16 BETWEEN A ROCK AND A HARDER ROCK: A REPORT ON RECENT INVESTIGATIONS OF THE ANCIENT MAYA GRANITIC ROCK QUARRIES OF THE MOUNTAIN PINE RIDGE, BELIZE

Jon Spenard, Michael J. Mirro and James Eighmey

Survey of the Mountain Pine Ridge, Belize in 2022 by the Rio Frio Regional Archaeological Project documented Buffalo Hill Quarries, the first ever ancient Maya granitic rock quarry and ground stone tool workshop site documented in the Maya Lowlands. A concurrent aerial LiDAR survey suggested the site was much larger than recorded and that other similar sites remained undocumented in the region. Subsequent research in the 2023 and 2024 seasons expanded on that work. Specifically, the project aimed to ground-truth the results of the aerial LiDAR survey and conduct regional reconnaissance outside the scanned areas to delineate the extent of ancient quarrying in the Mountain Pine Ridge. Questions about the ground stone tool production process represented at these sites related to topics including methods of raw material extraction through finishing were investigated. Addressing the latter question, we also undertook replicative experiments to define the chain of operations of ground stone tool manufacture. In this article, we present the results of these activities, and address areas for future research.

Introduction

The Mountain Pine Ridge in the Cayo District, Belize has long been recognized as the primary source of rock used by the ancient Maya for making granitic ground stone tools (manos and metates) found at sites throughout central and northern Belize, and adjacent regions of Guatemala and Mexico and dating from the Middle Preclassic through Historic periods (e.g. Abramiuk and Meurer 2006; Awe 1985:335-245, 1992:287-295; Duffy 2011:Appendix B and C; Graham 1987; Gunn et al. 2020:117; Halperin et al. 2020:Table 3; Hansen et al. 2020:331; Kidder 1947:34-35; Shipley and Graham 1987:Table 1; Sidris and Andreson 1976:184-185; Thompson 1942:27; Tibbits 2016, Willey et al 1965:453-482). Yet, as recently as 2021, "[v]ery little archaeological evidence exists in Belize to furnish understandings of where and how raw ground stone material such as granite was quarried by the ancient Maya" (Brouwer Berg et al. 2021). The discovery of the Buffalo Hill Quarries site in 2022 by the Rio Frio Regional Archaeological Project (RiFRAP) began to address that knowledge gap, revealing the first definitive evidence of the granitic rock extraction and ground stone tool production industry centered there (Spenard et al. 2023). While one other Late Classic period granite workshop is known from the nearby site of Pacbitun (Skaggs et al. 2020), it is some distance from the granite batholith. Our research presented here thus stands apart from that work because it begins at the point of rock extraction, the earliest stage of stone tool crafting. To date our research into the ancient Maya quarry-workshop sites has focused on four main topics;

1) conducting regional reconnaissance to identify the geographic extent of the industry;
2) understanding site formation processes;
3) investigating extraction methods; and
4) determining the chain of operations of mano and metate production.

Here, we report on the results of these studies to reveal what is currently known about the ancient Maya granitic ground stone tool industry of the Mountain Pine Ridge.

Background

The Mountain Pine Ridge Forest Reserve consists of two major ecoregions. Most of it is defined by its namesake, the Mountain Pine Ridge geologic formation, one of only three granite sources in the Maya Lowlands, and whose nutrient leached, sandy soils support a pine-scrub ecosystem (Weyl 1980). The other ecoregion consists of broadleaf tropical forest on limestone bedrock, part of the Vaca Plateau that has been cut off of its parent formation by the Macal River (Pendergast 1970). Hereafter, we use "Mountain Pine Ridge" when referring to the geological formation, and "the Reserve" when referring to the entire managed area.

Prior to the RiFRAP, only three archaeological studies had been undertaken on the Mountain Pine Ridge[1]. The earliest was an unsuccessful attempt to locate pre-agricultural

Research Reports in Belizean Archaeology, Vol. 19, 2025, pp. 195-208.

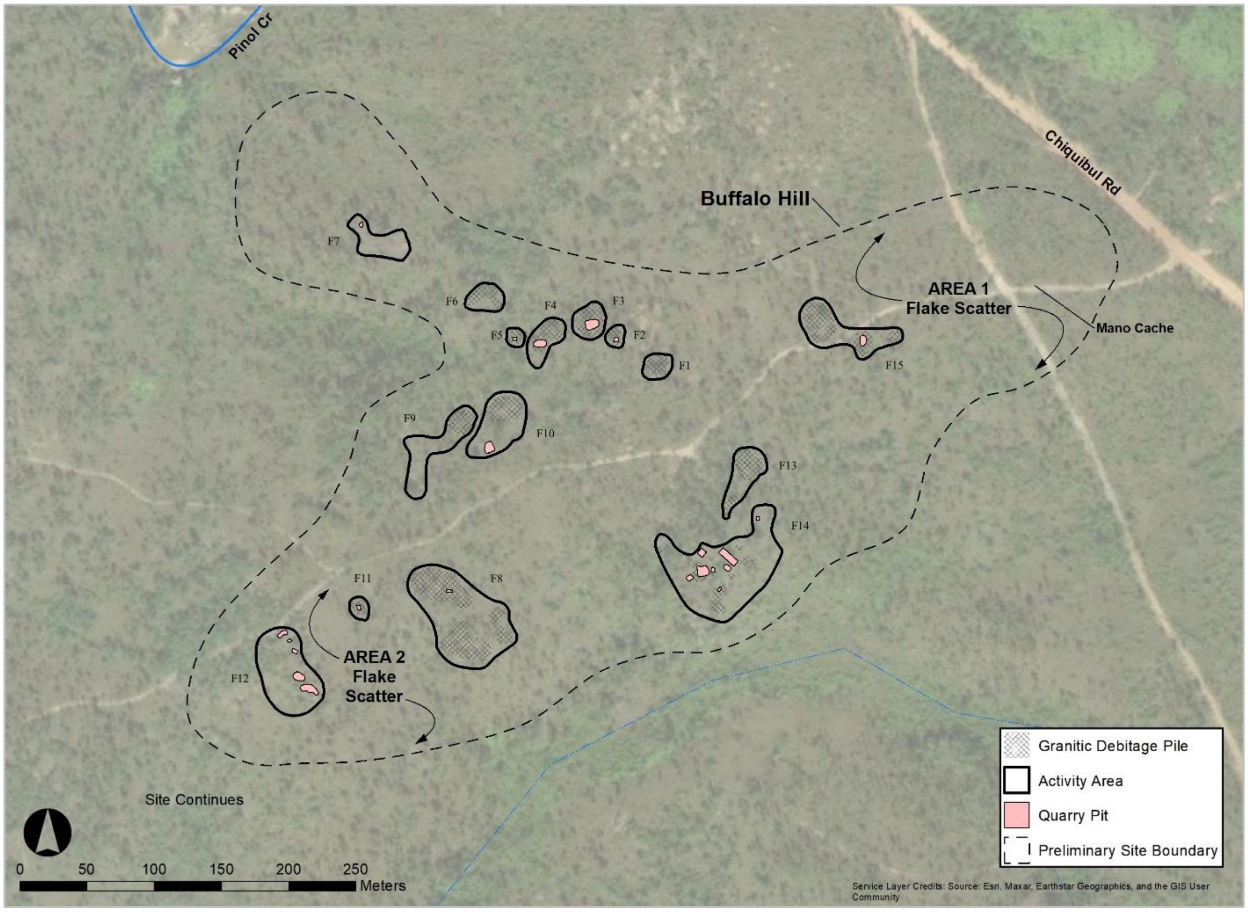

Figure 1. Working map of the Buffalo Hill Quarries following the 2022 field season.

deposits but that also recorded stone cairns erected around slate shafts attributed to the ancient Maya (Thompson 1938). Another study reported a "unique" shrine site composed of two altars and a stepped platform associated with a granitic outcrop (Bullard 1963:98). No excavations were undertaken but an obsidian blade fragment and single nondiagnostic sherd were recovered suggesting its ancient Maya origins. Though not exclusively focused on the Mountain Pine Ridge, the most recent study was a geoarchaeological investigation attempting to source ancient Maya granitic tools recovered from sites throughout Belize (Tibbits 2016). That project revealed the Mountain Pine Ridge to have been the preferred source of granite by far used at all but one of the sites studied.

Through 2022, RiFRAP's investigations of the Mountain Pine Ridge were non-systematic and limited to opportunistic survey along the Caracol Road, the main thoroughfare through the Reserve. By the end of that season, we had produced a partial site map of Buffalo Hill Quarries, revealing it covered at least 16 hectares (Figure 1). Within the 15 activity areas that we located while mapping, we documented two kinds of extraction sites (cut faces and quarry pits) "bedrock mortars" (polished circular depressions carved into the bedrock), and an assemblage of artifacts including hammerstones, debitage, (quarrying waste and tool making debitage), and a few dozen blanks for, and discards from, mano and metate production (Spenard et al. 2023).

Many questions arose from our preliminary mapping efforts. Thick grass covered much of the site preventing a full accounting of the surface assemblage; therefore, what does a full assemblage look like? We knew the site continued beyond the surveyed area, but what was its extent? How was raw material extracted from quarry pits? While some metate discards were recorded, most of the rejected artifacts appeared to be manos. Were metates produced elsewhere? How much finishing occurred at the quarries? What was the full chain of operations of mano and metate production? Lastly, was Buffalo Hill Quarries unique in the Mountain Pine Ridge or were there other similar sites that remained undocumented? Aerial LiDAR data for a 37 km^2 portion of the RiFRAP concession area acquired after the season helped answer many of those questions (Figure 2) (Spenard 2023)[2]. Analysis of the data suggested Buffalo Hill Quarries was about three times as large as was currently mapped, and that there are three other large-scale quarry areas, including one on the Rio Frio near Nohoch Batsó, and over a dozen smaller extraction sites.

Methods

Goals of the 2023 season included ground truthing the LiDAR data, documenting a full surface assemblage at an activity area, and investigating site formation processes. Ground-truthing LiDAR data is vital in the Maya region because scanning does not differentiate between cultural and non-cultural features and some archaeological data may visualize poorly making it difficult to identify (Horn and Ford 2019). The process is straight forward. An analyst systematically investigates the LiDAR data marking all suspected cultural features (targets) in a GIS. In the field, the targets are visited, visually inspected, and either confirmed or rejected. Through this process, we identified over 300 potential archaeological features including urban and rural monumental architecture, settlement, agricultural terraces, cave entrances, and quarry-workshop sites (Spenard 2023). Initial ground truthing efforts focused on the Buffalo Hill Quarries region and outlying settlement in the periphery of Nohoch Batsó, but it remains ongoing (Spenard 2023; Spenard 2024).

To document a full surface assemblage of an extraction-workshop area, a single activity area within Buffalo Hill Quarries was selected for intensive investigation. The one chosen, labeled "Feature 25," was selected because it was comparable to others from the site in terms of size, location, and thus presumably composition (Figure 3). It is ovular in shape, reaches a

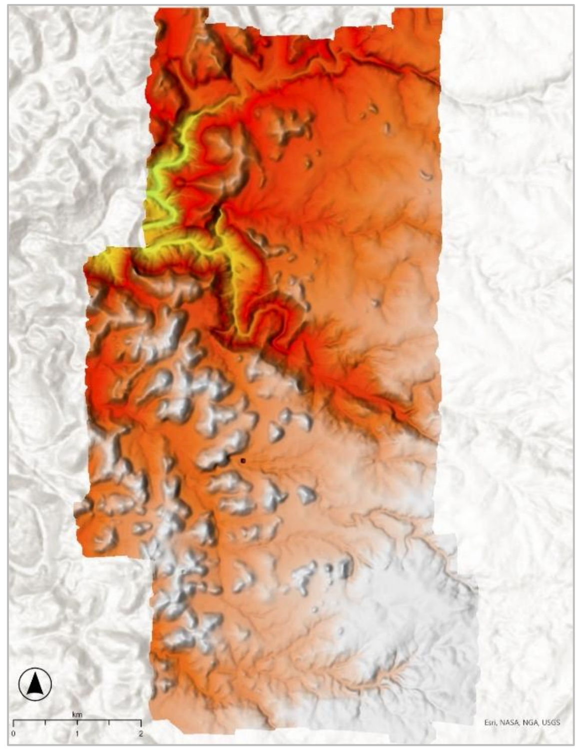

Figure 2. Satellite image showing RiFRAP concession area (orange polygon) and the area of LiDAR coverage (yellow polygon).

maximum diameter of 40 m, and consists of two adjacent extraction areas, although they appear to have originally been a single pit (for smaller pit: https://tinyurl.com/ycw8z5tt). Once vegetation was removed, the entire site was systematically surveyed and all non-debitage artifacts including hammerstones, full- and half-loafs, metate discards and blanks, and ceramics were plotted (Figure 4).

Three stratigraphic units were excavated to investigate site formation. They include a 9 m x 2 m trench from the center of the larger of the two quarry pits to just past the outer berm of debitage surrounding it (Figure 5). Another was a 1 m x 2 m pit on a debitage berm dug to investigate a small, erected granite pillar with charcoal and residue adjacent to it. The third was a 2 m x 2 m square on the tallest berm of debitage surrounding the pit located to investigate a concentration of surface ceramics.

The 2024 field season focused on regional survey away from Buffalo Hill Quarries and outside the LiDAR-scanned portions of the research area to determine the limits of ancient Maya quarrying activity in the Mountain Pine

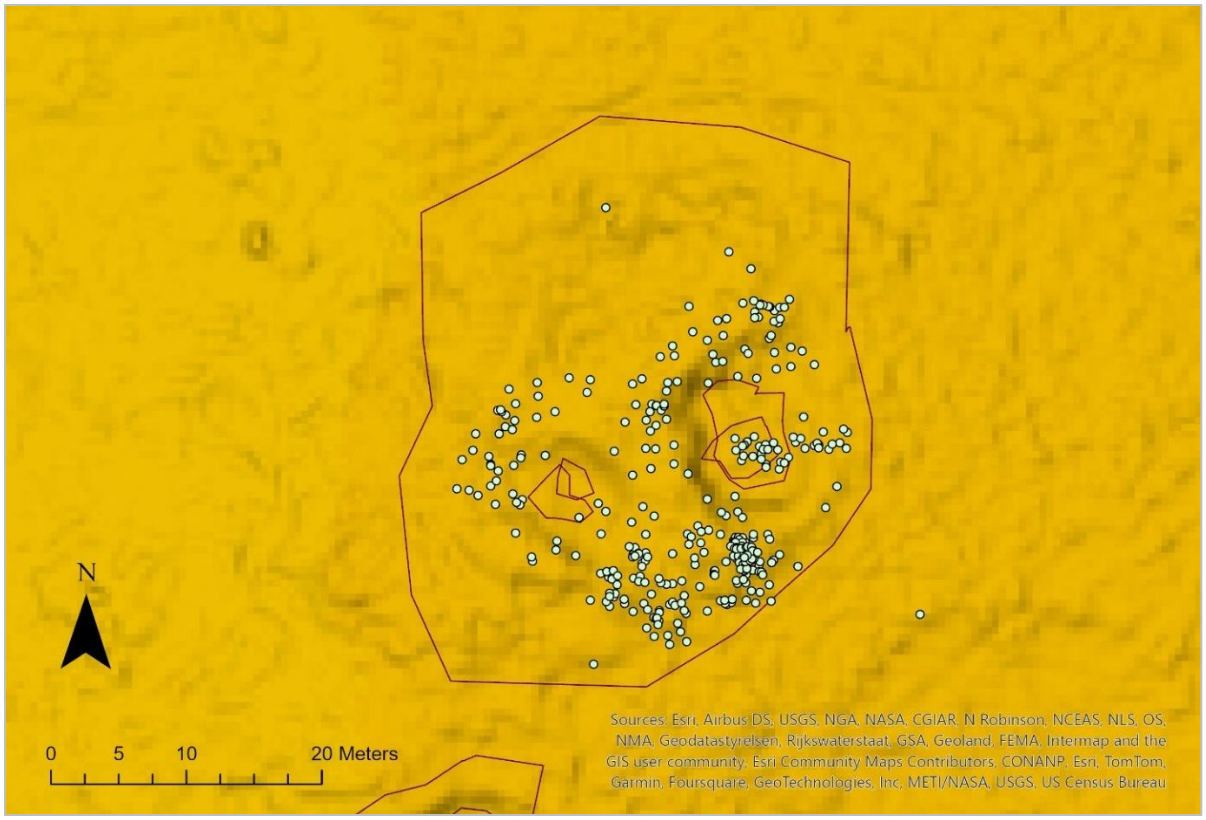

Figure 3. Close up of Buffalo Hill Quarries site Feature 25 in hillshade derived from aerial LiDAR scan. Note that all dots represent the location of a non-debitage artifact.

Ridge. The technique employed is referred to in the US CRM industry as "windshield survey." short, a road is driven slowly and the team riding in the vehicle visually inspects the roadsides for objects of interest, in this case any outcrops and piles of debitage. Each time one was identified, the team disembarked and inspected the potential site, confirming or rejecting it. For confirmed sites, we plotted boundaries, and described the sites noting activity areas and artifact classes present. Because of an irregular maintenance schedule, survey areas were dictated by drivability of roads.

Results

In this section, we present the results of the activities discussed above starting with our ground truthing activities at Buffalo Hill Quarries and survey and excavations of the Feature 25 activity area within it, followed by the results of our regional survey. The section is concluded with a presentation on the results of the chain of operations experiments.

Figure 4. Photograph of Buffalo Hill Quarries site Feature 25 after it had been cleared of vegetation (photo by J. Spenard, courtesy of the RiFRAP).

Before continuing, we note that establishing site-specific dates and a regional chronology for extraction is an on-going focus of investigation. Archaeological materials commonly used for establishing site chronologies in the Maya area–namely ceramics and charcoal

Figure 5. Photograph of excavation trench opened in Buffalo Hill Quarries site Feature 25 (photo by J. Spenard, courtesy of the RiFRAP).

from secure contexts–are rare at the quarry-workshop sites, and our excavations have been limited to testing a single extraction pit. To date, we have recovered fewer than 200 sherds from all quarry-workshop sites, the vast majority of which are highly eroded utilitarian wares. The only diagnostic pieces identified so far are from Feature 25 and include ten volcanic ash tempered sherds with completely eroded slips, and a single red slipped Pine Ridge Carbonate ware body sherd, tentatively suggestive of a Late to Terminal Classic period date for that pit. Charcoal was recovered, and samples have been submitted for radiocarbon dating, but at time of writing, the results are unavailable. How representative those dates will be for all of the sites requires further study.

Unfortunately, as a result we are currently unable to address broader questions related to the spatial and temporal distribution of granite manos and metates across the Maya lowlands beyond referring back to our opening statement where we review where and what time periods they have been recovered from. We further note that that the references offer a representative snap shot, rather than comprehensive listing of where granite artifacts have been recovered. As more chronological information is acquired, we can begin to investigate bigger questions such as the role their trade played in the development of social complexity (e.g. Rathje 1972), if and how the resource was controlled (e.g. Awe 1985:383; Chase et al. 2014), and how they were distributed (e.g. Brouwer Burg et al. 2021), and how those changed over time.

Raw Material Extraction

Review of the Buffalo Hill Quarries LiDAR data identified 18 potential activity areas that were unmapped in 2022. Ground truthing confirmed all but two. We also recorded several other extraction features that were overlooked or otherwise not visualized in the data. As we started that work, we counted 27 activity areas, but as ground truthing efforts continued, we recognized that debitage and spoil piles frequently overlap, and multiple extraction events occurred in the same pit making counts meaningless as they arbitrarily divided the site. As such, we discontinued tallying and instead simply recorded the boundaries of distinct debitage piles, recognizing that they may be the result of multiple extraction events. But the spoil piles are only partially indicative of the totality of the site. Tested boulders and outcrops, low-density granitic rock debitage and chert flake scatters are found throughout the area. By the end of the season our work revealed that Buffalo Hill Quarries covers an area of 50-hectares (~123 acres), measuring 1km east-west by 0.5 km north-south (Figure 6).

Ground truthing efforts identified a previously unrecorded form of extraction feature, strip mining, that was prominent at the site but largely unrecognizable in the LiDAR data. Elsewhere, we have defined strip mines as extraction loci on low-profile bedrock exposures where natural jointing was common (Spenard 2024:11). The joints commonly appear as vertical fractures and horizontal bedding planes. Tabular jointing where bedrock is naturally fractured into blocks is rare, at least on a scale that produces regular workable pieces. Strip mines

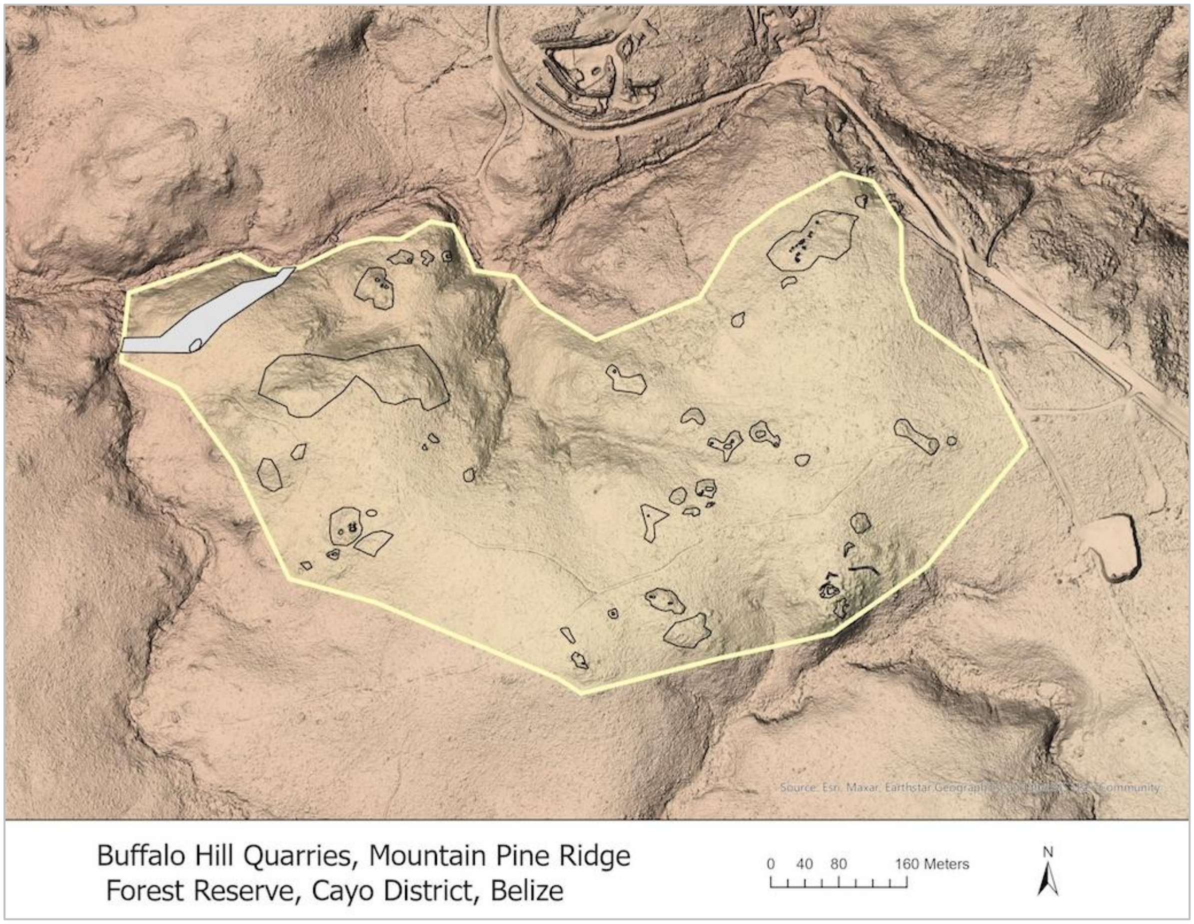

Figure 6. Completed map of Buffalo Hill Quarries site.

are distinguished from quarry pits because they are not excavated below the ground surface, but the method used to extract raw material from them was similar. In the former, scars left behind from extraction could be visually traced to joints running along sections of unmodified rock revealing their exploitation in the removal process (Figure 7).

Excavations of Feature 25 revealed that rock removal from quarry pits also exploited natural jointing as well as how it was likely accomplished. There, Maya stone workers encountered an exposed section of bedrock on a downslope of a low rise that they followed into the side of the hill by removing the overlying sediment. Our excavations uncovered the limits of sediment removal, which coincided with the termination of extraction activities (Figure 8). Like at strip mines, wedges of some kind were used to force the rock from the ground using the

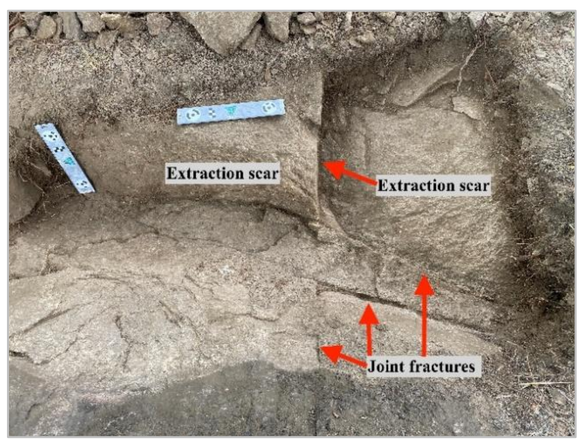

Figure 7. Photograph of an extraction scar following a joint fracture that continues into unmodified rock (photo by J. Spenard, courtesy of the RiFRAP).

natural horizontal bedding planes to facilitate the process. For example, in Figure 8, four bedding planes are visible, each bearing the scars of where extraction activities ended. Note that the mottled

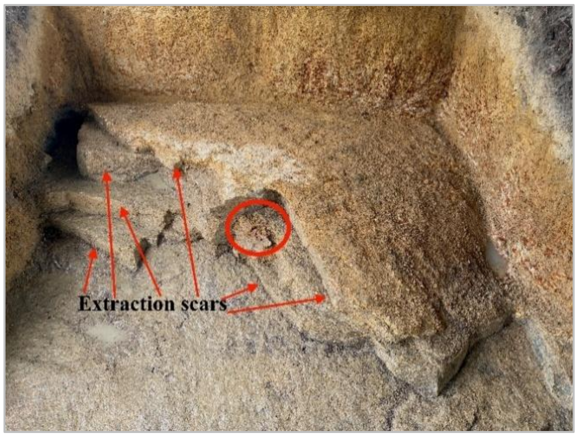

Figure 8. Detail photograph of the excavation trench in Buffalo Hill Quarries site Feature 25 showing stacked extraction scars representing the edge of quarrying activity. Note the ceramic sherd in the center of the image (circled), and mottled matrix in walls of trench indicating undisturbed area (photo by J. Spenard, courtesy of the RiFRAP).

matrix above the top, weathered layer of granitic rock is the undisturbed matrix. As seen in the unit profile in Figure 9, that mottled matrix ends abruptly where the quarrying activity begins (https://tinyurl.com/5n6d59tj).

How the joints travel through the rock is largely unpredictable, and, as a result, their use in raw material extraction by Maya stone workers produced vast quantities of waste. Much of the matrix cleared from the excavations resembles that found surrounding all of the quarry pits and cut faces: large, thin slabs of granite, the remains of extracted material that was too thin to be worked into tools (Figure 10). Rejected, it was tossed to the side of the quarries, creating the berms that surround the pits. It is important to note that the granite is very hard, and working it tested the upper limits of technology available to the Maya. Once joints stopped producing workable material, either because the slabs were consistently too thin, or because the joints ran too deep and rock could no longer be wedged out, or if no other joints were present, or if they were but stone workers were unable to get purchase on them, the quarry was abandoned because the technology to cut into, drill, or otherwise penetrate the granite was unavailable.

Ground truthing efforts also led to the identification of one of the probable sources of quartzite used to make hammerstones. A vein of the material was located on a low ridge on the southern bank of Pinol Creek in the northwest corner of the site. The entire ridge is covered in boulders, tested cobbles, and flakes. Additionally, a 1 m-tall x 10 m-long mound of debitage surrounds a large, tested outcrop of the material, a possible hammerstone workshop. Regional survey revealed that such veins are common throughout the Mountain Pine Ridge.

Defining an Extraction Site Assemblage

During the 2022 field season, we had plotted 69 hammerstones, 10 metate preforms, and 53 objects identified as “half loafs,” which we now understand to be manos broken during production (Mirro et al. 2023), in the 15 hectares of Buffalo Hill Quarries that we had mapped. Nevertheless, with limited visibility resulting from tall, dense grass growing over much of the site, how representative the assemblage was remined uncertain. With permission from the Forest Department, we removed all vegetation except trees from Feature 25 to prepare it for our excavations and to fully document a surface assemblage of a single activity area. The results of the latter far exceeded our expectations.

As noted above, Feature 25 is 40 m in diameter, or approximately 0.15 hectares in size. In that feature, we recorded 103 hammerstones (including fragments), 13 metate discards or blanks, 145 half-loafs, 59 objects we identified as “pics,” which we now believe to also be manos broken during production, and 2 potential wedges. Using those numbers, we can estimate the total expected number of surface artifacts at the site. Of the 50 hectares the site encompasses, an estimated 3.5 hectares are quarry pits and large-scale strip mines. The total worked area is a conservative estimate as it does not account for unrecorded strip mines, and the low-density scatters and tested outcrops known to be in the area. Applying a percentage proportion equation to the total number of each type of artifact recorded in Feature 25, can be used to estimate the total number of each per hectare. In this case the 0.15-hectare size of Feature 25 is understood to be 15% of 1 hectare. The calculation of artifacts per acre is thus n/0.15 where n= the number of artifacts recorded. Those results are then multiplied by the 3.5 (the total number of hectares of quarried areas recorded). Running those calculations, if we completed a 100-percent survey of all mapped activity areas in Buffalo Hill

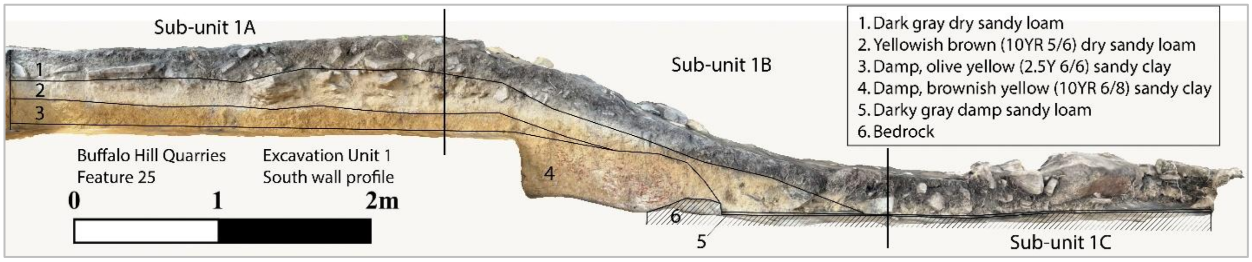

Figure 9. Screenshot of digital 3D model and profile drawing of south wall of Buffalo Hill Quarries site Feature 25 excavation Trench.

Figure 10. Photograph debitage uncovered during excavations of Buffalo Hill Quarries site Feature 25, highlighting discarded slabs (photo by J. Spenard, courtesy of the RiFRAP).

Quarries, we would expect to find 2,404 hammerstones, 4,760 half loafs, and 304 metates. It is important to clarify that we also recovered artifacts from our excavations, and thus those totals only represent expected surface artifacts. Additionally, they are not calculations of how many tools were produced but rather estimates of how many were discarded.

Regional Survey

An earlier geological survey of the Mountain Pine Ridge revealed it is composed largely of four granitic rock types, each resulting from a distinct eruption, but to date we have only surveyed in the largest three (Shipley 1978: Plate 1). The largest is described as a pink, coarse granite to coarse porphyritic granite (hereafter "pink granite"). The second largest is a discontinuous formation in the northeast and southwest corners of the Mountain Pine Ridge, defined as a red-brown, inequigranular, porphyritic-phaneritic, quartz monzonite porphyry with variable texture (hereafter "red-brown granite"). The third largest consists of a gray, medium grained, hypidiomorphic-granular granodiorite (hereafter "gray granite"), located between the pink and southern red-brown granite.

Granitic rock areas captured in the LiDAR data are all in the pink granite, except for a small portion of the southern extent of the survey that captured a section of the gray granite. An attempt to ground truth one of the suspected large quarry sites (approximately 7 hectares) near Buffalo Hill Quarries was unsuccessful, stopped because another large site, nicknamed Moshy's Hill, was encountered on the way there. Much more compact than Buffalo Hill Quarries, the 4.5-hectare Moshy's Hill site is 300 m downriver from it on a prominent hill rising up from the northern banks of Pinol Creek. No quarry pits have been identified there, instead, the slopes of the hill and hilltop are covered in extensive cut faces and strip mines. Though some concentrations of debitage are present on the hilltop, most of the waste rock was tossed over the hillside toward the river as evidenced by a deep, continuous scatter of debitage of unknown depth covering the 60 m slope up from the creek shore. Some of the debitage has been piled into terraces, some over 2 m tall, serving unknown functions (https://tinyurl.com/55h7xadh).

The quantity of debitage at Moshy's Hill compared to that found at the dispersed activity areas at Buffalo Hill Quarries suggests much more intensive production at the former. Over a dozen "bedrock milling features" were recorded on the hilltop (https://tinyurl.com/yfzcncux), most in the areas that were strip minded. We previously hypothesized that such features were created during mano finishing, specifically that the tool was supported by the ground and the act of turning it as it was pecked into shape would carve out the pit in the bedrock (Mirro et al. 2023:46). Our chain of operations experiments discussed below suggests that rather than milling, they were the result of pounding actions. That hypothesis was supported during documentation of a 4 to 5 m tall x 12 m in diameter outcrop that had another dozen pits carved into it (https://tinyurl.com/yc6dbtsh). Unlike the others at the site, several on the outcrop were oriented vertically, and could have only been created by swinging up or sideways.

Outside of the LiDAR scanned area, windshield survey was conducted along five primary transects, each beginning at the Caracol Road and proceeded east. Route 1 surveyed the Privasion Line to its intersection with the Orchid Hill Line, which we followed to the eastern boundary of the RiFRAP permit area near Cooma Cairn Military Barracks. Those roads pass through regions of pink and red-brown granite, and reduction sites were recorded in both areas. Route 2 proceeded along the Oak Burn Line to the intersection of Granite Cairn Road, which we followed until the junction with the 1961 Road. Route 3 followed Granite Cairn Road to its intersection with the Oak Burn Line. Both Routes 2 and 3 passed only through pink granite. Route 4 was the shortest driven. It included the first 1,000 meters of the Mahogany Line west of the Caracol Road, and the first 800 m of Inner Circle Road to its east. Though the shortest survey route, all three major MPR granites were surveyed. Route 5 was the southernmost, proceeding along Brunton Trail for approximately 750 m past Tower No. 2 Road. That road largely parallels the junction of the red-brown and gray granites.

As noted, most quarry sites were identified in the pink granite although a few were recorded in the northern red-brown areas. Site size varies, and though each has its own idiosyncrasies, the artifact assemblages consistently resemble those described above from Buffalo Hill Quarries. Interestingly, although outcrops are abundant in the pink granite in the north, few were noted in it in the south along the Mahogany line in Route 4. That survey brought us to within approximately 2.5 km of the Mahogany site (Moyes et al. 2017), and the lack of quarries in any of the granites in that region hints to the fact that if the ground stone tool industry of the Mountain Pine Ridge was centralized or under elite control it was not by the inhabitants of that site. If it were, we would expect to find extensive evidence for extraction in the areas immediately surrounding it, especially in the areas where favorable rock is found. Instead, nearly all known extraction is far from that site with some closer to Nohoch Batsó.

Experimental Archaeology

Replicative experimentation is commonly employed in lithic studies because it can answer questions such as what is the chain of operations of production and how were the tools used (e.g. Adams 2013). Several questions about mano and metate production arose during the research described above, but two of the most prominent are related to the most commonly encountered non-debitage artifacts at the sites, hammerstones and half-loafs. Hammerstones of various sizes ranging from basketballs to fist-size are used in the process of metate production and are found in substantial numbers at the quarry sites (Figure 11). Questions remain as to what type and size of the tools were preferred for different stages of reduction and how their availability might influence the manufacturing processes. Next to debitage, half-loafs are by far the most common artifact class at the quarry sites, and our initial impression was that at least some of them were purposefully produced pics used to shape the items being made at the quarry workshops (Mirro et al. 2023; Spenard et al. 2025). Yet, much of the debitage at the sites appears to be the result of shaping metate blanks. The co-occurrence of both metate and mano discards at nearly all activity areas indicates that the artifact classes shared a raw material source. Thus, what is not clear is the process by which the manos were produced. Why are so many discarded mano fragments (“half loafs”) of approximately the same size found on sites, but few completed or partially completed ones? Were half loafs intentionally created, were they manufacturing failures or something else?

To gain insight into these questions, unmodified samples of granite slabs and hammerstones from various quarry areas in Mountain Pine Ridge were collected during regional survey activities and brought back to the lab for experimental use. These samples were subjected to a series of simple experiments

Figure 11. Photograph of basketball-sized hammerstone, presumed to be used for initial stages of rock extraction (photo by J. Spenard, courtesy of the RiFRAP).

Figure 12. Photograph of experimental hammerstones (photo by J. Eighmey, courtesy of the RiFRAP).

simulating the suspected manufacturing techniques with the goal of providing some direction for future studies.

Hammerstone trials began with a selection of unmodified and unrounded quartzite cobbles from several different veins of local stone (Figure

Figure 13. Photograph of geode nodule and containing matrix discovered during experimental activities (photo by J. Eighmey, courtesy of the RiFRAP).

12). Each was put to three tasks, pecking a granite slab, grinding the same slab, and modifying the edges of a metate blank through direct percussion. Despite being quite common at the quarries, they performed poorly. Even under a very short use period they showed substantial wear against the granite, and it became clear that not all quartzite was adequate to the task. Only one quartzite hammerstone avoided major damage in 15 minutes of use. Every other one disintegrated, which explains the large amount of quartzite debitage at the quarry sites. Much of what would seem to be robust tool stone is worthless for the task given the hardness of the local granite. It was the hardest stone they could get, but it was barely adequate for the job.

Having revealed the inadequacies of quartzite for working the Mountain Pine Ridge granite, we were left wondering if there was something we were missing. The answer was found in the project geology sample pile. After rapidly destroying all our available hammerstones we picked up a brown, semi-porous cobble, and, on a whim used it as the hammer of last resort. The outer matrix immediately flaked off to reveal a dense, smooth, and globular precipitate in the center (Figure 13). It was, in fact, a form of geode. Reviewing the quarry assemblages in the lab, we recognized several had been collected, but were misidentified as quartzite.

The geodes turned out to be amazing hammerstones. They are very dense and virtually indestructible. Even after hours of continuous pecking, little ware was seen on them. The stones are even tough enough to be used for driving flakes off the margins of the metates. Clearly, they would have been the preferred tools of the ancient stone workers. We suspect that they could also have a wide trade distribution, but they might be overlooked or misidentified as a form of quartzite by researchers. Unfortunately, we are not sure of the source of the cobbles but suspect they may originate in the Santa Rosa Formation.

The presence of "half-loafs" at the quarry sites suggests the initial production of manos used the same raw materials as the metates. One mystery was in what sequence this was accomplished. Another surrounds the high number of fractured pieces. To investigate these patterns, we used the surviving hammerstones from the first trials to work small slabs of granite collected from road cuts and waste rock from an abandoned modern quarry.

Our efforts at creating manos were not entirely successful. Every one of the blanks shattered at some point, from which we derived several very clear lessons. First, using direct percussion to shape slabs into an elongated form is difficult and results in a high number of failures. This is simply because granite is much stronger in compression than in tensile strength. The best way to prevent breakage is to keep the form relatively thick, or loaf-like, but the ends are difficult to shape and often remain pointed. In such a form, the general outline of the desired object can be gradually pecked into shape, but any sharp impact will likely result in a fracture, especially if the piece is unsupported. The latter case results in what flintknappers call "end shock," wherein the force transfers through the struck object and drives off the opposite tip. Such failures–half-loafs–are common in the quarry site assemblage, likely the result of these errors.

Using hammerstones to shape the pointed ends into the desired rounded form proved difficult with any method, but we found that pounding them on a granite anvil accomplished the task. Moreover, as the anvil was struck by the mano preform, a rounded dimple was carved into its surface after a just a short time (approximately 30 minutes). With continued pounding, a shallow pit would form within a few hours, resulting in a feature that resembles the "bedrock mortars" found at the quarries.

Conclusions

Recent research in the Mountain Pine Ridge, Belize by the Rio Frio Regional Archaeological Project has demonstrated the existence of an extensive, granitic rock ground stone tool production industry originating there. Though several different types of the stone make up the geological formation, our research has shown the ancient Maya had a strong preference for just one of them, although why they did remains unanswered. The preferred rock is very hard, especially for the tools and technology available to the stoneworkers to extract and work it. Yet, they found a way. Aided by natural fracturing, they pried out blocks of workable material and shaped it into desired forms using an array of hammerstones, some acquired locally, others carried in from further afield. Failures were common, but some were undoubtedly repurposed, for example, if a metate blank broke the right way, it could become multiple mano blanks. Undoubtedly causing frustration levels to rise, even those failed at high rate, the evidence of which–half-loafs–remains strewn amongst the debitage at the sites in disproportionally large numbers. Those that survived shaping were rounded into their final form by pounding them on the bedrock they were recently pried from, a process that left pits scattered across the sites. Such scenes played out throughout the pink granite regions of the northern Mountain Pine Ridge, but when they first started or for how long each site was worked, we still do not know. But the temporal distribution of artifacts (Middle Preclassic through Historic periods) made from granite originating there suggest several millennia of extraction. Did processes and methods change over time? Even less clear is who the stone workers were. With several larger extraction sites in proximity to Nohoch Batsó, some stone workers were undoubtedly from that community but with many other sites in the middle of and toward the eastern side of the Mountain Pine Ridge, between 10-16 km from any known major or minor settlement, the likelihood that they were all coming from that Nohoch Batsó seems unlikely. Though many questions remain unanswered about the granitic rock ground stone tool industry in the Mountain Pine Ridge, our research there has made great strides in understanding it.

Acknowledgements Funding for the research reported here was provided an Archaeological Institute of America-National Endowment for the Humanities Post-Fieldwork Research and Publication Grant, a Franklin Grant from the American Philosophical Society, and California State University San Marcos. We thank our excellent field crews, "the RiFRAPpers," including Dr. Konane Martinez, Andres Berdeja, Mr. Moses "Moshy" Flores, Mr. Antonio Mai, Mr. Boh Mai, Mr. Eric Mai, Ms. Mirna Mai, Mr. Javier "Chiich" Mai Sr., Mr. Javier Mai Jr., Mr. Ronny Mai, Mr. Asmid Mai, Eric Mendez, Adam Niesley, Brooke Olivier, Franklin Quiros, Alysa Ransom, Geary Smart, Mikala Weber, and Jaime "3 or 35" Wojak. Dr. Elizabeth Mathews has been an instrumental supporter and cheerleader for this project. Thanks also to Marieka Brouwer Berg, Rachel Horowitz, Adam King, Terry Powis, and Tawny Tibbits for continual riveting conversations about granite. Jon would like to extend special thanks, narwals, and llamas to Amy, Ellie, and Charlotte. Our friends at Cocopele Inn, William's Belize Shuttle, Crystal Auto, Erva's Restaurant, and Pop's Restaurant, provided clean rooms, transportation, excellent meals, and hearty laughs throughout our stays. Thank you to Chief Forest Officer Wilbur Sabido and the staff of the Belize Forest Department, especially Ms. Shanelly Carillo, and Mr. Raul Chun for providing permission to conduct our research in the reserve. Lastly, we thank Dr. Melissa Badillo and the entire staff of the Belize Institute of Archaeology, especially Mr. Josue Ramos and Ms. Rumari Ku for their permission and support of the RiFRAP's research, hosting the BAAS conference, and their efforts editing this volume.

[1] We recognize that a few additional surveys (Mason 1928, Pendergast 1970; Moyes et al. 2017) have been conducted in the Reserve, but they focused on caves in the broadleaf areas rather than on the geological formation under discussion.

[2] Though a portion of the RiFRAP permit concession area was captured during the National Center for Airborne Laser Mapping's (NCALM) 2013 West-Central LiDAR Survey (Chase et al. 2014), and those data have been made available to us, the sites discussed here are outside the area surveyed by that project. The LiDAR data discussed here were acquired through our participation in the NCALM Belize 2022 LiDAR Campaign.

References Cited

Abramiuk, Marc A., and William P. Meurer
2006 A Preliminary Geoarchaeological Investigation of Ground Stone Tools in and around the Maya Mountains, Toledo District, Belize. Latin American Antiquity 17(3):335-354.

Adams, Jenny L.
2013 Ground Stone Analysis: A Technological Approach. 2nd ed. The University of Utah Press, Salt Lake City.

Awe, Jaime J.
1985 Archaeological Investigations at Caledonia, Cayo District, Belize, Master's thesis, Department of Anthropology, Trent University, Peterborough, Ontario.

Awe, Jaime J.
1992 Dawn in the Land Between Two Rivers: Formative Occupation at Cahal Pech, Belize and Its Implications for Preclassic Occupation in the Central Maya Lowlands, Ph.D. dissertation, Institute of Archaeology, University of London, London.

Brouwer Burg, Marieka, Tawny L.B. Tibbits, and Eleanor Harrison-Buck
2021 Advances in Geochemical Sourcing of Granite Ground Stone: Ancient Maya Artifacts from the Middle Belize Valley. Advances in Archaeological Practice 4:338-353.

Bullard Jr., William R.
1963 A Unique Maya Shrine Site on the Mountain Pine Ridge of British Honduras. American Antiquity 29:98-99.

Chase, Arlen F., Diane Z. Chase, Jaime J. Awe, John F. Weishampel, Gyles Iannone, Holley Moyes, Jason Yaeger, et al.
2014 Ancient Maya Regional Settlement and Inter-Site Analysis: The 2013 West-Central Belize LiDAR Survey. Remote Sensing 6:8671-8695.

Duffy, Lisa Glynns
2011 Maize and Stone: A Functional Analysis of the Manos and Metates of Santa Rita Corozal, Belize, Unpublished M.A. thesis. Department of Anthropology, University of Central Florida, Orlando.

Graham, Elizabeth A.
1987 Resource Diversity in Belize and Its Implications for Models of Lowland Trade. American Antiquity 52(4):753-767.

Gunn, Joel D., William J. Folan, and Maria del Rosario Dominguez Carrasco
2020 The Stones of Calakmul: Lithics and Other Technologies Among the Maya at Calakmul,

Campeche, During the Late and Terminal Classic and Their Cultural Implications. Informacíon 17:143.

Halperin, Christina T., Jose Luis Garrido López, Miriam Salas, and Jean-Baptiste LeMoine
2020 Convergence Zone Politics at the Archaeological Site of Ucanal, Peten, Guatemala. Ancient Mesoamerica 31:476-493.

Hansen, Richard D., Edgar Suyuc, Stanley P. Guenter, Carlos Morales-Aguilar, Enrique Hernández, and Beatriz Balcárcel
2020 Economic Interactions and the Rise of Sociopolitical Complexity in the Maya Lowlands: A Perspective from the Mirador-Calakmul Basin. In The Real Business of Ancient Maya Economies: From Farmers' Fields to Rulers' Realms edited by Marilyn A. Masson, David A. Freidel, Arthur A. Demarest, Arlen F. Chase, and Diane Z. Chase, pp. 317-339. University Press of Florida, Gainesville.

Horn III, Sherman W., and Anabel Ford
2019 Beyond the Magic Wand: Methodological Developments and Results from Integrated Lidar Survey at the Ancient Maya Center El Pilar. STAR: Science & Technology of Archaeological Research 5(2):164-178.

Kidder, Alfred V.
1947 The Artifacts of Uaxactun, Guatemala. Publication 576, Carnegie Institution of Washington, Washington, D.C.

Mason, Gregory
1928 Pottery and Other Artifacts from Caves in British Honduras and Guatemala. Indian Notes and Monographs, No. 47. Museum of the American Indian. Heye Foundation, New York.

Mirro, Michael, Javier Mai, Jon Spenard, and Konane Martinez
2023 The Buffalo Hill Quarries Site. In Report on the Third Field Season of the Rio Frio Regional Archaeological Project (RiFRAP) (June-July 2022, January 2023), edited by Jon Spenard, pp. 39-54. Report Submitted to the Institute of Archaeology, and Forest Department, Belmopan, Belize.

Moyes, Holley, Laura J. Kosakowsky, Erin E. Ray, and Jaime J. Awe
2017 The Chronology of Ancient Maya Cave Use in Belize. Research Reports in Belizean Archaeology 14:327-338.

Pendergast, David M.
1970 A.H. Anderson's Excavations at Rio Frio Cave E, British Honduras (Belize). Occasional Paper, 20. Royal Ontario Museum, Division of Art and Archaeology, Toronto.

Rathje, William L.
1972 Praise the Gods and Pass the Metates: A Hypothesis of the Development of Lowland Rainforest Civilizations in Mesoamerica. In Contemporary Archaeology; A Guide to Theory and Contributions, edited by Mark P. Leone, pp. 365-385. Southern Illinois University Press, Carbondale.

Shipley III, Webster E.
1978 Geology, Petrology, and Geochemistry of the Mountain Pine Ridge Batholith, Belize, Central America. Master's thesis. Department of Geology, Colorado School of Mines.

Shipley III, Webster E., and Elizabeth Graham
1987 Petrographic Analysis and Preliminary Source Identification of Selected Stone Artifacts from the Maya Sites of Seibal and Uaxactun, Guatemala. Journal of Archaeological Science 14:367-383.

Sidrys, Ramond V, and John Andreson
1976 Metate Import in Northern Belize. In Maya Lithic Studies: Papers from the 1976 Belize Field Symposium, edited by Thomas R. Hester, and Norman Hammond, pp. 177-190. Center for Archaeological Research, The University of Texas at San Antonio, San Antonio.

Skaggs, Sheldon, George Micheletti, Michael Lawrence, Nicaela Cartagena, and Terry G. Powis
2020 Identification of an Ancient Groundstone Production Site in the Periphery of Pacbitun, Belize. In An Archaeological Reconstruction of Ancient Maya Life at Pacbitun, Belize, edited by Terry G. Powis, Sheldon Skaggs, and George J. Micheletti, pp. 159-174. BAR Publishing Series, Oxford.

Spenard, Jon
2023 Initial Observations of the NCALM Belize 2022 LiDAR Campaign Aerial Survey of the Mountain Pine Ridge. In Report on the Third Field Season of the Rio Frio Regional Archaeological Project (RiFRAP) (June-July 2022, January 2023), edited by Jon Spenard, pp. 55-64. Report Submitted to the Institute of Archaeology, and Forest Department, Belmopan, Belize.

Spenard, Jon
2024 Rio Frio Regional Archaeological Project (RiFRAP): Report on the Fourth (2023) Field Season. Report Submitted to the Institute of Archaeology, and Forest Department, Belmopan, Belize.

Spenard, Jon, Michael J. Mirro, and Javier Mai
2023 Ancient Maya Archaeology of the Mountain Pine Ridge Forest Reserve. Research Reports in Belizean Archaeology 18:313-326.

Spenard, Jon, Michael J. Mirro, Javier Mai, Konane Martinez, Moses Flores, Mikaela Weber, Andres Berdeja, et al.
2025 An Introduction to the Ancient Maya Granitic Rock Workshops of the Mountain Pine Ridge Forest Reserve, Belize. Ancient Mesoamerica, in press.

Thompson, J. Eric S.
1938 Reconnaissance and Excavation in British Honduras. In Carnegie Institute of Washington Year Book No. 37, Annual Report of the Division of Historical Research, pp. 152-153, Washington, D.C.

Thompson, J. Eric S.
1939 Excavations at San Jose, British Honduras: With an Appendix by Anna O. Shepard. Carnegie Institution of Washington Publication No. 506, Washington, D.C.

Thompson, J. Eric S.
1942 Late Ceramic Horizons at Benque Viejo, British Honduras with notes: Classification of the Painted Wares by Anna O. Shepard. Contributions to American Anthropology and History, Volume 7, No. 35. Carnegie Institution of Washington, Washington, D.C.

Thompson, J. Eric S.
1990 Maya History and Religion. Reprinted. University of Oklahoma Press, Norman.

Tibbits, Tawny
2016 Geochemical Sourcing of Granite Ground Stone Tools from Belize Ph.D., unpublished Ph.D. dissertation, Department of Earth and Environmental Sciences, The University of Iowa.

Tibbits, Tawny L.B., Meaghan M. Perumäki-Brown, Marieka Brouwer Burg, Matthew A. Tibbits, and Eleanor Harrison-Buck
2023 Using X-ray Fluorescence to Examine Ancient Maya Granite Ground Stone in Belize. Geoarchaeology: 38(2):156-173.

Weyl, Richard
1980 Geology of Central America. Second ed. Gebrüder Borntraeger, Berlin.

Willey, Gordon R., William R. Bullard Jr., John B. Glass, and James C. Gifford
1965 Prehistoric Maya Settlements in the Belize Valley. Papers of the Peabody Museum of Archaeology and Ethnology 54. Harvard University, Cambridge.