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Geochemical Evidence of Ancient Maya Marketplace Activities in the Puuc Hills of Mexico and at Caracol, Belize

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ABSTRACT

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The large public plazas of the ancient Maya were likely swept clear of debris and durable artifacts that could have provided evidence of the ancient anthropogenic activities. However, geochemical residues of food or mineral ores and pigments became affixed to soil and floor particles. These particles chemically bound so that natural movement of water is insufficient to cause them to move, leaving invisible geochemical signatures of ancient activities. This line of study is focused on the relationship between the geospatial distribution of element concentrations and ancient human activities using current laboratory techniques and isopleths, or chemical concentration contour maps, to identify activity areas.

Surface samples were collected from ancient plazas at the sites of Kiuic and Sayil in the Puuc Hills of Yucatan and at the site of Caracol Belize. Mehlich II and DTPA extraction procedures were used to determine the elemental concentrations of P, Cu, Fe, Mn, Pb, and Zn. Total elemental levels of additional elements were determined by portable X-ray fluorescence. The objective was to discover geochemical evidence of economic exchange activities at these important site centers. The Kuche Plaza at Kiuic produced evidence of ancient food storage, consumption, or trade activities but such evidence was lacking from the largest open space at the site. The Mirador group at Sayil failed to produce compelling evidence of any market activities. In the Conchita plaza at Caracol there are significant chemical signatures of human activities including evidence of ancient food storage, consumption, or trade activities and evidence of workshop activities potentially including the use production or trade of pigments. Our results from the Conchita plaza suggest ancient marketplace activity, and a geospatial division for the use of the Conchita plaza at Caracol.

Key words: Maya economics, geochemical techniques, geochemistry, portable x-ray fluorescence, pXRF

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THE SEARCH FOR GEOCHEMICAL EVIDENCE OF ANCIENT MAYA ACTIVITIES AT SELECT PLAZAS IN THE PUUC HILLS OF THE YUCATAN

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ABSTRACT – CHAPTER 1

The large public plazas of the ancient Maya were likely swept clear of debris and durable artifacts that could have provided evidence of the activities that took place there. Geochemical residues of food or mineral ores and pigments became affixed to soil and floor particles and remain as invisible artifacts of ancient activities. This line of study is focused on finding evidence of ancient anthropogenic activities using the relationship of these activities and the geospatial distribution of chemical concentrations. Gridded surface samples were collected from ancient plazas at the site of Kiuic and a proposed marketplace near the Mirador group of Sayil in the Puuc Hills of Yucatan, Mexico. Mehlich II and DTPA extraction procedures were used to determine the elemental concentrations of P, Cu, Fe, Mn, Pb, and Zn. Total elemental levels of additional elements were determined by portable X-ray fluorescence. The largest open spaces at the site of Kiuic were lacking in geochemical evidence of marketplace activities suggesting that this space was not used for production, trade, or consumption of goods. However, the Kuche Plaza at Kiuic produced evidence of ancient food storage, consumption, or trade activities causing the accumulated deposition of vegetable matter. Our findings for the proposed marketplace near the Mirador group at Sayil failed to produce compelling geochemical evidence of marketplace activities.

Key words: Maya economics, geochemical techniques, geochemistry, portable x-ray fluorescence, pXRF

The Puuc Region and the Site of Kiuic

The word Puuc is a Mayan term meaning "hill country" used to describe the region of karst limestone outcrop in the Yucatan (Smyth and Dore, 1992). The Maya occupation of the Puuc region appears to be continuous from the early Middle Preclassic period (B.C. 600) through the end of the Terminal Classic period (after A.D. 1000) of Maya history (Simms, et al., 2012). The population in the Puuc region grew rapidly during the Terminal Classic period (A.D. 800-1000), and some suggest that it was one of the most populated regions of the Yucatan during this period (Rands, 1954). This idea is supported by the fact that the Puuc region has some of the best soils of the peninsula, earning recognition as the "bread basket" region of the Yucatan (Simms, et al., 2012, Smyth, et al., 1998). The Puuc region is best known for its architectural style, which has been well documented in various studies (Carmean, 1991, Pollock, 1980, Ringle and Bey, 2012). This region is also known for getting very little rainfall during the dry season requiring the ancient Maya to construct chultuns (underground water basins) and aguadas (small reservoirs) designed to capture and store rainwater (Smyth and Dore, 1992).

With a history covering 1800 years Kiuic is a site with a very long occupation (Cervera, 2010), and is expected to have had a long history of economic activity. Kiuic was a growing site with many labor intensive economic activities happening at the time of its abandonment including a large unfinished plaza and unfinished structures with materials ready for completion of the projects (Bey, et al., 2010). This is evidence that the site was suddenly abandoned by its inhabitants; however the inhabitants were also thoughtful in how they left the site indicating that they expected to return (Stevenson, 1982). Large metates were well preserved and functional because the inhabitants turned them on their sides before abandoning the site presumably to protect them until they return. Ceramics were also better preserved at Kiuic than at other rapidly abandoned sites because they were stored at floor level and near walls, also indicating an intent to return (Simms, et al., 2012). The final abandonment of Kiuic happened close to the same time period that the rest of the Maya culture collapsed in the Puuc region.

Kiuic and Sayil and Marketplace Activities

This site is particularly interesting to the present study of plaza activities because *k'iwik* (or *kiuik*) is a Mayan term meaning market, fair, or where one buys or sells (Dahlin, et al., 2007, Wurtzburg, 1991). The analysis of the soil from this site was intended to reveal more information about ancient trade and exchange activities in this ancient city.

Evidence of market activity is an issue much debated in Mesoamerican archeology because of the likelihood that the overwhelming majority of market items traded by the ancient Maya are archeologically invisible. With this admitted restraint on availability of basic data, it is entirely possible that the ancient Maya society was intensely commercialized with very little artifactual evidence being left for archeologists to consider (Hutson, et al., 2009).

Sayil, another site in the Puuc region, was selected as a site in this study because archaeological research on ancient marketplaces was previously performed at the site. Extensive mapping of structures has been done at Sayil showing that the site has well defined borders making it 4.5 km^2. Over 2,500 features of archaeological interest have been identified on the surface including, structures, plazas, rock alignments, causeways, and over 300 chultuns to provide water to the population (Sabloff and Tourtellot, 1992, Smyth, et al., 1995). Large amounts of ceramics have been found at the Sayil site and a number of ceramic production areas have also been identified. One of these ceramic production sites was found west of the Mirador Complex (Smyth and Dore, 1992).

The Mirador Group at Sayil was proposed as a marketplace by Susan Wurtzburg in 1991 (Wurtzburg, 1991). She used many different lines of evidence to characterize a marketplace, many of which are being used for this study. In response to Wurtzburg's dissertation the Mirador Group has been tested for geochemical evidence to support the hypothesis that this group was indeed a marketplace.

Marketplace Hypothesis

Several authors have listed attributes or lines of evidence that should exist at ancient Mesoamerican marketplaces (Dahlin, et al., 2010a, Dahlin, et al., 2007, Fox, 1977, Wurtzburg, 1991). Some of these attributes were described at the time of the conquest while others are visible in contemporary marketplaces. The Attributes associated with ancient Mesoamerican marketplaces include:

(1) Urban centers that are located on trade routes and artifactual evidence of trade;

(2) Designated open space for a marketplace adjacent to transportation arteries;

(3) Proximity to public structures (e.g. ballcourt or sweatbath structures);

(4) Specific areas of trade for different classes of goods and post holes or stone alignments to denote assignment of market spaces or kiosks; and

(5) Regular patterns in the chemical concentrations of phosphorus (P) and metallic ions aligned with pathways (low concentrations), areas of foodstuff distribution (high levels of P), and the marketing of workshop items or craft materials (high levels of metal ions).

Soil Geochemistry in Archeological Research

The use of soil chemical testing to assist archeologists in prospection for important archeological features has been accepted since the 1930's (Arrhenius, 1931, Lorch, 1940). Many others since that time have done a wide variety of studies using the relationship between the soil chemical concentrations and the presence of ancient and modern activities (Ball and Kelsay, 1992, Barba, et al., 1996, Coultas, et al., 1993, Dunning, 1993, Eidt, 1973, Fernández, et al., 2002, Hutson, et al., 2009, Hutson and Terry, 2006, Jacob, 1995, Manzanilla and Barba 1990, Wells, et al., 2000b). Anthropogenic activities can be recognized by identifying chemical signatures which have remained in the same location, as long as the soil has not been displaced, since the activities took place. This makes it possible to test the soil chemistry of a site and offer elemental evidence of specific ancient activities. The relationship between the chemical signatures and the geospatial position of these signatures in a particular area can be very useful in ascertaining what the activities potentially involved.

Soil geochemical techniques have been employed to identify ancient human activity patterns on ancient Maya plazas and patios. Chemical residues derived from particular activities, which were performed repetitively, in given locations remain immobile on the surfaces of soil particles and leave enduring chemical residues. For example, elevated soil concentrations of P help to identify areas of food preparation, consumption, trade, and refuse zones (Fernández, et al., 2002, Luzzadder-Beach, et al., 2011, Parnell, et al., 2002a, Terry, et al., 2000a). Heavy metal concentrations are indicative of workshop activities, as well as ritual and funerary spaces (Barba and Ortiz, 2001, Manzanilla and Barba 1990, Terry, et al., 2004). Lower levels of P and trace metals have been associated with pathways, sleeping quarters, and sweeping patterns.

Quantitative Phosphorus Measurement

Phosphorus is an essential element in all living cells and is a critical component in cell membranes and nucleic acids. The use of P tests in archaeology is well established and is most often used as a preliminary test for pre-excavation prospecting. The presence of P in the majority of perishable goods has made it a standard technique in archaeology where artifactual remains are insufficient to offer a clear picture of the site (Bair, et al., 2006, Ball and Kelsay, 1992, Cavanagh, et al., 1988, Eidt, 1984, Parnell, et al., 2001, Provan, 1973, Sweetwood, et al., 2009).

Phosphorus tests are well suited for identifying the locations of market exchange because P contained in food becomes insoluble and chemically fixed on the surface of soil and floor particles. This fixation prevents removal by percolating water making it possible to measure elevated levels of P in the soil centuries after it is deposited (Holliday and Gartner, 2007, Parnell, et al., 2001, Terry, et al., 2000b, Wells, 2004). The correlation between geochemical residues of P concentrations and anthropogenic activities such as, agriculture, fertilization, waste, habitation, and other cultural activities has been demonstrated in many archeological studies (Barba, et al., 1987, Bethell and Máté, 1989, Craddock, et al., 1986, Dauncy, 1952, Dunning, 1993, Griffith, 1981, Hammond, 1983, Konrad, et al., 1983, Manzanilla and Barba 1990, Middleton and Price, 1996, Ortiz and Barba, 1993, Proudfoot, 1976, Sánchez, et al., 1996, Scudder, et al., 1996, Solecki, 1951, Terry, et al., 2000b, Wells, et al., 2000b, Weston, 1995).

Trace Element Testing

Trace element concentrations can be used to indicate specific activities, which can be associated with mineral workshop items and pigments. Metals are often found attached to the mineral surfaces of the soils and the stucco floors commonly found at Maya archeology sites (Bair, et al., 2006, Bintliff, et al., 1990, Entwistle, et al., 1998, Lambert, et al., 1984, Lewis, et al., 1993, Middleton and Price, 1996, Parnell, et al., 2002a, Parnell, et al., 2002b, Wells, et al., 2000a, Wells, et al., 2000b). The DTPA chelate extraction procedure is an accepted procedure when identifying concentrations for plant availability, environmental contamination, and mineral usage of heavy metal elements (Bair, et al., 2006, Dahlin, et al., 2007, Parnell, et al., 2002a, Terry, et al., 2004). This process coupled with the use of Inductively Coupled Plasma - Atomic Emission Spectrometer (ICP/AES) technology has made it possible to detect lower levels of trace metals and compare them in an attempt to find additional information about the activities associated with these soils (Cook, et al., 2006, Luzzadder-Beach, et al., 2011).

Zinc (Zn) is an element of interest because it is a metal that also serves as a micro nutrient in crops, and for all forms of life on earth. Zinc is often closely associated with P residues showing that large amounts of foodstuffs were brought into the particular location in the past (Dahlin, et al., 2010a, Dahlin, et al., 2007).

Iron (Fe) was used extensively in the production of pigments in the ancient Maya society, and may be associated with production and trade of any products that include the application of pigments. Other metals such as copper (Cu) and manganese (Mn) are components of many rocks and minerals used in workshop activities and trade.

Total elemental analysis of metals in soils and floors can be determined by X-ray fluorescence. Portable X-ray fluorescence (pXRF) instruments facilitate analysis of samples in either formal laboratory or field lab settings. Prior to pXRF analysis samples are air-dried, crushed, and sieved but there is no need for strong acid digestion or for chemical extraction and spectrometric analysis. Total analysis is most useful in determining the origins of soil and floor materials by examining the relative differences in calcium (Ca) associated with limestone fill and stucco, and titanium (Ti), aluminum (Al), Fe, and other constituents of soil clays. Unfortunately, the tiny amounts of anthropogenic elements deposited on the surfaces of soil and floor particles are likely to be overwhelmed by the total elemental content of those particles.

Soil geochemistry has been a useful tool in the identification of ancient marketplace activities at Chunchucmil (Dahlin, et al., 2010a, Dahlin, et al., 2007, Luzzadder-Beach, et al., 2011), Mayapan, and Coba in the northern Yucatan peninsula (Coronel, et al., ND). Richard Terry and his students from Brigham Young University have identified geochemical patterns that suggest ancient marketplace activities at plazas in Ceibal (Bair, 2010), Trinadad de Nosotros (Dahlin, et al., 2010b), and Motul de San Jose (Bair, 2010) in Guatemala.

The purpose of this study is to determine geochemical accumulations related to ancient plaza activities in the Puuc region, Mexico (Figure 1-1). Various soil geochemical procedures were used to provide information on the use of open spaces in ancient Maya cities where only limited artifactual data are available. The soils from selected plazas at the sites of Kiuic and Sayil were tested for P, Fe, Zn, and other trace elements known to be associated with marketplace activities.

Systematic soil sampling of the floors of public plazas and elite residential patios was conducted and soils were prepared for testing. These tests were used to identify not only where activities were located, but also what the activities potentially involved: metal work, mineral materials, and evidence of P accumulation from food residues.

Materials and Methods

Plaza floor samples were collected at the intersections of a 10-m by 10-m rectangular gird. The locations were identified starting at a particular reference point, and then using measuring tape to lay out a grid of sampling points that intersect at perpendicular angles. This allowed for a simple and effective sampling system in the field.

Soil samples were acquired by removing the leaf litter from a 0.5 by 0.5 m area and taking the surface 0 to 10 cm of topsoil. Three samples were acquired using a plastic trowel totaling 200 to 500 g of soil which was then placed in a plastic bag and homogenized. The samples were then transported to the lab in Provo, Utah for chemical analysis.

Before the tests could be performed the samples were air dried, crushed with a mortar and pestle, and then sieved to less than 2 mm. The Mehlich II phosphate extraction procedure, as modified by Terry (Terry, et al., 2000b) was performed and P concentrations were determined by colorimeter. The chelate extractable trace element concentrations were determined by the DTPA extraction and concentrations were determined by ICP/AES. These procedures provided concentrations associated with the chemicals that are fixed to the surface of soil or plaza floor particles.

The total element analysis of all the surface soil samples was conducted with a Bruker Tracer IV SD pXRF instrument. Bagged samples are placed over the window of the pXRF and scanned to provide multi-element analysis of chemical constituents both on the surfaces and contained within the particles of the samples. The fundamental parameters analysis was standardized with the "Soils with Calcium Carbonate" calibration provided by Bruker, and the X-Ray fluorescence signal was collected for 120 seconds. X-Ray fluorescence is effective in obtaining total elemental concentrations instead of just the concentrations for chemicals attached to particle surfaces. When identifying differences in total and extractible concentrations it is possible to differentiate between plaza floor materials (constructed from soils) and plaza fill and stucco pavement (constructed from burnt calcium carbonate). It is also possible to find patterns that indicate modern rather than ancient activities associated with Fe (Coronel, 2011).

Surfer 8 software was used to produce elemental concentration isopleths showing the concentration contours for each of the elements of interest overlade on top of maps of the sampling areas. Tables were also produced for each set of samples showing the maximum, minimum, average, standard deviation (STDEV), and background chemical concentrations for each element of interest. JMP software was used to produce matrix tables of correlation coefficients for each of the elements. Significance of correlation coefficients (r) are denoted by, (**) for highly significant ($p < 0.01$), (*) for significant ($p < 0.05$), and (N.S.) for not significant ($p > 0.05$).

King (2008) used 40 off-site samples in an attempt to find useful background concentrations, but found that the native soils often have higher concentrations in elements such as P, in comparison with sampling sites constructed of plaza fill and stucco pavement. Sampling outside of the area of interest does not produce samples representative of the native soil because all of the soil in these sites are expected to have been affected by human activities similar to those being identified in this study. The use of samples that are not from the area of interest for background calculations also makes little sense when identifying changes within the sampling areas. Instead of comparing the sampling areas with areas that have experienced different anthropogenic activities, background concentrations for this study were calculated by averaging the 10 percent of samples lowest in concentration (Coronel, et al., ND, King, 2008).

Results and Discussion

Yaxche Plaza

The Yaxche Plaza of Kiuic holds evidence of at least seven phases of construction covering 1800 years (Figure 1-2). Recent studies conducted by Bey et al. (2006) indicated that the Yaxche Plaza had its original construction in the Middle Preclassic. The platform is 1 m high and at 28 by 28 m in length and width, with a 14-m long structure to the East and a 13-m long structure to the South (Bey, 2006).

The Yaxche Plaza was likely a ritual or an elite residential patio within the Yaxche Group. This area is currently under archaeological investigation and the North edge of the plaza had been excavated and back filled by the archeologists (Cervera, 2010).

The plaza floor was sampled at 4 m grid intervals and a total of 40 samples were collected. The isolation of this plaza from public access and view suggested it was not used in marketplace activities and it served as a control for comparison with the publically accessible plazas of Kiuic.

The maximum, minimum, averages, and background levels of Mehlich extractable P, DTPA extractable metals, and pXRF total metals in the floor of the sacbe are shown in Table 1-1. Mehlich P concentrations in the plaza floor were between 4.3 and 7.8 mg/kg, and the background concentration was estimated to be 5.1 mg/kg. The concentration isopleths of extractable P in the floor of Yaxche Plaza are shown in Figure 1-3. Low concentrations, just above background, were found along the outer edges of the plaza floor that may be related to ancient sweeping of debris or possibly to food consumption activities. DTPA extractable Zn concentrations in this plaza were between 0.9 and 2.4 mg/kg, and the background concentration was about 1.0 mg/kg (Table 1-1). The DTPA Zn and Mehlich P concentrations for this plaza were significantly correlated with an r = 0.377** (Table 1-2). DTPA extractable Fe concentrations in the plaza floor ranged from 3.1 to 7.1 mg/kg, and the background level was 3.2 mg/kg (Table 1-1).

The pXRF was used to measure total elemental concentrations for the soils on this plaza. The total Fe concentrations were very near the background level of 0.43 percent (Table 1-1). Low levels of extractable and total iron suggest that the plaza floor was made of ancient plaza fill and stucco pavement. The total Fe concentrations were significantly correlated with the DTPA extractable Fe (r = 0.475**; Table 1-2). This correlation is consistent with the idea that trace levels of Fe in the floor were highly weathered and very insoluble. Several studies have demonstrated that contemporary deposits of Fe from rakes and machetes have significantly greater extractable iron concentrations and that those levels are independent of the total iron concentrations (Bair, 2010, Coronel, et al., ND, Terry, et al., 2004).

Kiuic, site center sampled in 2010

The site center of Kiuic contains a large open space centered on a cave opening and surrounded by three large plaza platforms and ornate public structures (Figure 1-2). The site center was sampled using a 10-m grid and a more detailed 5 m sampling of Sacbe 1 located between the Yaxche and Kuche plazas. A total of 198 samples were collected and analyzed from the site center. The sampling locations are shown in Figure 1-2. The entire open area between the groups of buildings with the exception of the Yaxche and Kuche plazas and the sacbe contained little plaza fill or soil. The area was mainly limestone outcrop. The large Chulul plaza was not sampled because it was apparent that the plaza leveling and filling process was incomplete at the time of abandonment. The Chulul Plaza was never paved or occupied.

Most samples obtained outside of the Kuche Group were very low in Mehlich P and concentrations were near the background level of 5.2 mg/kg (Table 1-3). Within the floors of the Kuche Group P concentrations were as high as 25 mg/kg (Figure 1-4). The geospatial distribution of P in the Kuche Plaza suggested a food related activity such as trade, storage, or feasting. A more detailed sampling of the Kuche Plaza was performed in 2011 and is discussed hereafter.

The DTPA chelate extractable Zn in the site center ranged from less than 1 to 20.4 mg/kg and the background level was estimated at 0.7 mg/kg (Table 1-3). Extractable Zn has been shown to be correlated with extractable P, and is often found in high concentration where P has accumulated from with food preparation, consumption, and waste disposal (Dahlin, et al., 2007, Fernandez, et al., 2005, Terry, et al., 2004). A highly significant correlation between DTPA extractable Zn and Mehlich P has been identified in the site center (r = 0.211**; Table 1-4). This indicates that the extractable Zn and P concentrations are a result of accumulated deposits of foodstuffs. As with P the majority of the samples with elevated Zn was associated with the Kuche Group and is discussed in more depth with the results from the 2011 sampling.

Concentrations for DTPA Fe at the cite center ranged from not detectable to 69.7 mg/kg with a background level of 2.5 mg/kg (Table 1-3). There was no correlation between DTPA extractable Fe and Mehlich P (Table 1-4). Extractable Fe and Zn show a highly significant correlation (r = 0.468**; Table 1-4). The highest concentration extractable Fe was found at the mouth of the cave (Figure 1-5). This indicates that there may have been significant amounts of iron deposited from cave rituals or that the water removed from the cave contained Fe. At the mouth of the cave there were also accumulations of extractable Zn, Mn and Cu.

Total Fe contents obtained by pXRF sample analysis shows Fe concentrations between 0.12 and 8.09 percent with background levels calculated at 0.51 percent (Table 1-3). The spatial distribution of total Fe in the soils of the site center is shown in Figure 1-6. The areas of elevated total Fe begin at the mouth of the cave and generally follow the elevator contours, suggesting that Fe contaminated water may have flowed from the cave in the past. Total pXRF Fe shows a highly significant negative correlation with Mehlich P, producing an r value of -0.405**, and a negative correlation with DTPA Zn (r = -0.157*). The pXRF Fe does not show any significant correlation with DTPA iron where r = 0.118 (N.S.). The lack of correlation between extractable and total Fe may be a result of the presence of relatively high concentrations of extractable metals near the cave entrance while total Fe levels follow the elevation contours from higher elevations to lower elevations at the mouth of the cave. The total Fe extending away from the cave entrance was likely older and more weathered Fe contained in deposited sediments. The highly weathered Fe is lower in solubility and thus was not picked up in the DTPA chelate extraction.

The section within the main sampling area that was given closer attention and sampled every five meters surrounded Sacbe 1. Extractable P levels were also very low at this location (Figure 1-4). This area was of interest because it was expected that sacbes were regularly traveled and did not accumulate P or other elemental signatures, but elevated P levels were expected on either side of the sacbe where debris and trash was swept. This was the case along sacbeob at Chunchucmil (Dahlin, et al., 2007, Terry, et al., 2004). The results from this study show no significant change in P levels at or around this ancient causeway. There was however a line of significantly higher total Fe concentrations located between 5-m and 10-m North of Sacbe 1 (Figure 1-6).

The sampling and analysis of Kiuic soils give insufficient evidence to support the belief that there was a long standing ancient marketplace in the large open area centered on the cave entrance at Kiuic (Figure 1-2). The highest levels of extractable P and Zn were found in the floor of Kuche plaza. This indicates that the activities in the plaza included regular preparation, trade, or consumption of food. A trip to acquire a more detailed sampling at the Kuche group in 2011 was conducted in response to these initial findings.

Kuche Plaza sampled in 2011

The plaza within group Kuche is relatively small, about 3000 m^2, but it is near entrances to the site center from the West and the North and is at the terminus of Sacbe 1. These attributes along with the elevated P concentrations in the plaza floor suggest that market related activities took place there. In 2011, a more detailed 5-m grid sampling was conducted focusing on the Kuche Plaza and its surroundings.

The concentrations of Mehlich P range between 4.4 and 32.0 mg/kg with background levels calculated at 5.0 mg/kg (Table 1-5). The geospatial distribution of P concentrations in this plaza appears to show organized linear patterns extending from the southwest to the northeast (Figure 1-7). This indicates that there were ancient food related activities within the Kuche plaza. The plaza is at the terminus of Sacbe 1 and is located at the North and West entrances to the site center. The plaza is surrounded on three sides by public structures and there are public water sources nearby. At least three large metates were seen at the plaza indicating food preparation and consumption within the plaza.

Concentrations of DTPA extractable Zn in this plaza were between 0.2 and 20.4 mg/kg with a background calculated at 0.6 mg/kg (Table 1-5). The geospatial distribution of Zn moderate concentrations of less than 12 mg/kg in this plaza appeared to follow the same organized linear patterns as the P concentrations (Figure 1-8). The highest concentrations of Zn were along the Sacbe, outside of the plaza. There was a highly significant correlation between extractable P and Zn concentrations in this plaza (r = 0.234**; Table 1-6). The linear patters of, and correlation between, extractable P and Zn in the plaza suggests organized marketplace activities involving foodstuffs, however, elevated levels of P and Zn could have also resulted from food storage for later distribution or feasting activities.

The DTPA Fe concentrations were between undetectable levels and 69.8 mg/kg with calculated background levels at 1.3 mg/kg, for the 2011 samples (Table 1-5). DTPA Fe was not significantly associated with Mehlich P with r = -0.106 (N.S.). The correlation coefficient for DTPA Fe and DTPA Zn is highly significant where r = 0.447** (Table 1-6). The pXRF total Fe concentrations ranged between 0.12 and 7.69 percent with background levels at 0.32 percent (Table 1-5).

Elevated levels of P were identified in the Kuche plaza suggesting that food related activities took place anciently in the plaza. These activities could have included feasting, a small vegetable market, or storage of foodstuffs in preparation for distribution by trade or tribute. Food preparation or storage are also supported as potential ancient uses for this plaza (Smyth, et al., 1995). Whatever the human activities may have been, the results are consistent with foodstuffs being brought into the Kuche plaza.

Sayil, Mexico 2010

In December 2010, 124 soil samples were taken at Sayil near the Mirador Group (Figure 1-9) that was proposed by Wurtzburg (1991) to have been an ancient marketplace. The central location adjacent to public buildings, a sacbe, and stele along with artifactual evidence of trade goods at the site, suggested this area as a candidate for marketplace activities. In addition, the area contains a number of low platforms, rock alignments, and C-shaped structures that could have been used in the marketplace. The Mehlich P concentrations were found to be between 5.2 and 52.6 mg/kg with background concentrations calculated at or below 5.7 mg/kg (Table 1-7). The concentrations of P were found to be low in the area that has been specifically identified by Wurtzburg (1991) to have been a likely location of an ancient marketplace. Moderate levels of P were found on the outside extremes of the group, but the lowest concentrations of P were among the rock alignments and low platforms thought to be part of an ancient marketplace. Highest levels of P were found just outside of the southwest household in the Mirador group (Figure 1-10). This may have been a signature associated with the waste deposited from the household group.

Extractable Zn concentrations ranged from 0.7 to 10.0 mg/kg and the background concentrations for DTPA Zn at Sayil were estimated at 0.9 mg/kg (Table 1-7). Elevated Zn concentrations were found in the southwest corner of the group (Figure 1-11) at the same location as the elevated P was found (Figure 1-10). The correlation between extractable Zn and P was highly significant where $r = 0.459^{**}$ (Table 1-8), indicating that these concentrations are associated with the accumulation of foodstuffs. The geospatial locations of elevated concentrations of P and Zn was just outside a structure and is likely associated with food preparation or disposal.

The concentrations of extractable Fe at Sayil ranged between 2.2 and 11.6 mg/kg with background concentrations of 2.9 mg/kg (Table 1-7). The DTPA Fe concentrations showed a highly significant correlation with the DTPA Zn concentrations where $r = 0.302^{**}$, but did not show a significant relationship with Mehlich P concentrations where r = -0.111 (N.S.) (Table 1-8).

The pXRF total Fe concentrations for the Sayil samples ranged between 0.34 and 7.99 percent with background levels of 0.72 percent (Table 1-7). The areas of highest total Fe were at the East and West perimeters of the Mirador Group. Elevated Fe levels in the area reveal the differences between natural soils at those locations as opposed to limestone derived plaza fill and weathered stucco. The correlation coefficient for Fe concentrations using the DTPA method and the pXRF is r = -0.050 (N.S.). This indicates that the two measurements for Fe are not correlated (Table 1-8). The Mehlich P and DTPA Zn concentrations both show significant negative correlation with the pXRF Fe concentrations where r = -0.389** and -0.625**, respectively (Table 1-8).

The results for the Mirador Group at Sayil failed to indicate compelling evidence for marketplace activities. This does not indicate the absence of a marketplace, but it does indicate that if there was one, it saw little use before the site was abandoned. This is consistent with the architecture of the C-shaped structures dating to the Terminal Classic and the Post Classic periods (Gallereta, personal communication 2011). The geochemical results for the Mirador Group at Sayil do not support the marketplace hypothesis.

Conclusions

The sampling at the Puuc plazas offered geochemical evidence from only one plaza supporting the marketplace hypothesis. Everything sampled at Kiuic, with the exception of the Kuche plaza, offer geochemical patterns suggestive of marketplace activity. Sampling at Sayil failed to produce evidence from, extractable P or other elemental concentrations, to suggest a marketplace at the Mirador Group.

The Kuche plaza at Kiuic did offer elevated levels of extractable P, which constitutes weak evidence in support of the marketplace hypothesis. The Kuche plaza is small and formal marketplace stalls may not have been set up in the plaza making it difficult to show specific organization in the chemical signature. This chemical signature is consistent with a variety of food-related activities such as feasting, small vegetable market, or storage of foodstuffs in preparation for distribution by trade or tribute.

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Table 1-1. Maximum, minimum, average, standard deviation, and background chemical concentrations for each element of interest at the Yaxche plaza. Background levels are calculated as the average of the 10% of samples lowest in concentration.

	Mehlich P	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
	- - - - - - - - - - - - - - - - - - mg kg^{-1} -							%	mg kg^{-1}		%	- - - -mg kg^{-1} - - - -		
Maximum	7.80	0.41	7.08	21.36	1.06	2.39	4370	29.64	1140	686	0.82	58	56	13
Minimum	4.31	0.16	3.06	7.78	0.35	0.87	2720	22.64	575	198	0.42	37	44	6
Average	6.20	0.31	4.83	14.46	0.62	1.41	3896	26.89	819	348	0.58	45	49	9
STDEV	0.76	0.05	1.12	3.18	0.14	0.37	295	1.62	138	83	0.10	3	3	2
Background	5.08	0.22	3.23	9.17	0.39	0.95	3283	23.42	609	238	0.43	40	45	7

Table 1-2. Correlation matrix for the Yaxche plaza results; * denotes significance at $p < 0.05$ and ** denotes highly significant at $p < 0.01$.

n=40	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
Mehlich P	0.292	-0.156	0.069	-0.119	0.105	-0.186	-0.104	-0.127	0.100	-0.027	0.013	0.377*	-0.027
	DTPA Cu	0.134	0.640**	0.587**	0.678**	0.006	-0.508**	0.108	0.360*	0.126	-0.066	0.338*	0.227
		DTPA Fe	0.030	0.393**	0.094	0.303	-0.045	0.406**	0.271	0.475**	-0.077	0.189	0.362*
			DTPA Mn	0.430**	0.451**	-0.022	-0.558**	0.079	0.194	0.197	-0.063	0.173	0.350*
				DTPA Pb	0.652**	0.107	-0.431**	0.354*	0.627**	0.362*	-0.184	0.288	0.329*
					DTPA Zn	0.167	-0.115	-0.111	0.213	0.002	-0.098	0.177	-0.135
						pXRF K	0.475**	0.101	-0.100	0.177	0.277	0.023	-0.034
							pXRF Ca	-0.320*	-0.554**	-0.277	0.226	-0.303	-0.395
								pXRF Ti	0.541**	0.838**	-0.157	0.445**	0.501**
									pXRF Mn	0.560**	-0.039	0.442**	0.475**
										pXRF Fe	-0.109	0.484**	0.534**
											pXRF Cu	0.269	-0.052
												pXRF Zn	0.385*

Table 1-3. Maximum, minimum, average, standard deviation, and background chemical concentrations for each element of interest at the Kiuic site center in 2010. Background levels are calculated as the average of the 10% of samples lowest in concentration.

	Mehlich P	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
	- - - - - - - - - - - - - - - - - - mg kg^{-1} -							%	mg kg^{-1}		%	- - - -mg kg^{-1} - - - -		
Maximum	25.45	2.45	69.72	125.92	3.61	20.42	4490	35.40	6190	3840	8.09	68	196	88
Minimum	4.53	0.02	0.01	0.03	0.18	0.22	927	0.45	237	69	0.12	36	36	0
Average	7.55	0.90	8.00	26.43	1.62	3.04	2603	7.51	3539	1471	4.12	47	105	46
STDEV	2.98	0.48	6.77	16.02	0.60	3.13	668	7.01	1530	735	2.33	6	25	20
Background	5.16	0.17	2.52	9.29	0.70	0.66	1661	0.71	652	363	0.51	39	59	7

Table 1-4. Correlation matrix for the Kiuic site center results in 2010; * denotes significance at $p < 0.05$ and ** denotes highly significant at $p < 0.01$.

n=198	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca*	pXRF Ti	pXRF Mn	pXRF Fe*	pXRF Cu	pXRF Zn	pXRF Rb
Mehlich P	-0.109	0.000	-0.020	-0.065	0.211**	-0.048	0.339**	-0.512**	-0.402**	-0.405**	-0.106	-0.286**	-0.474**
	DTPA Cu	0.485**	0.718**	0.741**	0.003	0.004	-0.418**	0.412**	0.448**	0.420**	0.229**	0.357**	0.434**
		DTPA Fe	0.283**	0.211**	0.468**	0.002	-0.112	0.080	0.149*	0.118	0.282**	0.260**	0.098
			DTPA Mn	0.756**	-0.033	0.050	-0.283**	0.326**	0.356**	0.348**	-0.031	0.246**	0.291**
				DTPA Pb	-0.097	-0.065	-0.378**	0.386**	0.397**	0.395**	-0.026	0.264**	0.360**
					DTPA Zn	0.017	0.131	-0.208**	-0.087	-0.178*	0.212**	0.068	-0.173*
						pXRF K	0.433**	-0.168*	-0.137	-0.157*	0.054	-0.226**	-0.051
							pXRF Ca	-0.878**	-0.838**	-0.855**	-0.215**	-0.683**	-0.884**
								pXRF Ti	0.900**	0.940**	0.132	0.606**	0.926**
									pXRF Mn	0.932**	0.218**	0.631**	0.879**
										pXRF Fe	0.144*	0.632**	0.903**
											pXRF Cu	0.508**	0.259**
												pXRF Zn	0.664**

Table 1-5. Maximum, minimum, average, standard deviation, and background chemical concentrations for each element of interest at the Kuche plaza in 2011. Background levels are calculated as the average of the 10% of samples lowest in concentration.

	Mehlich P	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
	- - - - - - - - - - - - - - - - - - mg kg^{-1} -							%	mg kg^{-1}		%	- - - -mg kg^{-1} - - - -		
Maximum	31.98	2.05	69.72	73.58	3.20	20.42	4160	29.00	6060	3470	7.69	69	196	74
Minimum	4.36	0.02	0.01	0.03	0.23	0.16	927	0.69	237	199	0.12	36	55	4
Average	9.09	0.66	6.43	20.57	1.26	2.89	2462	9.15	2892	1218	3.37	49	99	38
STDEV	5.03	0.39	6.77	11.98	0.54	2.86	581	6.99	1672	707	2.45	7	27	22
Background	4.98	0.13	1.33	6.54	0.55	0.59	1528	0.96	396	330	0.32	39	59	6

Table 1-6. Correlation matrix for the Kuche plaza results in 2011; * denotes significance at $p < 0.05$ and ** denotes highly significant at $p < 0.01$.

n=201	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
Mehlich P	-0.182**	-0.106	-0.105	-0.187**	0.234**	-0.242**	0.347**	-0.558**	-0.435**	-0.455**	-0.315**	-0.413**	-0.541**
DTPA Cu		0.651**	0.750**	0.757**	0.147*	-0.177*	-0.429**	0.409**	0.395**	0.385**	0.165*	0.469**	0.393**
DTPA Fe			0.443**	0.432**	0.447**	-0.043	-0.141*	0.138*	0.163*	0.142*	0.101	0.287**	0.126
DTPA Mn				0.807**	0.095	-0.084	-0.316**	0.332**	0.353**	0.332**	-0.020	0.360**	0.287**
DTPA Pb					0.118	-0.174*	-0.322**	0.333**	0.288**	0.306**	-0.107	0.374**	0.283**
DTPA Zn						-0.041	0.292**	-0.351**	-0.251**	-0.331**	-0.150*	-0.104	-0.358**
pXRF K							0.386**	0.005	-0.056	-0.039	0.117	-0.114	0.002
pXRF Ca								-0.863**	-0.848**	-0.863**	-0.499**	-0.731**	-0.883**
pXRF Ti									0.903**	0.942**	0.501**	0.730**	0.965**
pXRF Mn										0.942**	0.521**	0.711**	0.898**
pXRF Fe											0.528**	0.729**	0.939**
pXRF Cu												0.584**	0.602**
pXRF Zn													0.767**

Table 1-7. Maximum, minimum, average, standard deviation, and background chemical concentrations for each element of interest at the proposed Sayil marketplace. Background levels are calculated as the average of the 10% of samples lowest in concentration.

	Mehlich P	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
	- - - - - - - - - - - - - - - - - - - mg kg^{-1} -							%	mg kg^{-1}		%	- - - -mg kg^{-1} - - - -		
Maximum	52.60	1.80	11.55	112.72	3.62	10.01	4540	31.32	6790	3960	7.99	56	178	60
Minimum	5.20	0.31	2.22	7.08	0.32	0.68	1320	0.38	581	180	0.34	40	106	4
Average	8.28	0.99	5.15	32.82	2.10	2.77	2221	6.61	3982	1933	4.28	47	149	37
STDEV	4.71	0.29	1.77	20.60	0.59	1.55	632	6.50	1466	904	2.23	4	13	13
Background	5.68	0.54	2.87	13.99	0.99	0.93	1518	0.48	1075	530	0.72	41	117	10

Table 1-8. Correlation matrix for the proposed Sayil marketplace results; * denotes significance at $p < 0.05$ and ** denotes highly significant at $p < 0.01$.

n=124	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
Mehlich P	-0.339**	-0.111	-0.223*	-0.430**	0.459**	0.287**	0.420**	-0.462**	-0.371**	-0.389**	0.012	-0.423**	0.032
DTPA Cu		0.323**	0.790**	0.822**	-0.336**	-0.442**	-0.659**	0.752**	0.757**	0.721**	0.119	0.546**	-0.046
DTPA Fe			0.459**	0.182*	0.302**	0.098	0.031	0.002	-0.020	-0.050	0.030	0.083	-0.155
DTPA Mn				0.695**	-0.271**	-0.271**	-0.448**	0.617**	0.587**	0.551**	-0.124	0.245**	-0.068
DTPA Pb					-0.381**	-0.596**	-0.799**	0.843**	0.788**	0.800**	0.001	0.620**	-0.020
DTPA Zn						0.353**	0.501**	-0.634**	-0.581**	-0.625**	0.052	-0.218*	-0.076
pXRF K							0.831**	-0.661**	-0.566**	-0.633**	-0.019	-0.636**	0.033
pXRF Ca								-0.907**	-0.823**	-0.862**	-0.077	-0.814**	0.096
pXRF Ti									0.928**	0.935**	0.005	0.692**	-0.016
pXRF Mn										0.931**	0.031	0.597**	-0.023
pXRF Fe											-0.040	0.634**	-0.009
pXRF Cu												0.293**	-0.042
pXRF Zn													-0.053

Sayil.

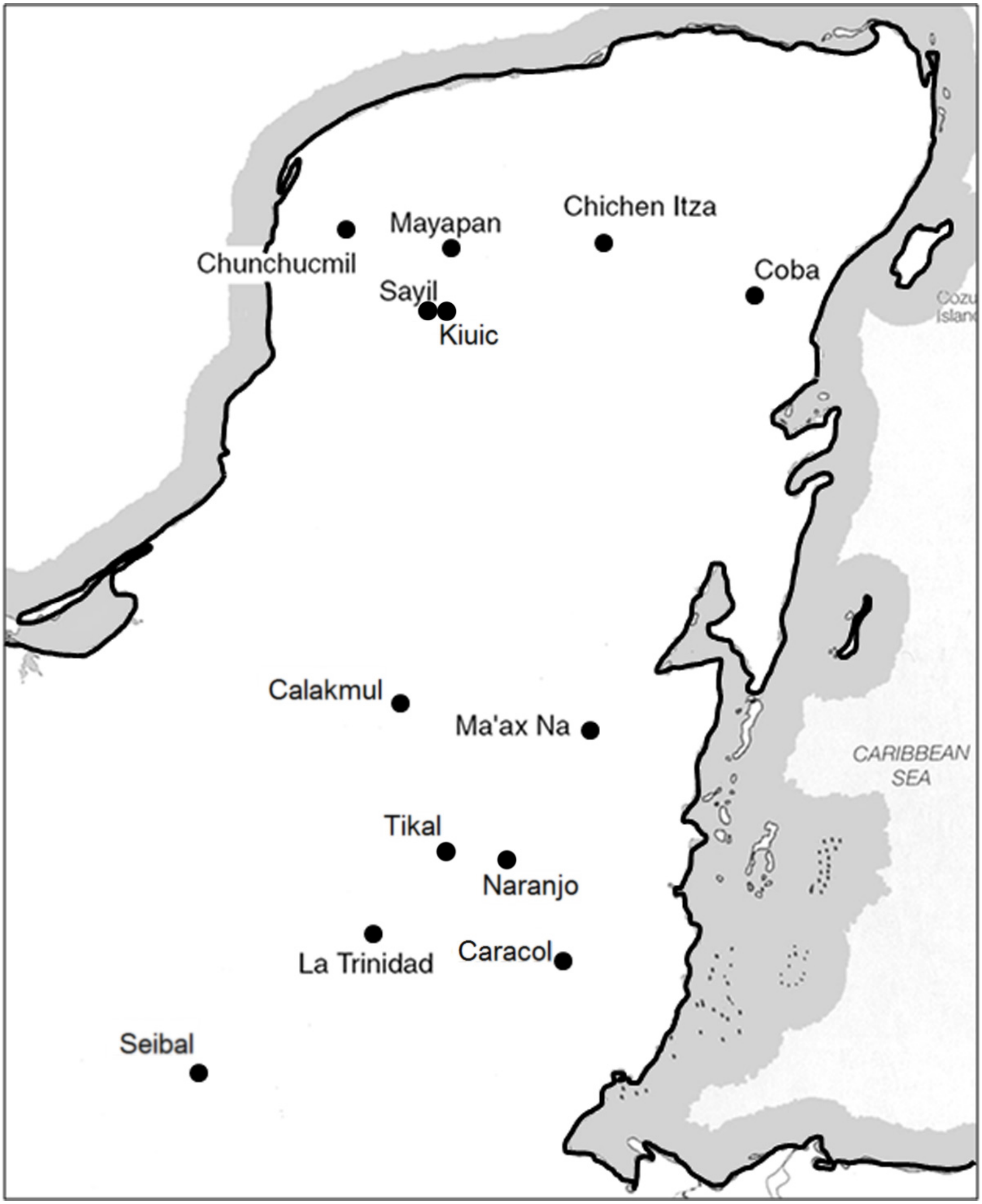

Figure 1-1. Map of Yucatan Peninsula marking relevant Maya sites including Kiuic and Sayil.

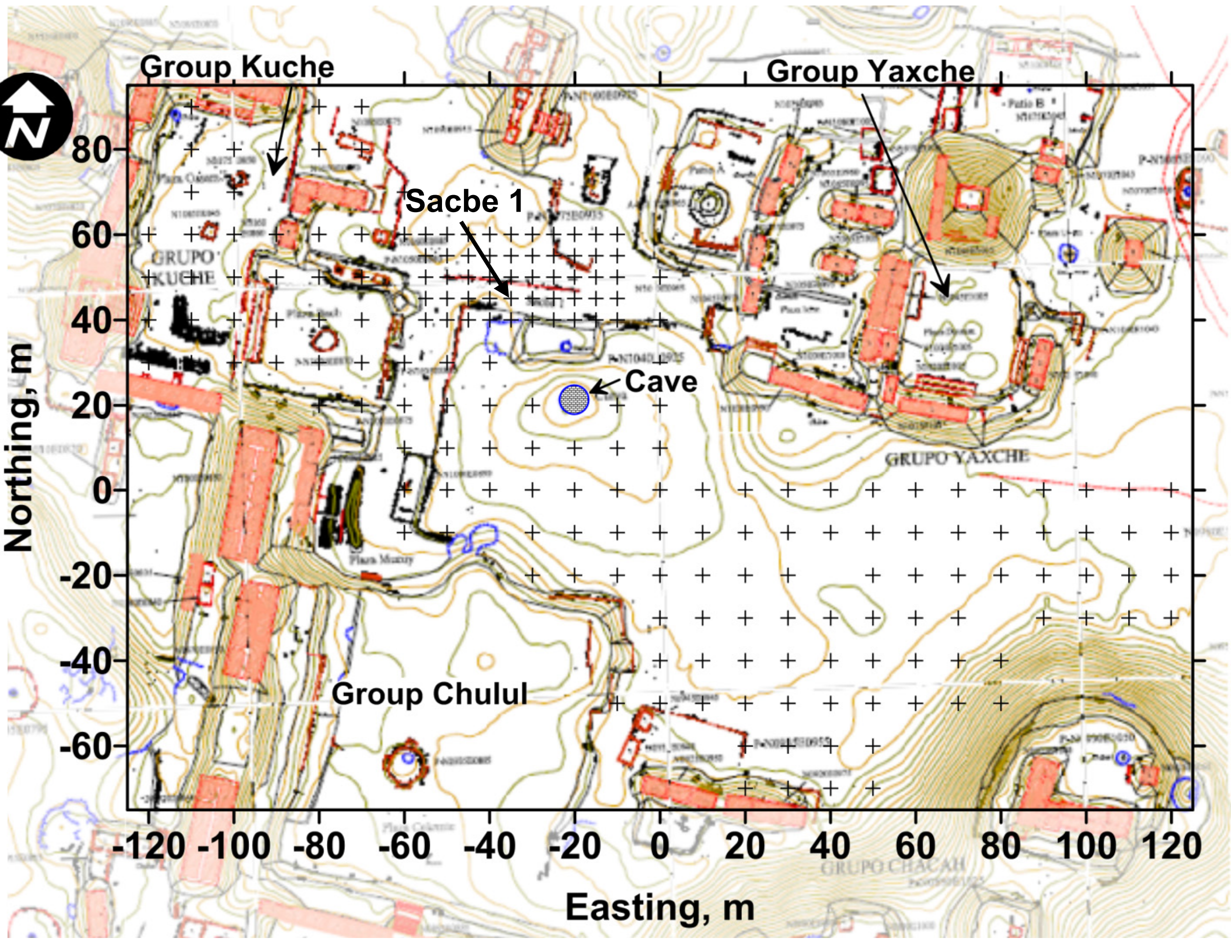

Figure 1-2. Map of the site center of Kiuic. Sampling locations collected in Spring 2010 are marked by +.

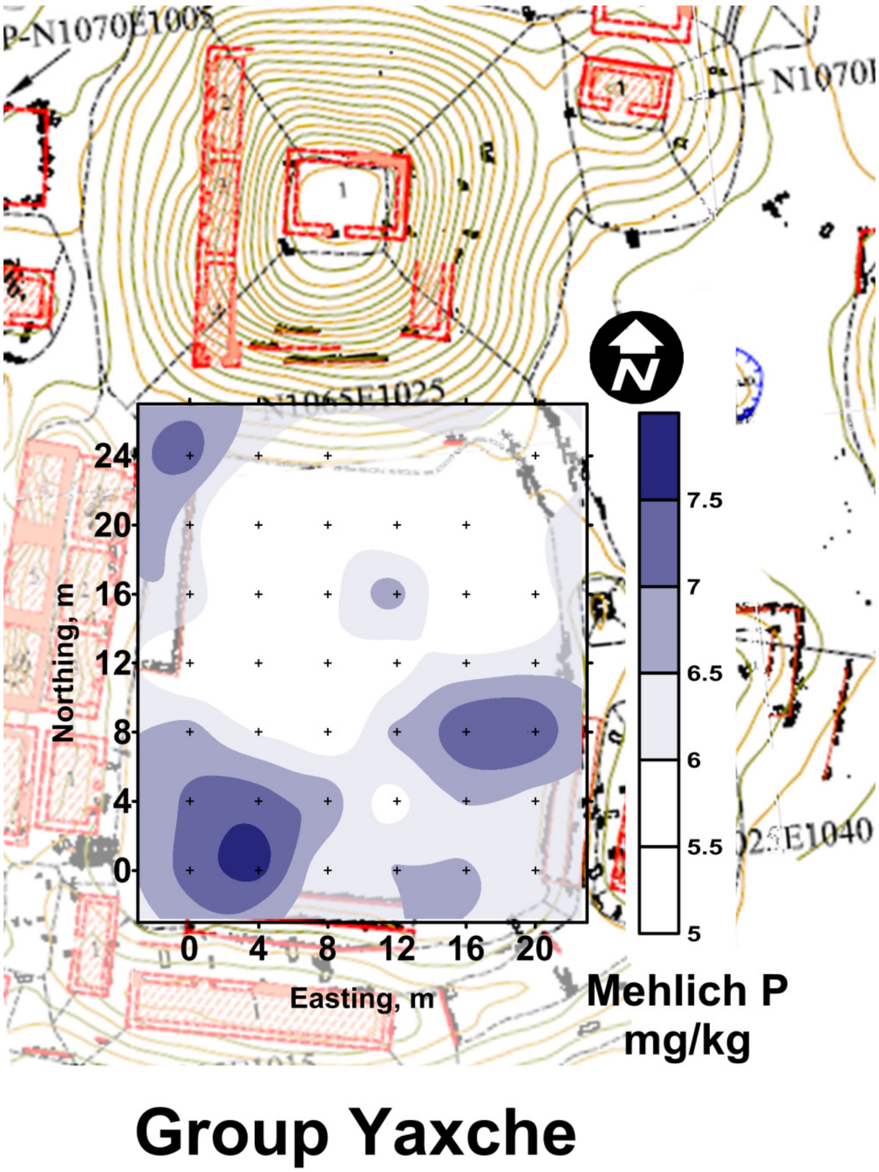

Figure 1-3. Concentration isopleths of Mehlich extractable P within the Yaxche group Plaza. The sample locations are marked with +.

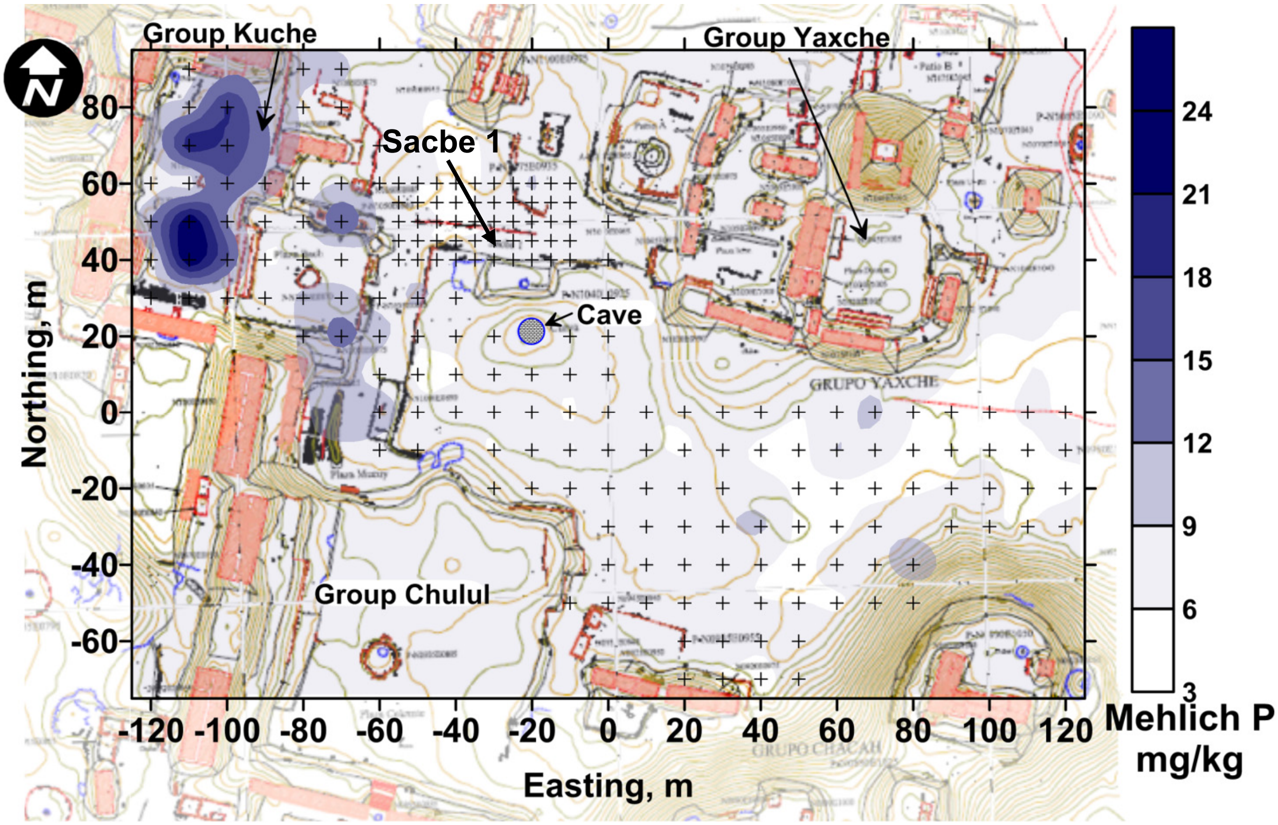

Figure 1-4. Mehlich II extractable P concentration isopleths of samples collected at the site center of Kiuic in 2010.

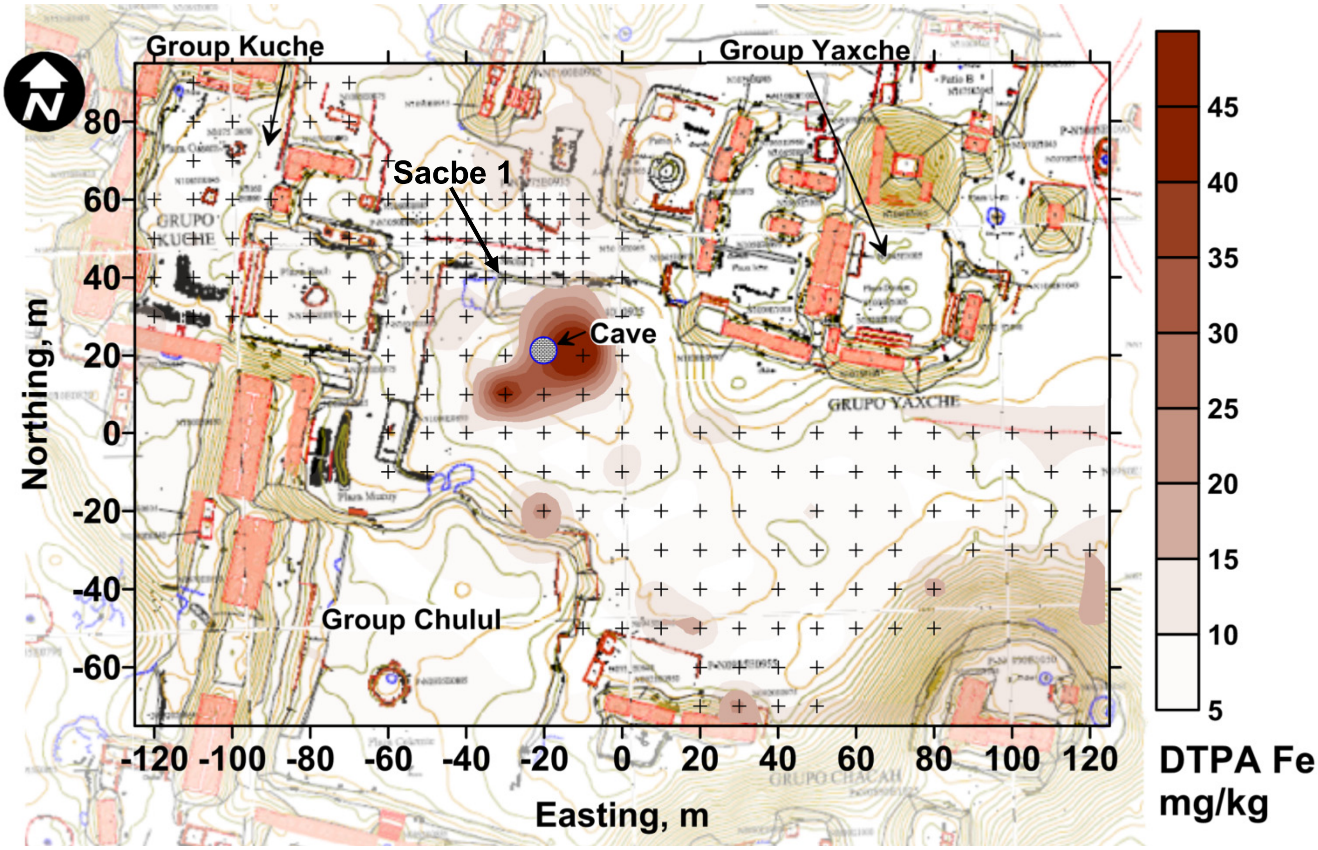

Figure 1-5. DTPA extractable Fe concentration isopleths of samples collected at the site center of Kiuic in 2010.

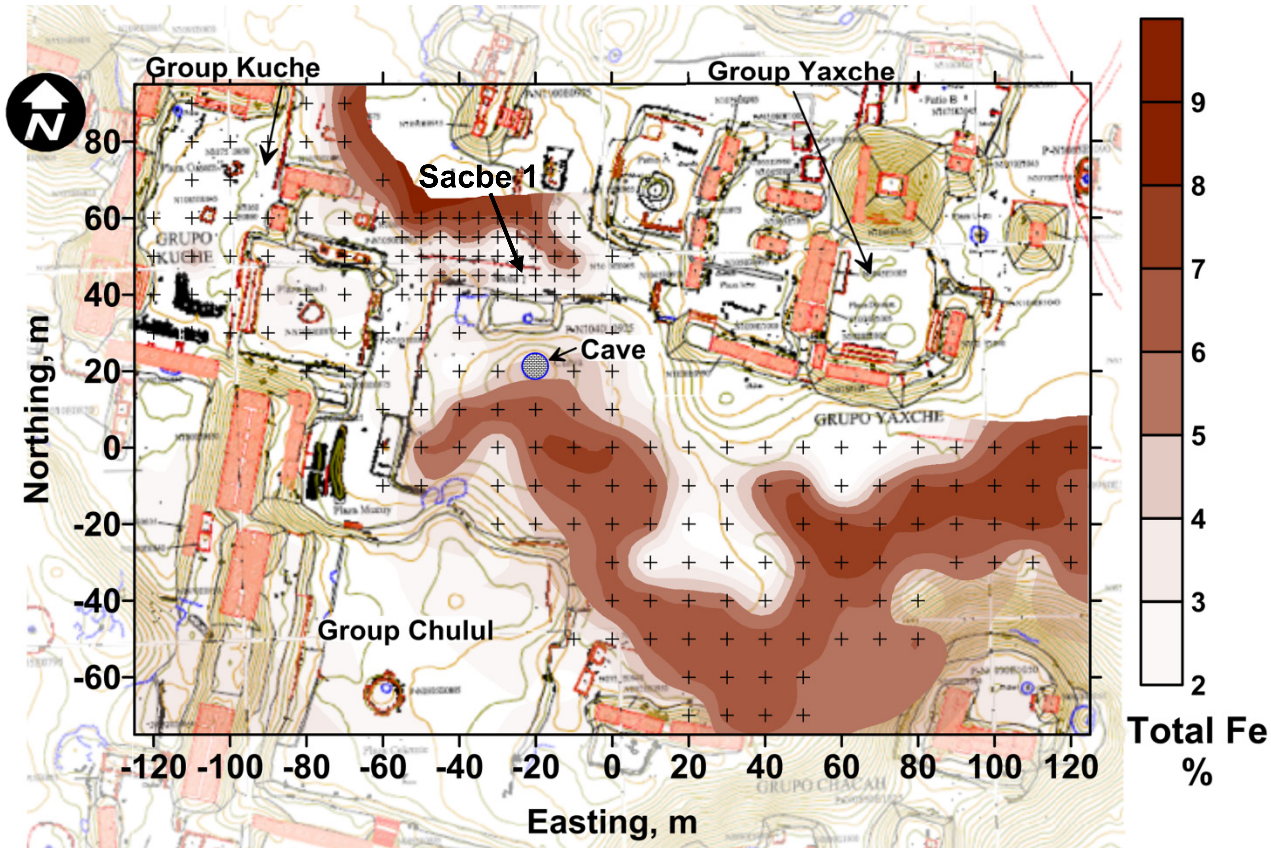

Figure 1-6. PXRF total Fe concentration isopleths of samples collected at the site center of Kiuic in 2010.

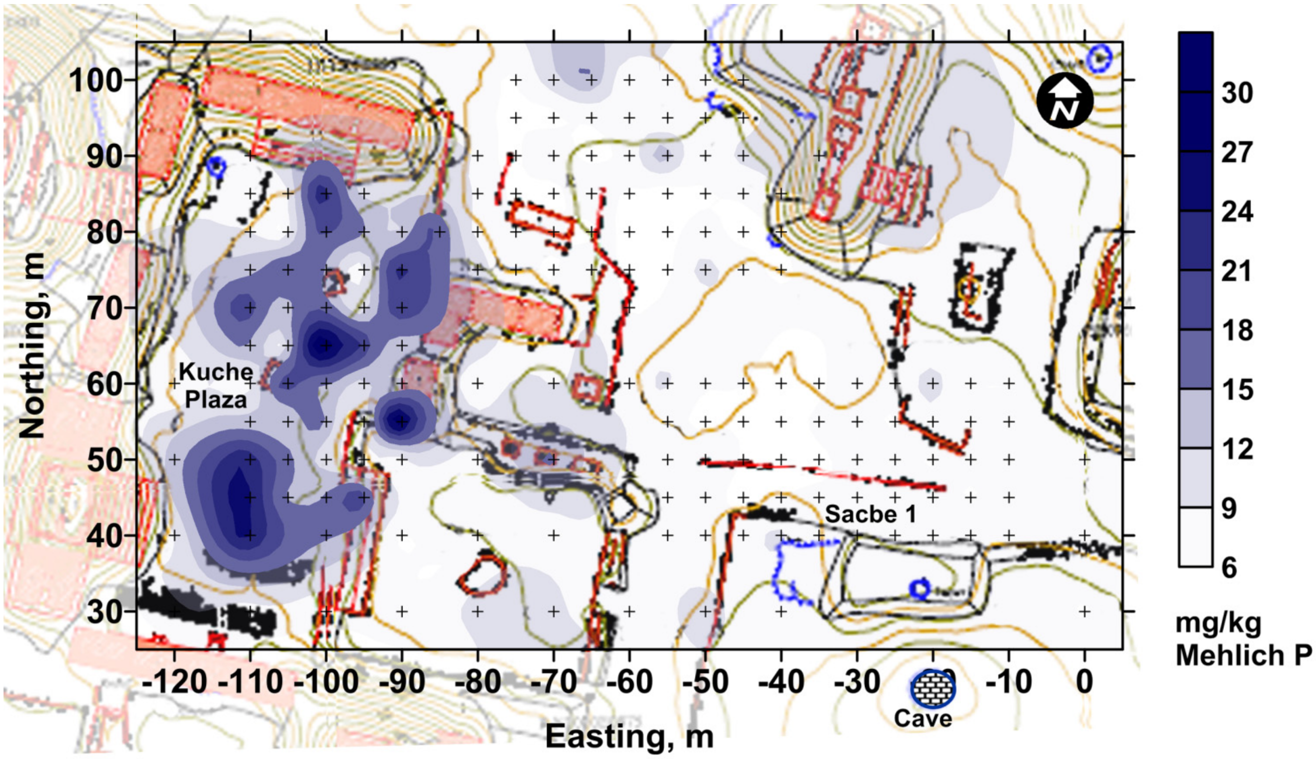

Figure 1-7. Mehlich II extractable P concentration isopleths of samples collected at the Kuche Plaza and Sacbe 1 in 2011.

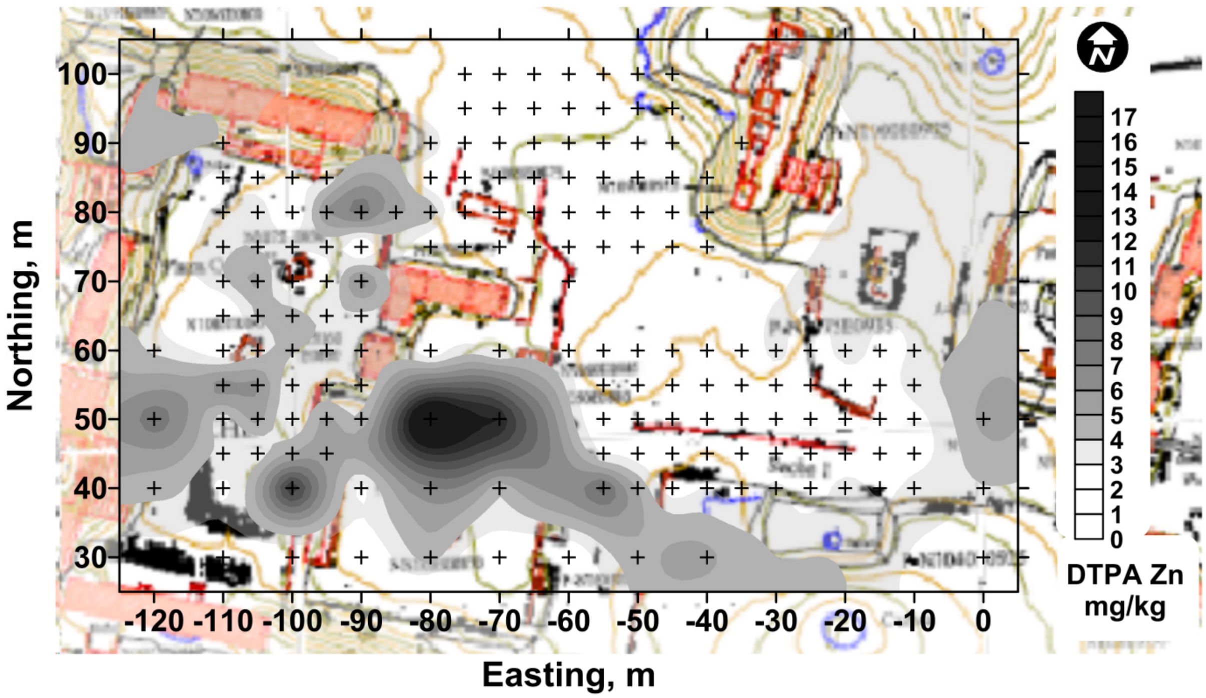

Figure 1-8. DTPA extractable Zn concentration isopleths of samples collected at the Kuche Plaza and Sacbe 1 in 2011.

Figure 1-9. Map of the Mirador group at Sayil, Mexico. The sample locations are marked with +.

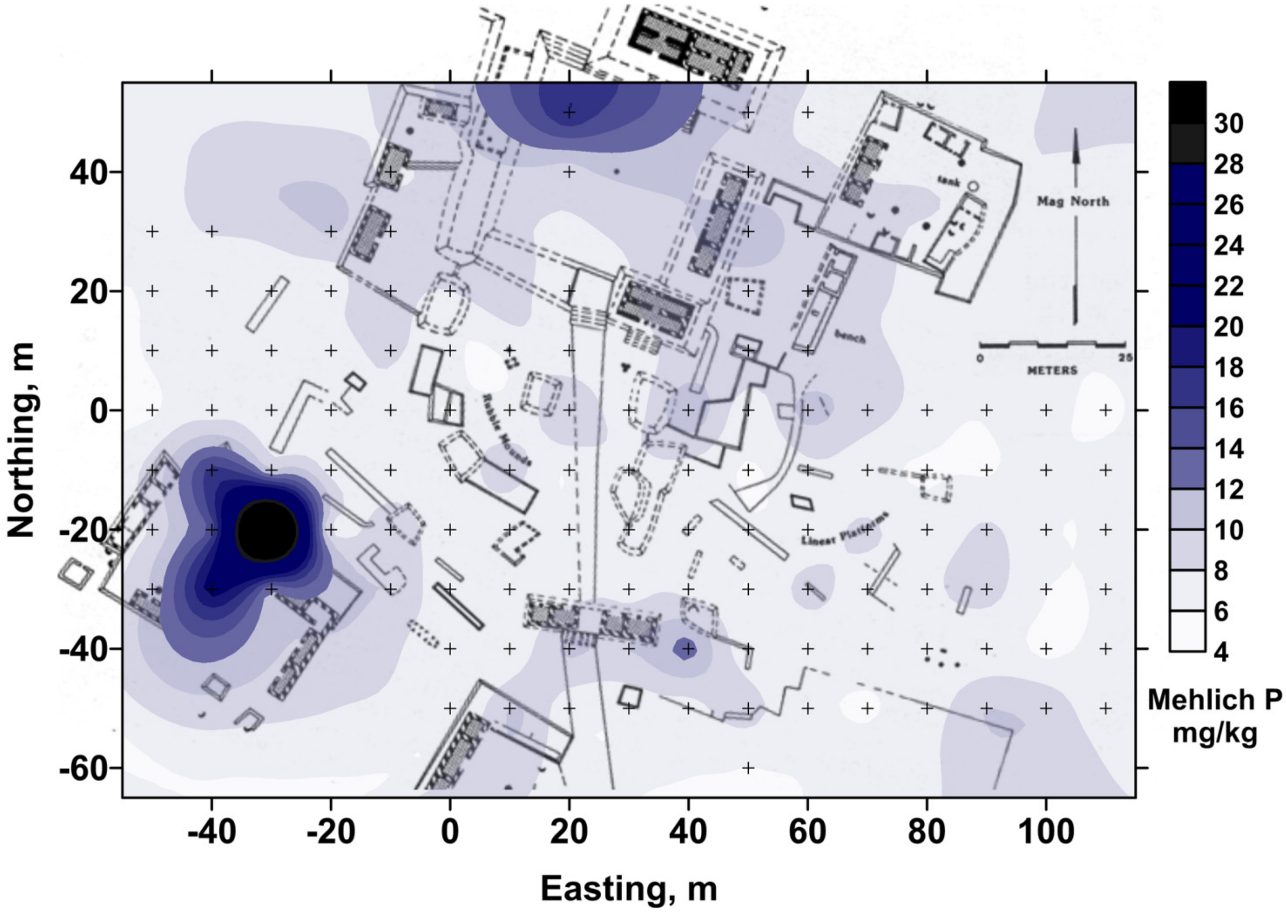

Figure 1-10. Concentration isopleths of Mehlich II extractable P in the Mirador group of Sayil.

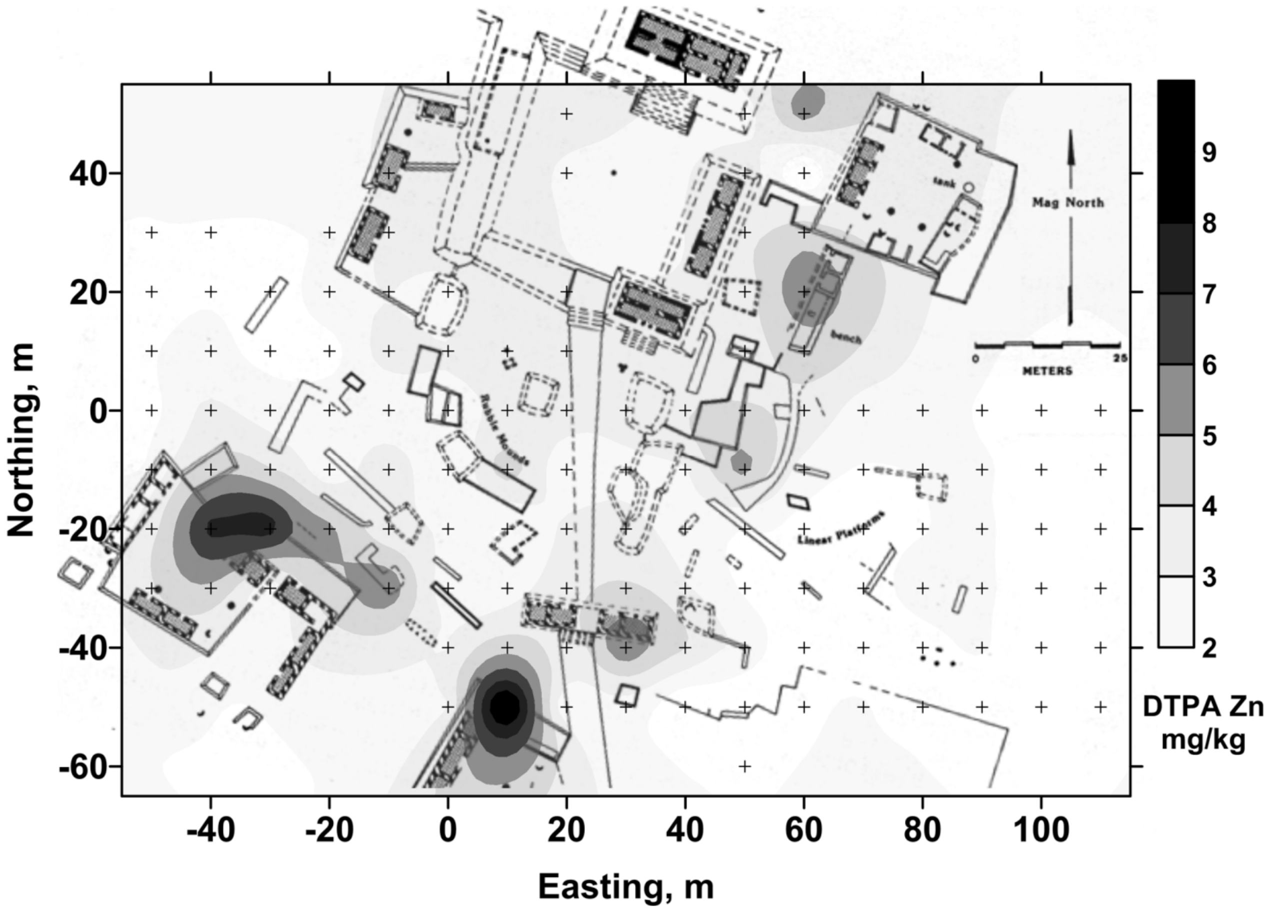

Figure 1-11. Concentration isopleths of DTPA extractable Zn in the Mirador group of Sayil.

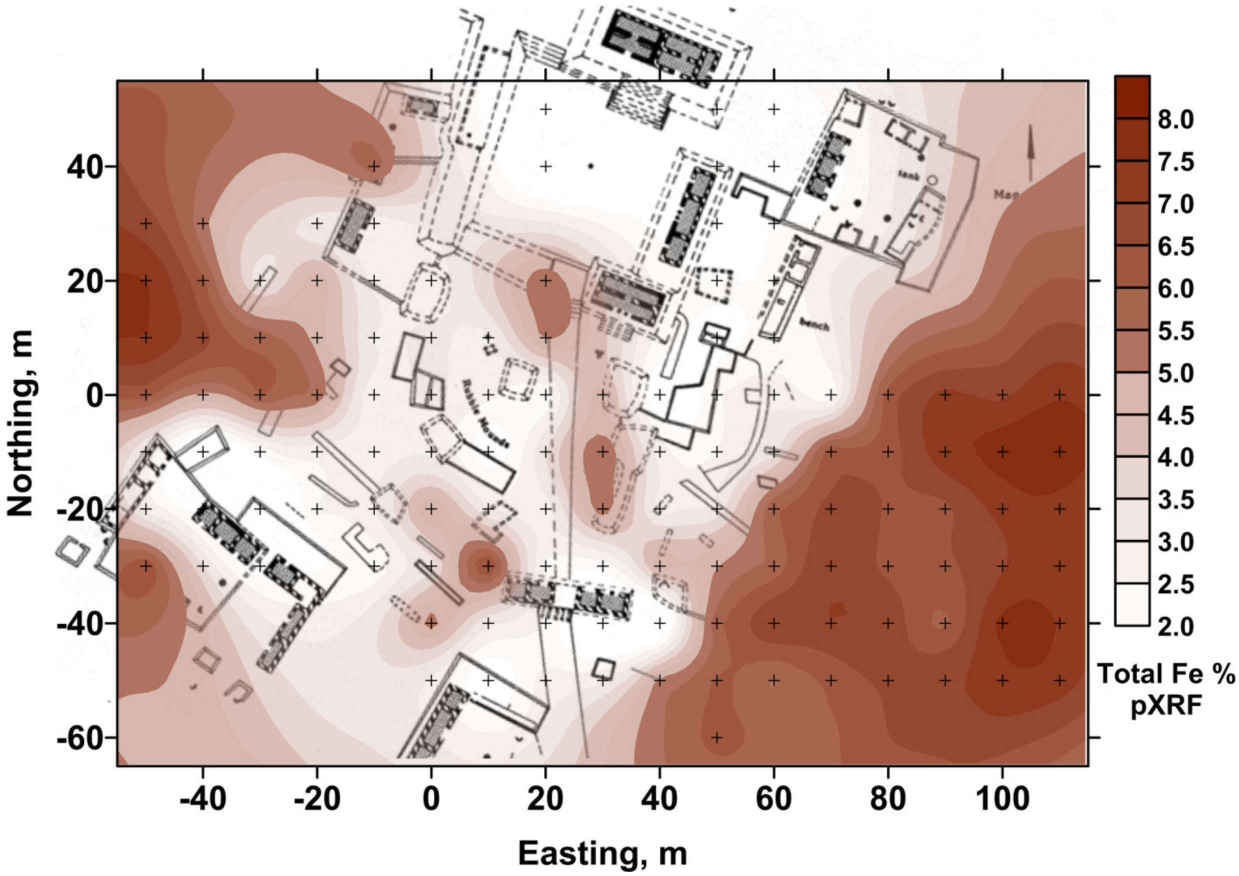

Figure 1-12. Concentration isopleths of pXRF total Fe in the Mirador group of Sayil.

Chapter 2

GEOCHEMICAL ANALYSIS OF ANCIENT MAYA ACTIVITIES AT SELECT PLAZAS AT CARACOL, BELIZE

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ABSTRACT – CHAPTER 2

The large public plazas of the ancient Maya were likely swept clear of debris and durable artifacts that could have provided evidence of the activities that took place there. Geochemical residues of food or mineral ores and pigments became affixed to soil and floor particles and remain as invisible artifacts of ancient anthropogenic activities. The objective of this study was to discover geochemical evidence of economic exchange activities at plazas recognized as likely sites for marketplace activities. Surface samples were collected from Ramonal and Conchita plazas located at sacbe termini, and the area near the South West sacbe entrance to the Caana Complex at the site of Caracol, Belize. Mehlich II and DTPA extraction procedures were used to determine the elemental concentrations of P, Cu, Fe, Mn, Pb, and Zn. Total elemental levels of additional elements were determined by portable X-ray fluorescence. The special pattern of P and trace elements in the Ramonal Plaza failed to offer convincing evidence of marketplace activity. In the Conchita plaza the linear patterns of extractable P, Zn, and Fe provide chemical signatures of human activities including evidence of ancient food storage, consumption, or trade activities and of workshop activities potentially including the use, production, or trade of pigments. Our geochemical findings provided compelling evidence that marketplace activities were associated with the terminal complexes at Caracol, and that such activities were not necessarily located in each of the terminal plazas. Geochemical results from the Conchita plaza also suggested that there was a geospatial division of activities implying administrative control of the terminal complex.

Key words: Maya economics, geochemical techniques, geochemistry, portable x-ray fluorescence, pXRF

Caracol, Belize the Discovery of an Ancient People

The discovery of Caracol, Belize was first reported in 1938 by a logger named Rosa Mai. That same year Mr. A.H. Anderson and Mr. H.B. Jex visited the site locating and documenting eight monuments (Anderson, 1951, Anderson, 1952). It was not until 1950 that the site was visited by Satterthwaite, who returned in 1951 and 1953 to further explore and document the ruins (Satterwaite, 1951, Satterwaite, 1954). By the end of these trips there were 39 documented monuments, which had all been transported to museums (Stone, 1985, Wilcox, 1954). Anderson worked in Caracol in 1953, 1955, and 1958 (Anderson, 1958, Anderson, 1959). He excavated tombs 1-5 and found one additional monument, which was not actually removed until 1978 (Beetz, 1981). Next came Paul Healy studying environmental resources recording evidence of terraces, properties of their construction, their agricultural function, dating of their construction in the Classic Period, and chemical properties that suggest intensive farming of the terraced slopes (Healy, et al., 1983).

Caracol is located in the Chiquibul Forest Reserve and National Park, which is a protected area located in the Maya Mountains of Belize. The elevation ranges from 300 to 900 m above sea level and receives nearly 2 m of rain each year. This area has abundant wildlife and many endangered species (Duke, 2004). The carbonate qualities of the karst parent material for the soils in Caracol make it so there is very little water that moves on the surface. This becomes particularly important when considering the agricultural practices at the Caracol. The epicenter of the site is 4 km from the nearest fresh water resource and over 15 km from the nearest source of running water (Chase, 2012).

The earliest evidence of occupation at Caracol comes from a burial dating to B.C. 600 (Chase, 1997). The main site center of Caracol shows activity starting in the Late Preclassic

B.C. 300 and hitting its apex after a time of successful warfare between A.D. 550 and A.D. 650 (Chase, 1987, Chase, 1997). After the Classic Period the largest structure at the site, Caana, was rebuilt after A.D. 800, and there was additional warfare at this time as well. The latest monuments from this site date from A.D. 950 to A.D. 1100. The unburied human remains found on Caana suggest that the final abandonment of the site may have come about quite suddenly (Chase and Chase, 1994).

The site of Caracol may be best known for an inscription on a ball court marker that refers to a victory over Tikal's lord in A.D. 562 (Chase, 1987, Chase, 2003, Grube, 1994, Houston, 1991, Martin, 1995) and later their recorded defeat of Naranjo in A.D. 631 (Chase, 2003, Chase, 1990). These victories are of significance because Tikal and Naranjo are both well-known political players in Classic Lowland Maya archeology. Investigations at Caracol have indicated a period of rapid complex urban development from A.D. 550 to A.D. 700 which is believed to be a result of successful militaristic ventures (Chase, 1989, Chase, 1990).

Caracol, Belize an Organized Metropolis with Limited Elite Control

The complicated causeway system at the site of Caracol, Belize shows significant interaction and even direct administrative control of locations as far as 11.5 km from the site center of Caracol (Chase, 1990). The causeways at Caracol have many clear functional qualities including transportation and communication, political and economic initiatives, and providing administrative control over this large metropolitan region (Chase and Chase, 2001). The causeway system stretches over a region that is 177 km^2 and has elevations from 450 to 650 m above sea level (Chase, 1998).

A population study has been done in the area that included the Conchita and Ramonal causeways and the surrounding areas. The study found that there were 244 residential houses per square km translating into 1,220 people in the same area (Chase, 1990). A later study indicated that there was a population of 35,000 to 61,000 in the 4 km from the site center, and approximately 150,000 in the entire Caracol Polity at its apex (Chase, 1998, Chase and Chase, 1994, Chase, 1990).

Such a dense population would have to be supported by impressive amounts of agricultural production. In 2003, Elizabeth Webb and her colleagues used stable carbon isotopic signatures from the terraced portions of Caracol as evidence of ancient agricultural activity. They reported evidence that maize production was a primary use for the terraces for some time after their construction (Webb, et al., 2004). This confirmed that the purpose and use of these terraces was agricultural.

Paul Healy first identified the need for this kind of agriculture with his investigation of the agricultural terracing at Caracol in 1980 (Healy, et al., 1983). More recent surveys by the Caracol Archeological Project, which started in 1985 and continues to the present, led by Arlen and Diane Chase, have shown that the dense settlement in this area was embedded in a very complex system of agriculture. The large-scale terracing found at Caracol and the surrounding region represented significant planning and labor investments (Chase, 1998). These terraces have Early Classic architectural elements, but appear to be Late Classic constructions, consistent with the timing of the large population increase at the site (Dunning and Beach, 1994).

The terracing itself does not appear to be associated with household units, but appears to have been organized and worked by organizations larger than individual or even extended families (Chase and Chase, 1994). While it appears that the planning for the terracing system was well organized, the distribution of water indicates that construction and maintenance were likely taken as household responsibilities and were not directly regulated by any major administrative powers (Chase, 2012, Crandall, 2009).

LiDAR findings at Caracol indicate that the distribution of water sources left them in control of household groups (Chase, 2012). This is significantly different from other large sites where the water was accessed in such a way that it was possible for the elite class to take administrative control over the resource. It also appears that during the most active period at Caracol there is a large group of people, which may be described as being middle class having access to tombs and artifacts such as elaborate pottery, jadeite, and spondylous shell (Chase and Chase, 1994).

Studies of household groups in Caracol have indicated that chert tools are standardized for use in craft production. This study also shows that the production of crafts can be associated with specific groups and are in household units that seem to be outside of administrative control (Johnson, 2008). It has been recognized that elites use both inclusion and exclusion material construction practices to control interaction between groups (Love, 1999). It appears that the elite at Caracol constructed a complex and extensive system of causeways (sacbeob; plural for sacbe meaning white road) to control economic interactions associated with the exchange of goods, and could do very little to control the production of these goods.

With over 70 km of known intrasite sacbeob at Caracol it is clear that these served not only transportation, but also important administrative and economic functions (Chase and Chase, 1996b). There are large architectural complexes and plazas found at the end of each major sacbe which are called termini and are embedded in continuous settlement from the site center (Chase, 1998). The complex causeway system as well as the architecture at the terminal ends of the sacbeob indicates that economic production and redistribution happened not only at the site center, but also at various locations in the same polity of Caracol (Chase, 1990).

Caracol, Belize and Marketplace Activities

The plazas associated with these termini have been proposed as markets based on the criteria associated with the marketplace hypothesis (Chase, 2011). The sacbeob and terminal architecture with the plaza were all contemporary constructions for each terminal group (Chase, 2011, Chase, 1990). The object of this study was to apply geochemical techniques to provide further evidence as to whether these plazas served as marketplaces. The two termini of concern in this study are Ramonal and Conchita. Samples were also collected at the start of a sacbe that enters to the Southeast of the Caana Group in the site center at Caracol, Belize.

There are many compelling reasons to consider Caracol as a candidate for the marketplace study. These include a large population, a healthy trade route, and a large middle class (Chase, 1998, Chase and Chase, 1994, Chase and Chase, 1996a, Chase and Chase, 2012, Cunningham-Smith, 2011). The most significant difference from this site and many others is the rapid development of a middle class that was under limited political control (Chase and Chase, 1996a, Chase, 2012).

The site construction and organization allowed political powers to control points of exchange, but did not require intense control over production activities. This supports the hypothesis that there were several marketplaces in Caracol during the Classic Maya occupation. Chase has proposed that there was a central marketplace and several satellite markets at Caracol (Chase, 2011). There are several sacbeob that enter the main site center in Caracol and all of them seem to have another satellite center of structures 3-km to 5-km from the site center. These potential satellite markets were considered to be good candidates for this study because of the artifacts that have already been uncovered supporting the existence of long-distance trade at Caracol.

Marketplace Hypothesis

Several authors have listed attributes or lines of evidence that should exist at ancient Mesoamerican marketplaces (Dahlin, et al., 2010a, Dahlin, et al., 2007, Fox, 1977, Wurtzburg, 1991). Some of these attributes were described at the time of the conquest while others are visible in contemporary marketplaces. The Attributes associated with ancient Mesoamerican marketplaces include:

(1) Urban centers that are located on trade routes and artifactual evidence of trade;

(2) Designated open space for a marketplace adjacent to transportation arteries;

(3) Proximity to public structures (e.g. ballcourt or sweatbath structures);

(4) Specific areas of trade for different classes of goods and post holes or stone alignments to denote assignment of market spaces or kiosks; and

(5) Regular patterns in the chemical concentrations of phosphorus (P) and metallic ions aligned with pathways (low concentrations), areas of foodstuff distribution (high levels of P), and the marketing of workshop items or craft materials (high levels of metal ions).

Geochemical Techniques Used in Archeology

Geochemical applications in archaeology started initially in Sweden (Arrhenius, 1931). These techniques have since been used throughout Europe and more recently in the Americas (Barba and Ortiz, 2001, Benedetti, et al., 2011, Brothwell, 1963, Herz, 1998, Meltzer, 1983, Pollard, 1999, Rapp, 1985, Rapp, 1998). Human activities can be identified by chemical signatures that remain fixed on the surface of soils and floors since the activities took place. This makes it possible to examine the elemental residues that resulted from anthropogenic activities. The relationship between the chemical signatures and the geospatial position of the signatures in a specific area can be used to identify what the activities potentially involved.

Soil geochemical techniques have been used to detect ancient human activity patterns on ancient Maya plazas and patios. Chemical residues derived from specific activities, that were repeatedly performed, in specific positions remain persist on the surfaces of soil particles and leave long lasting chemical traces. For example, elevated soil chemical concentrations of P help to identify areas of food preparation, consumption, trade, and refuse zones (Fernández, et al., 2002, Luzzadder-Beach, et al., 2011, Parnell, et al., 2002a, Terry, et al., 2004, Terry, et al., 2000). Heavy metal concentrations are indicative of workshop activities, as well as ritual and funerary spaces (Manzanilla and Barba 1990, Terry, et al., 2004). Lower levels of phosphorous and trace metals have been associated with pathways, sleeping quarters, sweeping, and modern disturbance due to excavation (Barba and Ortiz, 2001, Manzanilla and Barba 1990).

Quantitative Phosphorus Measurement

Phosphorus is essential in living cells and is a critical element in the basic composition of cell membranes and nucleic acids. The use of P tests in archaeology is a conventional method used as a preliminary test for pre-excavation prospecting. The presence of P in the majority of perishable goods has made it a standard procedure in archeology where artifactual remains are scarce (Bair, et al., 2006, Ball and Kelsay, 1992, Cavanagh, et al., 1988, Eidt, 1984, Parnell, et al., 2001, Provan, 1973, Sweetwood, et al., 2009).

Phosphorus tests are well suited for identifying the locations of market exchange because P contained in food becomes rapidly insoluble and fixed on soil and floor particles, preventing its removal by percolating water. This makes it possible to measure elevated levels of P in the soil centuries after it is deposited (Holliday and Gartner, 2007, Parnell, et al., 2001, Terry, et al., 2000, Wells, 2004). The correlation between P concentrations and human activities such as, agriculture, fertilization, waste, habitation, and other cultural activities has been demonstrated in many archeological studies (Barba, et al., 1987, Bethell and Máté, 1989, Craddock, et al., 1986, Dauncy, 1952, Dunning, 1993, Griffith, 1981, Hammond, 1983, Konrad, et al., 1983, Manzanilla and Barba 1990, Middleton and Price, 1996, Ortiz and Barba, 1993, Proudfoot, 1976, Sánchez, et al., 1996, Scudder, et al., 1996, Solecki, 1951, Terry, et al., 2000, Wells, et al., 2000a, Weston, 1995).

Trace Element Testing

Trace element concentrations can be used to indicate specific activities, which can be associated with mineral workshop items and pigments. Metals are often found attached to the mineral surfaces of the soils and the stucco pavement commonly found at Maya archeology sites (Bair, et al., 2006, Bintliff, et al., 1990, Entwistle, et al., 1998, Lambert, et al., 1984, Lewis, et al., 1993, Middleton and Price, 1996, Parnell, et al., 2002a, Parnell, et al., 2002b, Wells, et al., 2000a, Wells, et al., 2000b). The DTPA chelate extraction procedure is an accepted procedure when identifying concentrations for plant availability, environmental contamination, and mineral usage of heavy metal elements (Bair, et al., 2006, Dahlin, et al., 2007, Parnell, et al., 2002a, Terry, et al., 2004). This process coupled with the use of Inductively Coupled Plasma - Atomic Emission Spectrometer (ICP/AES) technology has made it possible to detect lower levels of trace metals and compare them in an attempt to find additional information about the activities associated with these soils (Cook, et al., 2006, Luzzadder-Beach, et al., 2011).

Zinc (Zn) is an element of interest because it is a metal that also serves as a micro nutrient in crops, and all forms of life on earth. Zinc is often closely associated with P residues showing that large amounts of foodstuffs were brought into the particular location in the past (Dahlin, et al., 2010a, Dahlin, et al., 2007).

Iron (Fe) is used extensively in the production of pigments in the ancient Maya society, and may be associated with production and trade of any products that include the application of pigments. Other metals such as copper (Cu) and manganese (Mn) are components of many rocks and minerals used in workshop activities and trade.

Total elemental analysis of metals in soils and floors can be determined by X-ray fluorescence. Portable X-ray fluorescence (pXRF) instruments facilitate analysis of samples in either formal laboratory or field lab settings. Prior to pXRF analysis samples are air-dried, crushed, and sieved, but there is no need for strong acid digestion or for chemical extraction and spectrometric analysis. Total analysis is most useful in determining the origins of soil and floor materials by examining the relative differences in calcium (Ca) associated with limestone fill and stucco and titanium (Ti), aluminum (Al), Fe, and other constituents of soil clays. Unfortunately, the tiny amounts of anthropogenic elements deposited on the surfaces of soil and floor particles are likely to be overwhelmed by the total elemental content of those particles.

Soil geochemistry has been a useful tool in the identification of ancient marketplace activities at Chunchucmil (Dahlin, et al., 2010a, Dahlin, et al., 2007, Luzzadder-Beach, et al., 2011), Mayapan, and Coba in the northern Yucatan peninsula (Coronel, et al., ND). Richard Terry and his students from Brigham Young University have identified geochemical patterns that suggest ancient marketplace activities at plazas in Ceibal (Bair, 2010), Trinadad de Nosotros (Dahlin, et al., 2010b), and Motul de San Jose (Bair, 2010) in Guatemala.

The purpose of this study is to determine geochemical accumulation and the ancient Maya plaza activities at Caracol, Belize (Figure 2-1) using various soil studies. The plazas at the Conchita and Ramonal sacbe termini, and an area near the Caana Complex were tested for extractable P, Fe, Zn, and other trace elements known to be associated with marketplace activities.

Systematic sampling of the floors of public plazas and elite residential patios were collected and prepared for testing. These tests were used to identify not only where the activity was present, but also what the activities potentially involved: metal work, plastering, and evidence of organic matter accumulation including food residues.

Materials and Methods

The predetermined sampling locations were identified starting at a particular reference point and then using measuring tape to triangulate the locations for equidistant sampling of the plazas. This allows any particular sample to be equal distance from the six nearest samples. Though more complicated than methods used in the past, this change in the sampling pattern is to effectively improve the value of the data collected when applying geospatial statistics. For the sampling at the site of Caracol, both 5 and 10 m distances between samples were employed.

Soil samples were acquired by removing surface leaf litter and the first couple centimeters of topsoil, then 200 to 300 g of soil were placed in a bag and homogenized, next the samples were transported to the Brigham Young University Soil Analysis Lab in Provo, Utah for chemical analysis. Before the tests could be performed the soil was air dried, crushed by using mortar and pestle, and then sieved to less than 2 mm. The Mehlich II phosphate extraction procedure, as modified by Terry (Terry, et al., 2000) was used in the lab and P concentrations were determined by colorimeter. The heavy metal concentrations were found using the DTPA extraction procedure and specific concentrations were determined using an ICP/AES.

The total element analysis of all the surface soil samples was conducted with a Bruker Tracer IV SD pXRF instrument. Bagged samples are placed over the window of the pXRF and scanned to provide multi-element analysis of chemical constituents both on the surfaces and contained within the particles of the samples. The fundamental parameters analysis was standardized with the "Soils with Calcium Carbonate" calibration provided by Bruker, and the X-Ray fluorescence signal was collected for 120 seconds. X-Ray fluorescence is effective in obtaining total elemental concentrations instead of just the concentrations for chemicals attached to particle surfaces. When identifying differences in total and extractible concentrations it is possible to differentiate between plaza floor materials (constructed from soils) and plaza fill and stucco pavement (constructed from burnt calcium carbonate). It is also possible to find patterns that indicate modern rather than ancient activities associated with Fe (Coronel, 2011).

Surfer 8 software was used to produce elemental concentration isopleths showing the concentration contours for each of the elements of interest overlade on top of maps of the sampling areas. Tables were also produced for each set of samples showing the maximum, minimum, average, standard deviation (STDEV), and background chemical concentrations for each element of interest. JMP software was used to produce matrix tables of correlation coefficients for each of the elements. Significance of correlation coefficients (r) are denoted by, (**) for highly significant ($p < 0.01$), (*) for significant ($p < 0.05$), and (N.S.) for not significant ($p > 0.05$).

King (2008) used 40 off-site samples in an attempt to find useful background concentrations, but found that the native soils often have higher concentrations in elements such as P, especially when the sampling site is associated with plaza fill or stucco pavement. Sampling outside of the area of interest does not produce samples representative of the native soil because all of the soil in these sites are expected to have been affected by human activities similar to those being identified in this study. The use of samples that are not from the area of interest for background calculations also makes little sense when considering changes within the sampling areas. Instead of comparing the sampling areas with areas that have experienced different anthropogenic activities, background levels for this study were calculated by taking the average of the 10 percent of samples with the lowest concentration acquired from the plazas of interest (Coronel, et al., ND, King, 2008).

Results and Discussion

Ramonal Plaza

The Ramonal plaza was sampled on a 10-m equal distance grid and 93 floor samples were collected. The summarized data and correlation matrix of those data are shown in Tables 2-1 and 2-2. Mehlich P concentrations ranged from 4.8 to 21.0 mg/kg with a background level of 5.6 mg/kg. Concentration isopleths of extractable P are shown in Figure 2-3. No discernible linear patterns of elevated P concentrations were found in the Ramonal Plaza, but rather the distribution of P concentrations appear along and just outside the edges of the plaza and levels were very low with an average of 8.6 mg/kg (Figure 2-3). Extractable P is associated with accumulation of plant material on soil particles, and the random distribution of this signature indicates that little plant material was deposited from anthropogenic activities.

Concentrations of DTPA extractable Zn in this plaza were between 1.0 and 20.5 mg/kg with a calculated background of 1.3 mg/kg (Table 2-1). The accumulation of Zn in the same location as P has been reported at other suspected marketplaces where food has been processed or traded in significant quantities. There were no linear patterns in the concentrations of either P or Zn in the Ramonal Plaza (Figures 2-3 and 2-4, respectively), but there was a significant correlation (r = 0.433**). The lack of anthropogenic organization in the geospatial distribution of this chemical signature does not suggest activities consistent with the processing or trade of foodstuffs at the Ramonal Plaza.

DTPA chelate extractable Fe concentrations in the plaza floor ranged from undetectable concentrations to 22.5 mg/kg with background levels at 0.92 mg/kg (Table 2-1). Extractable Fe associated with mineral pigments and workshop activities was found at elevated concentrations in the central portion of the plaza with low levels found along the edges of the plaza (Figure 2-5). Elevated levels of extractable Fe were also found on the sacbe and adjacent area south of the plaza. The geospatial distribution of this chemical signature in relation to the ancient architecture did suggest anthropogenic activities, such as painting of structures, workshop activities, or trade of mineral goods that contained Fe. DTPA extractable Fe concentrations shows highly significant negative correlations with Mehlich P and DTPA Zn concentrations where r = -0.610** and r = -0.365** respectively (Table 2-2). This indicates that the accumulation of foodstuffs and plant material was less frequent in the locations where the DTPA Fe was found in higher concentrations, specifically the area just south of the Ramonal Plaza.

Concentrations of total Fe measured by pXRF ranged from 0.15 to 5.16 percent in the Ramonal Plaza floor (Table 2-1). The pXRF total Fe concentrations were closely associated with the DTPA Fe concentrations, r = 0.573**, and had a very similar negative correlation with

Mehlich P (r = -0.608**) and DTPA Zn (r = -0.343**; Table 2-2). This correlation was consistent with the idea that long standing Fe or a basic Fe composition of the soil cause a correlation between pXRF total Fe and DTPA extractable Fe, while recent deposits of Fe have significantly greater effect on the extractable Fe concentrations than they do on the total Fe concentrations. This relationship makes sense because recent activities depositing Fe does not make a large difference on the total Fe content, however it does leave Fe on the soil particles which can be more easily extracted by the DTPA chelate extraction procedure (Coronel, 2011). This indicated that the elevated concentrations of both extractable and total Fe in the central section of the plaza and the area just south of the Ramonal Plaza were caused by ancient anthropogenic activities.

Conchita Plaza

The Conchita Plaza is the terminus of a 3-km long sacbe from the site center of Caracol. The sacbe enters the plaza from the Northwest and there are two patio groups adjacent to the plaza on the North and the West sides (Figure 2-6). There was a structure within the West central floor of the plaza. The linear pattern of extractable P concentration on the Western portion of the plaza floor of Conchita Plaza (Figure 2-7) is in contrast to the more random pattern of P concentration in the floor of Ramonal Plaza (Figure 2-3). Mehlich extractable P concentrations ranged from 5.4 to15.2 mg/kg for the samples collected from the Conchita Plaza, with background concentrations of 8.4 mg/kg (Table 2-3). The distributions of elevated P concentrations in this plaza were consistent with the possible linear arrangement of market stalls on the West side of the plaza near the entrance of the sacbe to the plaza. These concentrations seemed to be associated with human activities between the sacbe coming from the site center of Caracol and the large structure that was constructed in the middle of the Conchita plaza.

Concentrations on DTPA extractable Zn ranged from 1.3 to 24.1 mg/kg with background levels at 2.1 mg/kg (Table 2-3). Concentration isopleths of DTPA Zn indicated elevated levels of Zn in the same West and slightly North portions of the plaza that showed elevated levels of Mehlich P (Figure 2-8). The statistical correlation between DTPA Zn and Mehlich P was found to be highly significant ($r = 0.660^{**}$; Table 2-4). The concentrations of extractable P and Zn in the North and West portion of the plaza were raised to levels twice as high as other portions of the plaza. The linear patterns and location of elevated P and Zn between the sacbe entrance and the central structure in the plaza provide compelling evidence for the ancient trade in foodstuffs at the Conchita plaza.

The DTPA extractable Fe concentrations ranged between 0.7 and 21.8 mg/kg with background concentrations at 2.0 mg/kg (Table 2-3). A linear pattern of elevated extractable concentrations was found on the East side of the plaza (Figure 2-9). Extractable Fe were negatively correlated with extractable Zn and P, where $r = -0.216^{**}$ and -0.407^{**}, respectively (Table 2-4).

Concentrations of pXRF total Fe for the Conchita plaza ranged from 0.27 and 4.67 percent with a background of 0.35 percent (Table 2-3). The concentration isopleths for extractable Fe (Figure 2-9) and total Fe (data not shown) matched with a highly significant correlation between the two forms of Fe ($r = 0.598^{**}$; Table 2-4). The total Fe concentrations also showed highly significant negative correlations with Mehlich P and DTPA Zn concentrations with correlation coefficients of $r = -0.428^{**}$ and $r = -0.329^{**}$, respectively (Table 2-4). This strong correlation and the geospatial distribution of chemical concentrations, in relation to the architecture, shown in the matching isopleths suggest that the Fe deposited in this plaza is related to ancient anthropogenic activities. The presence of this strong signature for Fe concentrations offers strong evidence that the East side of the plaza was used for production or trade of mineral workshop items. This pattern of extractable Fe on the East side of the plaza is consistent with what would be expected from trade of mineral pigments and workshop goods, or possible from paint or pigments used in the Ramonal Group.

The clear change in the signature on each side of the plaza is particularly worthy of note. This seems to be indicating that the activities on this plaza were segregated, dividing the use of the plaza into two distinctly different kinds of tasks or economic activities. The clear and abrupt change in chemical signatures in their geospatial arrangement in relation to the ancient architecture constitutes compelling evidence that this plaza had two distinct and different uses that could have involved the trade of foodstuffs or production of mineral workshop items. The administrative expertise and control expected to be present suggests that administrative control would have been required to first develop then maintain the segregation of activities on the Conchita Plaza.

Caana Sacbe

A total of 97 samples were collected at the conjunction of a sacbe and the Caana Plaza at the site center of Caracol. For this plaza, equal distance sampling methods were employed with a 5 m distance between samples (Figure 2-10). It is important to note that this sampling area was in the site center at Caracol and had a modern path going through it where samples are missing. The area on the North side of the path has been consolidated meaning the native soil has been disturbed while the area to the South is soil derived from fill and stucco, but is regularly cleared of vegetation.

The maximum, minimum, averages, and background levels of Mehlich extractable P, DTPA extractable metals, and pXRF total metals in the floor of the sacbe are shown in Table 2-5. The levels Mehlich extractable P ranged from 6.1 to 470.2 mg/kg with a background concentration of 10.9 mg/kg. Isopleths for Mehlich P concentrations show that concentrations were significantly higher in the South section of the sampling area (Figure 2-11). The sampling area has had many modern disturbances and the areas with elevated P appear to be charred black from the burning of leaves and vegetative debris. This is what should be expected as a result of these recent activities, so it is difficult to distinguish contemporary geochemical deposition from ancient chemical signatures of activities in this area.

DTPA extractable Zn was found in concentrations ranging from 0.5 to 18.8 mg/kg and background concentrations at 0.1 mg/kg (Table 2-5). Figure 2-12 shows concentration isopleths for DTPA Zn in the Canna sampling area. A highly significant correlation, r = 0.448**, has been found between Mehlich P and DTPA Zn concentrations (Table 2-6). This is also expected because DTPA Zn has been found to consistently correlate with Mehlich P when the source of the elements is accumulated vegetative sources in the burn areas. Both extractable P and Zn have higher concentrations in the ancient plaza floor, to the South, as opposed to the soil consisting of consolidated fill, to the North, which could also explain this correlation.

Fe extracted with the DTPA chelate procedure offered concentrations between 1.2 and 46.1 mg/kg with background levels at 2.1 mg/kg (Table 2-5). The concentration isopleths for DTPA Fe show that most of the higher concentrations of extractable Fe were in the South area consisting of ancient plaza floor material (Figure 2-13), much like the concentration isopleths of

Mehlich P (Figure 2-11) and DTPA Zn (Firgure 2-4). However, this does not produce any significant correlation between DTPA Fe with Mehlich P and DTPA Zn, r = 0.021 (N.S.) and r = 0.200 (N.S.) respectively (Table 2-6). This is evidence that the correlations are not being too drastically affected by difference in consolidation material and ancient plaza floor.

Total Fe measured by pXRF offered concentrations of 0.03 to 0.11 percent with background concentrations calculated at 0.04 percent (Table 2-5). Concentration isopleths for pXRF total Fe are shown in Figure 2-14, and indicate a similar pattern to the other elements discussed with high concentration in the South section of the Caana sampling area. This highlights the importance of sampling such areas of interest before consolidation takes place. Table 2-6 indicates that there was a weak, but significant correlation between pXRF Fe and DTPA Fe, r = 0.224*. This appears to indicate both the ancient and modern signatures for the DTPA Fe, and that where the two line up indicates ancient activity (Coronel, et al., ND). It is difficult, however, to accurately consider each sample and decide which ones indicate ancient activity because natural occurrences in the soil can produce changes in concentrations at random locations. It is difficult to distinguish modern geochemical activity from ancient geochemical signatures in the Caana sampling area.

Conclusions

Modern disturbances in the sampling area at the sacbe in Caana make the results difficult to interpret for any useful information regarding marketplace activities. The results from this sampling area illustrate the importance of having the surface soil of a site sampled for chemical analysis before any large projects are undertaken that will disturb large sections of the soil.

The Ramonal Plaza possessed insufficient geochemical evidence to support the marketplace hypothesis, where the patterns of P and other elements were somewhat random. It is a relatively small plaza and may have been used for other functions requiring the marketplace to be at another location. There were anthropogenic activities just south of the plaza that may have may have been associated with Fe-rich goods or activities in the past.

The Conchita Plaza is significantly larger than the Ramonal Plaza and shows significant evidence of organized human activities. The separation into the two chemical signatures with elevated P indicating ancient foodstuffs on the North and West side of the plaza, and Fe associated with Fe-rich minerals and pigments on the East side of the plaza is particularly interesting because it shows a spatial separation of functions for the plaza.

This geospatial separation of activities within the Conchita Plaza suggests that the elites had established and maintained administrative control over how the plaza was to be used. The East side, with a signature consistent with workshop production or trade, has a retention wall and seems to parallel somewhat with the locations at which higher end goods are sold in today's marketplaces. While the West and North portion of the plaza was used for the trade or processing of foodstuffs in this P-enriched area, and has an entrance from the causeway. This seems to parallel the easily accessible vegetable vendors at modern Mesoamerican marketplaces. The Conchita plaza has all the elements consistent with a marketplace as defined by the marketplace hypothesis.

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Table 2-1. Maximum, minimum, average, standard deviation, and background chemical concentrations for each element of interest at the Ramonal plaza. Background levels are calculated as the average of the 10% of samples lowest in concentration.

	Mehlich P	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
	------------------- mg kg^{-1} ----------------------							%	mg kg^{-1}		%	------mg kg^{-1} ----		
Maximum	20.99	1.94	22.52	62.12	2.34	20.46	3340	21.24	2480	834	5.16	71	101	30
Minimum	4.77	0.23	0.15	4.34	0.82	0.95	482	3.69	124	43	0.15	38	46	5
Average	8.56	1.02	6.90	25.52	1.44	3.99	1500	10.93	1283	308	1.52	48	60	12
STDEV	2.46	0.35	4.67	10.34	0.29	2.68	566.26	3.42	614.64	129.43	0.84	4.63	8.09	4.70
Background	5.62	0.47	0.92	11.13	0.97	1.33	703.56	5.78	301.00	116.89	0.39	41.44	49.56	5.39

Table 2-2. Correlation matrix for the Ramonal plaza results; * denotes significance at $p < 0.05$ and ** denotes highly significant at $p < 0.01$.

n=94	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
Mehlich P	-0.138	-0.610**	0.026	-0.335**	0.433**	-0.249*	-0.308**	-0.715**	-0.450**	-0.608**	0.118	0.068	-0.383**
	DTPA Cu	0.378**	0.822**	0.623**	0.079	-0.144	-0.329**	0.345**	0.504**	0.469**	0.344**	0.418**	0.308**
		DTPA Fe	0.236*	0.406**	-0.365**	0.095	0.034	0.690**	0.455**	0.573**	0.158	0.084	0.293**
			DTPA Mn	0.675**	0.250*	-0.219*	-0.385**	0.187	0.433**	0.358**	0.255*	0.396**	0.155
				DTPA Pb	0.005	-0.206*	-0.320**	0.555**	0.633**	0.570**	0.266*	0.374**	0.420**
					DTPA Zn	-0.071	-0.070	-0.435**	-0.158	-0.343**	-0.023	0.568**	-0.188
						pXRF K	0.833**	0.145	0.017	0.019	-0.190	-0.268**	0.227*
							pXRF Ca	0.041	-0.147	-0.145	-0.308**	-0.428	0.002
								pXRF Ti	0.715**	0.886**	0.025	0.171	0.624**
									pXRF Mn	0.797**	0.383**	0.391**	0.597**
										pXRF Fe	0.083	0.282**	0.606**
											pXRF Cu	0.495**	0.296**
												pXRF Zn	0.366**

Table 2-3. Maximum, minimum, average, standard deviation, and background chemical concentrations for each element of interest at the Conchita plaza. Background levels are calculated as the average of the 10% of samples lowest in concentration.

	Mehlich P	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
	- - - - - - - - - - - - - - - - - - - mg kg^{-1} -							%	mg kg^{-1}		%	- - - - - -mg kg^{-1} - - - -		
Maximum	15.2	2.9	21.8	116.8	2.5	24.1	4300	19.24	3750	1280	4.69	66	120	30
Minimum	5.4	0.8	0.7	14.9	0.7	1.3	689	2.86	326	183	0.27	46	53	8
Average	8.4	1.8	8.7	39.6	1.5	8.1	1741	9.42	1615	606	1.64	55	77	18
STDEV	2.5	0.4	4.8	20.4	0.3	5.2	708	3.80	801	226	1.10	5	11	5
Background	5.6	1.2	2.0	18.9	1.1	2.1	870	4.09	406	288	0.35	48	59	9

Table 2-4. Correlation matrix for the Conchita plaza results; * denotes significance at $p < 0.05$ and ** denotes highly significant at $p < 0.01$.

n=94	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
Mehlich P	0.186	-0.407**	0.582**	0.410**	0.660**	0.240*	0.236*	-0.568**	-0.066	-0.428**	0.133	0.139	-0.446**
	DTPA Cu	0.209*	0.467**	0.402**	0.457**	-0.012	-0.094	0.164	0.552**	0.218*	0.577**	0.599**	0.273**
		DTPA Fe	-0.203	0.177	-0.216*	0.110	0.068	0.709**	0.489**	0.598**	0.288**	0.301**	0.618**
			DTPA Mn	0.648**	0.512**	-0.026	-0.122	-0.280**	0.146	-0.092	0.239*	0.267**	-0.244*
				DTPA Pb	0.419**	-0.200	-0.324**	0.084	0.571**	0.243*	0.536**	0.494**	-0.006
					DTPA Zn	0.187	0.223*	-0.436**	0.191	-0.329**	0.358**	0.619**	-0.287**
						pXRF K	0.877**	-0.085	-0.138	-0.250*	-0.044	-0.078	0.216*
							pXRF Ca	-0.209*	-0.279**	-0.404**	-0.082	-0.131	0.060
								pXRF Ti	0.556**	0.897**	0.150	0.225*	0.760**
									pXRF Mn	0.618**	0.549**	0.633**	0.526**
										pXRF Fe	0.190	0.303**	0.642**
											pXRF Cu	0.596**	0.207*
												pXRF Zn	0.265*

Table 2-5. Maximum, minimum, average, standard deviation, and background chemical concentrations for each element of interest at the Caana plaza. Background levels are calculated as the average of the 10% of samples lowest in concentration.

	Mehlich P	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
	- - - - - - - - - - - - - - - - - - mg kg^{-1} -							%	mg kg^{-1}		%	- - - - - -mg kg^{-1} - - - -		
Maximum	470.19	1.87	46.08	35.54	1.80	18.79	7000	34.08	1560	521	0.11	59	127	41
Minimum	6.06	0.17	1.19	2.34	0.28	0.45	2650	12.44	490	39	0.03	38	41	6
Average	69.76	0.96	13.88	17.37	1.00	6.60	4672	22.87	1016	266	0.07	50	78	24
STDEV	66.12	0.38	8.37	8.15	0.28	3.52	938	3.97	215	140	0.02	6	18	10
Background	10.94	0.31	2.12	3.48	0.47	0.91	3195	16.41	627	52	0.04	40	51	8

Table 2-6. Correlation matrix for the Caana plaza results; * denotes significance at $p < 0.05$ and ** denotes highly significant at $p < 0.01$.

n=97	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF K	pXRF Ca	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb
Mehlich P	0.337**	0.021	0.169	0.231*	0.448**	-0.280**	-0.139	0.074	0.293**	0.164	0.264*	0.325**	0.238*
	DTPA Cu	0.300**	0.821**	0.739**	0.823**	-0.475**	-0.421**	0.442**	0.575**	0.486**	0.569**	0.541**	0.550**
		DTPA Fe	0.177	0.242*	0.200	-0.083	0.109	0.198	0.222*	0.224*	0.177	0.190	0.167
			DTPA Mn	0.787**	0.726**	-0.520**	-0.482**	0.453**	0.579**	0.468**	0.519**	0.560**	0.538**
				DTPA Pb	0.628**	-0.507**	-0.558**	0.603**	0.682**	0.634**	0.616**	0.611**	0.662**
					DTPA Zn	-0.545**	-0.457**	0.391**	0.624**	0.477**	0.624**	0.681**	0.580**
						pXRF K	0.622**	-0.328**	-0.701**	-0.397**	-0.588**	-0.688**	-0.594**
							pXRF Ca	-0.626**	-0.621**	-0.658**	-0.727**	-0.720**	-0.709**
								pXRF Ti	0.719**	0.930**	0.649**	0.647**	0.829**
									pXRF Mn	0.817**	0.774**	0.823**	0.889**
										pXRF Fe	0.722**	0.716**	0.897**
											pXRF Cu	0.822**	0.799**
												pXRF Zn	0.848**

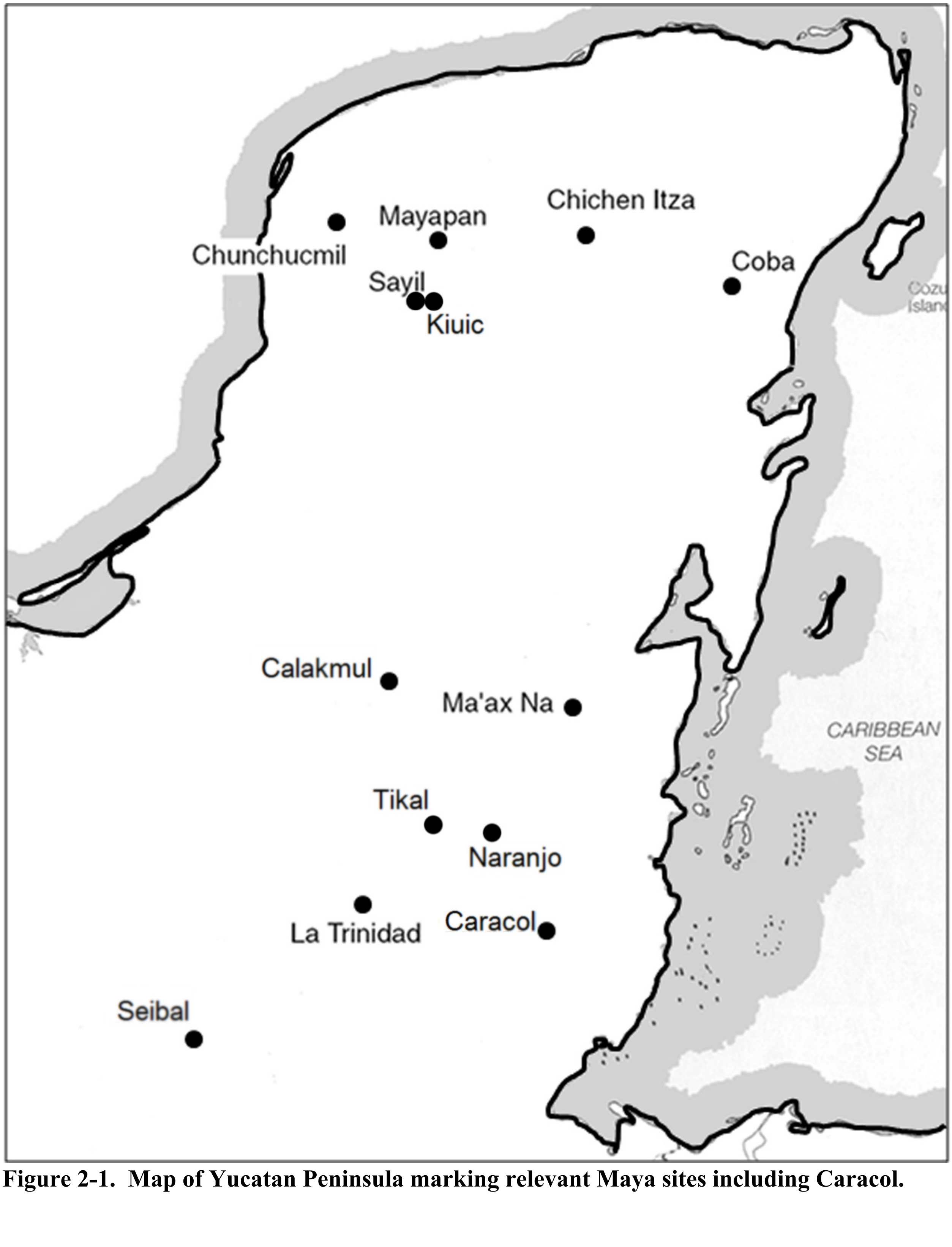

Figure 2-1. Map of Yucatan Peninsula marking relevant Maya sites including Caracol.

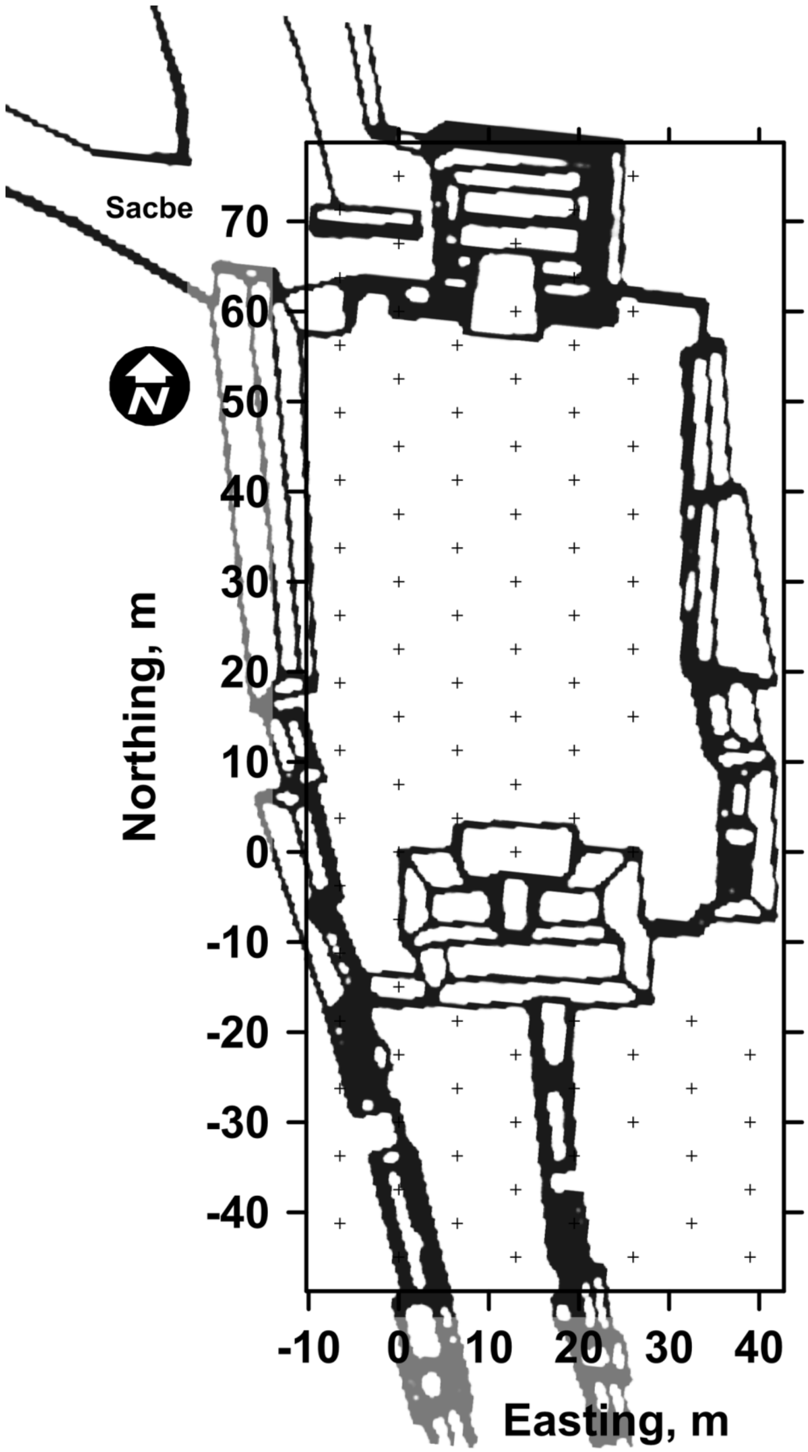

Figure 2-2. The Ramonal Plaza located 2.5 km south of Caracol. The sampling locations are shown as +.

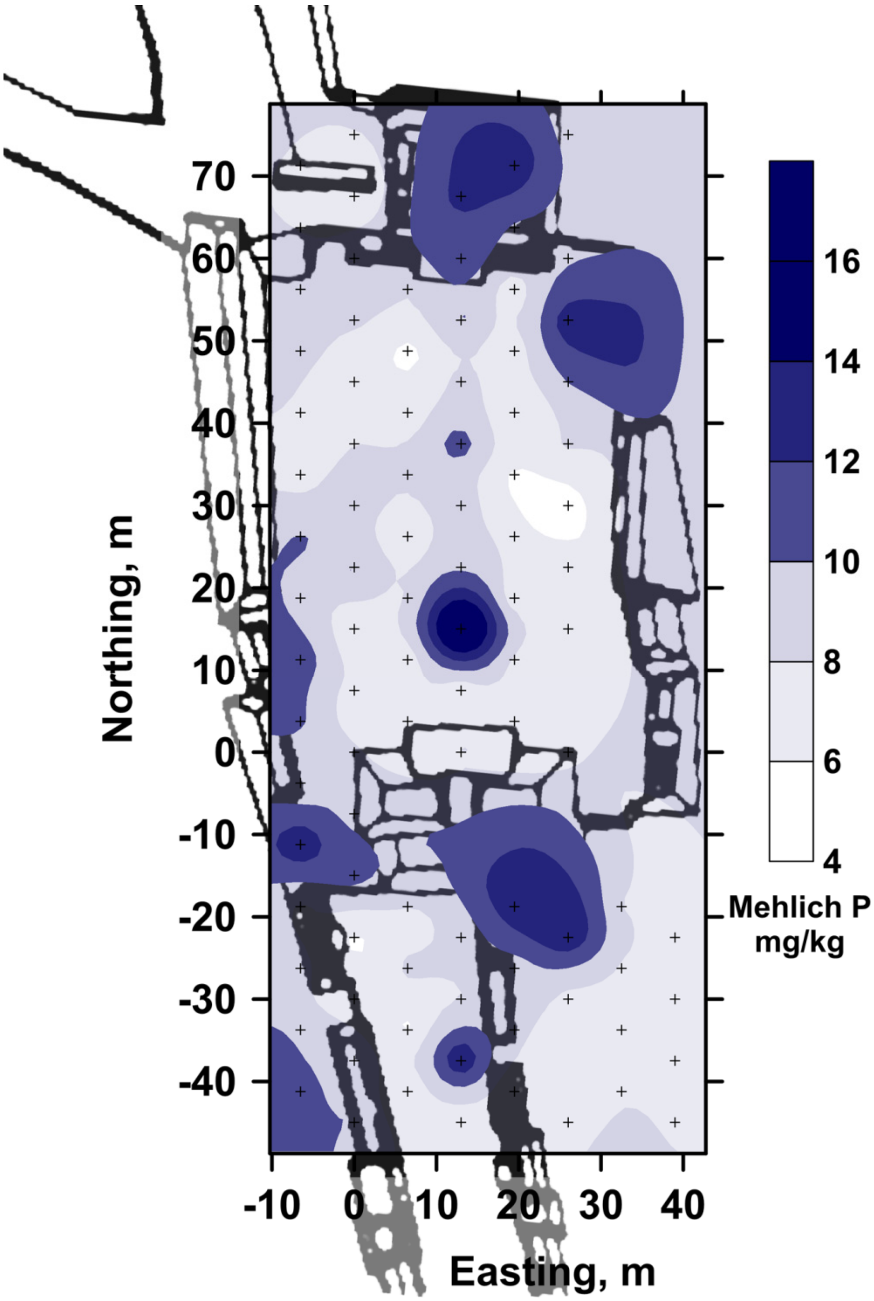

Figure 2-3. Concentration isopleths of Mehlich II extractable P in the Ramonal Plaza near Caracol, Belize.

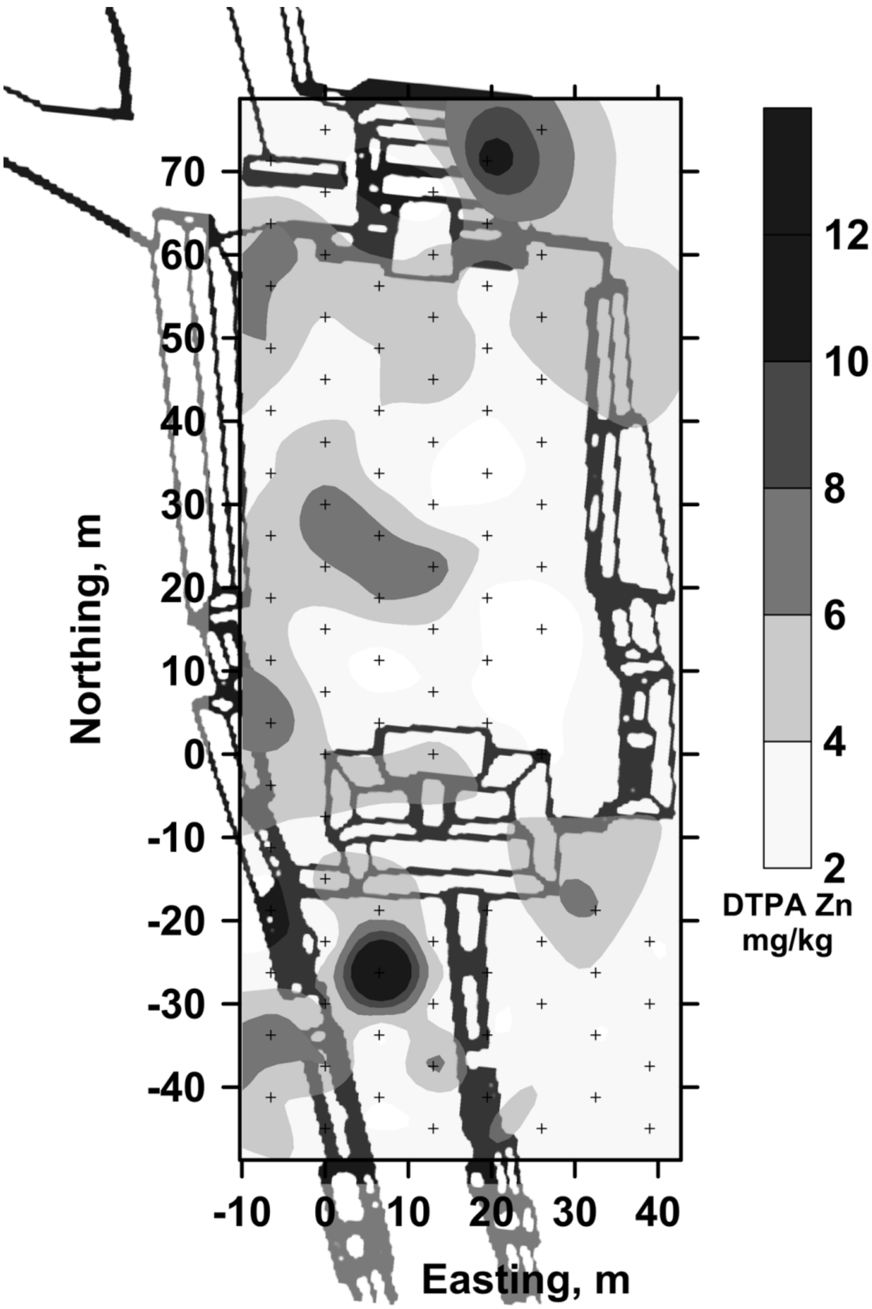

Figure 2-4. Concentration isopleths of DTPA extractable Zn in the Ramonal Plaza near Caracol, Belize.

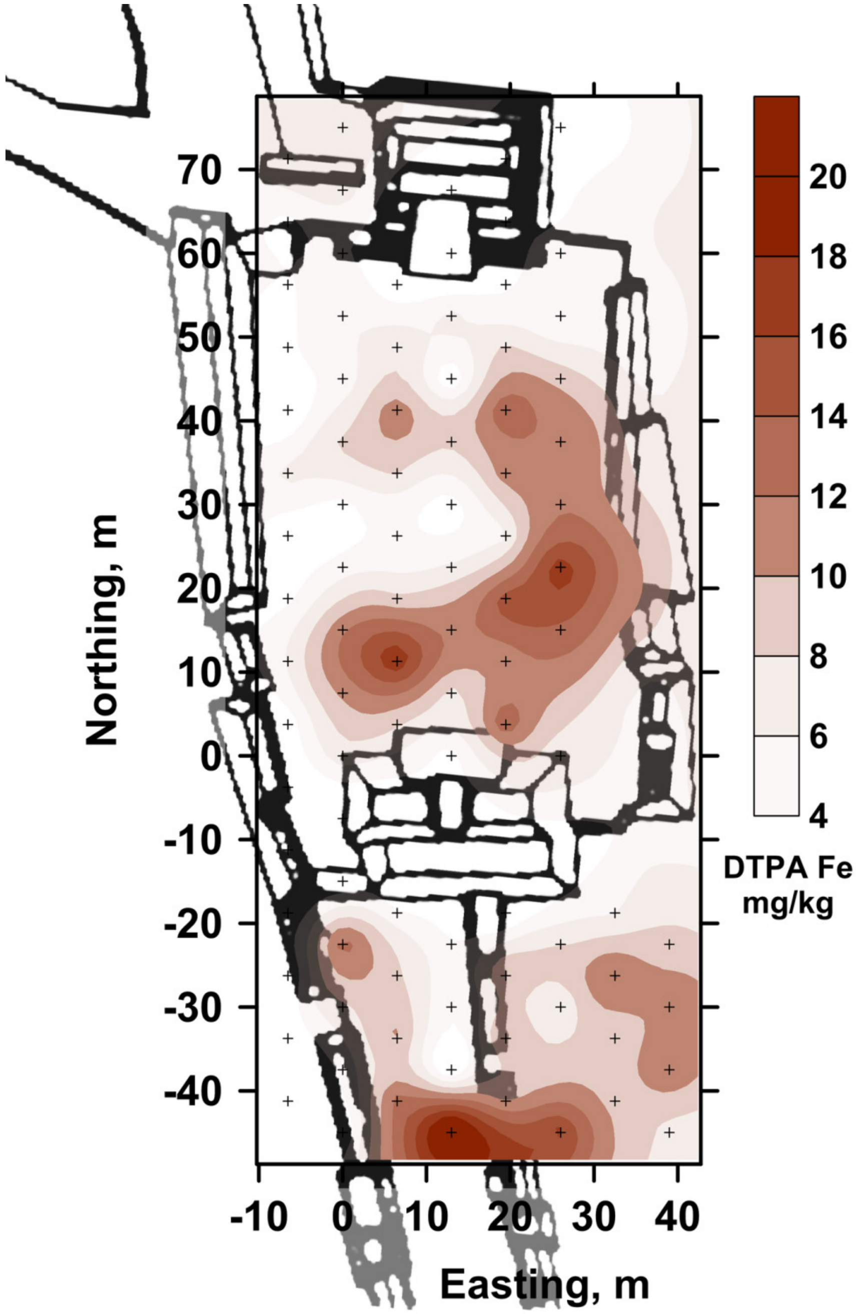

Figure 2-5. Concentration isopleths of DTPA extractable Fe in the Ramonal Plaza near Caracol, Belize.

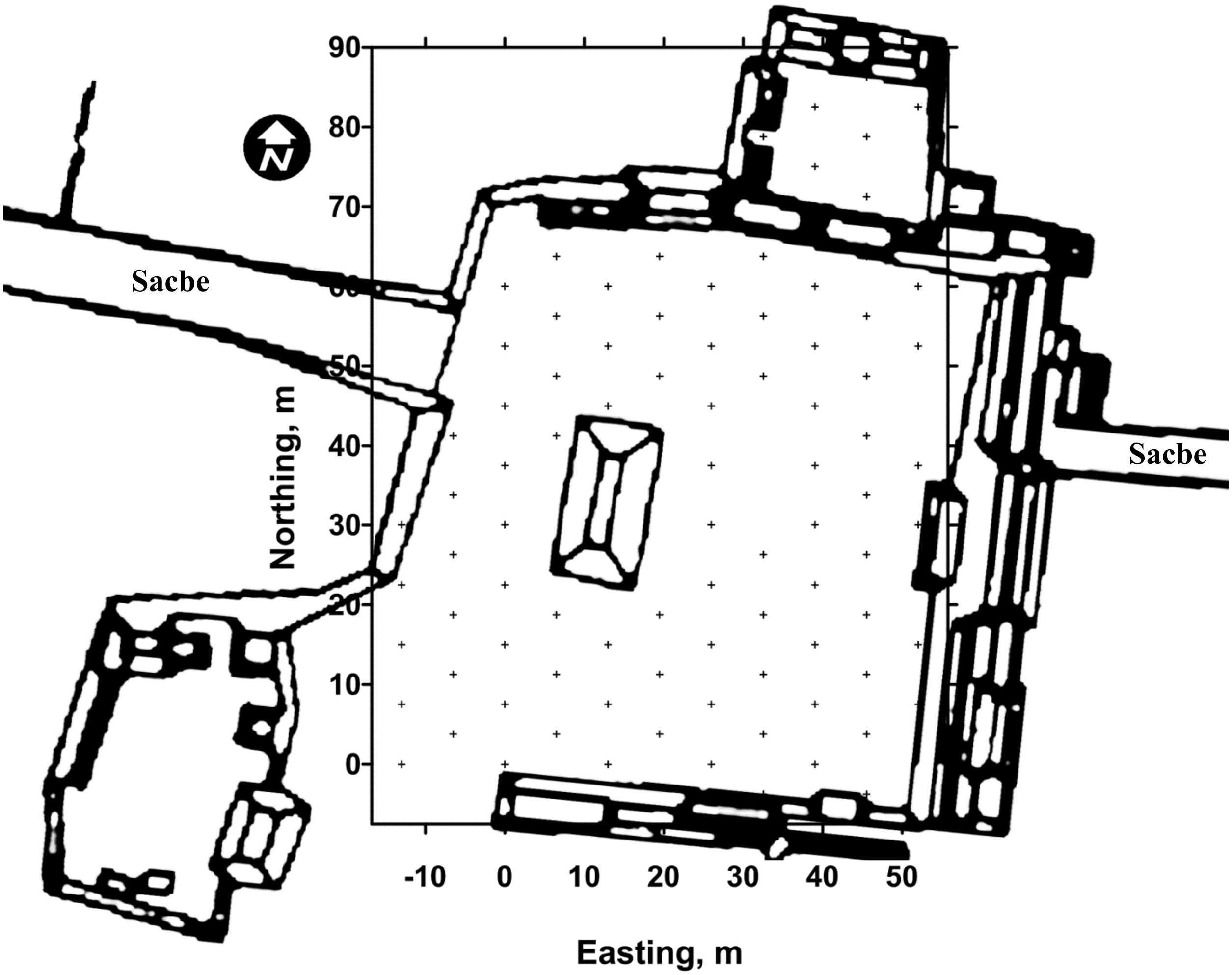

Figure 2-6. The Conchita Plaza located 3.0 km southeast of Caracol. The sampling locations are shown as +.

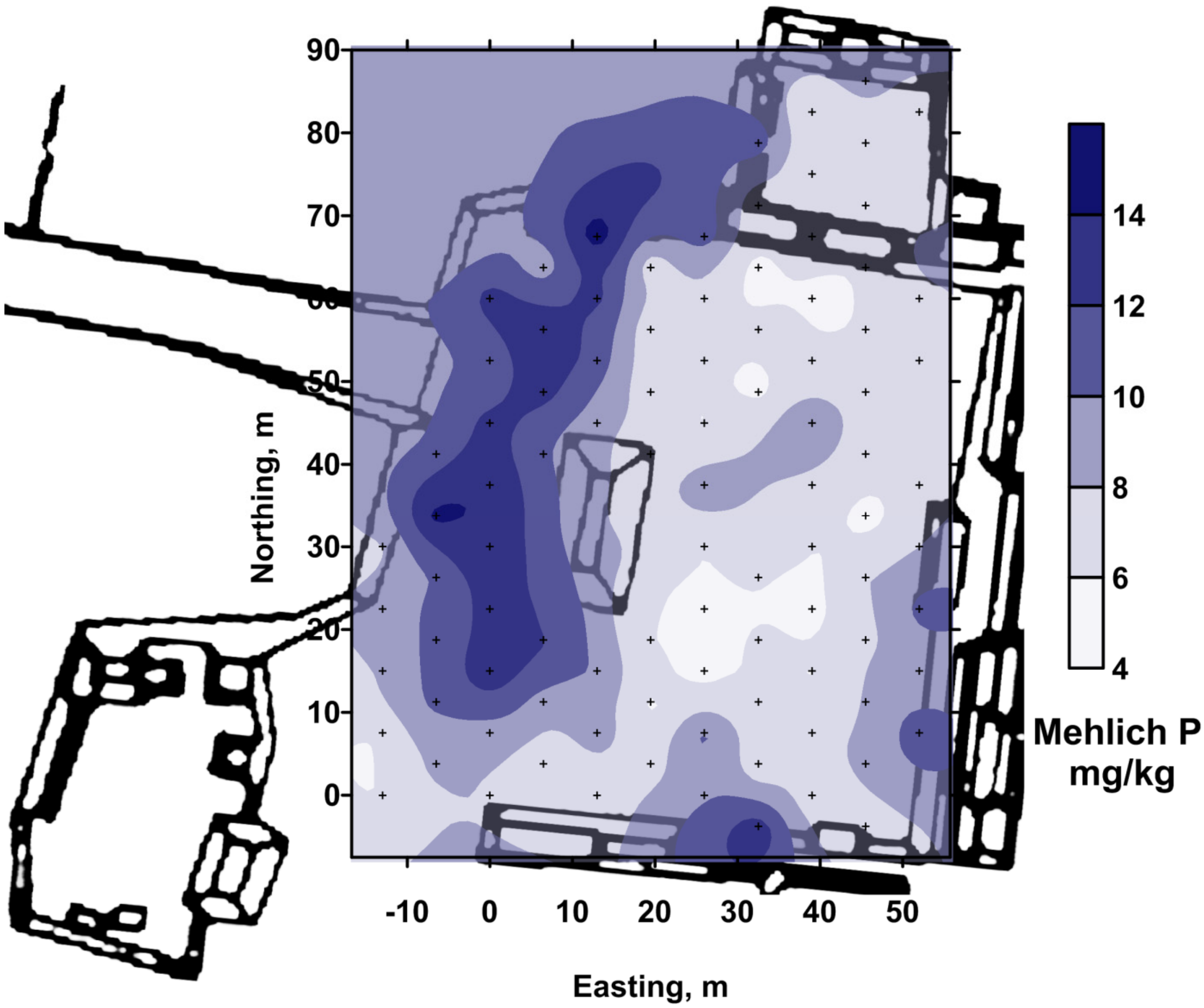

Figure 2-7. Concentration isopleths of Mehlich II extractable P in the Conchita Plaza near Caracol.

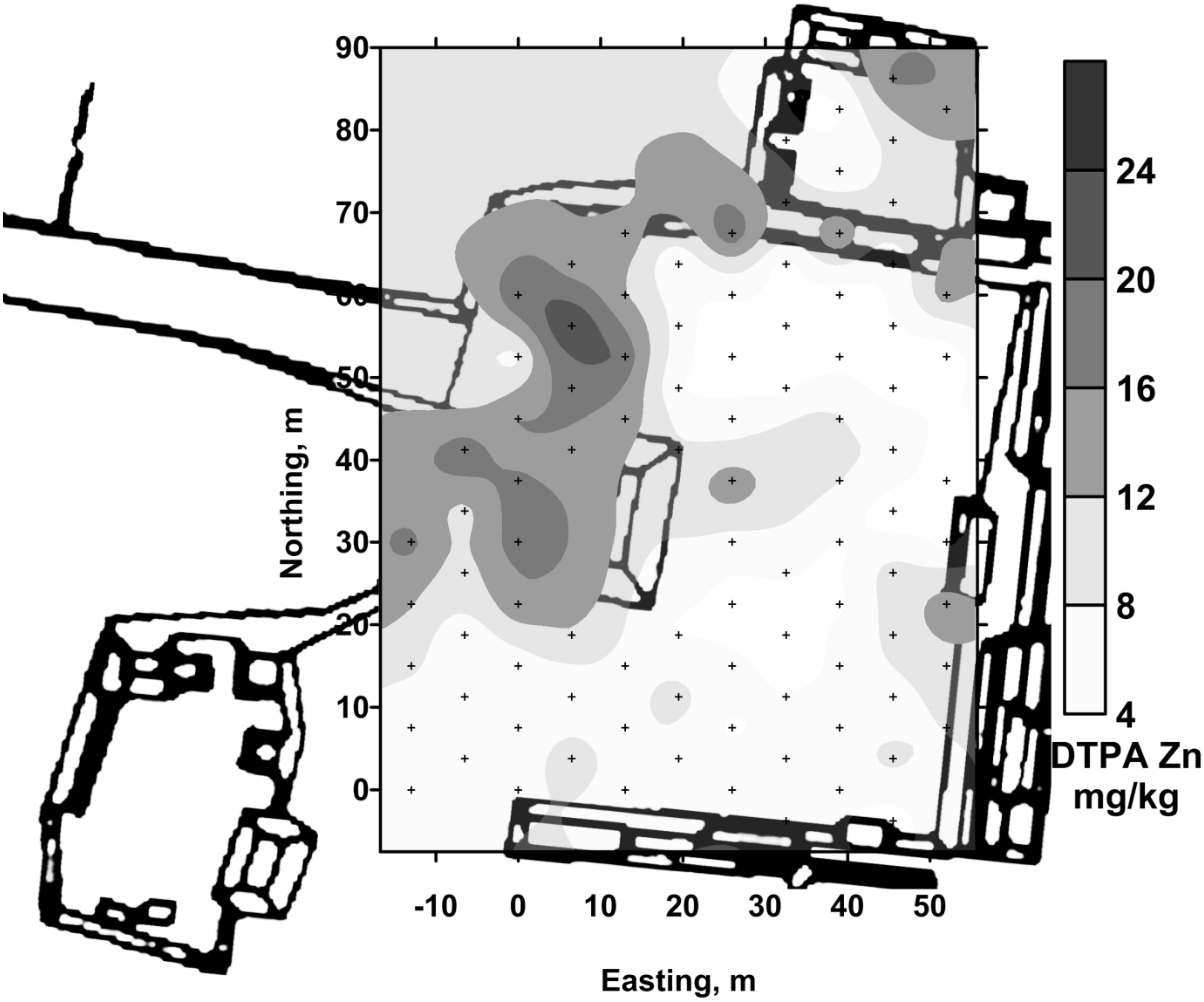

Figure 2-8. Concentration isopleths of DTPA extractable Zn in the Conchita Plaza near Caracol.

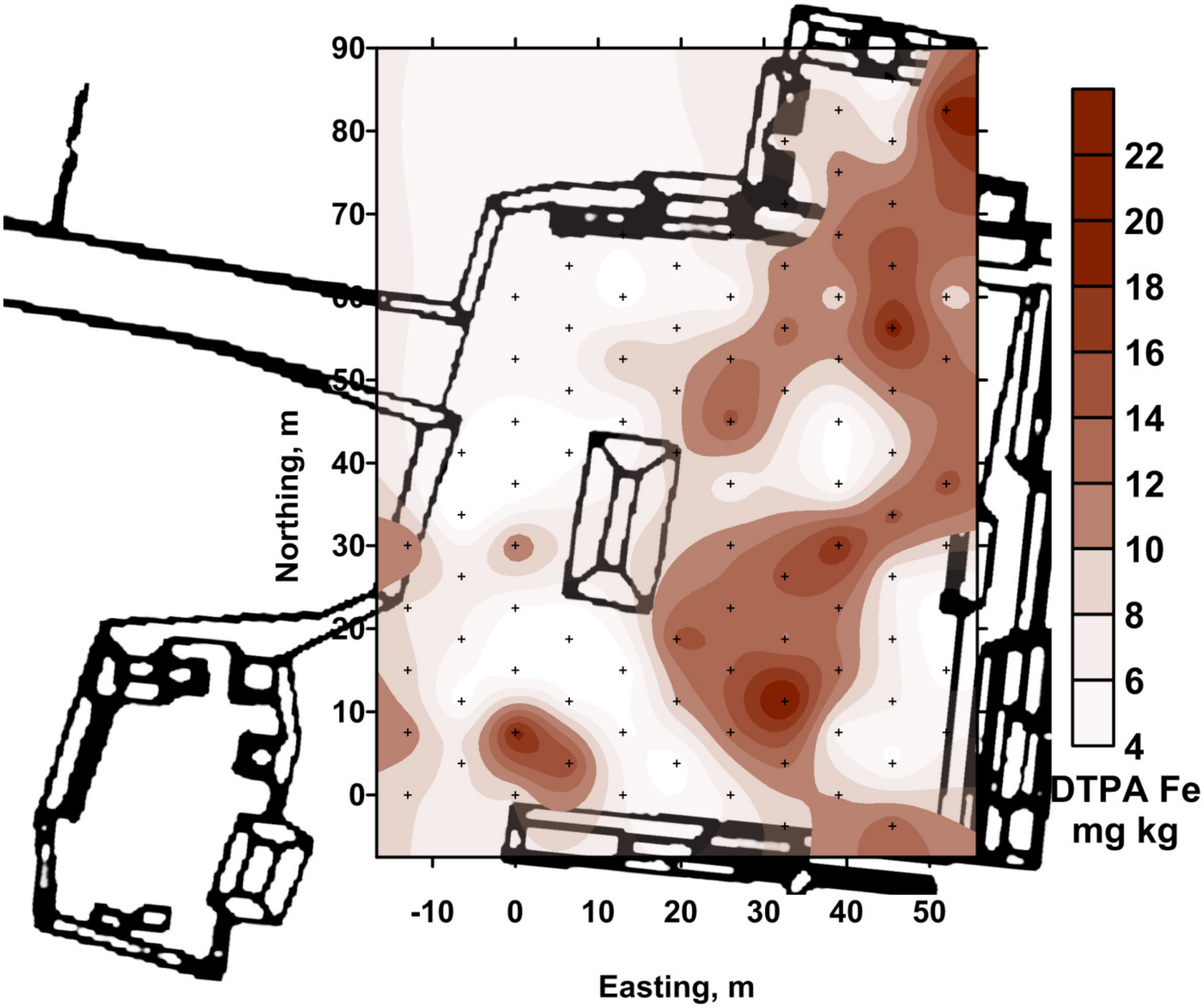

Figure 2-9. Concentration isopleths of DTPA extractable Fe in the Conchita Plaza near Caracol.

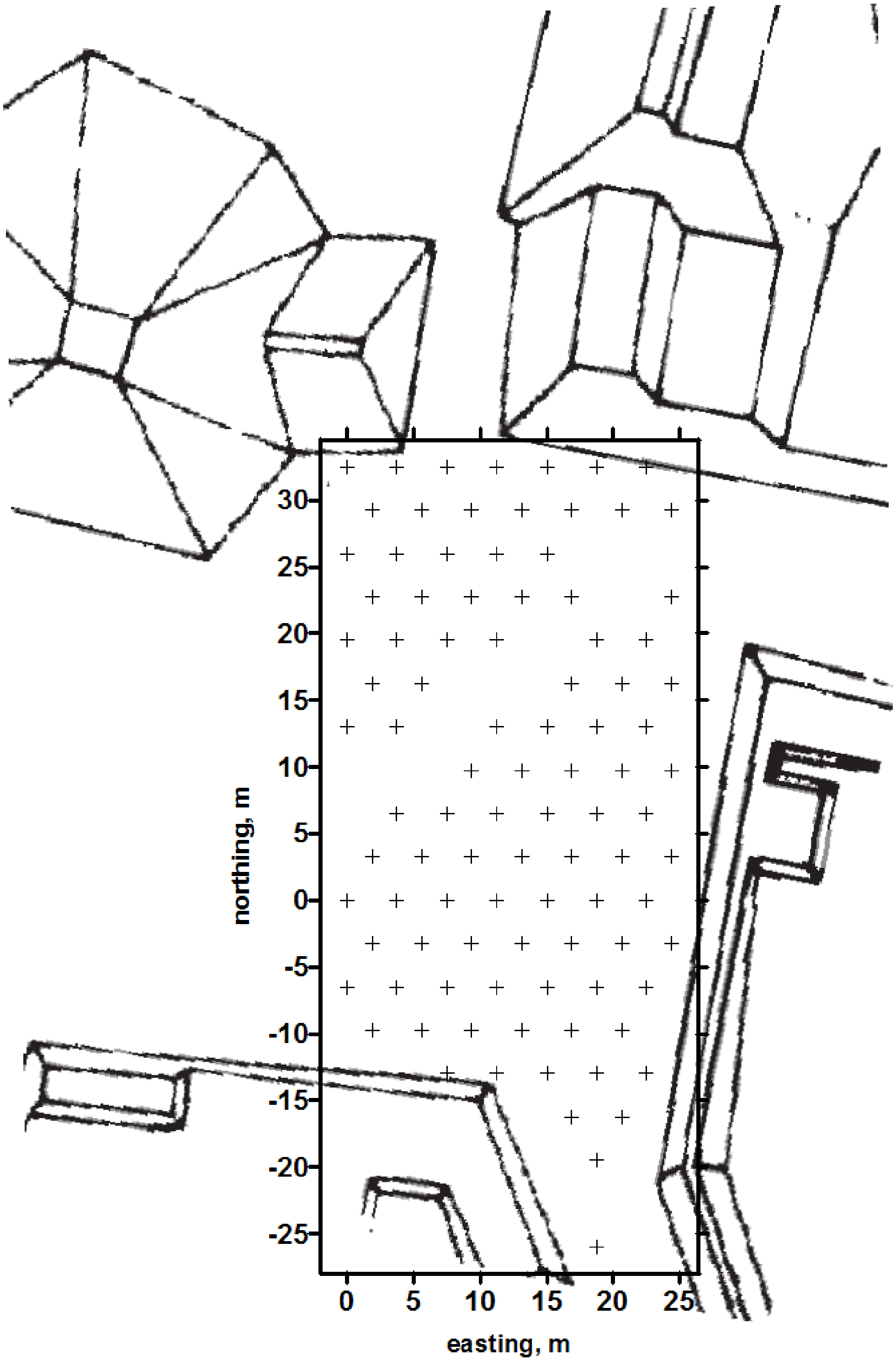

Figure 2-10. Sampling area and locations (marked by +) near the sacbe entering the Caana Complex from the southeast.

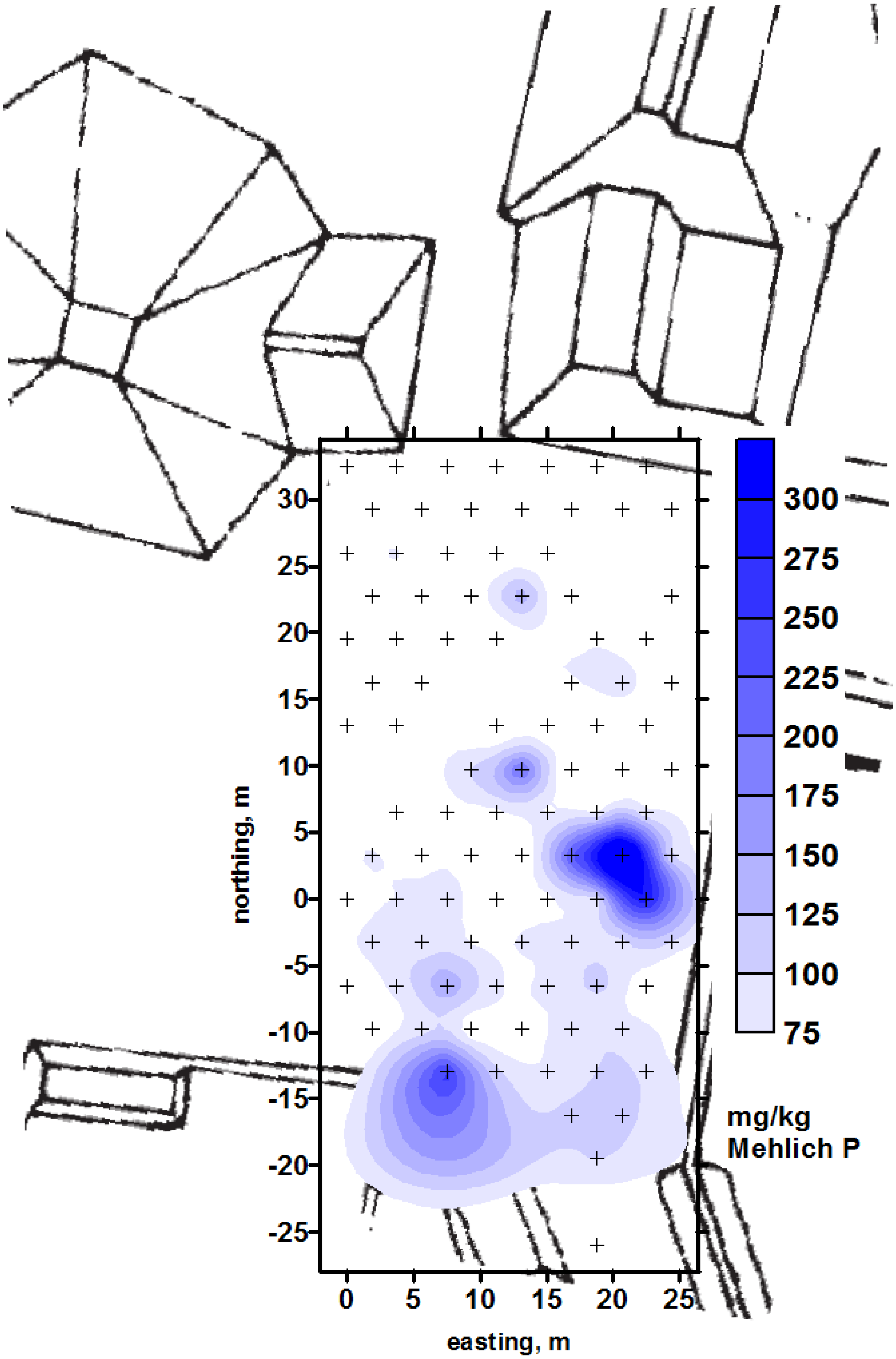

Figure 2-11. Concentration isopleths of Mehlich extractable P within the sampling area near Caana.

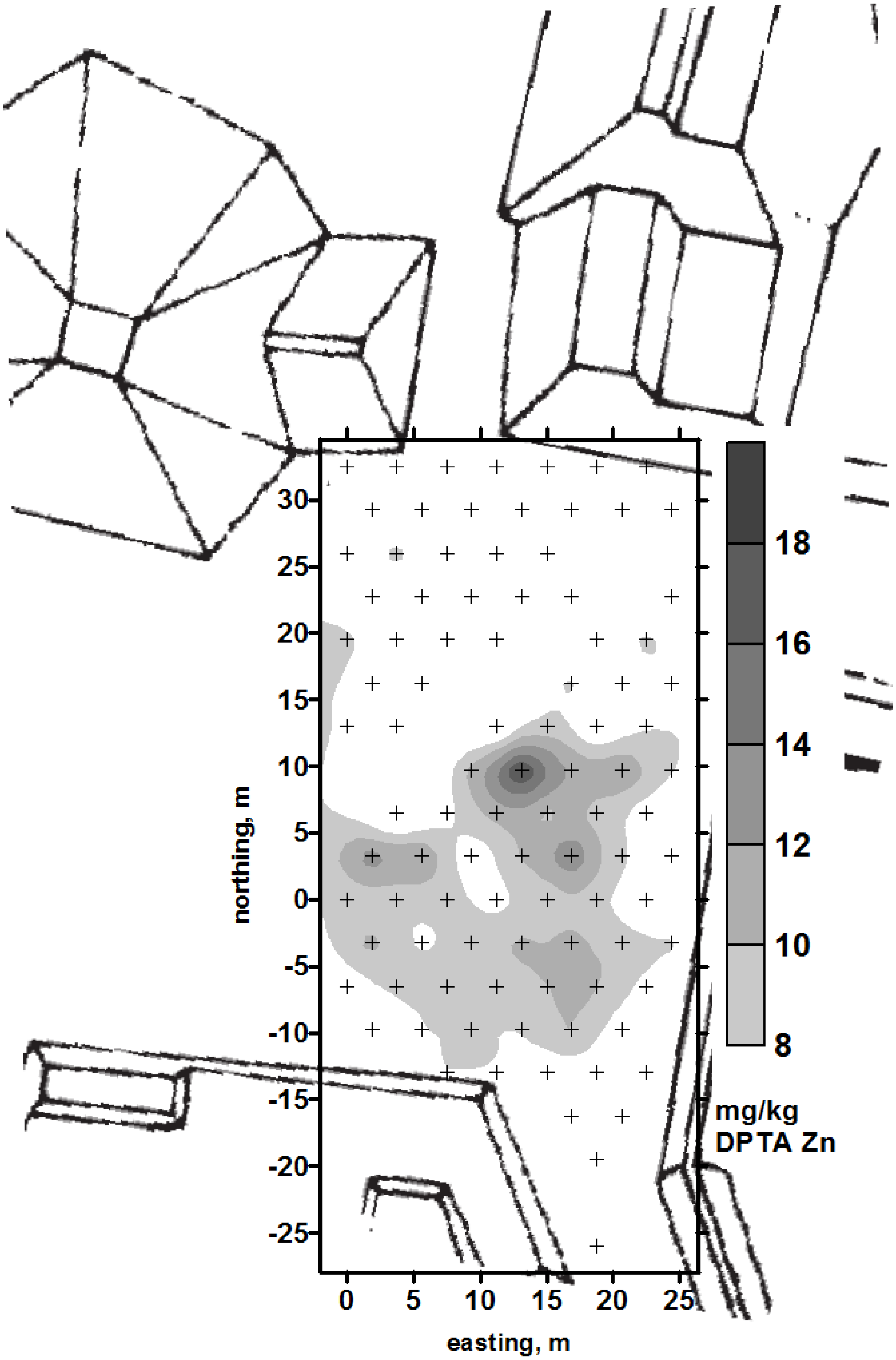

Figure 2-12. Concentration isopleths of DTPA extractable Zn within the sampling area near Caana.

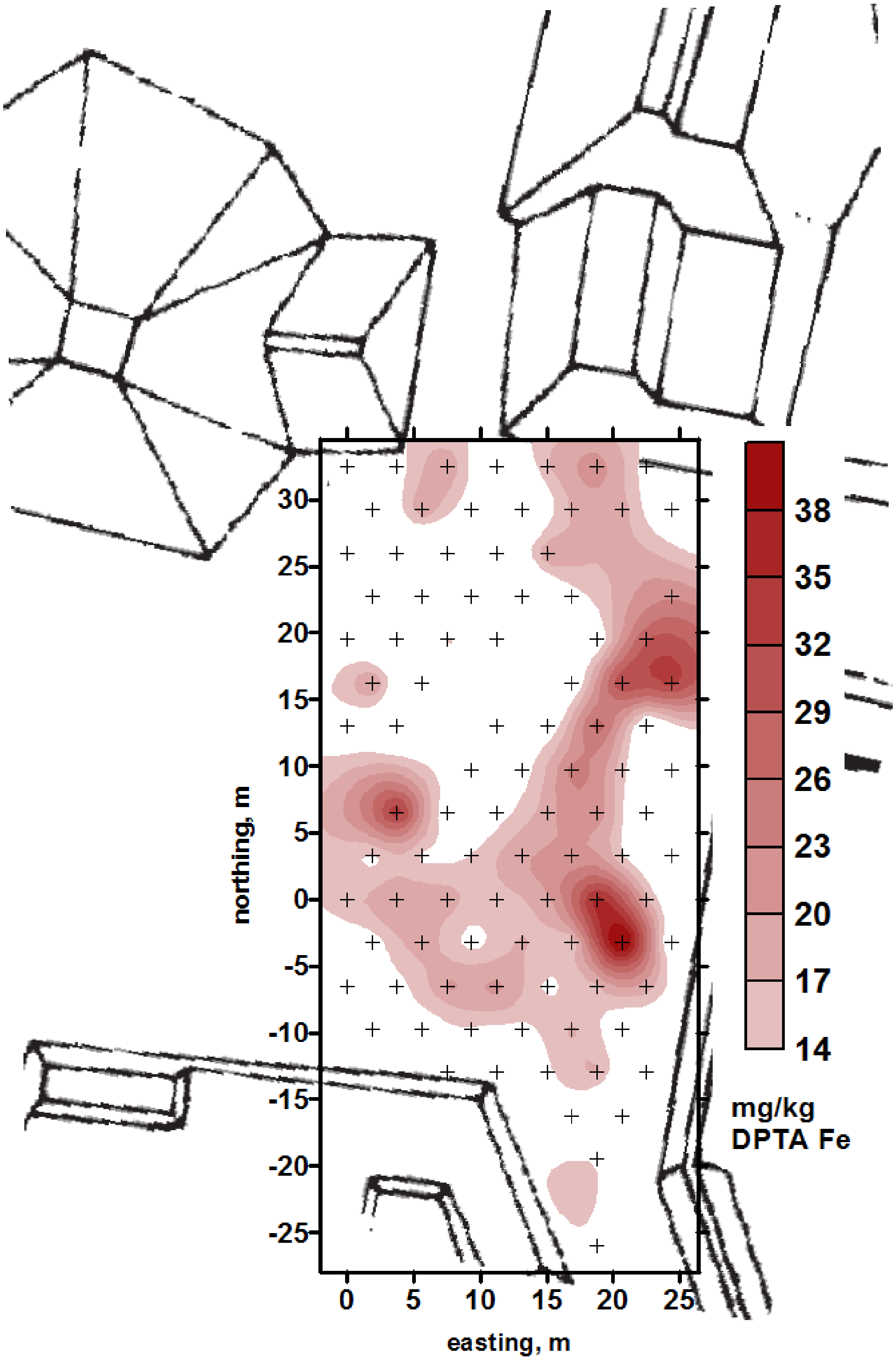

Figure 2-13. Concentration isopleths of DTPA extractable Fe within the sampling area near Caana.

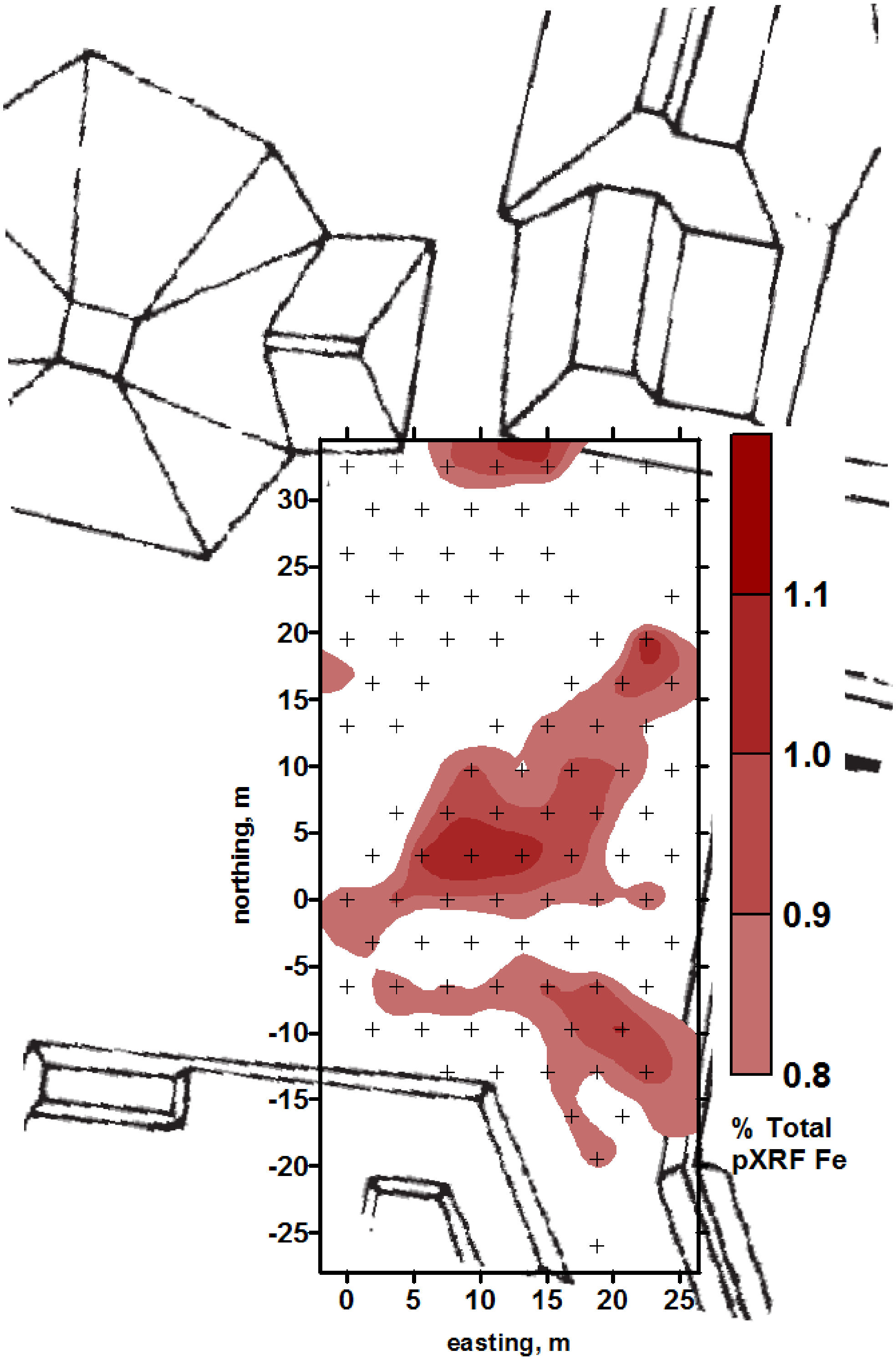

Figure 2-14. Concentration isopleths of pXRF total Fe within the sampling area near Caana.