomata et al., 2013:468) indicating a communal ritual function for E-Group plaza spaces, which were gathering places for residents engaged in commensalism likely related to rituals that took place in the backdrop of the surrounding structures. Our evidence suggests that soil geochemical analysis can help to identify varying use and function of E-Groups.

4.5. Plaza F-A, Floor FA1

Four plaster floors dating to the Late Preclassic and Middle Preclassic were identified in Plaza F-A, the residential patio directly north and adjacent to the E-Group monumental core (Fig. 8). Late and Terminal Classic period floors were present, but not well-preserved enough to sample in this case. This domestic patio was significantly built up to be equal to the height of the E-Group plaza during the Middle Preclassic (Kovacevich et al., 2011) and was probably inhabited by residents that were intimately involved in the rituals and activities that took place in the more public plaza. These floors were the best preserved of those sampled at the site and were easily identifiable during excavation and augering. Floor FA1, the uppermost and latest floor, dates to the Late

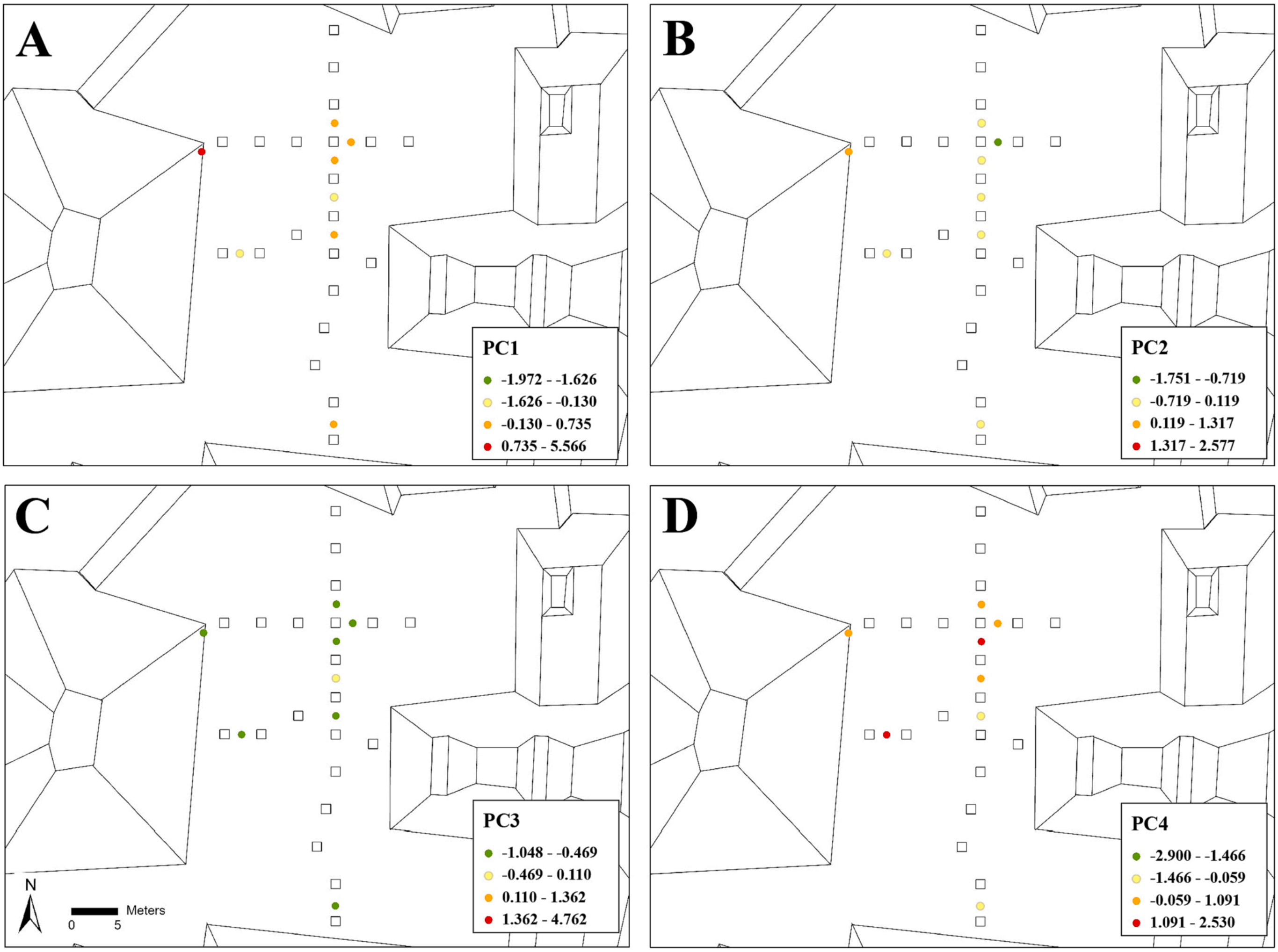

Fig. 7. a–d. Map of the distribution of PC scores across Floor FB3 in Plaza F-B. Scores represent the presence above and below the mean for PC 1–4 throughout the site. Blank spaces indicate samples that were contaminated or not viable (Maps by Alejandro Figueroa and Rodrigo Guzmán).

Preclassic period. Dating was determined by type:variety classification of pottery sherds above and below the floor as well as correlation to radiocarbon dates from contiguous stratigraphy in previous excavations in Plaza FA (Kovacevich and Callaghan, 2016). The floor was sampled through 3 north–south and 4 east–west excavation units and 4 north–south and 6 east–west auger probes. Of these, only 10 soil samples yielded adequate results for analysis.

Concentrations of elements associated with Component 1 in floor FA1 present a similar pattern to those of Plaza F-B in that they are overall low and widespread as opposed to localized in their distribution. Component 2 element concentrations are localized and high in front of the eastern and southern structures ringing this patio group and decrease significantly towards the center of the open space. Elements associated with Component 3 also present low throughout this plaza, with the exception of a high value near the center of this space. Component 4 element concentrations in this plaza are the lowest in our dataset, though there is a high localized concentration near the western side of the open space.

4.6. Plaza F-A, Floor FA2

The second plaster floor identified in Plaza F-A is also a Late Preclassic plaster floor. Dating was determined by type:variety classification of pottery sherds above and below the floor as well as correlation to radiocarbon dates from contiguous stratigraphy in previous excavations in Plaza FA (Fig. 9). The floor was sampled through 3 north–south and 4 east–west excavation units and 4 north–south and 6 east–west auger probes. Of these, only seven soil samples yielded adequate results for analysis. Elements associated with Component 1 have overall low concentrations in this floor, as do the elements associated with Component 2,with the exception of a high value on the western side of the plaza. Component 3 element concentrations are also relatively low. Elements associated with Component 4 are overall also low, with the exception of a high value near the front of the southern structure of this group.

4.7. Plaza F-A, Floor FA4

The third plaster floor identified in Plaza F-A, floor FA3, did not yield enough samples and is thus not considered in this analysis. The fourth and final floor in this plaza, FA4, is a Middle Preclassic plaster floor (Fig. 10). Dating was determined by type:variety classification of pottery sherds above and below the floor as well as correlation to radiocarbon dates from contiguous stratigraphy in previous excavations in Plaza FA. The floor was sampled through 3 north–south and 4 east–west excavation units and 4 north–south and 6 east–west auger probes. Of these, only seven soil samples yielded adequate results for analysis. Elements associated with Component 1 are also low throughout this plaza floor. Component 2 element concentrations are high in the very center of the plaza. The concentrations of elements associated with Component 3 are also very low in this plaza. Similar to floor FA2, the concentrations of

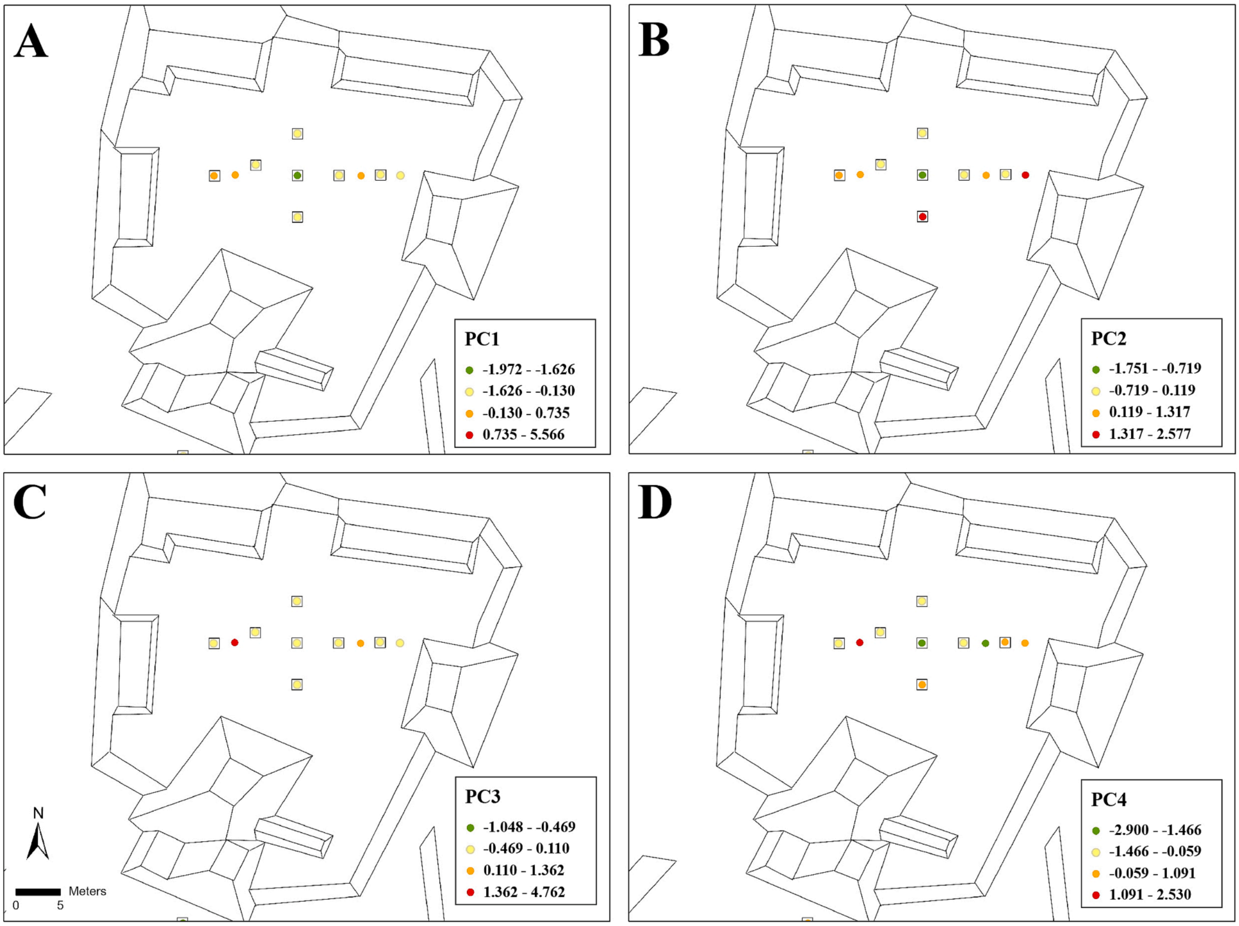

Fig. 8. a–d. Map of the distribution of PC scores across Floor FA1 in Plaza F-A. Scores represent the presence above and below the mean for PC 1–4 throughout the site. Blank spaces indicate samples that were contaminated or not viable (Maps by Alejandro Figueroa and Rodrigo Guzmán).

elements associated with Component 4 are high near the front of the southern structure of this group, with overall low values elsewhere.

4.8. Discussion Plaza F-A

Our geochemical data suggest few clear activities occurred in the domestic patio associated with the E-Group at Holtun. Charcoal deposition was low (as inferred through our geochemical analyses) throughout the history of use of this open space, as indicated by low overall Component 1 element concentrations. However, food preparation and consumption activities appear to have taken place in this open space, initially near the center of the plaza during the Middle Preclassic and then towards the eastern and western edges during the Late Preclassic. The concentrations of elements associated with Component 4, associated with the possible deposition of iron-rich materials, either as the result of craft production or ritual activity, did show some localized patterns over time, particularly in the southern end of this plaza.

4.9. Plaza D, Floor D1

Plaza D was sampled to provide a comparison to the activities observed in the elite residential group associated with the first monumental architecture at Holtun (Fig. 11). Plaza D likely also was home to high status individuals who did not have direct access to the E-Group. A burial of an aged individual with a partial human femur carved with a mat pattern suggests high status for the residents of this group (Kovacevich et al., 2011). A single highly eroded and fragmented floor dating to the Late Preclassic was identified and partially sampled in Plaza D. Dating was determined by type:variety classification of pottery sherds above and below the floor. This floor was sampled through 5 north–south and 6 east–west excavation units and 5 north–south and 6 east–west auger probes. Of these, only 13 soil samples yielded adequate results for analysis.

Elements associated with Component 1 have moderate concentrations throughout this plaza, indicating the deposition of wood ash or charcoal, particularly towards the northern end of the plaza as well as near where the burial was identified. Component 2 element concentrations are highest in this plaza than any of the others we sampled in our study. Values are high throughout the central, southern and western areas of the plaza. In contrast, however, the concentrations of elements associated with Component 3 are low throughout this plaza, providing equivocal results as to what sorts of activities were taking place within this open space. Lastly, Component 4 element concentrations are relatively high in the central and eastern portions of the plaza, including near where an individual was buried.

4.10. Discussion Patio D1

The activity present in the single cohesive floor associated with this residential patio seem to revolve around the deposition of ash and iron-rich mineral products in the northern, central, and eastern portions of this plaza space. The association of these values with the burial of a high-status individual points towards ritual activity taking place in this plaza during the Late Preclassic, though additional investigations are necessary to provide better interpretations of these results. Very high Component 2 values suggest this plaza floor served as a latrine space or as a space for the preparation of food, though low Component 3 values (associated with organic byproducts) conflict with this interpretation.

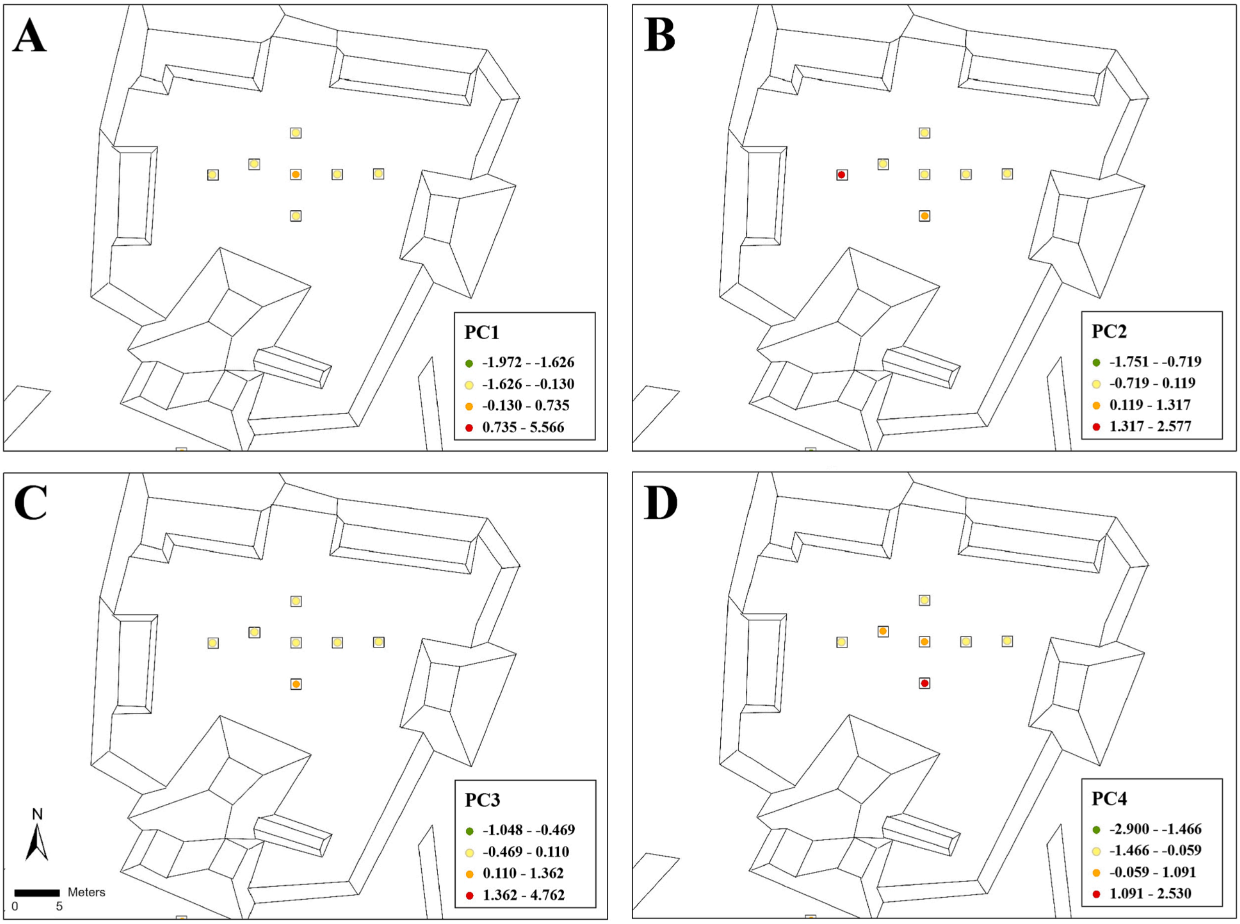

Fig. 9. a–d. Map of the distribution of PC scores across Floor FA2 in Plaza F-A. Scores represent the presence above and below the mean for PC 1–4 throughout the site. Blank spaces indicate samples that were contaminated or not viable (Maps by Alejandro Figueroa and Rodrigo Guzmán).

5. Conclusions

In general, Maya plaza and patio surfaces were often regularly swept clean of artifacts (e.g., Hayden and Cannon, 1983; Simova et al., 2018; Stanton et al., 2008). ICP-MS analysis of floor surfaces from open spaces from both public and private locations at Maya sites can give us clues as to how activities changed through time and across space when artifactual evidence is lacking. Results from this study have demonstrated that E-Group plazas can have well-preserved sequential evidence of soil chemistry resulting from human activity and that extensive human use of the plazas took place at Holtun throughout both the Preclassic and Classic periods, but the nature and location of the use likely changed and it may be different than the activity that takes place in domestic patios.

The geochemical data obtained from Holtun's E-Group complements that obtained in the course of a single prior study (Simova et al., 2018) in important ways. First, our data support the inference by Simova and colleagues that E-Group plazas were used for the preparation and/or consumption of food. While Simova and colleagues (2018) did not find direct evidence of food consumption and production, they interpreted its possibility indirectly through the presence of enriched P concentrations, which are generally indicative of human activity. Food preparation/consumption at the E-Group plaza at Holtun is indicated by high concentrations of elements correlated with PCA component 3. However, these activities appear to have only taken place during the Late Preclassic and Late Classic periods at this plaza and not so in the course its earliest phase of construction and use in the Middle Preclassic. Because our study was able to detect significant variation among a wider range of elements, we are also able to suggest that the E-Group plaza at Holtun was also used for many other activities, including the deposition of iron-rich minerals as part of craft production or ritual activities, particularly in front of the structures ringing this open space. Charcoal and wood ash were also at some point likely deposited in this open space, especially near the northwestern portion of the plaza, which could be the result of *in situ* burning. This shows that fires may have been created and maintained in this plaza throughout its long history of use, first in localized spots during the Middle and Late Preclassic periods and later in more widespread fashion during the Late Classic.

The two residential patios sampled in the course of this study suggest similar activities took place in these more restricted spaces of the city, though in different spatial configurations. Plaza F-A, the open space within the patio group adjacent to the Holtun's E-Group, seems to have been used to prepare and consume food, though at a much smaller scale and intensity as the E-Group plaza, as indicated by much lower concentrations of elements indicating the deposition of charcoal and wood ash and organic byproducts (Components 1 and 3, respectively). The southern portion of this plaza space was also used consistently over time for either craft or ritual activities that deposited mineral-rich (especially Fe) materials on its plaster floors. Additional research in this portion of the plaza might help to clarify how these activities were related to the status of the individuals inhabiting and using this space so close to the E-Group. The residential patio we sampled that is not adjacent to the E-Group, Plaza D, appears to not have been used for the preparation, consumption or discard of food or organic refuse. Instead, our geochemical data point to this space being used to deposit wood ash, charcoal, and mineral-rich materials, often associated with the burial of a high-status individual within this floor. This space thus appears to have been much more restricted in terms of the types of activities that took place within it, especially when compared to the open spaces

Fig. 10. a–d. Map of the distribution of PC scores across Floor FA4 in Plaza F-A. Scores represent the presence above and below the mean for PC 1–4 throughout the site. Blank spaces indicate samples that were contaminated or not viable (Maps by Alejandro Figueroa and Rodrigo Guzmán).

associated with or near the E-Group.

Our results show that individually distinguishable chemical signatures of human activity are preserved in multiple overlapping stucco floors within the plazas of monumental Maya centers. This research continues a recent implementation of soil chemistry analysis on Mesoamerican plaza and patio surfaces to determine activities and use of these areas as they were often swept clean and often have few associated artifacts. Our research for the first time includes samples from an E-Group plaza and associated "acropolis" residential patio. These findings preliminarily suggest a continuous function for the E-Group plaza surface as a food production and consumption area from the Preclassic through the Late Classic, though the location and intensity of these activities varied slightly over time. This study confirms that ritual associated with E-Group structures probably included commensalism and most likely that crowds gathered at the center of the plaza to witness and perhaps participate in events during the Late Preclassic period. This line of evidence supports our argument that power strategies during the Preclassic period were more inclusive, facilitating the gathering of large crowds in the E-Group Plaza to witness ritual events, accompanied by food production and consumption on the margins of the plaza. Access may have become more open in the Classic period, with food production and consumption activities more widespread, possibly facilitating the involvement of larger numbers of people that could have gathered there. This evidence is preliminary and needs to be corroborated with other findings. Simova and colleagues (2018) did find evidence of phosphorous, which is indicative of human activity in the E-Group plaza at Actuncan, Belize. Phosphorous can also indicate food production/consumption/deposition among other activities, but our results provide more corroborating evidence of food activity in E-Group plazas and continue to confirm the importance of commensality in the development of elite power strategies (McAnany, 2013).

This research shows the importance of using geochemical soil analysis to recognize regional variations in use and function of E-Groups, and further research at other sites can begin to fill in data about regional or site-to-site variation. These findings support the argument that all E-Groups are not alike and need further investigation (Doyle, 2012). These findings also suggest that a cross pattern of sampling can yield preliminary results that can be followed by more extensive sampling or other corroboration. While preliminary, these findings can be compared to other ceremonial plazas in the Maya area as well as further researched at Holtun itself.

Despite the insights offered by our results, the present study is limited by the rapid nature of our sampling strategy, which maximized the collection of samples across vertical as opposed to horizontal space. This strategy, however, takes into account the time and effort required to identify and expose plaza surfaces in monumental Maya sites, which are often covered by fill composed of large blocks of stone that are difficult to penetrate using traditional geoarchaeological equipment such as auger probes and soil corers. We recommend a similar sampling strategy to colleagues aiming to obtain an initial understanding of how activity surfaces such as stuccoed plaza floors were utilized over time, with the ultimate goal of obtaining a more detailed understanding of the distribution of human activity across each of these identified surfaces via a more intensive sampling strategy (i.e., Wells, 2010). Importantly, our research shows that multiple methods of sediment sampling (augering, coring, and excavation) can yield vertical deposits with distinct chemical signatures, suggesting that vertical leaching and cross-contamination is not a major issue in these types of deposits.

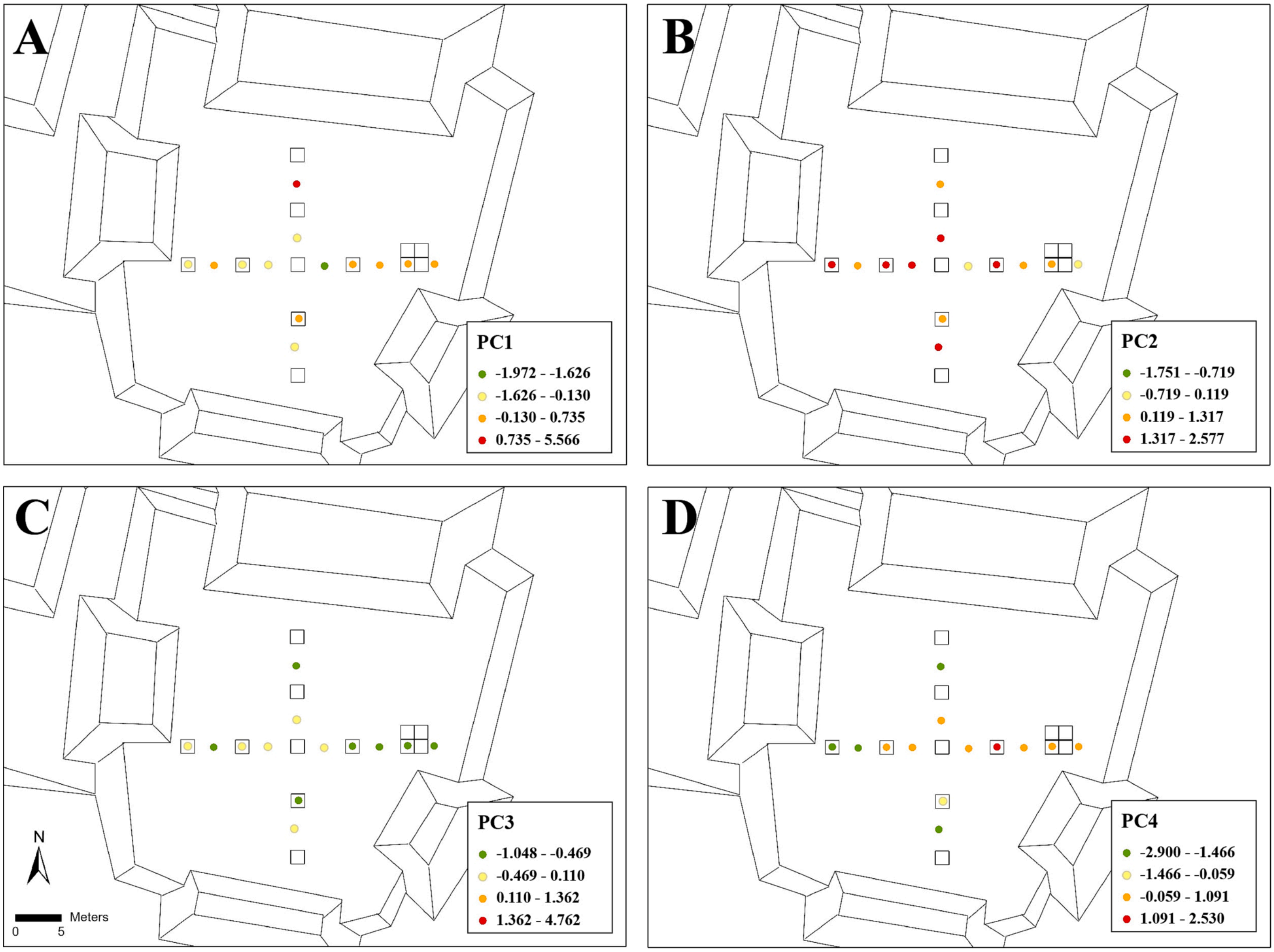

Fig. 11. a–d. Map of the distribution of PC scores across Floor D1 in Patio D. Scores represent the presence above and below the mean for PC 1–4 throughout the site. Blank spaces indicate samples that were contaminated or not viable (Maps by Alejandro Figueroa and Rodrigo Guzmán).

Our study, while preliminary, continues to shed light on the importance of conducting multi-elemental geochemical analysis of plaster surfaces in Mesoamerica as an additional proxy for human activity. Most importantly, this work demonstrates that: (1) rapid testing of plaza surfaces using a combination of text excavations and auger probes can yield results and guide future research, and; (2) overlapping plaster floors can maintain the fidelity of signatures of particular human activities, potentially providing archaeologists with a chronology of the use of these spaces over broad spans of time. These results are broadly applicable within Mesoamerica and beyond.

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Code availability

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Ethics approval

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Consent to participate

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Consent for publication

Not applicable.

CRediT authorship contribution statement

Whitney Goodwin: Methodology, Writing – original draft. **Alejandro Figueroa:** Writing – original draft. **Brigitte Kovacevich:** Writing – original draft, Conceptualization, Funding acquisition. **Michael Callaghan:** Writing – review & editing, Conceptualization, Funding acquisition. **Christopher Roos:** Writing – review & editing. **E. Christian Wells:** Writing – review & editing. **Melvin Rodrigo Guzman Piedrasanta:** Conceptualization. **Karla Julieta Cardona Caravantes:** Writing – review & editing, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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