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Querying Quarries: Stone Extraction Practices and Socioeconomic Organization in Three Sub-Regions of the Maya Lowlands

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ABSTRACT
Stone raw material in the past was often extracted, processed, and used by different individuals. The relationships among these practices make quarries important spaces for understanding how economic interactions function within society and what role access to resources plays in economic organization. This paper addresses the acquisition of raw materials through a focus on chert and limestone quarrying practices in the Maya area. Using three Classic period (200–950 A.D.) case studies from different sub-regions of the Maya lowlands, we highlight both shared and distinct practices and illustrate the roles that these extraction spaces played within Classic Maya economies. We find that heterogeneous aspects of quarrying techniques throughout the Maya lowlands result from variability in local geologic conditions, management structures, and the intended uses of the raw materials. As a result, this paper establishes methods for archaeologists to integrate quarries into their studies of past economies and anthropogenic landscapes.

KEYWORDS
quarry; limestone; chert; Mesoamerica; socioeconomies

Introduction

Objects and features, over the course of their use-lives, present considerable economic variability. Recent research in the Maya area has attributed these value changes to the production process where, with the addition of skilled labor and ritual modes of production, the value of raw material generally increases (e.g., Appadurai 1986; Graeber 2001; Kovacevich and Callaghan 2014; Mathews and Guderjan 2017). As such, access to and the exchange of extracted raw material —be it stone, clay, or other resources—in pre-Colonial Maya society intersected multiple economic spheres and scales of negotiation. Stone, for instance, was often extracted, processed, and used by different individuals, with each step representing a key point for economic interaction. Although scholars have evaluated the organization of labor and exchange mechanisms for the production and use of raw materials, the extraction locales or quarries themselves remain relatively understudied. Investigations within quarries offer a deeper understanding of the economic activities and political interests that guided non-renewable resource management within Classic Maya society, as well as specific extraction techniques. Due to the variability in a raw material's characteristics and frequency, quarries were, at times, controlled and integrated into local political economies. Discrete source areas, for example, allowed for greater restriction of access; however, when sources extended over large areas, they presented challenges. These distinctions—in quarry locations and management strategies—informed how populations extracted and exchanged resources and to what extent these actions and spaces were integrated into the political economy.

The organization of Classic Maya political economies continues to be a source of debate. Although socioeconomic studies have long been anchored to forms of elite political power during the Classic period (200–950 A.D.), scholars now recognize diversity among political systems (e.g., Aoyama 2001; Golden and Scherer 2013; Houston et al. 2003; Martin and Grube 2008). Specifically, degrees of economic centralization and decentralization varied from community to community, as well as between sub-regions (Masson 2020). Researchers have demonstrated that, in certain circumstances, rulers and elites managed some economic resources used for ritual, as well as day-to-day activities, such as jadeite, clay, or limestone (e.g., Andrieu, Rodas, and Lujan 2014; Houston and Stuart 1996; Kovacevich 2013); however, they were in no way monolithic in their management (e.g., Andrieu 2020; Horowitz, Canuto, and Andrieu 2020; Inomata and Triadan 2000; Taube, Hruby, and Romero 2011). Emerging views of Classic Maya economies frame them as arenas where householders were both autonomous and interdependent (Masson 2020), able to engage in multi-crafting strategies and marketplace exchanges while also entangled in tribute agreements and requisite labor and resource offerings. In some cases, stone extraction and processing may have been organized from the bottom-up or overseen by specialized professional groups such as guilds or communities of practice decoupled from centralized political or elite control. The variation in management and organization of quarries in the Maya region echoes the types of organizational frameworks identified in quarry studies in other regions (e.g., Cantarutti 2013; Cobb 2000; Harrell and Storemyr 2009; Heldal 2009). As spaces that support the entrepreneurial activities of households and state-sponsored projects, quarries offer an important lens through which we may evaluate the roles that individuals and households, both elite and non-elite, played in the extraction, circulation, and exchange of raw materials, contributing a holistic and inclusive understanding of Classic Maya political economies.

In this paper, we address the acquisition of chert and limestone raw materials through a focus on quarrying

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practices in the Maya area during the Classic period (Table 1). Following an introduction to the geology of the Maya lowlands, as well as the value systems applied to and the ritual significance of chert and limestone resources, we briefly summarize previous work on quarries within Mesoamerica. In addition, we contribute common feature descriptions and updated definitions for quarry-related terms to establish a foundation for updating comparisons of stone resource extraction systems between different sub-regions of the Maya lowlands, as well as with other societies around the world. To that end, we offer three case studies from different sub-regions of the Maya lowlands: the northern lowlands, northern Guatemala, and western Belize (Figure 1). These case studies highlight both the shared and distinctive extraction practices within quarries, as well as illustrate the role that these extractive spaces played within Classic Maya socioeconomies. Variations in quarrying practices and techniques point to the involvement of different actors working on distinct processing stages and within the various economic spheres in which quarried materials circulated. Ultimately, we find that heterogeneous aspects of quarrying techniques result from variability in the intended uses of the raw materials, local geologic conditions, and management structures for quarrying activities. Situating our case studies within the broader context of both quarry studies and Maya culture history, this article establishes the role of quarries in the past, their significance to different actors over time, and the diverse ways that quarries can inform our present studies of ancient economies and anthropogenic landscapes. The recognition that quarrying processes and organization frameworks varied widely within what is too often glossed as the "Maya area" contributes to a growing corpus of more nuanced studies of resource extraction variability within large geographic areas designated as culture regions elsewhere in Mesoamerica and further abroad.

Geology of the Maya Lowlands

The bedrock of the Maya lowlands is composed mainly of limestone beds, which exhibit a wide variety of grades and types resulting from an array of diagenetic and weathering processes. Limestone deposits range from Cretaceous to Quaternary in age and include both karstic and alluvial features (Espinosa, Ceron, and Sulub 1998; Gondwe et al. 2010, 3; Smith 1998; Ward 1985). Young Quaternary stone deposits are soft and friable, whereas older limestones from the Miocene or Pliocene are denser. Importantly, these traits directly influenced the uses of the extracted resources (Carmean, McAnany, and Sabloff 2011, 147) as well as informed perceptions of the source's value (Smith 1998). Indeed, ethnographic studies illustrate a profound understanding of these particulars today. For example, in the Puuc region of the Yucatan, potters in the 1960s were able to identify twenty different types and grades of limestone within their local extraction area (Seligson 2016). Emic categories such as *chac tunich* (red stone) and *tok' tunich* (hard/flint stone) show that understandings of stone variability are inextricably linked to quarrying practices, informing decisions to use specific materials for specific tasks (Carmean, McAnany, and Sabloff 2011; Halperin and Garrido 2020; Ruiz 1985; Seligson et al. 2017).

Table 1. Pre-colonial chronology of the Maya lowlands.

Period	Years
Late Middle Preclassic	600–300 B.C.
Late Preclassic	300 B.C.–200 A.D.
Early Classic	200–550 A.D.
Late Classic	550–800 A.D.
Terminal Classic	800–950 A.D.
Postclassic	950–1500 A.D.

It is likely that past populations in the Maya lowlands also discerned differences inherent in their surrounding limestone resources. Ethnographic records (Brady and Ashmore 1999; Brown 2005; Bullard 1963; Wisdom 1940, 428) indicate that relationships with specific stone resource locales were ritually significant (Kintz 1990; Vogt 1969; Woodfill 2019) and often perceived as animate (e.g., Houston 2014, 88–92; Stuart 2010, 286), leading others to suggest that stone extraction, which involves cutting into and extracting segments of the animate earth, would have been imbued with ritual significance (Clarke 2020). The location of extraction may have also contributed to the significance of finished products. Functioning as literal extensions of a living landscape, quarried limestone blocks contributed to constructed and embodied meanings within the built environment (Clarke 2020).

The diversity of limestone grades can be grouped into four broad compositional categories that are generally correlated with different functions (Espinosa, Ceron, and Sulub 1998; Ruiz 1985). The bedded thickness of each limestone grade varies across the lowlands, as well as within relatively small areas (Woods and Titmus 1996, 482). The first category includes densely consolidated hard limestone, which was often used for monuments and architecture (Brennan et al. 2013; Morris, Charlot, and Morris 1931; Ruiz 1985; Sapper 1896, 492). Carmean, McAnany, and Sabloff's (2011) analysis of architectural limestone use in the Puuc demonstrated that the finest grades were employed in exterior facades, while lesser grades were used as fill. The second category includes especially hard re-crystallized limestone varieties, which have the appearance of marble and were prized for their capacity to be shaped. For instance, Ulua marble from western Honduras was used to make decorative vases, among other luxury items (Luke and Tykot 2007; Luke, Tykot, and Scott 2006). Some of the older, silicified limestones are also useful in the production of flaked stone tools (Horowitz et al. 2019). The third category of limestone is *sascab* (or *sah cab*, "white earth")—a softer, chalky limestone marl with a high clay content that was used primarily as architectural fill (Brennan et al. 2013; Folan 1978; Ruiz 1985, 423). The fourth category includes a range of more loosely-consolidated limestone types, often glossed as *coquina*, which are used as fill or foundation braces for perishable structures or can be crushed for use in earthen or non-plastered floors (Barba Pingarrón and Villaseñor Alonso 2013; Brennan et al. 2013; Hansen 2000). Coquina can range from softer, less concentrated varieties to harder, more compacted varieties. Some researchers distinguish a fifth category, known as oolitic limestone, which is composed of tiny spheres cemented together (Ruiz 1985).

An additional variable characteristic of limestone concerns the frequency of other types of stone resources embedded within the limestone bedrock matrix, most notably chert. One of the most common materials for making flaked stone tools in the Maya lowlands, chert is a fine-grained silica precipitate that forms within the parent

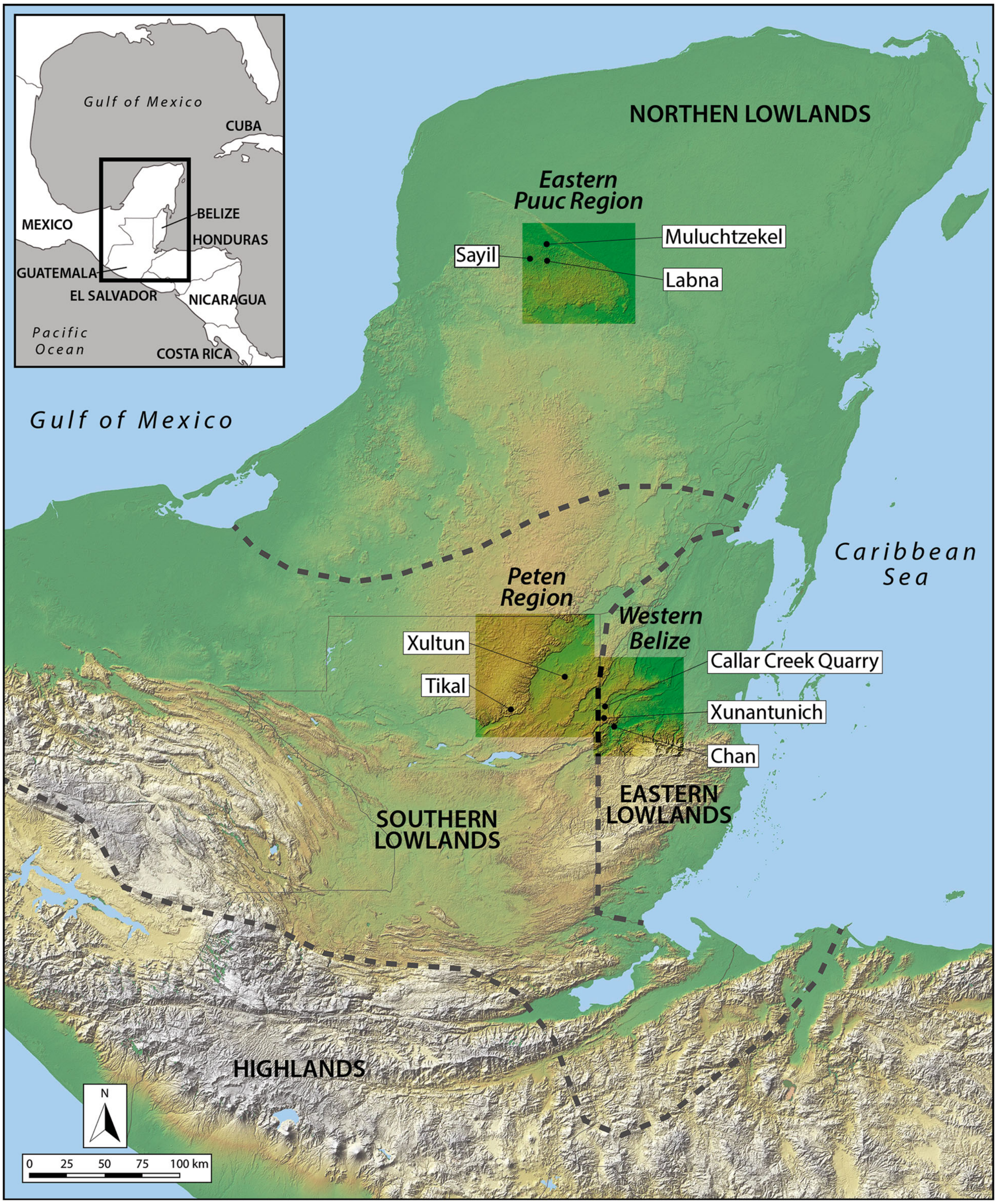

Figure 1. Map of the Maya area, highlighting sites mentioned in text. Map by M. Clarke.

limestone bedrock. Chert formation is impacted by that of the surrounding limestone, which in turn determines how chert is extracted and used. Although investigations of chert quarrying practices are lacking, there is a robust literature that attests to the uneven distribution of chert resources in the Maya area. For example, the northern Yucatan is almost devoid of chert (Dahlin et al. 2011; Hearth and Fedick 2011), although small nodules (Anderson 2011, 310) and possible chert workshops have been reported in the Puuc (Potter 1993, 288–290) and at Mayapan (Masson et al. 2016, 245). Further south in the Maya lowlands, chert appears in varying quantities and qualities. Areas such as the Northern Belize Chert Bearing Zone (NBCBZ) have large deposits of high-quality chert (Hester and Shafer 1984, 1991; Shafer and Hester 1983). Meanwhile, chert is found in additional primary deposits throughout Belize, particularly beds of chert (Barrett 2004, 2011; Horowitz 2017; VandenBosch 1999) and in secondary deposits resulting from erosion and fluvial action (e.g., Yaeger 2000). The Peten region, in comparison, has spotty access. Most chert resources appear in pockets within the karstic limestone bedrock and were likely extracted through intentional quarrying or were recovered during limestone quarrying (Hansen 2016, 355; Kwoka 2014; Woods and Titmus 1996).

Previous Studies of Limestone and Chert Quarries

Quarry studies in Mesoamerica have contributed important information regarding the socioeconomic and political importance of raw material resource extraction, processing, and distribution (e.g., Kovacevich 2013; Kwoka 2014; Pastrana 2002) (Supplemental Material 1). For example, G. Braswell (1996) identified non-standardized production activities at the San Martín Jilotepeque obsidian source, concluding that independent producers extracted, produced, and exchanged obsidian outside the purview of a centralized authority. Similarly, studies of jadeite suggest that although quarrying jade was an independent activity, the subsequent production and distribution of the extracted resources was controlled by elites and/or centralized authorities (Andrieu, Rodas, and Lujan 2014; Kovacevich 2013; Rochette 2014; Taube, Hruby, and Romero 2011). Studies of chert quarries have yielded similar results. In northern Belize, Barrett (2011) examined chert extraction and found that raw material access was controlled by elites. Studies in western Belize, in contrast, suggest a more decentralized access, where local producers managed chert materials (Horowitz 2017, 2018a; VandenBosch 1999). The quality of the chert also impacted socioeconomic organization and related exchange mechanisms. Northern Belize Chert Bearing Zone (NBCBZ) chert, for example, was widely distributed because of its quality (Hester and Shafer 1984, 1991; Shafer and Hester 1983). Despite the widespread distribution of NBCBZ tools, their production was decentralized (King 2000; Masson 2001; McAnany 1989). These examples indicate variability in chert management, perhaps a result of the availability and perceived quality of chert resources.

The widespread availability of limestone presents certain challenges to evaluating the socioeconomic dimensions of its extraction and processing. One way archaeologists have attempted to account for this dilemma, however, is through a consideration of quarry location. A large quantity of *sascaberas* (sascab extraction locales) have, for example, been identified alongside the internal causeways at Chichén Itzá, leading Cobos and Winemiller (2001, 285) to propose that the related quarrying practices were centrally administered. Likewise, at Mayapán, researchers identified large quarries close to the exterior of the city's walls (Russell 2015), indicating the important role that expediency played in deciding on quarry locations. Quarries located near constructed features are, therefore, seen as related (Folan 2014 [1983], 24); the extraction of one produced the construction of the other (e.g., Brewer 2018; Brewer et al. 2017; Bullard 1960; Scarborough 1983). This level of coordination suggests that resource extraction at these sites was organized alongside state projects that constructed or maintained an urban infrastructure. However, limestone quarries are not exclusive to urban centers. In the Río Bec nuclear zone, for example, quarries are so numerous and in such proximity to households that they take up surface area that would otherwise have been used for cultivation (Gillot 2014). These features and the associated labor were embedded within both state sponsored work and domestic economies.

Studies of access and extraction locations present evidence of exchange networks for limestone resources. At Chunchucmil, Dahlin and colleagues (2005; 2009, 351) found that only 20–25% of households had access to a sascabera and many were surrounded by small *albarradas* (walls), indicating that access to sascab was likely restricted and would have required intra-site exchange. The Chunchucmil example thus provides a possible example of household-level control over quarry zones and products. In the Petexbatún region of Guatemala, the Las Planchas limestone quarry yielded more material than was used locally (Beekman 1992, 99). Beekman (1992) argues for the export of the large cut blocks extracted from the quarry, due to an absence of neighboring settlements. Geochemical studies of limestone monuments at Maax Na, Belize also identified imported limestone (Brennan et al. 2013, 3190). Although the example from Maax Na illustrates that some limestone was integrated into the political economy, it remains unclear how other extracted limestone resources moved through exchange networks and to what extent extraction locations intersected with the various economic domains of Classic Maya society.

The inherent challenges in discerning access and management strategies for quarries have led some to question what exactly was being managed (e.g., Carmean 1991; Carmean, McAnany, and Sabloff 2011, 156). Specifically, was it the access to the resources or perhaps the labor needed to quarry and transport the extracted materials? The prevailing hypothesis for the organization of labor contributions is based on the French system of *corvée* labor (Abrams 1994, 100), wherein labor demands were coercive and rotated between or drafted from households or kin-groups. Evidence from Classic Maya ceremonial architecture and public work projects support this theory. For example, plaster at Piedras Negras varied in chemical composition among structures, reflecting, as Abrams and colleagues (2012, 1653) argue, the work and resource obligations of different groups. However, critics of the corvée hypothesis cite its inability to explain emic perceptions of resource or labor contributions (McCurdy 2016), as well as how such contributions aligned with the strategic aims of households (Clarke 2020). Labor and resource management schemes likely varied between different sub-regions of the Maya lowlands, as well as potentially within individual communities. To advance the study of labor and resource management, a greater understanding of resource extraction is needed. As we demonstrate in the following sections, this must begin with a clear terminology to facilitate comparisons across sites and regions. Through these comparisons, we present a unique dataset with which to evaluate socioeconomies.

Quarry Terminology

An evaluation of quarry studies makes it clear that a common terminology is necessary to standardize discussions of the economic significance of stone extraction and processing across regional boundaries. For example, "quarries" and "mines" are often discussed as interrelated concepts, with many scholars failing to differentiate between the two (e.g., Stocker and Cobean 1984, 83). The matter is further confused by the interchangeability of the verbs "to quarry" and "to mine" in the literature, with researchers referring to past Mesoamericans mining materials from quarries (e.g., Barba Pingarrón et al. 2009). We use the term quarrying to refer to extraction activities within features that are open to the surface. This includes both the removal of materials from surface deposits and the excavation of materials below surface level as long as the pit is open to the air. In contrast, we use mining to refer to the excavation of materials below the surface in an underground, covered area. In the

Figure 2. A partially collapsed subterranean sascabera at Kiuic. Image by K. Seligson.

Maya area, mines are often related to sascab extraction (Figure 2), though sascaberas may also be open to the surface (Folan 1978). Extracting materials from cave settings is therefore inherently mining, not quarrying (see Bloxam [2010] for a similar distinction for Egyptian mining and quarrying). Based on this distinction, most stone extraction locales in Mesoamerica should be considered quarries, although there are exceptions (e.g., Folan 1978; Pastrana 2002). The focus of this paper is the extraction of stone from quarries.

Classic Maya quarries come in a wide range of shapes and sizes resulting from variations in topography, raw material composition, and the techniques used for extraction. Previous attempts at categorization divided quarries into broad "horizontal" (Bullard 1960; Carr and Hazard 1986 [1961], 12; Gallegos Gomora 1994) and "vertical" (Beekman 1992; Kestle 2012; Morris, Charlot, and Morris 1931, 215) groups, but such terms are used differently by different researchers. We believe a more useful classification framework for inter-regional comparison eschews such broad categorizations in favor of more descriptive categories derived from topographical contexts and/or physical appearances. Table 2 is a brief outline of the several types of quarries thus far investigated in the Maya lowlands.

Extraction techniques may also be studied using tool marks preserved on, as well as within, quarry features (Table 3). Regular versus irregular scarring patterns can indicate whether quarrying was conducted in a systematic fashion. Irregular tool mark patterns may result partly from unevenness of stone grades within the bedrock matrix, but a holistic survey of individual quarries should indicate whether populations were continuously replicating the same extraction methods. Sharp discrepancies in extraction markings within one quarry may indicate either unsystematic expedient exploitation by different groups of extractors, different periods of quarry exploitation, the extraction of a resource for different purposes, or the use of different extraction tools. Prior studies have identified chert and limestone bifaces that would likely have been hafted to wooden handles, as well as hammerstones, chisels, and other tools (see Paling, Horowitz, and Clarke [2020] for a detailed discussion of quarry tools). Few tools are recovered in situ in quarry contexts (see Clarke [2020] for a summary of these finds), but here we discuss those that have been identified within our study areas.

The creation of a shared system of language around quarrying practice in Mesoamerica will help prevent confusion in future discussions of quarrying activities, as well as provide a common language with which to discuss these extraction techniques and quarrying methodologies. From this shared language, it becomes possible to compare the socioeconomic implications of extraction techniques across three subregions of the Maya lowlands.

Table 2. Types and definitions of quarry forms.

Descriptor	Definition	Material	Citations
Topographic Descriptors			
Hillside	quarries excavated into the slope of hills or ridges	Chert; Limestone	Barrett 2011; Braswell 1992, 1993, 1998; Church 1996; Keller 1993, 1997; Hester and Shafer 1984; Horowitz 2017; Meadows 2000
Outcrop	quarries excavated into the sides or on top of bedrock outcrops	Limestone	Beekman 1992; Ringle et al. 2018; Seligson and Ringle 2018
Planar	quarries excavated into relatively flat terrain	Limestone	
Form-Based Descriptors			
Gridded (or checkerboard)	rectangular blocks with narrow channels between them	Limestone	Clarke 2020; Gallegos Gomora 1994, 11–18; Hammond and Tourtellot 2003, 292; Ruiz 1985, 435; Titmus and Woods 2002, 189; Wernecke 2005, 18
Islands	isolated areas of raw material remaining from removal of surrounding materials	Chert; Limestone	Barrett 2004, 2011; Ruiz 1985, 433; Titmus and Woods 2002
Ledge (or Stepped)	quarries excavated into sloping terrain that take the form of a series of ledges or steps	Limestone	
Linear Straight Edge (or Zipper)	quarries exhibiting a zig-zag pattern of sheer faces	Chert; Limestone	Clarke 2020; Horowitz 2017; Ruane 2015
Pits (including sunken or open)	a broad category of quarries excavated downward into relatively flat terrain, forming a depression	Chert; Limestone	Barrett 2004; Brewer et al. 2017; Clarke 2020; Folan 1978, 2014 [1983]; Gallareta Negrón and May Ciau 2014; Horowitz 2017; Kestle 2012; Mejía 1999; Ringle et al. 2018; Sabloff and Tourtellot 1991; Yaeger 2000

Table 3. Markings indicative of quarry extraction techniques.

Tool Marks	Description	Citation
Vertical ribbing	Vertical scars	Carr and Hazard 1986 [1961], 12; Beekman 1992; Puleston 1971, 328; Titmus and Woods 2002; Woods and Titmus 1996, 481–482; Clarke 2020
Slots/half holes/ conical marks	Semicircular depressions, larger at the top	Carr and Hazard 1986 [1961], 12; Clarke 2020; Cook 1982, 185–187; 2014, 2, 53; Holmes 1895, 281; Nelson 1987, 123; Seligson and Ringle 2018
Channeling/ isolation trenches	Digging or cutting narrow trenches around blocks for extraction—may result in vertical ribbing	Gallegos Gomora 1994; Hammond and Tourtellot 2003, 292; Morley 1933, 201–203; Navarrete and Luján Muñoz 1963, 8, 63; Ruppert and Denison 1943, 9, 15; Villa Rojas 1934, 181–184; Woods and Titmus 1996, 481–482
Undermining or undercutting	Extraction continued beneath the stone block after the desired depth had been reached—may result in "tabs," "pegs," or "quarry stumps"	Gallegos Gomora 1994, 13; Hansen et al. 2018, 167; Holmes 1895; Morley 1933; Strómsvik 1942, 79, 92

Regional Quarry Case Studies

Case study 1: eastern Puuc region, northern lowlands

As in much of the Maya lowlands, the limestone bedrock of the eastern Puuc Region of the northern Yucatan provided an abundant source of construction materials for pre-Colonial Maya communities (see Figure 1). Archaeological surveys in the eastern Puuc have identified hundreds of quarry locations. During their 10 km^2 survey of the hinterlands between the Classic period sites of Labná and Kiuic, Tomás Gallareta Negrón and May Ciau (2014) found that nearly all of the hundreds of small residential compounds were associated with a sascabera or mixed sascabera/quarry. The larger quarries identified on the outskirts of population clusters were likely used by multiple households. The Sayíl Mapping Project (Sabloff and Tourtellot 1991) likewise identified many pit quarries and sascaberas. More recently, a 200 km^2-plus lidar flyover of the eastern Puuc (Ringle et al. 2021) revealed a landscape pockmarked with pit and ledge quarries and collapsed sascabera mines.

The largest individual quarries by volume and territorial extent are located close to site centers with monumental architecture. The Puuc bedrock matrix, which is generally older than other areas of the northern lowlands, tends to have relatively higher proportions of the compacted limestone desirable for the facades of elite structures (Carmean, McAnany, and Sabloff 2011). However, the finest grades are not evenly distributed across the landscape. It is thus possible that the siting of elite and civic architecture may have been at least partly based on the location of outcrops of the most desirable architectural stone (see also Hutson and Davies 2015). Larger quarries may have also served as temporary water reservoirs (Akpinar-Ferrand et al. 2012; Brewer 2018).

Several site centers in the eastern Puuc exhibit examples of hillsides transformed into multi-story structures, exemplified by the two-story palace at Labná (Ringle et al. 2021) and a three-story palace at Sayíl (Figure 3). The palace represents palimpsests of the stone industry chaîne opératoire, from extraction to finished product. Stone was quarried from the side of the hill, shaped into architectural blocks, and then fitted back together along with mortar and plaster likely derived from the hill quarry's stone. Although these represent extreme examples of limiting transportation costs, the proximity of quarries to buildings across the eastern Puuc reflects both the desire to limit transportation efforts and the widespread availability of architecturally viable stone resources.

Kaxnak quarry at Muluchtzekel

A lidar survey laid the foundation for a targeted investigation of a large hillside ledge quarry at the eastern Puuc site of Muluchtzekel by the third author (Seligson and Ringle 2018). Muluchtzekel is a large site with occupation levels dating from the Middle Preclassic through the Terminal Classic period (Figure 4). It is located on the border between the hilly Bolonchén District and flatter expanse of the Valley of Santa Elena and may have served as a trade hub between the two regions (Ringle et al. 2018).

The Kaxnak Quarry is in the southwestern sector of Muluchtzekel, close to the base of a low hill. Excavations revealed that the 50-plus m long quarry was excavated into a natural slope in the terrain as a series of three or four ledges at different points along its length. The ledges were approximately 1 m high and 2–4.5 m wide, with many running the full length of the quarry (Figure 5) (Seligson and Ringle 2018). The regularly stepped appearance of the ledges suggests that stone was extracted in a systematic fashion. However, due to the varied nature of the limestone bedrock at this quarry, the actual stones that were removed were irregularly shaped boulders averaging approximately 75 × 50 × 50 cm in size. These boulders would likely have been further reduced and shaped nearby either for use as facing stones or as fill in platform or wall construction. Unfortunately, no lithic tools were recovered from the excavations. An assortment of tiny chert, limestone, and quartz flakes (1.2–5.2 cm long) likely represent pieces of the flaked stone excavation tools which were removed during extraction episodes, either through extraction activities or tool retouching (Seligson and Ringle 2018).

The bedrock visible in the remaining ledges was dominated by chac tunich and tok' tunich (Seligson 2016; Seligson et al. 2017). Both types are found throughout the Maya lowlands in both hard surface caprock layers and deeper foundational bedrock layers. The reddish/pinkish hue of chac tunich results from higher levels of iron and usually makes it less desirable for architectural facings, though there are notable exceptions. Tok' tunich would have been a preferable source of architectural stone partly for its durability and partly because it could not be transformed into burnt lime and would have been more difficult to break down into fill. The ubiquity of chac and tok' tunich throughout the Kaxnak quarry suggests that these were the two main grades extracted, though it is also possible that other types of limestone were dominant in the sections that had already been quarried away.

In addition to the consistency of the ledges extending the length of the quarry, another indication that stone extraction

Figure 3. The three-story palace of Sayil, built into and on top of a low hill. Image by K. Seligson.

was completed in a systematic manner was the identification of small notches in the edges of the tiers. These markings represent the locations where laborers used small stone (most likely chert) points to chip or drill holes into which they could insert wooden stakes to pry the irregular boulders away from the matrix. The notches averaged 4 cm wide, were spaced approximately 15 cm apart, and appeared in groups of four or five. In one instance, semi-circular notches from a tier edge could be matched with semi-circular notches on an irregularly-shaped boulder that had been removed from that ledge but was then left in situ. The fact that boulders were left in situ suggests that the quarry was in use at the time of Muluchtzekel's final abandonment, which likely occurred during the early 10th century A.D. (Seligson and Ringle 2018).

Models for stone industry management in the Puuc

Despite a lack of investigations specifically about quarries and stone extraction mechanisms, the relatively high frequency of vaulted and masonry architecture in the Puuc suggests that the limestone industry played an important in the local economy (Carmean, McAnany, and Sabloff 2011; Ringle et al. 2018; Ringle, Gallareta Negrón, and Bey 2020). The scattered distribution of quarries around sites like Labná, Kiuic, Sayíl, and Muluchtzekel would suggest on its face a largely decentralized limestone extraction and processing industry. However, the dispersed patterning of the quarries may merely represent the naturally dispersed distribution of quality limestone outcrops, and it is still possible that central authorities controlled access to higher quality sources.

Carmean, McAnany, and Sabloff's (2011) study of limestone at Sayíl raises the possibility that control over patches of desirable grades of limestone may have served as a source of economic wealth, similar to control over prime agricultural lands. They suggest that control of such prized limestone locales may have likewise been established through a founders' priority framework. Ethnohistoric literature from the northern Yucatán suggests that land tenure systems were largely based on ancestral lineage-based inheritance (McAnany 1995, 1998). Although the texts focus on managed forests and farmlands, such ancestral plots would presumably also include control over the underlying bedrock resources. Studies at Cobá (Folan 1982) and the Santa Amelia region of Guatemala (Beekman 1992) suggest that the more widely available sascab would have been communally owned, while more restricted, higher quality architectural stone may have been privately owned.

Although community members may have had broader access to a wide range of limestone grades, control over quarries with truly prime construction-grade limestone may have been a means by which high-status households bolstered their economic and political power. In this quarry-control model, elite households, and possibly central authorities, managed the limestone industry and generated wealth through control over access to extraction locations. Kin-based and co-residential obligations may have formed the backbone of the actual limestone quarrying and processing activities (see Hutson and Davies 2015), but extra-household labor groups would have been assembled for large construction projects. However, this model is predicated on the existence of sizable stretches of uniform, high-quality limestone —a circumstance that may in fact be quite rare.

An alternative model (Ringle, Gallareta Negrón, and Bey 2020) focuses instead on control over labor as the key point of intervention in the limestone industry. In this model, central authorities restricted access to the extraction and/or construction process itself and thus the ability to create tangible expressions of status through control over work or tribute obligations. The frequency of masonry architecture in the Puuc region therefore reflects a sumptuary system in which house sizes and decorations were mediated by broader considerations of rank and family that may well have involved high-ranking permissions. The actual quarrying and

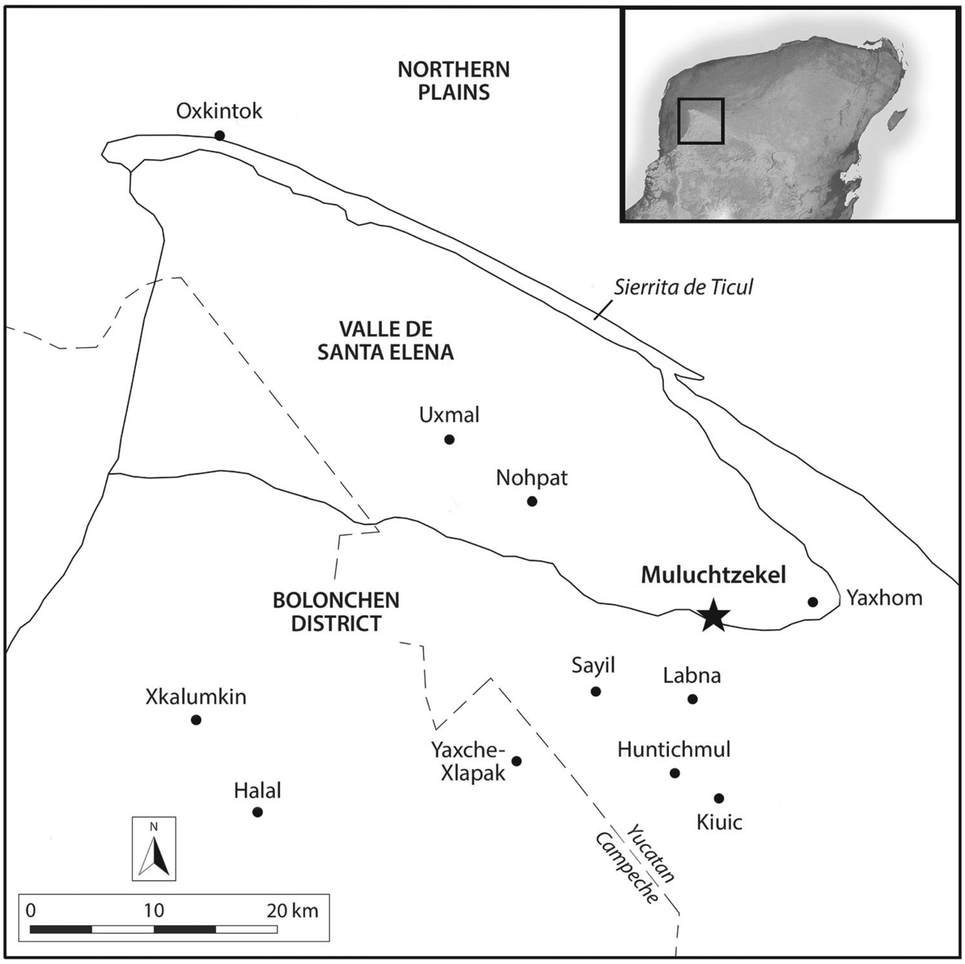

Figure 4. Map of eastern Puuc showing the location of Muluchtzekel. Map by K. Seligson.

processing work would most likely have been completed by conscripted labor gangs periodically assigned to quarries. In this model, limestone architecture would have been a means for converting foodstuffs into more durable wealth, providing an avenue for central authorities to grow the local economy (Ringle, Gallareta Negrón, and Bey 2020).

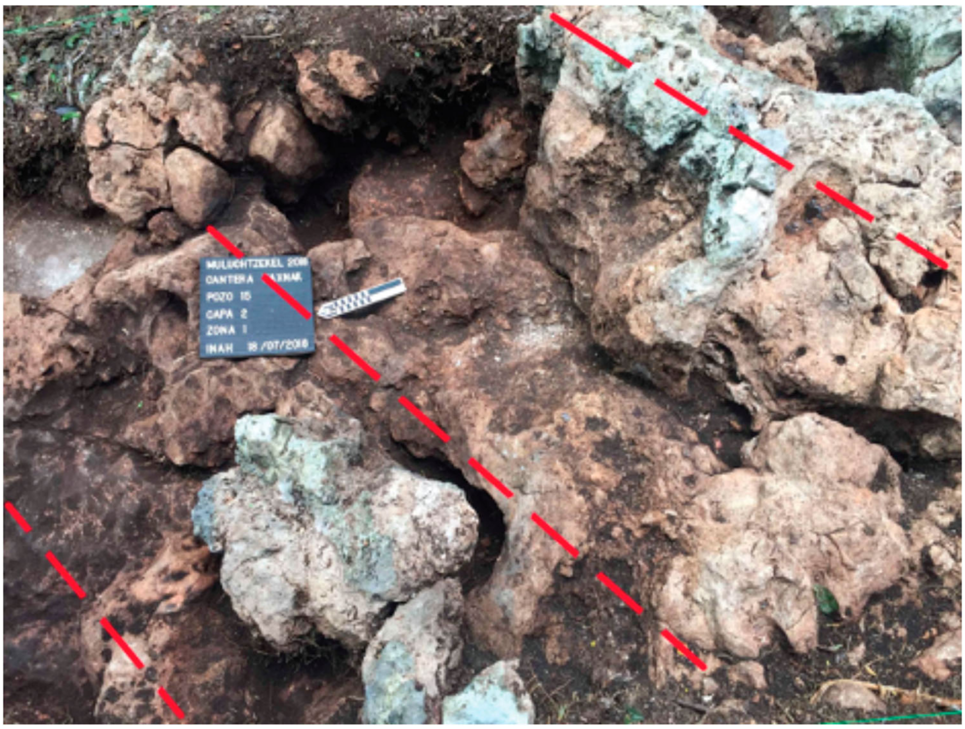

Figure 5. Photograph of Kaxnak quarry with dotted red lines indicating the edges of three of the excavated tiers. Image by K. Seligson.

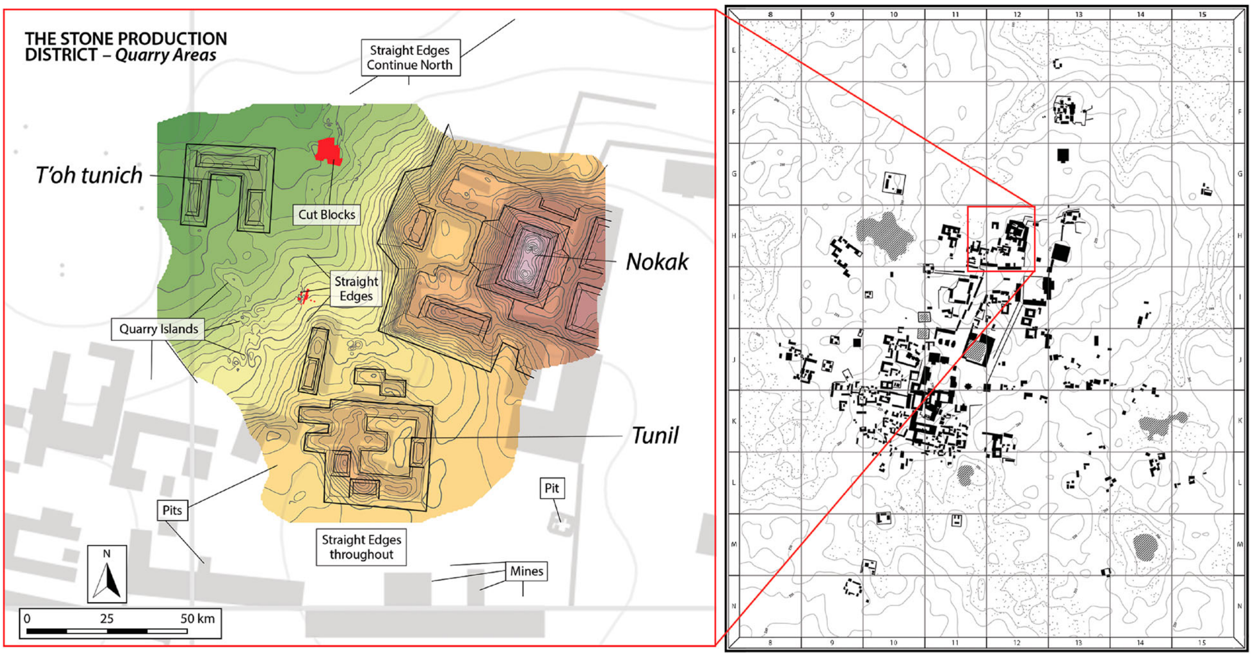

Figure 6. Map showing the location of the stone district within Xultun. Map by M. Clarke.

Case study 2: the Petén region, northern Guatemala

The Petén region of the Maya lowlands encompasses many Classic Maya urban centers (see Figure 1). One trait shared among them is the volume of limestone used to construct their ceremonial architecture. The process of this resource's extraction resulted in an extensively modified landscape, a process perhaps best indicated by the large depressions adjacent to monumental architecture where much of the construction materials were acquired. These features were not, however, left idle; they were reused as reservoirs and integrated into complex hydraulic water catchment and purification systems. As Scarborough (1998, 139) explains, "the location of quarry fill and the depression that resulted [was] a deliberate act, possibly as important to the built environment as the pyramids themselves." Further reuse is seen in the foundations of plazas and patios which were leveled, as well as irregularly cut bedrock which was encompassed into constructions, in some cases functioning as house platforms. This landscape modification illustrates a level of coordination in city planning and civic engineering, as well as a flexible approach to reusing extraction locales.

Despite the propensity towards reuse, site surveys in the Petén region have located countless quarry features. During their work at Tikal, for example, Carr and Hazard (1986 [1961], 12) found that limestone quarries were "virtually everywhere," and their feature descriptions (e.g., vertical ribbing, conical half-holes, quarry islands, straight edges, and zigzag) have been instrumental in establishing our proposed terminology (see Tables 2, 3). At the site of Nakbe, similar quarry features were identified by Titmus and Woods (2002, 189). These scholars investigated a gridded quarry where they documented the process of limestone extraction. Through a method termed channeling, approximately seven parallel rows of limestone sections (52 cm in width) were subdivided into quadrangular and triangular block segments. Not unique to Nakbe, these features are located, more often than not, within the ceremonial core and immediate periphery of Classic Maya centers in the northern lowlands (Clarke 2020; Gallegos Gomora 1994, 11–18; Hammond and Tourtellot 2003, 292; Ruiz 1985, 435; Titmus and Woods 2002, 189). With the growing number of lidar studies in the Petén (e.g., Canuto et al. 2018; Garrison, Houston O, and Firpi 2019), our knowledge of their distribution will certainly become more resolved. The on-site location of large-volume limestone quarries at urban centers within the Petén suggests a centralized system of management, as does the presumed use of extracted resources; however, this has yet to be framed as a hypothesis and tested.

Limestone production at Xultun, Guatemala

Akin to other urban centers within the Petén, surveys conducted at Xultun identified various quarry features. Garrison (2007, 166) located chert and limestone quarries during his extensive intersite survey of Xultun's periphery, with select chert features excavated by Kwoka and Griffin (2005; see also Kwoka 2014, 88). A total of 22 individual limestone quarries with a combined total area of 10,345 m^2 were later added to the map of Xultun's urban center (Ruane 2015). The low volume of extraction, as well as proximity to residential architecture, suggests small-scale use by the surrounding households (Ruane 2015, 123–124). In addition to these dispersed quarries, Xultun also contains a large (13,894 m^2), centrally located quarry district, referred to here as a Stone Production District (Figure 6; Clarke 2020). With over 50 distinct features, as well as residential and administrative architectural complexes, recent investigations of this district's production and domestic contexts offer an opportunity to evaluate a localized organization scheme for limestone extraction at Xultun from a bottom-up perspective.

Stone extraction features including linear straight edges, pits, islands, and gridded quarries are found throughout Xultun's Stone Production District. Similar types of features occur in clusters: mines are located at the northern- and southernmost limits, pits and linear straight edges are in the south, islands are in the west, and gridded quarries

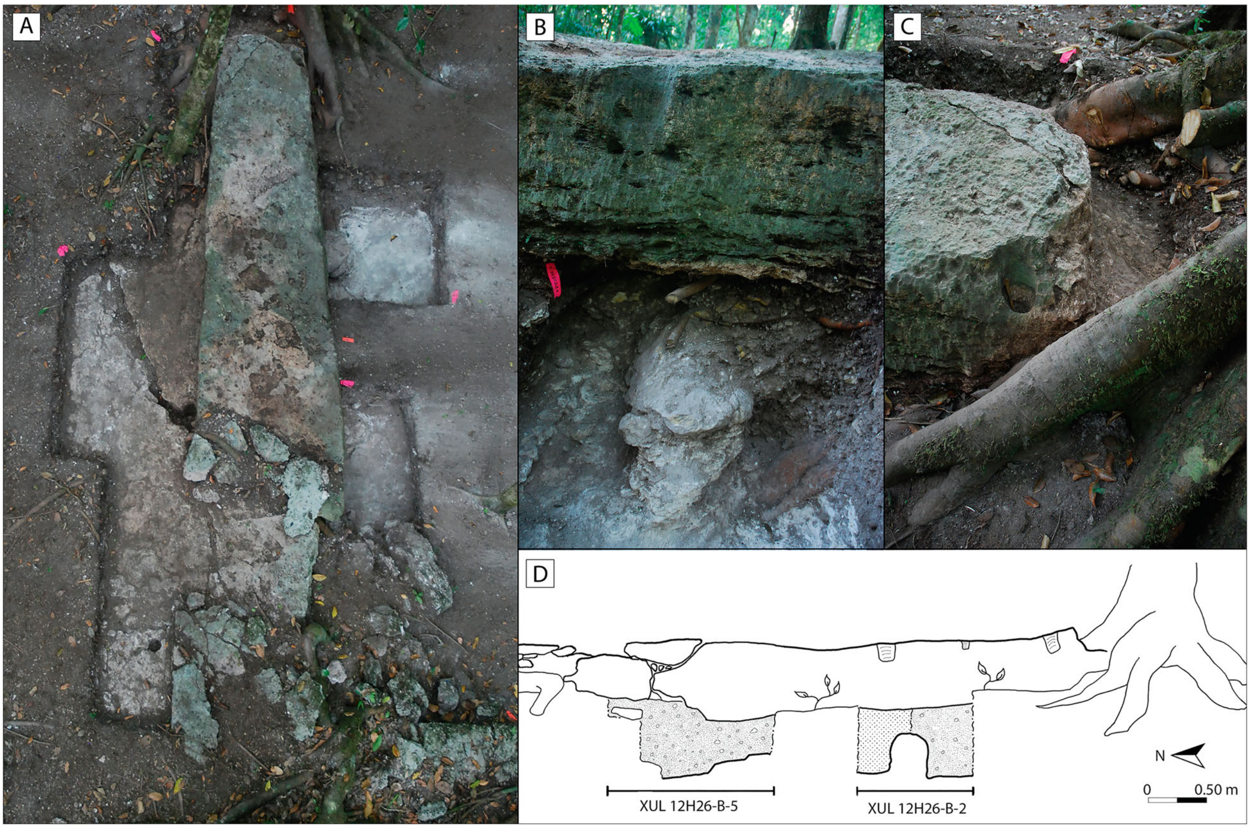

Figure 7. Image of a zipper quarry from Xultun where A) is an aerial image (photo by Henry Vicente Perez, 2016), B) illustrates the process of undercutting, as well as a drill hole in profile (photo by Rachel Gill, 2016), C) depicts the process of shaping the spiga through both drilling and grinding methods (photo by Rachel Gill, 2016), and D) is a profile illustration showing the distribution and spacing of drill holes on the exposed quarry face (illustration by Rachel Gill, Emmette Nahil, and Mary Clarke, 2016).

are in the north. Linear straight edge or zipper quarries are the most common type where evidence of production is present on both the horizontal and vertical surfaces (Figure 7). In contrast to pit quarries, extraction from the linear straight edges created consistent and diagnostic marks: inverted, conical shapes, referred to here as drill holes, are located along the top of the exposed edge with a depth of approximately 0.20–0.30 m. Complete drill holes are infrequent and are instead found halved, viewed in profile along linear straight edge features or quarry islands. The dimensions of the extracted segments are best noted in the zipper formations, which suggest elongated rectangular blocks were quarried (4.85 m × 0.46 m × 0.84 m). In one example, the feature appears to include a monumental stela partially quarried from the surrounding bedrock. Drill holes were placed along the perimeter of the designated stone section, after which the surrounding limestone was cut away (see also Clarke 2020).

Quarry features indicating extraction of cut blocks for masonry architecture were also noted. Among the islands studied, cut edges exhibit non-patterned methods of extraction in the form of irregular sizes, angles of cuts, and quarry edges. This variability may correlate with low-demand, decentralized, and/or intermittent/repair projects. It may also reflect an output of smaller facing stones employed in vernacular architecture, akin to that of the surrounding residential groups. The size and volume of extracted blocks significantly increase when looking at gridded features. One such feature at Xultun exhibits a sequence of squared limestone blocks of roughly equal dimensions (1.50–1.75 m in both length and width) separated by narrow channels (0.15–0.25 m in width) (Figure 8). The uniform sides and large scale of this feature suggests extraction by an organized group of multiple individuals. An associated lithic assemblage (predominantly elongate thick bifaces) was recovered within the channels or isolation trenches of a gridded feature. A distinct pattern of scarring resulted from this extraction, as did an absence of conical drill holes. These observations suggest discrete extraction methods determined by the intended use of quarried resources.

Socioeconomic organization of limestone extraction at Xultun

Researchers identified multiple residential groups within Xultun's Stone Production District. Excavations directed by Clarke (2020) focused on three in particular: the Nokak, Tunil, and T'oh Tunich groups. While both the Tunil and T'oh tunich groups are comparable in their overall constructed volume to most centrally located groups at Xultun, the Nokak group is one of three palatial administrative complexes at the site (Ruane 2015, 117). To determine the relationship between households and quarry contexts, Clarke (2020, 224–244) examined the distribution of limestone production tools, the definitions of which were based on macro- and micro-wear analyses (e.g., Aldenderfer, Kimball, and Sievert 1989; Aoyama 2001; Holmes 1895; Robles Garcia 1994; Stemp, Helmke, and Awe 2010; Woods and Titmus 1996). A site-wide analysis of tool distribution indicated that the Stone Production District presents a centralized area of limestone production and that the Nokak and T'oh tunich households were directly engaged in limestone

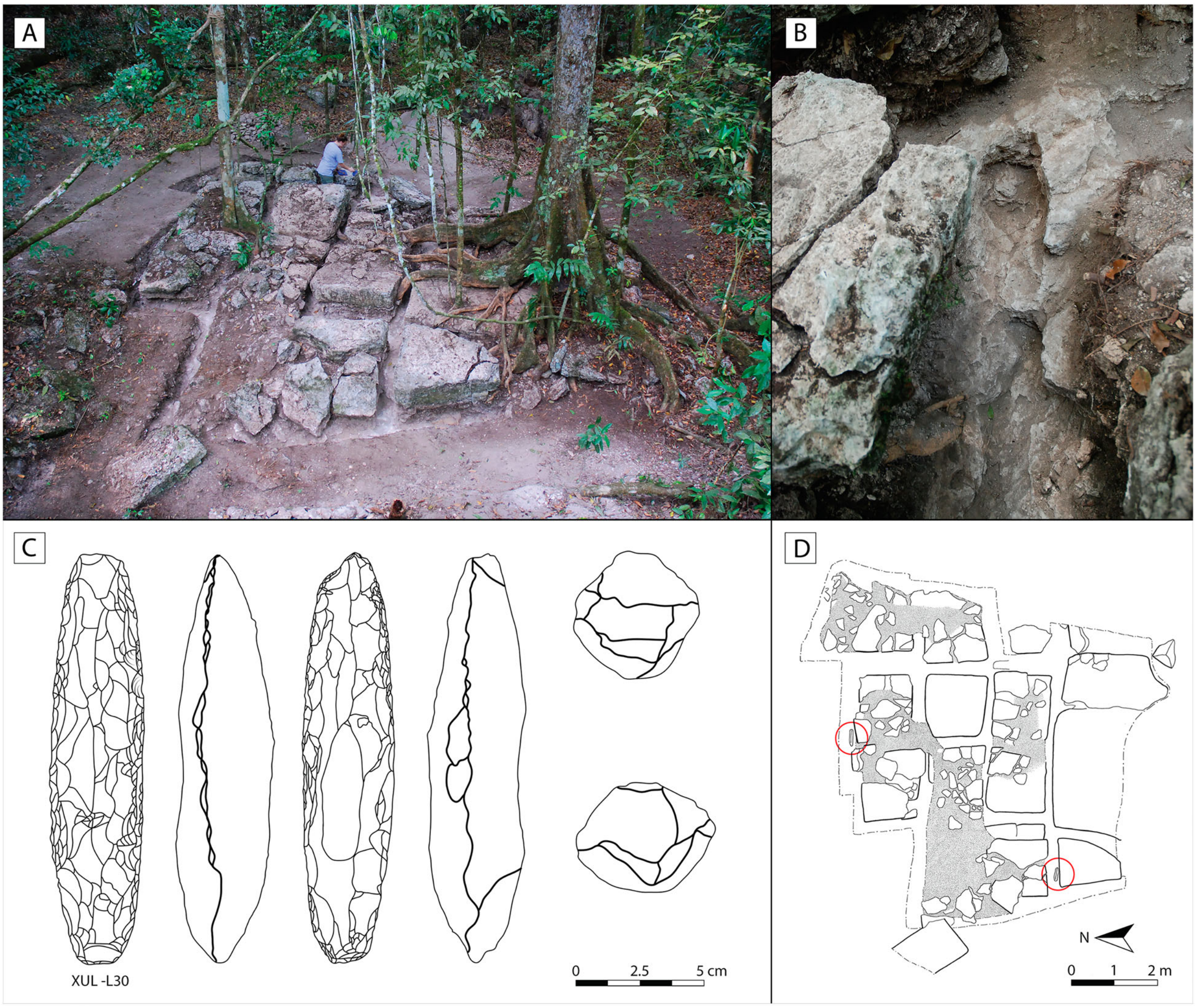

Figure 8. Images of a cut block feature from Xultun where A) is an aerial image (photo by Henry Vicente Perez, 2016), B) illustrates the process of channeling, as well as the scars left behind within the cut channels (photo by Mary Clarke, 2016), C) depicts the Elongate bifaces recovered within channels (illustration by Antonieta Cajas, 2019), and D) is a plan illustration of the feature indicating the locations of the quarry scars and tool recovery (illustration by Rachel Gill, Emmette Nahil, and Mary Clarke, 2016).

production (Clarke 2020, 273–265). Variability within household lithic assemblages suggests specific roles in production, as well as a relationship between producer households. For example, the T'oh tunich household drilled, quarried, cut, and shaped stone, whereas the Nokak household cut, shaped, and polished stone (Clarke 2020, 266–288). Their different, yet complementary, work implies coordination, which could be founded in social- or experience-based distinctions.

The economic underpinnings of producer households were also evaluated through an analysis of their provisioning strategies. Citing the exchange networks of 94 resource varieties between five Xultun households, Clarke (2020, 349–358) concluded that the Nokak household, which stored the state's surplus wealth and controlled its circulation and conversion through Xultun's marketplace, was not directly supporting the T'oh tunich household. After determining the scale of multi-crafting to be low and likely associated with other members of the T'oh tunich household, it became apparent that the primary mode of household provisioning was through the extraction, production, and exchange of limestone. Specifically, limestone extraction was the economic specialization of this household, and it was through the exchange of these resources within Xultun's marketplace that they provisioned themselves. This view of economic specialization and decentralized management within a centrally located limestone quarry suggests that top-down management was not through direct control, be it of a household's labor or extracted output. Contributions to monumental projects often sponsored by the state, as this evidence suggests, were otherwise managed.

Limestone work within Xultun's Stone Production District presents evidence that specialist households engaged in both independent and state output. These observations have a few significant implications. First, labor and resource contributions to monumental projects were not economically motivated, providing support for the use of rotational systems of service whereby both labor and resource tributes were organized. Second, not all extraction of limestone resources within the center of Xultun was centrally controlled. Households were able to extract limestone from the surrounding quarries in low volumes using non-systematic modes of extraction that reflected coordinated group labor. This decentralized approach to resource management within centrally located quarries makes it likely that other strategies, such as esoteric knowledge, ritual protocols, and access to labor, among others, were deployed to manage limestone resources or motivate household participation in their collaborative production. Lastly, extracted limestone resources appear to have been exchanged through a marketplace economy. Households could, therefore, directly profit from the extraction and production of quarried and cut limestone, suggesting that limestone resources were, to some degree, commercialized at Xultun. These results present a nuanced picture of resource management, one that eschews broad constructs of controlled access based on proximity alone. Instead, it highlights the socially and culturally embedded nature of limestone within society and the locally construed means through which outward expressions of identity, particularly those conveyed through limestone, were managed.

Case study 3: western Belize

The upper Belize River Valley (UBRV) of Western Belize presents a unique opportunity to examine aspects of quarrying, due to the quantity of research performed in the area. The Belize River Valley (see Figure 1) is defined by the Macal, Mopán, and Belize Rivers and is divided into the upper and central valleys. The upper Belize River Valley is the hilly region to the west of the confluence of the Macal and Mopan Rivers (Figure 9; Chase and Garber 2004). Although limestone quarries are frequently mentioned in the archaeological literature of the valley, particularly in association with large architecture, (e.g., Braswell 1998; Church 1996; Keller 1993, 2006; Kestle 2012; McCurdy 2016), relatively few have been intensively studied, and no systematic survey of limestone outcrops has yet been completed. The most well-studied quarries are from Xunantunich (Braswell 1998; Church 1996; Keller 1993, 2006) and Chan (Kestle 2012). These examples illustrate the variety of ways in which limestone quarries operated and were organized. Quarrying was aimed mainly at obtaining cut stone blocks for architecture and more friable limestone for use as mortar/plaster aggregate and construction fill. Although it was also extracted for use in flaked stone tool production activities (Horowitz et al. 2019), no known source areas for these activities have been identified.

Quarries varied in form at both large and small settlements. At the small hinterland settlement of Chan, quarry features took the form of both pits dug into the naturally eroding limestone bedrock and linear hillside quarries. Mechanisms of extraction varied and included fire cracking and digging (Kestle 2012, 211–216). Some of this variability is related to the type of materials being quarried, which consisted of tabular, hard limestone associated with quarry faces and softer, loosely-consolidated limestone associated with the quarry pits.

Xunantunich provides an example of larger-scale quarrying practices. Again, variability is present in the quarries, featuring mostly pocket-like pits and gridded features, including some with stepped areas indicative of the extraction of limestone blocks (Braswell 1998, 175–179; Church 1996; Keller 1993, 2006; see also McCurdy 2016). Extraction techniques varied, including the use of isolation trenches or channels for extraction of stone blocks (Church 1996, 43; Keller 1993, 91). Keller (2006, 283) identified a large quantity of quarried areas at Xunantunich, approximately 2,000 quarry faces per km^2. Like at Chan, Keller (1993) relates the quantity of closely packed quarry areas at Xunantunich to the limestone quality. She suggests that poor quality limestone led the Maya to use multiple quarries to find suitable material. Larger quarries, about 5 m in size, are in locations with harder raw materials, which may have been more valued (Keller 1993). Similarly, at El Pilar, a survey revealed the presence of small pit quarries on the sides and tops of hills and larger quarries that involved removing significant portions of hillsides (Horn and Ford 2019, 9–10). Few stone extraction tools have been found in association with quarries in the UBRV (Keller 1993, 2006; Kestle 2012). The bifaces that represent the most likely candidates for use in stone extraction activities were identified adjacent to quarry areas. These bifaces are generally referred to as General Utility Bifaces and are thick; similar implements are often used for farming, so it is difficult to distinguish their uses without further study of the implements themselves (see also Kestle 2012).

Chert quarrying in the UBRV

Archaeological surveys in the UBRV also identified several chert quarries, including San Lorenzo (Yaeger 2000), Succotz (VandenBosch 1999; VandenBosch, LeCount, and Yaeger 2010), and Callar Creek Quarry (CCQ; Horowitz 2017, 2018a, 2019). Although likely originating earlier, the quarries associated with all three communities appear to have been primarily exploited during the Late/Terminal Classic period (670–890 A.D.). Although all were located within house lots, the forms of extraction differ. The San Lorenzo quarry, excavated into a hillside, exhibited linear edge extraction patterns (Yaeger 2000). The targeted materials were deposited through secondary fluvial action, which may have impacted extraction activities. The Succotz quarries consist of pits dug to depths of between 5 and 8 m, as well as extraction from the faces of intact chert bed outcrops (VandenBosch 1999). Testing of raw materials occurred adjacent to the quarry pits, while further processing and reduction occurred in the adjacent house lots (VandenBosch 1999).

Callar Creek Quarry shows the most variability in quarry processes, probably due to the multiple forms in which chert was deposited. Workers extracted chert from the quarry in three different ways. The first was simply the extraction of chert cobbles that were eroding out of the bedrock and were present on the surface (Figure 10). Lithic debitage identified in areas of abundant chert cobbles likely represents the remains of on-site preliminary reduction (Horowitz 2017, 158–159). Secondly, linear hillside quarries extracted additional visible chert, creating a linear edge quarry face with a scalloped form, like that of San Lorenzo. This scalloped pattern resulted from the uneven extraction of materials along different points in the hillside, as well as the removal of cobbles eroding out of the parent limestone bedrock (see Figure 10). These materials were extracted through digging the chert materials out of the surrounding soil matrix. Thirdly, pits, between 1 and 2 m in depth, were dug to extract in situ bedded chert (see Figure 10). Identifications of chert debitage in areas near the quarry faces without any remaining intact chert beds likely represent the remains of extraction and preliminary reduction activities that resulted in the complete removal of the chert beds that had existed in those areas (Horowitz 2017). Few formal tools were collected from the quarrying areas, but the presence of some General Utility Bifaces (Horowitz 2018b) suggests their use for digging to extract raw materials.

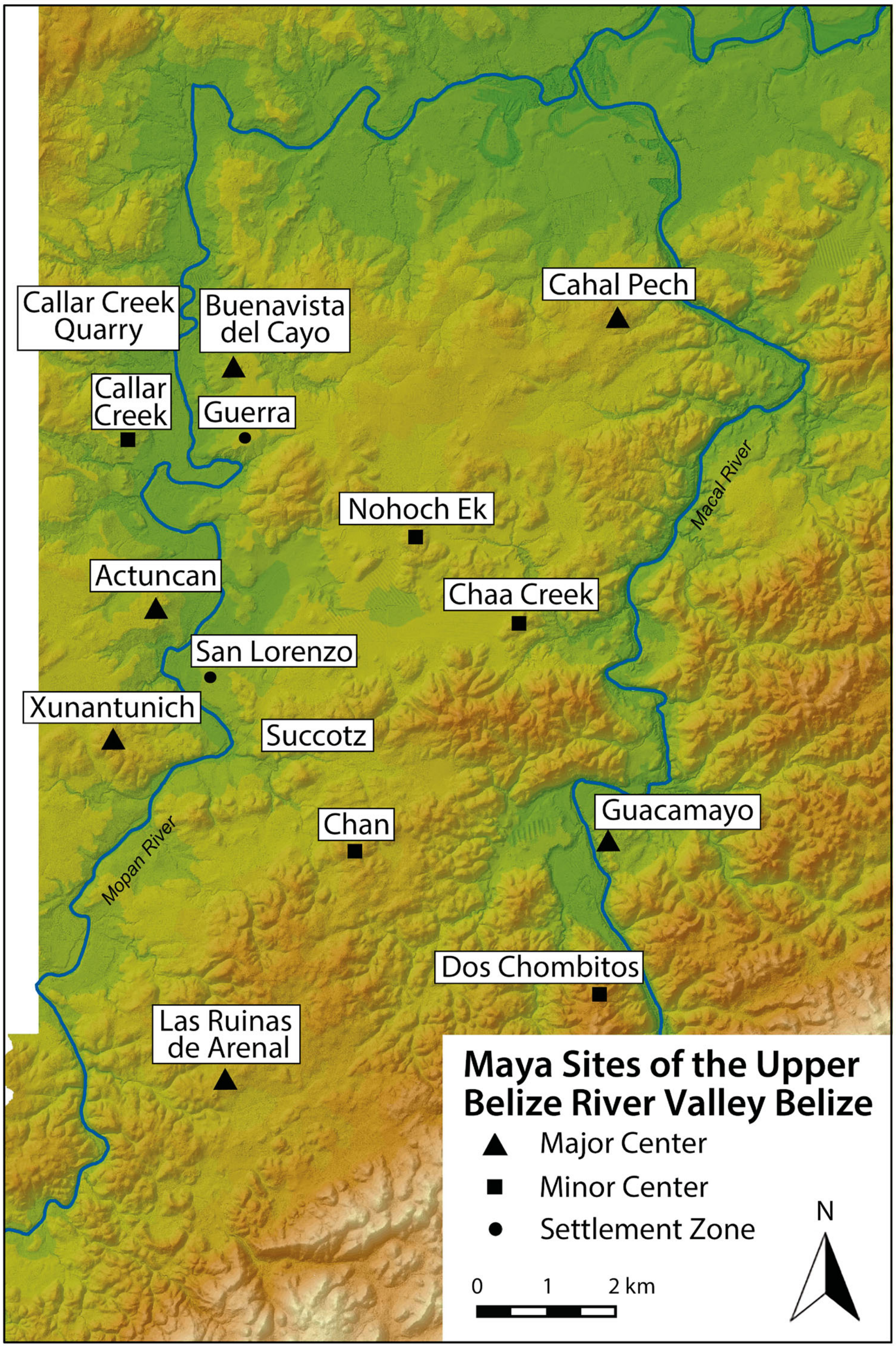

Figure 9. Map of the UBRV, highlighting areas of quarries referenced. Map by B. Cap, used with permission of the Mopan Valley Archaeological Project/Mopan Valley Preclassic Project (MVAP/MVPP).

Quarry forms at CCQ likely varied based on the grade of the materials extracted, as well as the labor organization of quarry operations. The quarry pits at Succotz and the quarry faces at CCQ and San Lorenzo were likely organized at the household level, given their location near house lots. The proximity to the residential areas allowed for more direct management of access and extraction of materials from the quarries by specific household members. Further variability between the quarries can be related to the intensity of quarry exploitation and reduction activities. The San Lorenzo quarry was the least utilized of the three examples discussed here, and has correspondingly less intensive associated reduction activities, based on the quantity of associated debris from reduction activities (Yaeger 2000, 1086–1087).

Management of limestone and chert quarrying

Management and organization of limestone quarries varies throughout the UBRV, both between and within individual sites. For instance, at Chan, Kestle (2012) proposes that the soft limestone used for the construction of nearby houses was quarried informally as desired by different individuals. This lesser quality limestone was widely available and thus less likely to be actively controlled or managed. Other quarries, like Kestle's (2012) Quarry A, were sources of harder limestone that could be used as facing stones. Based on ethnographic analogies, Kestle argues that such quarries would have been privately owned or managed, as the relatively limited availability of architectural-grade limestone would have made restricting access to it more feasible. At Xunantunich,

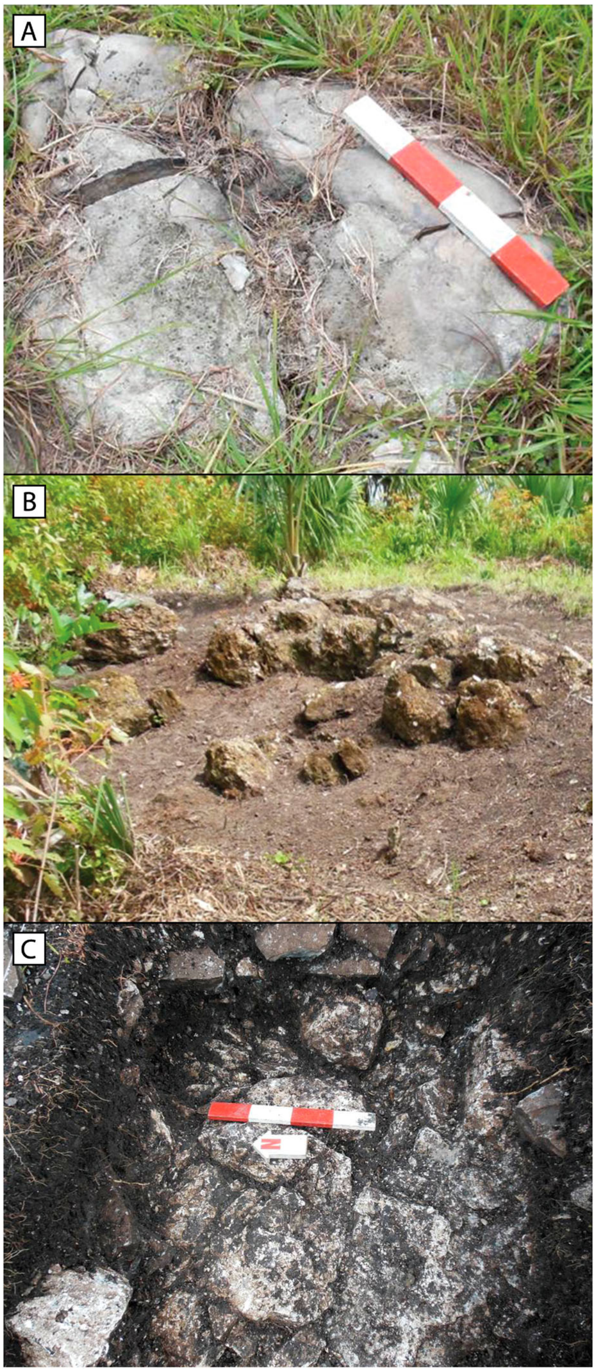

Figure 10. Callar Creek quarry showing A) cobbles visible on the surface; B) quarried hillside; and, C) intact chert beds. Photographs by R. Horowitz.

quarries within household groups are assumed to be connected to the construction of those spaces (Braswell 1998). Although not a topic which has been extensively addressed, quarries proximal to the monumental architecture in site cores were likely managed as part of the monumental construction efforts. The exact nature of this management and activity requires further exploration.

The chert quarries in the UBRV provide evidence for management of quarry resources by adjacent households who were also involved in flaked stone tool production. These households were specialized, part-time lithic producers who managed lithic extraction and production activities of formal and informal tools (Horowitz 2018a, 2019; VandenBosch 1999; VandenBosch, LeCount, and Yaeger 2010; Yaeger 2000). The association with reduction activities indicates that as a source of economic wealth, access to quarries was useful not just for access to the raw material but because it offered households the ability to produce finished products such as stone tools. At present, elite involvement is not indicated for extraction or processing. Household producers appear to be quarrying, producing, and distributing materials independent of state or political intervention or oversight.

The visual appearances of limestone and chert quarries in western Belize appear to be impacted most by the form, quality, and occurrence of the raw material exploited. Extraction methods were influenced by the raw material form and the intended purpose of the extracted materials. Limestone and chert resource management seem to have operated in similar ways. Materials located adjacent to household groups were managed by the residents of those groups with no evidence suggesting hierarchical management of quarry resources. The management of quarries associated with limestone for building larger, monumental structures is more complicated (see McCurdy 2016). In those cases, the harder stone quarries were likely managed by the individuals in charge of building the structures, although further investigations are necessary to clarify their management.

Discussion: Quarrying Practices Across the Lowlands

Excavation methods and techniques

A comparison of quarries and quarrying practices across three areas of the lowlands highlights both local idiosyncrasies and shared general practices. A conspicuous commonality is that a variety of quarry types existed within each study region; there is no standard form of Puuc quarry, let alone a stereotypical Classic Maya quarry. Unsurprisingly, the quality and purpose of the quarried stone appear to be the most important factors determining the extraction and management structures employed. This is exemplified by the variety of methods and quarry forms identified in the Stone Production District of Xultun or within the communities of the UBVR. Linear straight edge, island, and pit quarries all exist at Xultun, reflecting the various grades of limestone that existed at the site and the uses of each grade. The disheveled look of most of the harder limestone pit and ledge quarries in the eastern Puuc is likely related to the composition of the local bedrock and preferences that placed more emphasis on post-extraction stone processing. The mixture of different grades of stone, such as chak and tok' tunich at the Kaxnak Quarry would have made it more difficult to find large stretches of uniform stone grades allowing for extraction of larger, more standardized blocks. Similarly, the quantity of quarrying areas near sites in the UBRV might reflect the mixed quality of the available limestone (Keller 1993, 2006). Overall, limestone dominates the bedrock of all three study regions and exists in varying grades and forms. Harder grades with more densely-consolidated grains were preferred for architectural facades and monuments. The restricted nature of their availability in some regions made them inherently more valuable.

Despite commonalities in use, and potentially in value assigned to harder limestone, extraction methods differed from region to region. For instance, despite the widespread availability of hard, architecture-grade limestone in the eastern Puuc, there are few examples of smooth-sided linear cut quarries like the ones identified in the Xultun Stone Production District (Clarke 2020) or at Las Planchas (Beekman 1992). There is no evidence for the undercutting or channeling techniques identified at Xultun and Xunantunich (Church 1996, 43) being used at Muluchtzekel (though the sample yet investigated remains small). These techniques may be linked with an extraction and production process that places more emphasis on the extraction of ready-to-use materials, but it also depends on the local bedrock composition. The methods may also be linked with more direct oversight of extraction or a greater degree of extraction specialization. Certain locales or material grades may have also required certain ritual protocols, which would have necessitated special removal protocols, as well as the direct observation of their successful performance. Ethnographic literature (e.g., Cook and Offit 2013, 76–82; Hanks 1990, 349) identifies ritual activities which included "taming" the wild aspects of extracted materials so that they could then be brought into the ordered or civilized spaces of a community (see also Taube 2004). While our discussions focused on non-ritual aspects of production, Clarke (2020) argues that limestone production was positioned within similar ritual modes of making.

In comparison to limestone, chert availability is more naturally restricted, as pockets only exist in certain areas of the lowlands. Like limestone, even in areas where chert is relatively plentiful, there are a range of grades that were preferred for different uses. The type of chert, as well as the form and size of the natural deposits, dictated what types of quarrying methods were used, creating the resulting quarry forms. At Callar Creek Quarry, three types of chert extraction occurred—surface, linear hillside, and quarry pits—relating to the presence of chert cobbles and beds.

Despite these differences, extraction practices were shared across regions, suggesting connections via communication networks or the development of similar solutions to similar problems. Researchers have identified semi-circular or semi-conical drill hole markings in the bedrock of Kaxnak Quarry in the eastern Puuc and the straight edge stela block quarries of Xultun, as well as those noted at Tikal. Some quarriers employed similar techniques of drilling small holes to outline the stones that they intended to separate from the quarry walls. However, the techniques diverged after this initial stage, as the stones removed from Kaxnak Quarry were irregularly-shaped, while those from the Xultun linear features were excavated with straight edges. It appears that quarry workers in the eastern Puuc used these drill holes as leverage points in which they could stick poles to pry the boulder away from the quarry wall, apparently not worrying about the boulder's final form. At Xultun, however, the quarry workers must have carefully cut along the line outlined by the drill holes to form a straight-edged stone, perhaps using a string saw for their extraction (Paling, Horowitz, and Clarke 2020). The Xultun stones could then be further cut into customized masonry blocks on-site without excessive post-extraction shaping. In the eastern Puuc, in contrast, the bulk of the shaping occurred during the post-extraction phase. Similar holes and scars on the quarry walls indicate a systematic approach and perhaps a cultural understanding of how stone should be extracted. However, systematic approaches do not necessarily result in uniform results—that depends more on the composition of the bedrock, the intended uses of the extracted stone, and possibly the differential methods or requisite ritual knowledge of the quarriers.

The limited identification of quarry tools restricts extensive discussion of this topic. Bifaces found in situ at Xultun and proximal to quarries in the UBRV show variation in size and shape, with those in the UBRV resembling tools utilized for many other types of activities, while the Xultun examples appear to be more restricted to quarrying activities. The restricted range of possible tools suggests that quarry workers used harder varieties of limestone and chert for excavating stone from bedrock. Quarry tools identified in situ at the Xultun Stone District and adjacent to quarries in the UBRV suggest bifaces were used for quarrying. The similarity of tool marks at Muluchtzekel and Xultun also provide indirect evidence for similarity in tool shape, as well as a shared understanding of how to extract limestone. The nature of the bifaces associated with quarries must be studied further to investigate patterns in tool usage.

Socioeconomic dimensions of stone extraction

Growing spatial datasets demonstrate the prevalence of small pit quarries across the lowlands (e.g., Horn and Ford 2019; Ringle et al. 2018). It makes sense that the larger, often centralized quarries would be supplemented by smaller-scale stone extraction sites located in closer proximity to smaller household groups. Although we know that some types of preferred limestone were transported over greater distances, the heaviness of the raw material likely would have limited its widespread transportation (Hiquet 2020). It is even possible that some residence locations were dictated by the availability of architecture-grade limestone. Water-based transportation schemes akin to those proposed for the Olmec lowlands (see Hazell 2013) would be unlikely in most subregions of the Maya lowlands but may warrant consideration in the riparian environments of Belize and the western lowlands.

The dispersed nature of smaller pit quarries and their association with small household patio groups suggest that they would have been managed at the household or small corporate group level. A similar decentralized household-level organizational structure appears to have existed for chert extraction. Both in areas where chert is relatively abundant and in areas of less access, resources seem to have been managed by local households, even when large scale extraction occurred, such as at Colha (King 2000). These decentralized stone extraction and processing industries likely existed alongside a more centralized (or at least elite-managed) sector of the stone industry organized for the most desirable quarries and those from which stones were extracted for civic-ceremonial architecture and sculpted monuments. The naturally restricted availability of the finest grained limestone, even in areas with plenty of architecture-grade stones, would have facilitated rather than necessitated top-down control of access to the quarries and the use of their raw materials. It is therefore unsurprising that such larger-scale quarry sites with the finer grades are generally located in proximity to site centers, though there are notable exceptions such as the Las Planchas quarry (Beekman 1992).

The larger size of the quarries also reflects the fact that more stone would have been needed to construct the central buildings of the site. The construction processes would have required a mix of fine-grained facing stones and lower grade stones for wall-fill and mortar. Thus, these central quarries did not need to be restricted to only the finest-grade materials—quarriers could excavate stone from a wide patch of land, with the choicest samples refined into facing stones and put the rest to use "behind the scenes." It is unclear whether top-down control would have centered on physical access to the large quarries, the labor involved in extracting the high value stone, or the permission to use the quarried stone in architectural displays (Ringle, Gallareta Negrón, and Bey 2020). Indeed, the evidence from Xultun indicates that households extracting resources from a centrally located limestone quarry maintained both independent and state output, not to mention were able to provision their households through the exchange of produced limestone. These findings and the bottom-up perspective they offer challenge our perceptions of control predicated on proximity alone.

The systematic nature of excavation practices at quarries within each of the study regions do not necessarily indicate top-down management of excavation processes so much as they reflect local understandings of standard excavation practices. In fact, the uniformity of the stones excavated from the straight edge quarries of Xultun should be a stronger indicator of active management than the systematic repetition found at most quarry sites; however, evidence suggests decentralized management. The systematic repetition merely represents "the way" that things were done, not necessarily the mark of an attentive foreperson. Raw materials were also extracted from areas that do not present as quarries in the archaeological record. Archaeologists mainly interpret cisterns in terms of the utility of their final forms—as storage units. However, except for those that formed naturally, their excavation would have produced limestone that would undoubtedly have been put to use.

Another multi-purpose consideration of stone extraction sites is their reuse for other purposes, including water collection and agriculture. Studies across the lowlands have uncovered evidence of small pit quarries being converted to semi-watertight *aguaditas,* or water storage areas. These quarries were perhaps located at the lowest points near the households to serve as efficient catchment basins for water collection (Akpinar-Ferrand et al. 2012; Brewer 2018). Quarries may also have been reused as agricultural terraces, and quarry scars are found underneath buildings, indicating some structures may be built on top of quarries (Gillot 2018). The locations of small pit quarries highlight that quarry excavation was just one facet of a larger cultural understanding of how the natural environment should be modified and managed. Although we may see quarries as negative spaces from where stone was extracted, we cannot overlook their ongoing importance as the settings for water capture and storage, among other associated activities.

Conclusions

A comparison of quarrying methods, quarry forms, and management structures between the northern lowlands, northern Peten, and western Belize highlights the mix of variation and shared practice that characterized pre-Colonial Maya stone extraction industries. The study of limestone and chert illustrates a degree of heterogeneity in the techniques and methods of extraction, which is clearly associated with variability in the composition of the materials available for extraction and the uses for which the raw materials were intended. These factors in turn influence the socioeconomic and socio-political organizations of quarrying activities. Geologic conditions result in some of the variability observed in quarry practice. The presence of raw material on the surface versus in buried deposits impacts the ways in which raw materials were extracted, particularly the types of quarries that are seen today. Thus, when looking for quarry areas, archaeologists should be cognizant of the ways in which raw materials bed in the region. This will assist in identifying and locating quarries.

Increased variation in quarry form, as this comparison indicates, results from differences in the individuals who quarried. Different raw materials were quarried for various purposes and by distinct individuals, thus variability reflects varied motivations and formation processes. Although widespread communication networks and shared cultural traits likely underwrote a degree of commonality in the approaches, local quarrying methods were undoubtedly at least partial reflections of the preferences of the local quarriers. Additionally, the specific materials excavated and their ultimate purposes—chert for tools, limestone for construction, or sascab for fill—would have factored into the methods, processes, and tools involved in extraction.

Other sources of variation stem from the organization of extraction methods, including by local householders or organization by higher level authorities. Resource management on the local versus regional level results in differences in the organization of the quarry, quarrying tools, and the associated production facilities. Here scholars of quarries in Mesoamerica can draw on the study of quarry management in other world regions (e.g., Cantarutti 2013; Harrell and Storemyr 2009; Heldal 2009; Ogburn 2013; Salazar, Borie, and Onate 2013). The variation in organization of raw material extraction activity has implications for understanding Classic Maya economic organization and the role of different individuals in these activities. Quarrying was organized at multiple levels, indicating that there was no single stone "economy" but rather that different types of materials were managed in a variety of ways. Emerging from this study is a clear picture of value, both of quarried resources in the past and of quarries as a dataset that informs present studies of past economic practice, particularly for understanding variability therein.

Unfortunately, due to the lack of pre-Colonial texts dealing with stone extraction, the evidence for the socioeconomic models proposed for the stone extraction industries remains indirect. However, with the visibility of quarries and the conspicuousness of the materials excavated from them, there is ample room to grow our knowledge of pre-Colonial Maya quarrying practices through targeted investigations. These studies need to include systematic excavations of more quarry and quarry-adjacent sites, meticulous architectural energetics modeling (see Abrams 1994), and efforts to create a detailed intra-regional geological distribution map of available resources. It is also important that archaeologists working in different sectors of the Maya lowlands visit each other's field sites whenever possible to further refine a shared quarry terminology.

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The authors declare no conflict of interest.

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