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Preliminary geochemical assessment of limestone resources and stone use at Maya sites in the Three Rivers Region, Belize

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ABSTRACT

The carbonate bedrock of northwestern Belize is poorly understood from the standpoint of both geochemistry and the use of stone in prehispanic Maya sites for buildings and monuments. The friable nature of the rock in this topographically rugged area makes it especially difficult to distinguish monuments from bedrock spall, as little carving, if any, survives, and identification rests on location and positioning. The research presented here analyzed 63 limestone samples collected from two sites in the Three Rivers Region of Belize. ICP-MS and ICP-AES were used to characterize the major, minor, and trace element chemistry of the limestone bedrock of the region and determine the amount of geochemical variability. Another important objective was attempting to trace the movement of monument stone and determining whether it was imported from outside of the sites. Bedrock, quarries, and possible monuments were all sampled for these purposes. Bedrock proved to be similar across wide areas. However, at Chawak But'o'ob, along the flank of the Rio Bravo, changes downslope in Mg concentration suggest a leaching of the bedrock by meteoric waters based on differences in porosity. At Maax Na, a hilltop site, in contrast, such leaching is not as apparent. Many monuments at both sites were found to be composed of stone similar in chemistry to the local bedrock, including several of the identifiable stelae. However, our analyses also revealed that a few monuments at Maax Na were made of material with a different chemical composition, apparently from stone imported to the site. These results suggest that the Maya deliberately selected certain types of limestone for certain purposes, and may even have traded in non-local rock. Overall, the methods used in this pilot study indicate there is real potential in more intensive, regional assessments of the materials used at archaeological sites, even in areas where the local stone does not have a distinctive geochemical signature.

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1. Introduction

Investigations of stone use patterns at archaeological sites rely on interpretations of a modern landscape that, in many cases, has been heavily modified by natural processes since the time of the sites' abandonment. Therefore, such research requires an understanding of the local geology on both intra-site and regional scales. This is especially important in rainforest-covered areas like the Yucatan Peninsula where a lack of bedrock exposures and restricted access has inhibited formal geological studies. Geological research

in this region, however, can benefit from landscape modifications made by the prehispanic Maya at the archaeological sites being investigated. The extensive areas they quarried on the periphery of site centers provide a large number of accessible bedrock exposures. This study looks at two Maya sites in different karst environments of the Three Rivers Region of northwestern Belize (Fig. 1) to characterize the intra-site geochemical variability in the limestone bedrock, and also to begin to address differences on a regional scale. The primary objective is to shed more light on how the Maya selected and used stone resources. This is a crucial topic in northern Belize, where a lack of carved monuments has impeded historical understanding of the Maya presence there and of the relationship of its inhabitants to other parts of the Maya world. The bedrock of this area is soft and easily weathered, making it difficult to identify megaliths on the rainforest floor as fallen monuments or rock that

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Fig. 1. Map of the Three Rivers Region of northwestern Belize showing the boundary of the Programme for Belize Conservation and Management Area and major sites. Adapted from Scarborough et al., 2003.

has spalled off the bedrock by natural processes. The geochemical investigation of local variations in the bedrock chemistry can help determine the ways in which the Maya modified the landscape and moved stone to create their constructed environment. It also shows promise as a method to be used in other geographical areas where determining cultural choices and patterns of stone use has been similarly problematic.

1.1. Geology of northern Belize

Limestones are both a paleoenvironmental deposit and a modern landform, as the morphology and chemistry of these rocks reflect both formation conditions and the effects of post-diagenesis weathering processes. Carbonates dissolve in acidic waters, but do not dissolve at equal rates, a process dependent on joints and fractures in the bedrock, as well as porosity (Trudgill, 1985). Geological investigation of the carbonate bedrock is therefore important for understanding both paleo- and modern landscapes. However, the stratigraphic sequence of rock formations in northern Belize has not been formalized and requires further study (King et al., 2004). The limestones of the northeastern Petén region of Guatemala and northwestern Belize appear to be the same formation, which was described separately by two authors as the El

Cayo and Santa Amelia groups (Flores, 1952; Vinson, 1962). In a report summarizing the geological surveys conducted for the geological map of Belize, Flores (1952) provided only informal descriptions of the stratigraphy in northern Belize. Based on these descriptions, the Three Rivers Region is composed of the Lower Eocene limestone of the El Cayo Group. Similarly, in a report on the petroleum geology of the area, Vinson (1962) defined the Santa Amelia Formation as extending from the central Petén region of northern Guatemala toward the northeast into the northern half of Belize. Thus, both the formations identified seem to incorporate the area of northwestern Belize. While this conflicting nomenclature will no doubt be resolved in the future, for now it serves to underscore the lack of detailed geological knowledge of this region.

On a broader scale, the Yucatan peninsula is a carbonate platform composed of shallow water sediments of the Jurassic through Tertiary periods (Hartshorn et al., 1984). These limestones are formed from back-reef lagoonal environments (e.g., King et al., 2004; Vinson, 1962). A report on the physical properties of Yucatan limestones demonstrates a large amount of heterogeneity in their physical and mechanical properties, characteristic of those formed in shallow tropical seas (Espinosa et al., 1998). The stepped escarpment topography of this area on the northeastern edge of the Petén plateau is the result of tension faulting, which has

dramatically altered the carbonate landscape (Dunning et al., 2003). Weathering and karstification processes caused by the exposure of underlying carbonate strata add to the variability in composition, density, and porosity of the bedrock (Trudgill, 1985). Since its deposition, the limestone has been weathered into fractured formations of ridges and hills. Around the perimeter of these uplands are a series of swampy lowlands (*bajos*), which were used for resource procurement by the Maya (Dunning et al., 2003; Kunen, 2004; Kunen and Hughbanks, 2003).

1.2. Stone use and the Maya

The relationship between people and their natural environment has drawn increasing interest over the past few decades with the development of environmental and landscape archaeology as complementary approaches to investigating past landscapes (e.g., David and Thomas, 2008; Denham, 2008; Dincauze, 2000; Knapp and Ashmore, 1999). Aston and Rowley (1974) describe “landscape” as a palimpsest on which people leave their mark, building upon and overwriting the imprint of previous generations. An important consideration for both environmental and landscape studies of abandoned sites is that this process extends into the present day. Lowland Maya sites, in particular, have seen multiple periods since their abandonment that have left their mark and overprinted much of the original sites, including rainforest reclamation following the Maya period, deforestation and road-building in the eighteenth century due to inland mahogany logging (Bolland, 1977), and a second period of subsequent forest re-growth. These factors, along with karst processes and weathering over time, have created what we see today as the modern landscape of these sites. The masking of the ancient landscape becomes compounded for studies of Maya stone use at sites in northern Belize, where the limestone bedrock is soft and highly weathered, and, therefore so too are monuments and blocks that were shaped from it, blending all too easily into the contemporary natural landscape.

In Maya studies, environmental and landscape archaeology are closely tied, because Maya architecture and engineering typically built upon and accentuated, but rarely completely overwrote, the natural landscape (Brady and Ashmore, 1999). Understanding how the Maya visualized their world requires a broad grasp of how their constructed environment reflected their worldview, including elements of their civic plans and ceremonial landscapes, which often overlapped (Ashmore, 1991, 1992, 2008; Knapp and Ashmore, 1999). In many cases, natural features of the landscape were strategically incorporated into a site's civic plan, such as when a site was built around a cave as an *axis mundi* (Ashmore, 2008; Brady and Ashmore, 1999; King et al., 2012). The Maya constructed environment was also heavily influenced by quarrying and water-management engineering. Sites that used natural hills, such as La Milpa, required artificial reservoirs because they were built away from water sources (Scarborough et al., 1995). Quarries around the periphery of these hills contributed to construction and were often subsequently incorporated into the water management system (Scarborough, 1998). For example, stone from the excavation of reservoirs might be used to construct adjacent temples and structures. At the same time other areas of the natural topography were engineered into flat surfaces by cutting away or filling in, in order to make room for structures and control the flow of water. Water was not just a practical necessity, however. Throughout Mesoamerica, it was associated with the underworld and with a life-giving, sentient *Earth* accessible in caves (Brady, 1989, 1996, 1997; Brady and Prufer, 2005). Important water sources came from springs in water mountains at the mouths of these caves (Scarborough, 1998: 149). The creation of hilltop centers as artificial “water mountains” (Scarborough et al., 1995; Scarborough, 1998) thus exhibits the

Maya's ability to shape and engineer their natural landscape as physical representations of their worldview, while attending to the practical requirements of site construction.

The built environment of the Maya was composed predominantly of limestone, with exceptions in areas of the southern highlands, as at Copan, where igneous tuff was predominantly used (Abrams, 1994). In addition to architectural blocks, limestone was also burned to produce lime, a component of plaster, which was used as a surface finish on architecture and plazas where the landscape was filled in and smoothed over (Villaseñor, 2010). Studies of Maya stone use have focused on both the energetics of labor required for quarrying and construction (e.g., Abrams, 1994; Folan, 1982; Woods and Titmus, 1996) and the production of plaster (e.g., Mathews, 2002; Villaseñor, 2010). Quarries were commonly positioned near areas of construction, suggesting that stone would not have needed to be transported over large distances (Folan, 1982). For example, at the site of Kinal in Guatemala, extensive quarrying was observed along the margins of the central precinct (Scarborough et al., 1994). However, studies of the movement of stone per se across the Maya landscape have generally been limited to artifacts. Granite and obsidian items have been geochemically traced back to specific igneous sources in the highlands (e.g., Graham, 1987; Rice et al., 1985), giving a good idea of stone use and trading patterns. Limestone, however, like quartzite (e.g., Pitblado et al., 2008), is harder to source, as it lacks a clear geochemical signature. Studies throughout Mesoamerica have successfully sourced the movement of limestone only on a small scale. Barba et al. (2009) used X-ray Fluorescence (XRF) to source lumps of limestone from plaster floors at Teotihuacán in central Mexico to local quarries. Nation et al. (2012) used Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to establish the provenience of speleothem artifacts from excavations in the Sibun Valley Region to specific caves after chemically characterizing the limestone of multiple cave sites. Similarly, this study aims to characterize the geochemistry of limestone bedrock formations from two Maya sites in the Three Rivers Region of northern Belize to assess the potential for mapping the movement of quarried stone on both site and regional scales.

The sites in the Three Rivers Region of northwestern Belize have been defined as resource-specialized communities, a term that emphasizes the dependency relationships between sites of varying sizes and functions (Scarborough and Valdez, 2003). This region is also used as a prime example of a heterarchical social structure, which shows how the sites in this area developed in an unranked system as a result of its dispersed resources (Scarborough et al., 2003). Kunen and Hughbanks (2003) show that sites located near important resources developed systems of specialized production through the procurement and use of those resources. The Three Rivers Region contains a large number of sites, including large centers such as La Milpa and Dos Hombres, and mid-level sites, such as Las Abejas and Bolsa Verde, which may have acted as intermediaries between the larger sites (Tourtellot et al., 2003). Significantly, of these sites only La Milpa has carved stelae with readable texts, as stone in this area is generally too soft to support carving. Interpretation of the relationships among sites has therefore had to rely on other factors, such as their relative size and spacing. Important features of this region are the extensive bajo drainage areas that controlled both site locations as well as resources. Kunen (2004) defined three distinct zones for which the Maya had different uses near the bajos: residential on hilltops, agricultural on terraced slopes, and resource-extractive in the interior. This same differentiation can be extended more widely to incorporate parts of the Three Rivers Region away from the bajos, as the patterns found are similar. Most centers are located on hilltops, a factor that constrained building. The core of sites such as La Milpa

and Maax Na, for example, was limited to the plateaus upon which they were built, so the space had to be used effectively, planning architectural construction and resource procurement around one another for both stone acquisition and terrain shaping. Terraced hillsides and low-lying bajos provided highly varied landscapes for modification to aid the Maya settlement in a seasonally dynamic environment and for access to resources such as clay and chert. This diversity of landscapes and resources makes this region an important area for studying the intersection of the Maya's natural and built environments (Scarborough and Valdez, 2003).

The present research looks at the bedrock geochemistry of the sites of Maax Na, a large center on a hilltop near the Guatemalan border, and Chawak But'o'ob, a smaller residential site near the Rio Bravo (Fig. 1). These sites provide good access to bedrock exposures that is not commonly found in other areas of the rainforest-covered Petén plateau. In addition, they come from differing environments within the Three Rivers Region and provide a good basis for comparison. The modern condition of the landscape – uplifted carbonate deposits, weathered rock, eroded quarry faces, ruined buildings, and the rainforest cover – reflects some aspects of the ancient, overprinted landscape. Geochemistry is required, however, to be able to distinguish the original natural environment from the one the Maya built. The objective of this research is to examine the geochemical data from bedrock samples at these two sites to determine the intra-site and inter-site variability, then compare

these to samples taken from building blocks and possible monuments at each site. The ultimate goal is to determine whether the materials used in carving and construction come from local quarries at the two sites or from rock foreign to their underlying bedrock. By examining the modern landscapes of these two areas through the geochemistry of Eocene limestone formations, we can begin to infer Classic Maya stone use patterns and the movement of quarried material across the landscape.

1.2.1. Maax Na

Maax Na was initially mapped in 1995 as part of a Programme for Belize Archaeology Project survey and then investigated by the Maax Na Archaeology Project (Shaw and King, 1997; King and Shaw, 2003). Long-term goals of the research include looking at the site through an integration of economic, political, and ideological spheres in order to examine its multidimensional relationships with sites in the region (King and Shaw, 2003). Maax Na, an Early to Terminal Classic center (AD 250–900), follows a pattern of construction similar to other large site centers in the Three Rivers Region, such as La Milpa and Dos Hombres (Fig. 1), as well as to centers in the neighboring Petén area of Guatemala. It exhibits some unique features, however. Most notable are a large, centrally located reservoir and dam and the expansive North Plaza (Fig. 2), which is larger than those at all other centers in the region with the exception of La Milpa's (Shaw, 1999). This plaza also appears empty

Fig. 2. Map of Maax Na site core indicating location of samples. Map by L. Shaw, sample locations by M. Brennan.

in relation to plazas at those other sites; structures border it, but with a less dense spacing than is common elsewhere. Also, unlike sites such as Dos Hombres and La Milpa, Maax Na's main temple is isolated. Positioned to the south of the site core, it is juxtaposed to the North Plaza, in line with the ballcourt (King and Shaw, 2003). To the west of the temple and North Plaza lies a large, mostly enclosed courtyard with associated buildings known as the West Plaza. The North and West Plazas are linked by a causeway that extends past the main temple and upon which Stela 2, the only standing stela remaining at the site, was erected (Fig. 2). Maax Na dates to the Early Classic (AD 250–600), with possible small-scale occupation in the Late Preclassic (400 BC–AD 250), and appears to have been abandoned early in the Late-to-Terminal Classic (ca. AD 700–800), before the other large sites in the region, a factor that may in part account for the paucity of construction on the North Plaza (King and Shaw, 2003; King et al., 2012).

As noted earlier, the Maya placement of architecture and their constructed landscapes were greatly influenced by cosmology (Ashmore, 1991, 1992). The layout of Maax Na follows common trends in site planning for this part of the Maya world, including a strong north–south axis linked by a ballcourt and the use of causeways to link groups of structures (Ashmore, 1991, 1992; Houk, 1996, 2003). However, this template appears to have been modified to accommodate the natural topography at the site and highlight certain features of cultural significance. Maax Na has a number of caves and rock shelters, which are linked to a sentient *Earth* and the underworld in Maya cosmology (Brady, 1989, 1996, 1997; Brady and Prufer, 2005; King et al., 2012). Maax Na appears to have been intentionally positioned in alignment with the largest of these and away from the bulk of its residential and agricultural areas (King and Shaw, 2003; King et al., 2012), another factor accentuating its distinctive layout.

Surveys at Maax Na have documented areas on the periphery of the site core that include a large number of what are interpreted to be quarry locations. Two knolls near the reservoir appear to have been quarried, though some of the modifications visible may be from logging road construction, and other quarries have been located to the west and north of the North Plaza and east of the main temple. Other parts of the site farther on the periphery appear to have been modified, too, likely in part due to quarrying activities. Small-scale water management features may have been associated with some quarries, as keeping limestone moist allows for easier cutting (Scarborough et al., 1995). These features are exposed at Maax Na to a greater extent than at many other sites in the area, in part because they may not have been as well masked by architecture due to the site's relatively early abandonment. For this reason, Maax Na is the ideal site within the Three Rivers Region for this study, as its location on a hilltop and numerous quarries around its edges allow for broad sampling across the area of the site core.

1.2.2. Chawak But'o'ob

Chawak But'o'ob is a small residential, agricultural site located on the inclined slope of the Rio Bravo Escarpment about 7 km southeast of Maax Na, across the Rio Bravo from the large center of Dos Hombres (Fig. 1). This mid-to-late Late Classic (AD 600–800) site consists of residential terraces, dense commoner housing, and a series of complex water management features (Walling, 2005, 2011; Walling et al., 2006). Research here has uncovered primarily utilitarian artifacts and no formal ritual or elite structures. The number of houses constructed in the short period of time the site was occupied suggests that there was a rapid population growth, driven by an influx of immigrants to the area (Walling, 2005). A ballcourt at the southern extent of the site is one of the few ceremonial constructions. It was built as two mounds of small cobbles and appears to have had water running through it. The ballcourt is

in line with one of the two caves present at the site, which can be seen to the west of the ballcourt.

The slope of the site on the escarpment places it in an active karst region where water flows through the bedrock toward the Rio Bravo. The Maya constructed a series of terraces, collection surfaces, interconnected water basins, and a central reservoir to direct the water to the occupation and agricultural areas further down the escarpment (Walling, 2005). This site serves as a good comparison to Maax Na on two fronts. First, the small size of Chawak But'o'ob, in comparison to the large center of Maax Na, showcases a different aspect of Maya culture. Second, the carbonate environment of Chawak But'o'ob differs dramatically from the plateau upon which Maax Na sits, and is dominated by ridges and drainage gullies from the movement of water over the bedrock. However, both sites lie within the same drainage system of the Rio Hondo, so comparisons are between different karst landscapes, but over a similar hydrological region and within the same limestone formation.

2. Methods

2.1. Sampling

2.1.1. Maax Na

Since few studies have attempted the geochemical sourcing of limestone from an archaeological context, the goal of this research was first to determine if discrimination between different bedrock samples was possible. A survey of the limestone resources and features at Maax Na was undertaken during the 2005 and 2006 field seasons. To begin this process, limestone samples were collected throughout the site core of Maax Na (Fig. 2), including multiple locations where samples were taken both from megaliths identified as possible monuments and from the adjacent bedrock. The samples were chiseled off the stone with a hammer and collected in labeled bags with both a description of the stone and the zone code for the area of the site. In the case of known monuments, we only took a sample of the stone if pieces had already spalled or broken off and could be collected without further damaging the monument. At least one sample was taken from as many of the accessible bedrock outcrops as possible within the 1 km² area of the site core. A few duplicate samples were discarded in the field due to weight limitations for their export.

Seven samples were taken from and around Megalith 1, which is located southeast of the West Plaza adjacent to a linear series of chultuns (Shaw, 2002). Nine samples were taken from the underlying bedrock and possible monuments on the South Acropolis, including three small megaliths (a possible altar ca. 50 cm in diameter and two possible stelae) that may have been faced with plaster, and a possible broken stela nearby. Six samples came from megaliths and outcrops east of the main temple, including a large section of limestone that may have been uplifted by a tree-fall, and also from Stela 1, one of the few positively identified stelae at the site. In the North Plaza, a total of seven samples were collected, including one from a beveled stone removed from the face of the ballcourt during excavations in 2003. Other locations sampled here include a possible altar in the plaza north of the ballcourt, a possible monument east of the North Hill, and samples from inside and outside Spider Cave, the largest cave at the site, which is beneath the East Structure (King and Shaw, 2003; King et al., 2012). Six samples were collected from a quarried area north of the North Plaza, including two possible monuments. The final area sampled during this survey is the West Plaza, where seven samples were collected. Features included Altar 2 in Plaza D, a quarried area northwest of the West Acropolis, two quarried knolls bordering the reservoir entrance, and the easternmost of three possible altars from south of the South Building of the West Plaza. These three

small, round stones, which are grouped together, are similar in size and shape to the possible altar sampled on the South Acropolis. In surface appearance they resemble both that megalith and the possible stelae with which it is associated.

2.1.2. Chawak But'o'ob

In June 2007, a similar survey of the limestone bedrock outcrops and possible stone monument features was undertaken at Chawak But'o'ob (Fig. 3). Twenty-two samples were collected, primarily from bedrock outcrops along the sloped terrain of the site. Samples of cultural features included three cobbles from the ballcourt, a small spalled-off chip from a fallen stela in Group A, and possible plaster from beneath this megalith. Drainage and other water

management features at the site were included in the sampling, as was a knoll west of the ballcourt, and outcrops along the edge of the reservoir. As at Maax Na, samples were also taken from inside and outside the cave just west of Chawak But'o'ob's ballcourt.

2.2. Test analyses

The initial set of 37 samples collected at Maax Na in 2005 was thin sectioned and examined under a petrographic microscope. All of the samples are composed entirely of microcrystalline calcite (micrite), with one sample that had small veins of chert in the micrite. The lack of microfossils in the limestone for identification informed us that geochemical analysis would be necessary for this study. Six of these samples, a mix of possible monuments and bedrock, were selected for test analyses with a scanning electron microscope (SEM) and ICP-MS based on the varied color and hardness of the rocks in hand sample. The SEM results provided bulk chemistry data, which showed that Mg was an important element in these samples, but that additional minor and trace elements would be necessary to differentiate between them. ICP-MS is a geochemical method used to quantify trace elements in dissolved rock material and is capable of very low detection of trace elements. Ions from a dissolved sample are extracted from a plasma matrix into a pumped vacuum and focused with a lens into a mass spectrometer (Rollinson, 1993). The test using ICP-MS showed that Sr and other minor elements (e.g., the rare earth elements, or REE), may also be useful in discriminating between samples. This method was therefore selected for the current study over laser ablation and electron microscopy analytical methods because the dissolution of the samples allows for analysis of the bulk trace element composition rather than a series of small points on the sample, thus enabling a better determination of a specimen's bulk chemistry. For the same reason, atomic emission spectroscopy (ICP-AES), which measures bulk element chemistry, was used for this study instead of the SEM.

2.3. Solution preparation

ICP-MS and ICP-AES analyses require samples to be dissolved entirely into solution. In order to ensure that all components of each sample, including potential non-carbonate inclusions, were dissolved, the following procedures were followed. First, a rock hammer was used to break up the rock samples, and pieces were selected that did not contain any exterior, weathered surfaces. A mortar and pestle were then used to grind the stone into a fine powder, which was placed into a 2 ml centrifuge tube for storage. The mortar and pestle were cleaned with methanol between each sample. In a clean lab, 0.05 g of each powdered sample was weighed into a 23 ml Teflon Savillex beaker, followed by 2 ml of nitric acid (HNO_3) and 2 ml of ultrapure water, then placed on a hot plate at $<100^\circ\text{C}$ overnight, following methods for sediment dissolution outlined in Kelley et al. (2003) and Plank et al. (2007). Seven standards commonly used for calibration (AGV-1, EN026-100-3, JCP-1, NBS-88a, RGM-1, W-2, and either IOFM or JB-3) and a procedural blank were dissolved at the same time as the limestone samples following the same procedures. Once cooled, each solution was transferred to a 2 ml centrifuge tube and centrifuged at 11,000 rpm for 5 min. The supernatant liquid was transferred to 250 ml Nalgene dilution bottles. Each tube was rinsed $3\times$ with ultrapure water, and the remaining solid material in them was then returned to the Teflon beaker.

Since microcrystalline silica was observed in some of the samples in thin section, 1.5 ml of hydrofluoric acid (HF) was added to the undissolved solid along with 3 ml of HNO_3 and placed on a hot plate overnight at $<100^\circ\text{C}$. The beakers were then tapped down and the caps were removed to allow for the HF to evaporate off.

Fig. 3. Topographic map of Chawak But'o'ob site core indicating location of samples. Map by C. Coughenour, sample locations by M. Brennan.

Following this, 1.5 ml of hydrogen peroxide (H_2O_2) and 1.5 ml of HNO_3 were added to dissolve any organic matter present in the samples, which were again heated overnight. Calcium-rich spikes were calculated for the four non-carbonate standards in order to matrix-match the igneous standards to calcite. We added the appropriate amount of 10,000 ppm Ca solution to each of these four samples to the equivalent of 56 wt.% CaO in the rock (equivalent to pure calcite). Half of the procedural blank was spiked, while the other was not. The remaining liquid in the beakers was added to the dilution bottles, then the beakers each rinsed three times with MilliQ H_2O . Ultrapure water was added to bring each solution to 150 g for a 3000 $\times$ dilution. The bottles were sonicated for 5 min and 15 ml of the solution transferred to centrifuge tubes for analysis.

2.4. ICP-MS

The solutions were analyzed with a Thermo X-Series 2 quadrupole ICP-MS with an ESI SC-2 autosampler at the University of Rhode Island's Graduate School of Oceanography. Each sample was analyzed twice to constrain analytical precision. The concentrations of 43 elements selected for potential importance in carbonate minerals were determined for the samples (Li, Be, K, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Rb, Sr, Y, Zr, Nb, Sb, Cs, Ba, La, Ce, Pr, Nd, Pm, Sm, Eu, Tb, Gd, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, and U). Results for Be, K, Ti, As, and Sb are not reported because they were below the instrument's detection limits. Either IOFM or EN026 standards were analyzed periodically throughout each 10-sample run to correct for the instrument's drift to improve accuracy.

2.5. ICP-AES

Finally, the solutions were analyzed with a JY2000 Ultracore ICP-AES with a JY AS 421 autosampler and 2400 g/mm holographic grating at Brown University. The concentrations of seven elements that are major elements in carbonates were analyzed simultaneously (Na_2O , MgO , Al_2O_3 , SiO_2 , CaO , MnO , and Fe_2O_3). Five synthetic solutions of varying concentrations of these elements were made for calibrating the instrument. Results for Na_2O and SiO_2 are not reported because they were below the instrument's detection limits for most of the samples and the dissolution method does not conserve Si in solution. The standards analyzed with the ICP-MS analysis were also analyzed with the ICP-AES and the results from these solutions were used to calibrate the results from the limestone samples. Calibration curves are linear ($r \geq 0.9993$) and replicate analyses are $<3\%$ RSD.

3. Results

3.1. Rock samples

The limestone of the Three Rivers Region of northwestern Belize is soft, and many of the samples collected exhibited the common white, soft, micritic texture. A number of the bedrock samples from Maax Na, however, were composed of a denser, tan limestone. These less porous rocks comprise the few natural hills at the site, including the North Hill, two small knolls along the southeast edge of the reservoir, the bedrock of the west acropolis, and a small hill south of the West Plaza. A few samples from Chawak But'o'ob had small black inclusions in the micrite matrix, which were identified with the SEM as manganese oxides, and correspond to a harder white rock. This type of rock, as opposed to the more common, softer limestone at Chawak But'o'ob, occurs only along two of the three ridges that run across the site E–W. At both sites, these harder types of limestone are thus found on the naturally elevated features on the landscape, which is likely due to the fact that the lower porosity of these rocks allowed for less chemical erosion.

3.2. Geochemical data

The geochemical data provide a very fine-scaled look at the carbonate chemistry, in both major and trace elements. The nature of these data is such that even samples from the same location may not have completely identical results. Therefore, a statistical examination of some of the geochemical data is necessary to be able to draw appropriate comparisons between sample sets and sites. For each site, the results from the bedrock samples alone were examined to determine the variance in bedrock chemistry across the site. The coefficient of variation (CV), or percent relative standard deviation (%RSD), was calculated for each of the 38 reported elements within the bedrock samples from each site. This value is the standard deviation of each element divided by the mean. This is an important calculation because the variance of a trace element, such as the REEs, could be high, but its standard deviation would be orders of magnitude lower than that of a minor element, such as Sr. The CV instead reflects the variation per ppm of each element, showing the relative variance and illustrating which elements vary the most in the bedrock of the sites. Figs. 4 and 5 show graphs of the CV for Maax Na and Chawak But'o'ob, respectively. Low values reflect low variance. Elements such as Ca, Mg, Sr, Cr, and Ni that have low CV values are better elements to use for comparing possible monuments to bedrock samples, relative to those with a

Fig. 4. Plot of the coefficient of variation (CV) for elements from Maax Na samples.

Fig. 5. Plot of the coefficient of variation (CV) for elements from Chawak But'o'ob samples.

high CV, such as Rb, Ba, or Pb, because the low CV-elements reflect a better average standard chemistry of the sites' bedrock. The objective of this work is determining the expected variance over the space of each site's bedrock, which is best done with the elements that vary the least for the purposes of comparing to possible external material.

3.3. Maax Na

It is expected that the chemistry of the limestone bedrock will vary across the space of a site due to the epigenetic processes at work since its deposition. Forty-two limestone samples from Maax Na were included in this study (bedrock samples $n = 18$, possible monument samples $n = 24$). As Fig. 4 shows, elements vary differently among the bedrock samples analyzed. Highly variable elements, such as Ba and Pb, should not be used for comparison, as explained above, so their geochemistry will be discussed separately in Section 4.1. Certain elements important in carbonate processes, such as Ca, Mg, Sr, Cr, and Ni, are those that exhibit the least amount of variance. Specifically, ranges in Mg concentrations in limestones indicate the degree of dolomitization in this formation. The Maax Na bedrock ranges between 3 and 22 wt% MgO, all of which fall within the range of the dolomitic limestone classification (Trudgill, 1985), with an average of 14.5% MgO, corresponding to 28% dolomite (MgCO_3). One sample has a lower concentration of Mg due to large amounts of microcrystalline silica in the rock, but it is nonetheless still dolomitic. None of the Maax Na bedrock samples indicate a pure CaCO_3 limestone composition with $<5\%$ MgCO_3 .

To assess the possibility of sourcing stone to where it was quarried, a similarity index was applied for data from all samples based on the analysis of similarity by Borchardt et al. (1972). The similarity coefficient ($d_{(A,B)}$) indicates the similarity of each sample compared to all others. A value of 1.0 indicates perfectly similar samples. However, this method was developed for comparing volcanic ash layers, which have specific chemical signatures that can result in a similarity of $d = 1.0$ (Borchardt et al., 1972). Such a similarity is not expected for limestones, which are more chemically variable. All 38 elements reported in this study were compared, as well as the set of six elements with low CV values, to differentiate between samples more clearly. Certain samples from Maax Na that contain high amounts of silica (e.g. 41 and 44) have lower concentrations of CaO and MgO and have low similarity with other bedrock samples ($d_{(9,44)} = 0.484$), but are still similar relative

to one another, which is why ratios of CaO/MgO were used for comparative purposes.

The similarity index illustrates some interesting distributional patterns among the bedrock samples at Maax Na. Two samples of the bedrock from the South Acropolis at Maax Na (9 and 16; Fig. 1) are similar at $d_{(9,16)} = 0.706$, whereas samples 50, from south of the West Plaza, and 53, from north of the West Acropolis are similar at $d_{(50,53)} = 0.701$, showing little spatial variation. Two samples (29 and 30) were taken as a control for weathering from the inside floor of Spider Cave as well as the outside face above the entrance of the cave. These two samples are similar at $d_{(29,30)} = 0.726$. However, the exterior sample is more similar at $d_{(29,52)} = 0.846$ with a sample (52) from a megalith above the cave. The sample from the interior of the cave came from what was identified as a travertine surface during the excavation of this cave in 2008 (King et al., 2012). Travertine is formed from the movement of freshwater over carbonate (Flügel, 2004). The interior sample is depleted in all the elements relative to the exterior sample, with the exception of calcium, suggesting it is a more pure carbonate formed due to the leaching of trace elements from the rock by the movement of meteoric water, as illustrated by Fig. 6.

3.4. Chawak But'o'ob

The samples collected at Chawak But'o'ob show more heterogeneity than those from Maax Na. Twenty-one limestone samples were analyzed (bedrock samples $n = 15$, possible monument samples $n = 6$). Fig. 5 plots the CV for the Chawak But'o'ob bedrock samples, which shows a similar pattern to that from Maax Na, with Ca, Mg, Sr, and Ni among the least variable elements, and Rb one of the highest. The Mg concentrations at this site are somewhat higher than at Maax Na, ranging from 5 to 22 wt% MgO with an average of 17.4 wt%, or 33% dolomite, also all within the range of dolomitic limestone (Trudgill, 1985). Chawak But'o'ob sits on a lower escarpment than Maax Na, near the banks of the Rio Bravo, and where Maax Na was constructed on a plateau, this smaller site is situated in a more active karst landscape, heavily affected by the movement of water down-slope through the bedrock. As at Maax Na, the harder, denser rock type makes up the higher relief at Chawak But'o'ob. However, unlike at that hilltop center, Mg concentrations decrease with elevation. The highest MgO was sample 1 at the 100 m contour at the site with 22.2 wt%. Downslope to the west and in

Fig. 6. Trace and minor element plot of samples 30 and 52 from inside and above Spider Cave.

the drainage arroyo in the south samples ranged from 5.2 to 11.4 wt.%. The more porous, softer type of stone found off the ridges at the site is more easily eroded, which leaches Mg out. Fig. 7 shows the positive relationship of MgO concentration with elevation at Chawak But'o'ob.

Similarity tests were also run for all the samples at Chawak But'o'ob. A set of control samples was taken from the interior and exterior of the cave near the ballcourt at Chawak But'o'ob, which are similar at $d_{(15,16)} = 0.811$. In this cave, the interior sample was taken from the ceiling of the cave, as there is no evidence of a travertine surface here. Contrasts between bedrock samples were stronger with elevation than distance. Sample 1, from Group E at the northwestern part of the site at the 100 m contour, and sample 17, collected from a hill at the southwest of the site, both of which have similarly high MgO concentrations, are similar at $d_{(1,17)} = 0.832$. These two samples were from opposite ends of the site (Fig. 3), but at similar elevations. In contrast, sample 6 from the eastern end of the site and downslope correlates with sample 1 at $d_{(1,6)} = 0.646$. Elevation, porosity, and subsequent element leaching apparently govern the geochemistry of the limestone at this site. The differences between the two types of limestone observed in hand sample are in porosity and density, as well as MnO

concentrations, due to the Mn-oxide inclusions. The three samples with the highest MnO concentrations – 4, 10, and 14 – are those that had the most visible black oxide inclusions. These mineral inclusions are visible to the naked eye in hand sample, and are therefore useful for identifying this type in the field.

4. Discussion

4.1. Limestone geochemistry

For this research, it is important to understand carbonate geochemistry in order to interpret the variations in data from samples collected across large areas of the two sites. The behavior of minor and trace elements, as either part of the calcite crystal lattice or as inclusions in the limestone itself, are important for distinguishing between different limestone samples as such elements reflect different formation and epigenetic conditions. Not only is characterizing the spatial geochemical variations at these sites important for understanding the evolution of the surface bedrock, but also for distinguishing between rock natural to the local bedrock and rock moved into place by the Maya. Magnesium and other divalent metals, such as Sr, are able to replace Ca in the calcite lattice. The concentrations of these elements in limestone depend on many factors, including the temperature, salinity, and chemistry of the seawater during formation (Flügel, 2004). Post-diagenetic processes, such as the movement of water over the carbonate landscape, also greatly affect the chemistry of modern limestone formations. Meteoric water has a very low MgO/CaO ratio, and therefore leaches Mg from calcite, which occurs to a greater extent in more porous rock (Flügel, 2004). This explains the higher levels of Mg in the denser rocks of the ridges at Chawak But'o'ob, and the depletion of Mg in the softer rocks in-between.

The lattice structure of the calcite crystal is highly robust and can absorb a variety of divalent metal cations, in addition to Mg and Sr, without becoming disordered (Ford and Williams, 1989). Reeder et al. (1999) showed that divalent Co, Zn, Pb, and Ba commonly substitute in the Ca site of the calcite structure with varying degrees of local distortion, either dilation around Ba and Pb or contraction around the smaller ions, Co and Zn. This mode of sharing cations of

Fig. 7. Plot of MgO wt.% vs elevation for samples at Chawak But'o'ob.

varying sizes is favored by the calcite lattice because its corner-sharing structure can take in ions larger or smaller than calcium (Reeder, 1996; Reeder et al., 1999). Other metals commonly adsorb onto the calcite crystal surface rather than being incorporated into the crystal lattice. Studies have investigated the behaviors of elements' interaction with calcite including Ba, Sr, Cd, Mn, Cr, Zn, Co, and Ni (Garcia-Sanchez and Alvarez-Ayuso, 2002; Lakshtanov and Stipp, 2007; Zachara et al., 1991). A hydrating layer of water containing trace metals, adsorbed onto the calcite surface, initially interacts with partially unsatisfied charges of the Ca and CO₃ ions, which results in a hydrolyzed layer on the mineral surface that can become incorporated into the structure upon recrystallization (Lakshtanov and Stipp, 2007). However, the elements that substitute directly into the Ca site in the lattice are the most common minor components. The results from Maax Na and Chawak But'o'ob show low variance for Mg and Sr, but high CV values for Ba and Pb. These variable elements have much larger ionic radii than Ca, requiring the calcite lattice to dilate around the site of incorporation in order to allow for coprecipitation (Reeder et al., 1999), which explains the high variability between samples from across the area of the sites' bedrock, as the conditions for accepting a Ba or Pb ion into the mineral are more demanding than those for Mg and Sr, or smaller radius elements that can fill that space, such as Co and Zn.

The rare earth elements (REE) are indicators of the chemical evolution of waters flowing through carbonates (Vaniman and Chipera, 1996). The Tertiary carbonate sediments on the Yucatan peninsula became emergent by the late Oligocene and have been exposed to subaerial processes since then (King et al., 2003). The identification of all the samples collected from these sites as

microcrystalline calcite shows that the movement of meteoric water over and through the carbonate landscape since diagenesis has recrystallized the initial rock structure into micrite, leaving no microfossils preserved. While there are many epigenetic factors involved in such processes, recrystallization causes the leaching and migration of trace and minor elements (Wolf et al., 1967). REE concentrations are believed to be altered by dolomitization as well as other epigenetic weathering processes, but the exact relationship is unclear and under study (e.g., Northdurft et al., 2004). Ji et al. (2004) show that weathering of dolomites causes uneven transport of REE, which is dependent on the climatic weathering conditions and the stability of the REE-carrying rock. Cerium anomalies in REE profiles reflect the oxidation of Ce and its subsequent incorporation into manganese nodules, depleting Ce in seawater (Piper, 1974). However, the samples in this study do not depict a consistent depletion in Ce, as shown in the plot of the monument samples from Maax Na in Fig. 8, further discussed below. In the case of Maax Na and Chawak But'o'ob, the porosity of the bedrock, which we have shown varies at both sites, greatly affects the dissolution and weathering rates.

Strontium is also a mobile element during carbonate weathering and dissolution (e.g., Vaniman and Chipera, 1996). A positive correlation between Sr and Σ REE, as shown in Fig. 9 for the Maax Na bedrock samples, reflects the epigenetic influence of meteoric waters moving over the bedrock (Tlig and M'Rabet, 1985). The differences shown in the trace and minor element composition of the bedrock at these sites is demonstrated in the Ba, Rb, and Pb concentrations, and REE profiles illustrate the variable nature of bedrock components. This is why an understanding of the bedrock

Fig. 8. REE plot of Maax Na monument samples. Colors in web version. Red lines (MN18, 31, 36) represent three stela; orange lines (MN 24, 25) are the ballcourt and North Plaza altar; green lines (MN 10–15, 43) are the seven small monuments; possible monument samples are in light blue (MN 35, 37, 38, 52); and dark blue lines (MN 2, 4–6, 8) show samples collected from Megalith 1.

Fig. 9. Plot of Sr vs Σ REE for Maax Na samples.

geochemistry is essential to the identification of a set of elements appropriate for discriminating imported from local rock at each of the sites being investigated. For example, Nation et al. (2012) used Rb and Ni and some REE to source speleothems in the Sibun Valley, but these elements would not apply to Maax Na because Rb and the REE are more variable there due to uneven weathering. The combination of elements that best represents the sites' bedrock derives from those with low CVs (see Figs. 4 and 5) within the context of the geological framework discussed above. The ternary diagram in Fig. 10 shows the bedrock samples plotted in blue. CaO/MgO indicates the dolomite percentage as well as the leaching of Mg in the softer rocks. The Sr/La ratio links the mobility of Sr and the REEs during chemical weathering. Finally, Cr/Ni, the two transition metals with the lowest CV values, represent the elements adsorbed and incorporated into the calcite crystal. The ternary plot clearly illustrates a cluster of the Maax Na bedrock samples, which can be used as a starting point for comparison to samples from megaliths and possible monuments.

Fig. 10. Ternary diagram plotting Cr/Ni, Sr/La, and CaO/MgO. Blue open circles = Maax Na bedrock, red dots = Maax Na monuments, green open squares = Maax Na small monuments, and yellow filled squares = Chawak But'o'ob samples. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4.2. Sourcing monuments

Since limestone varies so widely due to formation conditions and post-diagenesis processes affecting its chemistry, absolute sourcing methods like those used for obsidian cannot be applied to limestone artifacts. Identifying a specific geochemical signature for Maax Na and Chawak But'o'ob is therefore not an end goal of this pilot study. Rather, we propose a multifaceted approach incorporating both geochemistry and archaeology to make inferences about stone use at these sites. Using the set of elements identified above as most important in the carbonate geology of the bedrock samples, this research compares them to the samples collected from megaliths and possible monuments at each site. The provenience of each sample within the site and any other archaeological information about it are then assessed to help place the geochemical data in context.

4.2.1. Maax Na

A series of monuments, megaliths, and other stone features at Maax Na were sampled to provide a comparative data set to that of the bedrock in order to determine if geochemistry could help identify monuments and, potentially, source the stone to local quarries. It was expected that many of the megaliths were spall from the bedrock and would have very similar chemistry, which in and of itself is a good test for this methodology. Such proved to be the case. For example, samples 16 and 17 came from a megalith and the adjacent bedrock directly underneath, north of the South Acropolis. An excavation conducted here in 2004 found little artifactual evidence supporting this as a monument feature. These two samples are similar at $d_{(16,17)} = 0.913$, suggesting that the megalith is indeed direct spall from the underlying bedrock and *in situ* in its original location. A number of other possible monument samples (e.g. 37, 38, and 52) are also similar to nearby bedrock samples at $d \geq 0.8$, as are several (e.g. 4–8) collected from Megalith 1, a series of megaliths giving the appearance of a broken monument south of the southeast corner of the West Plaza. Conversely, a possible stela at the eastern base of the North Hill and a bedrock sample from the hill are similar at $d_{(18,36)} = 0.389$, supporting the identification of the stela as a monument that was moved into place from elsewhere at the site or from outside Maax Na.

Fig. 10 plots all the samples from Maax Na and Chawak But'o'ob on the ternary diagram against the ratios of CaO/MgO, Cr/Ni, and Sr/La discussed above. The bedrock samples are plotted in blue, the possible monuments in red, and the set of five small megaliths in the South Acropolis and West Plaza (10–15, and 43), which will be discussed below, are plotted in green. There is a general clustering of bedrock samples with low CaO/MgO and high Sr/La values due to the dolomitic limestone composition of the bedrock at Maax Na. Most of the monuments plot within the range of the bedrock samples, showing that many of the megaliths sampled are either not monuments or were made from the local bedrock. There are, however, some samples that fall well outside the ranges established for the Maax Na bedrock. Three noticeable outliers among the monument samples (red dots) are three stela. Stela 1 to the east of the main temple, and the monument east of the North Hill, in sight of the entrance to Spider Cave, plot nearest the point of Cr/Ni, while Stela 3 north of the North Plaza plots to the far right on the graph. The remaining monument samples plot within the general range of the bedrock, although the cut ballcourt block and the possible altar in the North Plaza (24 and 25) plot somewhat above the Maax Na range.

The clearest and most intriguing outliers in the data set in Fig. 10 are plotted separately in green and fall toward the CaO/MgO corner. These were the small stones from groupings of three in two locations at Maax Na: the South Acropolis (samples 11–15) and south of

the West Plaza (sample 43; Fig. 2), as well as a single similar stone from outside the group at the South Acropolis (sample 10). As noted, the function of these stones is as yet undetermined, but they were sampled in each location because the “altars” were similarly shaped, and all seven had a smoother weathered surface than most megaliths (Fig. 11). Their weathering pattern is explained by the fact that they are composed of a dense, tan, fine-grained limestone with a conchoidal fracture rather than the common soft, white limestone at Maax Na. The chemistry of these stone features differs drastically from the Maax Na bedrock, primarily in the Sr and MgO concentrations. Magnesium is <0.5 wt.%, classifying these as pure limestone as opposed to the dolomitic limestone found elsewhere. Strontium concentrations are higher than those in most of the other samples, generally, because dolomites contain less Sr than calcite (Verheyden et al., 2000). The MgO/CaO and Sr/CaO ratios for all the Maax Na samples are plotted in Fig. 12 (after Aharon et al., 2006). The dolomitic limestone of the bedrock and the other monuments at Maax Na shows a positive relationship, and the samples plot together along one line. The seven limestone samples plot together on a nearly vertical line, indicating the purer limestone composition. The consistent dolomitic nature of the bedrock at both Maax Na and Chawak But'o'ob indicates that these small monuments may have been quarried at some distance from these sites. The small size of these stones makes it feasible that they were transported from outside this area.

Differences in the REE profiles for the monument samples from Maax Na also support some of them having been imported from quarries outside the site core. Fig. 8 plots the REE profiles for the Maax Na possible monument and megalith samples, normalized to an average bedrock composition for Maax Na, which was calculated from the bedrock samples analyzed. Four possible monument samples are plotted in light blue, comprising megaliths whose identification as natural or cultural was unclear during the survey. Dark blue lines plot samples collected from Megalith 1, the identification of which as a monument was also in question. All of these samples plot within the general cluster of samples for the Maax Na bedrock in Fig. 10 and have relatively flat REE profiles when normalized to the Maax Na bedrock average. Alternately, the monuments that plot outside the cluster of the bedrock samples show more varying REE profiles. The three stelae sampled during this survey are plotted in Fig. 8 in red (in the web version), the ballcourt sample and North Plaza altar in orange, and the seven small monuments in green. These samples show much more pronounced negative Ce anomalies. The small monuments in green

Fig. 11. Photograph of small unknown monument. Photo by M. Brennan.

Fig. 12. Bivariate plot of MgO/CaO vs Sr/Ca for Maax Na samples. Blue diamonds = bedrock, red squares = monuments, and green triangles = small monuments. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

also show a consistent negative Eu anomaly not present in the other samples, when normalized to the Maax Na bedrock, further confirming a difference between these rock samples and those from the site's bedrock.

4.2.2. Chawak But'o'ob

The sampling at Chawak But'o'ob was focused on the geochemical characterization of the site in an active karst environment as a comparison to Maax Na, which was constructed at the top of a plateau. Fewer monuments were included in the sampling at Chawak But'o'ob. Three cobbles from the ballcourt, a stela and the possible plaster surface beneath it, and a bridge base in a stream were the only cultural features sampled. The samples from this site are plotted in yellow against those from Maax Na on the ternary diagram in Fig. 10, and they plot primarily in the same area as the Maax Na bedrock, with some variation in the same range. This shows that, despite a 7 km distance and a vertical change over three escarpments, the general bedrock chemistry is relatively consistent between these sites.

A few exceptions can be noted, but they, too, still fall within the bedrock range and can be explained by local formation and post-diagenetic processes. Four samples plot near the Cr/Ni point of the diagram, away from the rest. These are two samples (3 and 4) from drainage channels, or arroyos, one at the southern end of the site and one near Group G (Fig. 3), as well as two cobbles from the ballcourt. These cobbles likely came from the southern drainage, which is near where the ballcourt was constructed. This set of samples may thus reflect the somewhat different chemistry present in a lower stratum of the bedrock than the rest of the outcrops that were sampled. Another sample, number 12, plots to the right of the others. This was collected from a possible bridge base in a small stream at the eastern edge of the site. The sample has extremely high values of Sr, Ba, and REE, and very low MgO compared to the other samples. This feature is at the bottom of the slope on which Chawak But'o'ob was built, and the water flowing through the bedrock pools here and flows through this stream and over the stone feature. The high concentrations are likely due to the movement of leached elements from the bedrock above. The ratios of Sr/La and Cr/Ni are similar to the other bedrock, and this sample would plot in the cluster in Fig. 10 with the exception of a higher CaO/MgO ratio due to the low Mg concentration. Meteoric waters have very low Ca/Mg, making Mg leaching more pronounced (Flügel, 2004).

In summary, despite the minor differences discussed, all the cultural features sampled at Chawak But'o'ob appear to be made of stone local to the area of the site. Sample 7A from the stela at Group

A matches the bedrock, but it is composed of a hard, tan stone, similar in appearance, but not chemistry, to that of the small limestone monuments at Maax Na. It seems likely, therefore, that the stone for this stela was carefully selected, although from a nearby source.

4.3. Maya stone use

The results of this pilot study indicate that the Maya were very knowledgeable about the rock beneath their feet and, in some cases, may have gone to extreme effort to acquire stone from elsewhere for specific purposes. The three stelae sampled at Maax Na are clearly cut from stone that is not local to the area of Maax Na's site core. Given the results from the Chawak But'o'ob arroyo samples, the chemistry of the stelae may be local, but from an unknown quarry somewhere near the site. The seven small, pure limestone monuments from two areas of Maax Na, however, are unlikely to have come from near the site, as no other low-Mg limestone was sampled in this study. The two unsampled monuments from south of the West Plaza likely share this chemistry, based on their appearance as well as their grouping with the monument that was sampled. These results show that the Maya at Maax Na carefully selected stone for the erection of certain monuments, but were able to use the local bedrock for other stone features. The same careful selection of stone is also apparent at Chawak But'o'ob based on the physical appearance of the rock that comprises the stela in Group A. All of the sampled cultural features at Chawak But'o'ob, however, were of local bedrock. This site was constructed late in the Late Classic period without the monumental focus of site centers such as Maax Na, so less cost and effort may have been put into acquiring materials from outside the site.

Despite this, Chawak But'o'ob still underwent extensive landscape modifications that included terracing and water drainage and catchment features (Walling, 2005). These features are primarily small-scale and engineered to take advantage of the slope of the escarpment to channel water as and where needed. Maax Na, on the other hand, is a hilltop center that underwent significant quarrying to shape the landscape of the plateau, like La Milpa and Kinal. The reservoir was carved out, but certain topographical features were left in place at the site, although shaped, such as the two knolls forming the southeast edge of the reservoir and the North Hill. The small hill containing Spider Cave is also natural, and the layout of the site and the incorporation of the North Hill into the plan of the North Plaza are hypothesized to be linked to the presence of caves (King and Shaw, 2003; King et al., 2012). The specific movement of stone from quarries at Maax Na to the final location of architecture and monuments was not possible to determine given the small number of samples in this study, and, especially, the few that came from quarries. However, such a research question would be possible with more intensive sampling, using this study as a baseline. Now that a general understanding of the variability of the bedrock at Maax Na and Chawak But'o'ob has been acquired, further characterization may be warranted. More intensive sampling, specifically along the perimeter of Maax Na, could help pinpoint the quarries from which certain stone was excavated. Additionally, more regional research may be able to elucidate the source of the pure limestone that the small monuments were quarried from, which may be some distance from Maax Na.

5. Conclusion

As has been shown for quartzite (Pitblado et al., 2008), variability was expected in the limestone samples from these sites.

However, the analysis discussed above shows a way to interpret such data so that geologically important comparisons can be made to determine the possible sources of stone at these sites. While there was a range in the geochemical results from samples across the areas of both sites, the majority of them cluster together. Further interpretation based on the context of sampled monuments help understand certain variations. While the sampling strategy was too sparse to source monuments to nearby quarries successfully, several stone features were identified as originating from quarries outside the sampled core of Maax Na: three stelae and the seven small possible altars. The sources of these stelae, and of the stela from Chawak But'o'ob, might be nearby quarries with better quality limestone, but the chemistry of the other seven monuments suggests that that material may have come from quite some distance based on the low-Mg, nearly pure limestone composition. The bedrock samples from both sites investigated proved to be of similar compositions for the elements plotted in Fig. 10, despite the fact that Chawak But'o'ob is below the escarpment and 7 km southeast of Maax Na. Further regional investigations could help discern from how far away other types of limestone would have needed to be imported by identifying quarries.

This is the first study to look at the geochemical composition of the surface bedrock in this area of northern Belize, in part thanks to the areas the Maya cut away and quarried, leaving easily accessible bedrock outcrops for sampling. While the bedrock of the Three Rivers Region is an extension of a large Eocene limestone formation spanning much of northern Guatemala and Belize, it is important to characterize it more locally to determine microvariations within the formation that can illustrate both post-diagenetic effects and the movement of stone by the ancient Maya. The bedrock of these two sites shows heavy epigenetic effects from the movement of water over the landscape that has changed both the chemistry and mineralogy of the limestone. The dolomitic limestone bedrock has been recrystallized into micrite, and ranges in porosity from a very soft, powdery white rock to a hard, dense tan type of rock. While the dolomite composition of the bedrock varies at both sites, the variation at Chawak But'o'ob indicates the removal of Mg from the bedrock due to leaching by meteoric waters moving through the bedrock. Because of Maax Na's location at the top of the plateau, that was not generally the case. However, this sort of leaching of trace metals by the movement of meteoric water is also seen in the travertine surface on the floor of Spider Cave, which we geochemically confirmed had water flowing through it. More importantly, the study shows that the bedrock has been affected unevenly based on the variability in porosity and density of the limestone.

This carbonate landscape was what the Maya used to construct their built environment and shape it according to their worldview. Their clear understanding of the local geology is evident in the types of stone used for certain stelae and monuments, and the transport of some of them to Maax Na from outside the site core. Our most important result is the identification of stone not derived from the same carbonate material as the bedrock at Maax Na, from which monuments were made and whose source may be some distance away. This deliberate choice speaks to the Maya's understanding of stone quality and the effort they expended to acquire certain types of stone. Graham (1987: 754) describes how far the Maya went to procure lithic resources in the Lowlands, even noting that the Maya did not always acquire rock at the source. While the stone materials she mentions include only obsidian, granite, and chert, our results suggest that limestone may have been another stone type that was traded. The seven possible altars and stelae at Maax Na are small enough to have been part of such a stone trade, which might also have included other limestone artifacts regularly

found in excavations, such as manos and metates. Our results indicate that basic geochemical data could be collected in the field that would help locate possible sources for this stone as well as find other monuments made from it. While ICP-MS and ICP-AES analyses of samples are optimal for initial characterization, handheld XRF and other such field devices can provide immediate bulk geochemical results, such as in this area the Mg concentration, or percent dolomite. Such implementation could accelerate and expand this form of research in the Three Rivers Region and beyond. Finally, and perhaps most significantly, the results of this pilot study indicate that it is possible to discriminate among stone sources, even in areas where the type of stone does not lend itself to clear visual and/or geochemical distinctions. Geochemistry by itself cannot provide all the answers, particularly where monuments were made from local bedrock. By using a combination of geochemical and archaeological approaches, however, we may begin to decipher stone selection, movement, and usage across past landscapes.

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