Ancient Mesoamerica (2025), **36**, 302–318
doi:10.1017/S0956536125100655

CAMBRIDGE UNIVERSITY PRESS

Research Article

Human-Stone Interactions in the Precolonial Maya Lowlands: Working and Learning with Limestone*

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Abstract

This paper considers the complex entanglements from which stones and stone craftspeople emerged in the precolonial Maya world. Drawing from recent scholarship that emphasizes the relational and processual nature of making and knowing, it adopts a multi-practice perspective to explore how humans transformed limestone into knowable and workable materials and how, in turn, limestone transformed humans into knowledgeable and skilled individuals. Geoarchaeological, archaeometric, and experimental data from the central and northern Maya lowlands are combined to identify choices and preferences in selecting, extracting, and processing calcareous materials, and to examine what these reveal about past knowledge and skills. We then turn our attention to the ways in which quarry workers, lime producers, and toolmakers learned to work with stone. We argue that becoming attuned to limestone was a sociomaterial process that involved repeated interactions with both material elements and social actors. Our discussion highlights the active role of limestone not only in shaping learning experiences but also in facilitating connections between diverse practices, and thus contributing to a dynamic, interconnected landscape of knowledge.

Resumen

Este artículo explora las dinámicas sociomateriales a partir de las cuales se co-constituyeron entidades pétreas y humanas en el mundo maya precolonial. Inspirándose en trabajos recientes que enfatizan la naturaleza relacional y procesual del hacer y del conocer, se adopta una perspectiva multipracticante para investigar cómo las personas transformaron la caliza en materiales inteligibles y trabajables, y cómo, de manera recíproca, la caliza transformó a las personas en sujetos conocedores y competentes. Se integran datos geoarqueológicos, arqueométricos y experimentales procedentes de las Tierras Bajas Mayas centrales y septentrionales con el fin de identificar las estrategias empleadas en la época precolonial para seleccionar, extraer y trabajar materiales calcáreos, así como los saberes y las habilidades que estas estrategias ponen de manifiesto. Luego, se considera cómo los individuos involucrados en la extracción de materiales constructivos, la producción de cal y la manufactura de herramientas adquirieron y perfeccionaron los conocimientos necesarios para desempeñarse como trabajadores competentes. Se sostiene que este proceso de aprendizaje se llevó a cabo mediante interacciones reiteradas y sostenidas tanto con elementos materiales como con redes de actores sociales. A través de este análisis, se destaca el papel activo de la piedra caliza no solo en la constitución de experiencias de aprendizaje, sino también en la formación de nexos entre diversas prácticas, contribuyendo así a un paisaje dinámico e interconectado de saberes.

Keywords: Human-Stone Interactions; Limestone; Knowledge Networks; Craft Learning

Stone has long been presented in archaeological literature as a raw material; a resource extracted, shaped, and used to meet human needs. However, in the wake of the "material turn" (Alberti et al. 2013; Drazin and Küchler 2015; Steel 2024; Van Dyke 2015), scholars have begun to challenge this view, pointing to other ways in which stone has mattered throughout human history (Bender et al. 2007; Boivin and Owoc 2004; Cohen 2015; Tilley 2004). Rather than seeing stone as an inert material awaiting human action, recent approaches foreground its active role in the formation and transformation of material and social worlds (Cooney et al. 2020; O'Connor et al. 2010; Weedman Arthur and Barkai 2024). Yet, to date, much of this work remains focused on how *things* made of stone, particularly landscape features and human-made objects, affected human experiences. Less attention has been paid to how stone, as a *material substance* with its own properties and affordances, shaped past perceptions and interactions.

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*This article has been updated since its original publication. A notice detailing the changes can be found here: https://doi.org/S095653612610090X

Cite this article: Gillot, Celine, Kenneth Seligson, Soledad Ortiz Ruiz, Bosiljka Glumac and Carlos Peraza Lope 2025 Human-Stone Interactions in the Precolonial Maya Lowlands: Working and Learning with Limestone. *Ancient Mesoamerica* 36:302–318. https://doi.org/10.1017/S0956536125100655.

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https://doi.org/10.1017/S0956536125100655 Published online by Cambridge University Press

This paper focuses on human–stone interactions in the precolonial Maya lowlands, with particular attention to how these interactions were intertwined with knowledge acquisition and transmission processes. Specifically, it considers how people transformed limestone into knowable and workable materials and how, in turn, limestone transformed people into knowledgeable and skilled individuals. Starting from the premise that material substances are not fixed or stable entities (Bennett 2010; Ingold 2007), we first examine how different types of limestone emerged through different modes of engagement. In line with Conneller's (2011) perspective, we argue that Maya communities did not engage with limestone as a singular, homogeneous material but with stones whose properties changed depending on the practice and web of relationships in which they were caught. In other words, even similar stones may have been experienced and understood differently according to who engaged and worked with them. And yet, as this paper shows, through their distinct practices (and thus shifting relationships and understandings), Maya communities also developed a collective familiarity with their mineral world and its heterogeneous components.

To explore how people's interactions with limestone gave rise to both specific and shared knowledge, we adopt a "zooming in" and "zooming out" strategy (Nicolini 2009). After a brief overview of previous work on precolonial Maya stone-working practices, we begin our analysis by zooming in on specific practices and following limestone materials as they emerged through multiple production processes. Using geoarchaeological, archaeometric, and experimental data from the central and northern Maya lowlands, we examine the choices quarry workers, lime producers, and toolmakers made while selecting, extracting, and processing limestone. While we acknowledge that these choices were influenced by various factors and the contexts in which these practices occurred, our focus lies less on these factors than on what these choices reveal about how people engaged with calcareous materials and made sense of their properties and capacities, or "affordances" (Gibson 1979; Knappett 2004). Beyond illustrating how stones conventionally classified as "limestone" in archaeological studies may have been perceived as distinct materials, this multi-practitioner approach also sheds light on the knowledge and skills required to recognize and respond to their properties, prompting us to consider the processes through which people learned to work with limestone.

Zooming out to consider the sociomaterial arrangements that shaped and were shaped by these practices allows us to (1) follow stone-workers as they navigated their environment, repeatedly engaged with calcareous substances, and gained the knowledge and skills necessary to work with them, and (2) trace connections among them. As we move from how limestone materials emerged to how people became attuned to their materiality, our focus moves from people–material interactions to people–people interactions. Although we use data from different archaeological settings, our analysis reveals a tightly interwoven web of practices, where material activities did not occur in isolation but rather intersected, overlapped, and informed one another. At this larger scale, limestone appears less as a material following multiple, shifting trajectories and more as a "point of convergence" around which connections were woven, experiences shared, and both individual and collective knowledge cultivated. In addition to contributing to recent discussions on past learning dynamics (Crown 2014; Forte et al. 2023; Pion and Schlanger 2020; Wendrich 2012), this paper also offers a new perspective on the role played by material substances in shaping ancient networks of practice and knowledge (Brysbaert 2011; Jürcke et al. 2021; Rebay-Salisbury et al. 2014; Roddick and Stahl 2016).

Limestone production in the maya lowlands

Although often described as a vast limestone slab, the Yucatan Peninsula exhibits significant geological diversity. Its surface formations vary in age and composition (Bonet and Butterlin 1979; Isphording 1975; López Ramos 1973) and are continuously altered by karst activity (Estrada Medina et al. 2019; Héraud-Piña 1996; Valera-Fernández et al. 2020). As prominent features of the landscape and sources of materials, these formations and their altered deposits have long played a key role in Maya practices. The region's oldest human remains, found in caves, point to an enduring relationship with the subterranean world (González etal. 2014; Wrobel et al. 2021), while early plazas and platforms indicate that, by the beginning of the first millennium B.C., local populations had begun to modify the bedrock to create spaces for communal life (Brown and Stanton 2020; Reese-Taylor et al. 2022). As permanent settlements developed, limestone became increasingly central to daily life—not only as a building material but also as a medium with which to produce a wide range of things, from imposing monuments to everyday tools and objects. Processed into lime, it also became integral to diverse practices, including masonry architecture, maize nixtamalization, dye preparation, and the production of other lime-based products (Cheetham 2010:346–347).

Despite its prevalence in the archaeological record, limestone has received limited attention until recently. The emphasis on finished objects and their forms, functions, or meanings has, to some extent, eclipsed its significance as a substance. In contrast to other stones (i.e., chert, obsidian, and jade), limestone has traditionally been perceived as a mundane and ubiquitous resource whose extraction and transformation required substantial human labor but minimal expertise and "common, unspecialized" knowledge (Abrams 1994:112; Erasmus 1965:278; Morley 1946:359). As a result, those involved in quarrying and working limestone have often been depicted as "generalized, low-skilled" laborers (Abrams and Bolland 1999)—except for some sculptors and lime producers credited with artistic skills (Houston 2016; Van Stone 2005) or ritual knowledge (Russell and Dahlin 2007; Schreiner 2002). This perception has also contributed to viewing stone-workers as subalterns or low-status members of society (Carmean et al. 2011; but see Clarke 2020; McCurdy and Hiquet, this issue). However, by projecting present-day Western categorizations of labor onto the past, these perspectives obscure the richness and depth of ancient knowledge and the meaningful role that such seemingly ordinary practices played in the lives of those who performed them.

https://doi.org/10.1017/S0956536125100655 Published online by Cambridge University Press

Following Ruiz Aguilar's (1985) ethnographic work, several studies have shown that limestone extraction and production required not only technical and experiential knowledge but also an intimate familiarity with the geological environment (Gillot 2018; Horowitz et al. 2021; Woods and Titmus 1994; see also Arnold 2018). Recent excavations of lime kilns (Goguitchaichvili et al. 2020; Ortiz Ruiz 2019; Ortiz Ruiz et al. 2021a, 2023; Seligson et al. 2017a, 2017b, 2017c, 2019) and archaeometric analyses of building materials (García Solís et al. 2016; Gillot 2014; Rodriguez-Navarro et al. 2023; Villaseñor and Graham 2010) demonstrate that lime and mortar production entailed advanced pyrotechnological knowledge and a keen understanding of the physicochemical properties of calcareous materials. Several of these studies further suggest that the Maya did not work with limestone indiscriminately but rather selected it carefully and occasionally traveled beyond local quarries to obtain higher-quality stones (Brennan et al. 2013). Careful selection of limestone materials is also apparent in tool production (Glumac et al. 2017, 2019; Howard et al. 2017). Despite its reputation as a "low-quality" material for toolmaking, limestone may even, in some regions, have had an almost exclusive relationship with certain types of tools, including bark beaters (Moholy-Nagy 2003:45; Parrott and Peraza Lope 2018), beehive covers (Paris et al. 2018, 2020), spindle whorls (Kamp et al. 2006), or shellfish processing tools (Herckis 2015:146).

In recent years, scholars have also started to examine more closely the social dimensions of limestone quarrying and working, highlighting how these activities were embedded in power dynamics and socioeconomic hierarchies (Carmean et al. 2011; Ringle et al. 2021) or how they fostered coordination and collaboration within and between households (Clarke 2020; Hutson and Davies 2015; Kestle 2012). Extending this body of work, this paper suggests that limestone-related practices enmeshed people not just in vertical or horizontal relations but also in broader networks of sociomaterial interactions. By emphasizing the relational nature of working and learning with limestone, it underscores how calcareous materials connected people making and knowing different things, and thus facilitated the flow of knowledge within and across practices.

Working with limestone

Limestone quarrying at Río Bec

With its numerous stone masonry houses and countless quarries, Río Bec offers an interesting setting for exploring the active role of limestone in shaping everyday life and drawing people into complex webs of relationships. Dispersed along the eastern edge of the Zoh Laguna Plateau, in the central Maya lowlands (for a map showing the location of the archaeological sites discussed in this article, see Gillot et al., this issue: Fig. 1), Río Bec's multiple residential compounds—and the elaborate masonry residences around which they were organized—attest to a sustained investment in construction activities (Nondédéo et al. 2013; Taladoire et al. 2013). For more than four hundred years, from the Late to the Terminal Classic periods (550–950/1000 B.C.), these activities unfolded within a dynamic social landscape shaped by both inter-neighborhood emulation and intra-neighborhood collaboration (Arnauld et al. 2012, 2013). The inhabitants of these small compounds *slowly* but *continuously* built and extended their residences (Michelet et al. 2013), and, in doing so, gradually and deeply altered the surrounding bedrock (Gillot 2018). As a result, people at Río Bec literally dwelled amidst quarries.

Conducted in one of the most densely occupied areas of Río Bec, the geoarchaeological study of these quarries sought to understand the strategies employed to obtain the materials needed to sustain construction activities. Combining surface survey with excavation and petrographic analyses, it provided valuable insights into the technical choices and preferences of Río Bec's quarry workers and masons, especially those involved in the selection, extraction, and preparation of limestone blocks. Lithostratigraphic observations of the exploited outcrops also revealed the heterogeneity of the geological substrate and allowed for its detailed characterization. Heavily altered by karstic processes, these outcrops belong to the Paleogene–Eocene Icaiché Formation, one of the oldest exposed geological formations found in the Yucatan Peninsula (Castro-Mora 2002; Perry et al. 2019; SGM 2007a).

Within the surveyed 110 ha, the scattered spatial distribution of the 70 extraction sites identified suggests a decentralized procurement strategy similar to what has been documented in the Puuc region and northern Yucatan (Folan 1982; Horowitz et al. 2021; Seligson and Ringle, this issue). The location of most of these sites (less than 50 m from a building and often within a 25 m radius, if not directly beneath the buildings themselves), along with the absence of large-scale quarries, further points to a tendency to extract building stones where needed. While this may suggest a strategy of minimal effort, various factors likely contributed to this pattern, including (1) a modest labor force, presumably the occupants of the future house, helped by neighbors and/or members of allied households (Arnauld et al. 2012; Gillot 2018), and (2) a highly structured and fragmented territorial organization (Lemonnier and Vannière 2013), with limited opportunities to exploit the substrate beyond the house lot's boundaries.

Most quarries are situated on the summits or flanks of interfluves, away from seasonally flooded areas (Figure 1). In these well-drained places, dissolution and precipitation processes have contributed to the formation of two secondary rock facies: a superficial, hardened caliche crust (*laja*) overlying unconsolidated limestone deposits (*sascab*). *Sascab*—a friable material used for floors, fills, and mortars—was exploited intensively, leaving the most visible traces: well-defined pits, sometimes several meters deep. In contrast, the extraction of building blocks required extensive exploitation. Due to the limited thickness of the *laja* (often less than 1 m), these operations extended over vast areas, leaving only subtle traces such as small unquarried outcrops and block removal imprints around and beneath buildings. Intensive and extensive quarrying could occur concurrently, resulting in depressions of varying size and depth (Figure 2). Such depressions usually cover less than 250 m^2, although some can exceed 1,000 m^2, with depths ranging from 0.25 to 2.50 m. Occasionally, quarrying activities also extended to hill slopes, creating terraces subsequently used for agricultural purposes.

https://doi.org/10.1017/S0956536125100655 Published online by Cambridge University Press



Figure 1. Map showing the distribution of limestone extraction sites within a residential area of Río Bec. Map by C. Gillot, base map courtesy of the Río Bec Project I.

The geological substrate exhibits significant variations, both between and within outcrops. The caprock (or caliche crust) is rarely a massive, homogeneous slab. Instead, it generally consists of successive layers that become less compact and more porous with depth, leading to the underlying *sascab* deposits (Figure 3). These layers provided materials

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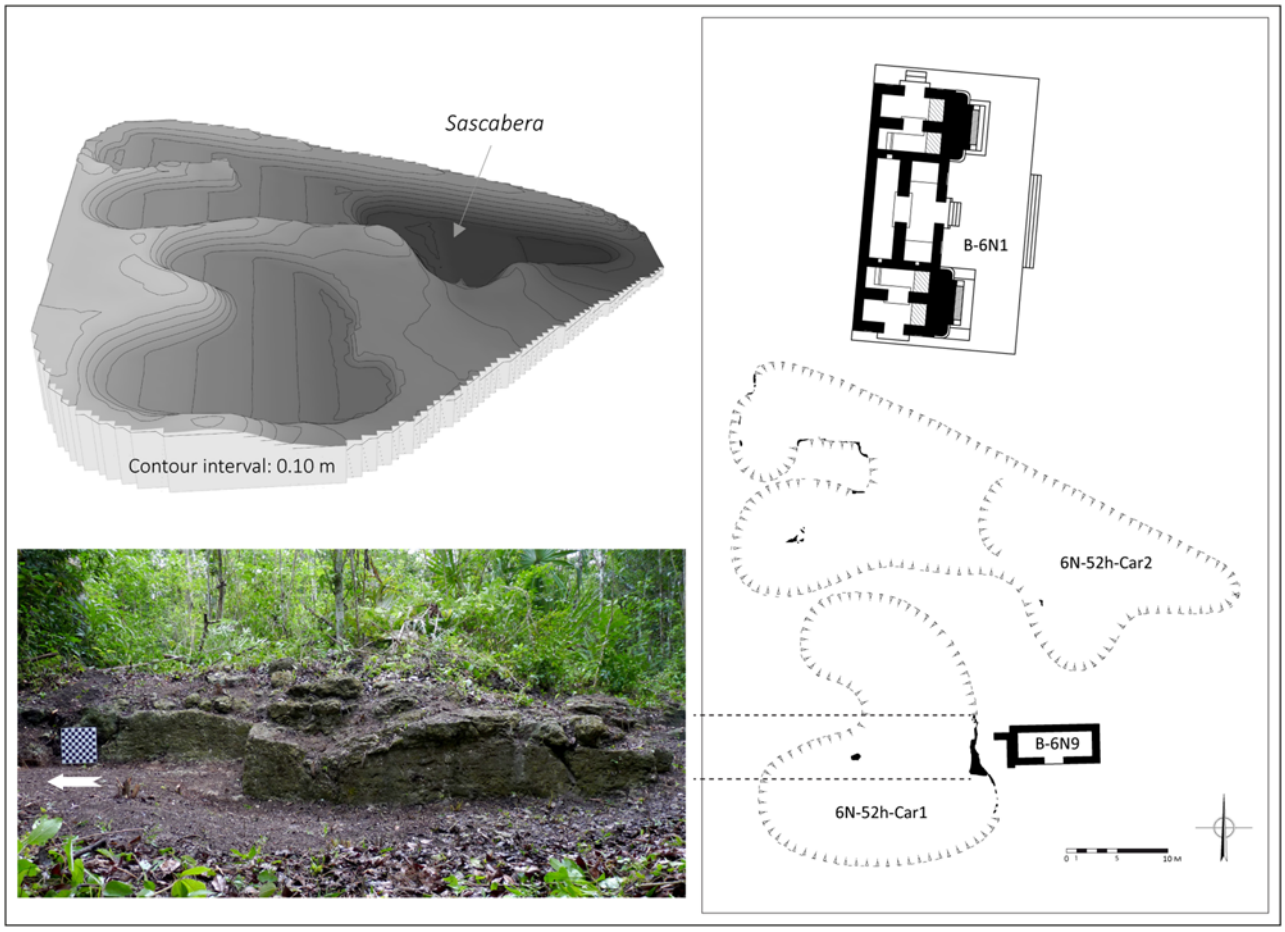


Figure 2. Map, digital elevation model, and photograph of Río Bec quarry 6N-52h-Car 1-2, showing evidence of both intensive and extensive exploitation strategies. Photograph and illustrations by C. Gillot.

with distinct properties. From the upper, most indurated layer, the quarriers extracted a porous stone, locally known today as *caliza sascabosa* (micritic limestone or mudstone; Dunham 1962). Its compact yet soft nature, with a cutting difficulty of 3 or less on AFNOR's 14-point scale (Bessac 2004), made it well-suited for shaping square building blocks. From the semi-indurated strata, they obtained a less compact stone characterized by a porous matrix interspersed with indurated nodules. Although this stone could be quarried in blocks, its heterogeneity, low density, and weak resistance made it unsuitable for fine dressing or carving. Lastly, from the lower unconsolidated *sascab* deposits, they extracted a particularly loose and porous stone, easily reduced to sand with minimal hand pressure. A few *sascaberas* located in low-lying drainage areas, where the caliche crust is absent, provided a *sascab* slightly richer in detrital particles, which may have been preferred for the preparation of some mortars (Gillot 2014).

The quarrying methods employed at Río Bec are similar to those documented elsewhere (e.g., Clarke 2020; Gallegos Gómora 1994). Once the outcrops were localized and cleared, trenches were dug to isolate square blocks of standardized size, typically 40–50 cm per side (Figure 4). Trench morphology and tool marks suggest this step was achieved using thrown percussion tools; likely stone picks hafted onto wooden handles. Traces on the quarry faces and floors further indicate that blocks were detached in successive layers, strategically following natural fractures where they occurred (Figure 5). No combustion traces were found, suggesting that the fire detachment technique mentioned and experimented in other contexts (Kestle 2012; Michelet et al. 2015) was not used at Río Bec. Block isolation and layer-by-layer extraction techniques were used for indurated and semi-indurated strata, whereas unconsolidated deposits appear to have been exploited through simple digging. At the end of the extraction process, quarrying wastes were removed and repurposed as construction fill.

Once extracted, the stones were selected and used with continued attention to their distinct material properties. The lighter stones were finely dressed for facing exterior facades, while the heavier, denser ones were shaped for structural elements or roughly cut for use in internal walls and vault intrados. This material awareness is also evident in how the stones were laid: non-structural blocks (e.g., facade veneers) were often set perpendicular to their bedding plane, while structural ones (e.g., cornices and vault stones) were always set parallel, enabling them to bear vertical forces more effectively.

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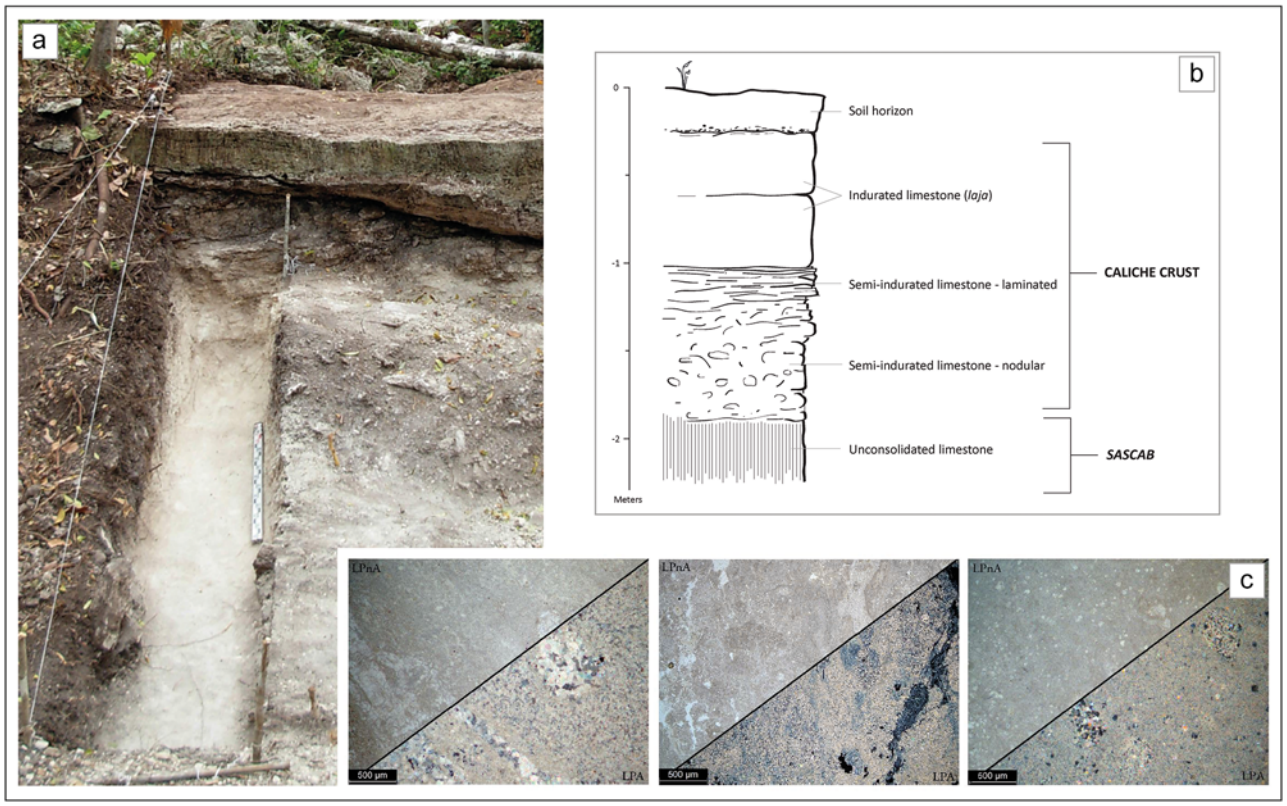


Figure 3. Views of Río Bec quarry 5N-46i-Car1 showing: (a) its quarry front; (b) its profile with lithological units; and (c) representative thin sections of samples from corresponding units (left to right: indurated, semi-indurated, and unconsolidated layers). Photographs and illustration by C. Gillot.

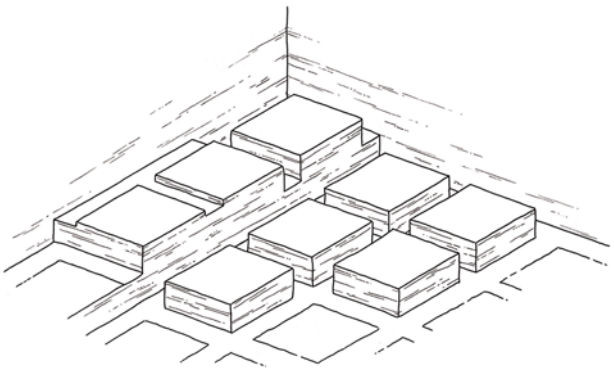


Figure 4. Schematic representation of the channeling system employed in the quarries of Río Bec. Illustration by C. Gillot.



Figure 5. Río Bec Quarry 7N-55g-Car5, with visible successive extraction layers and negative impressions of square blocks. Photograph by C. Gillot.

Lime production in the Puuc and northwestern Yucatan

The study of precolonial Maya lime production is not new, but investigations of annular lime pit-kilns in the northern Yucatan over the past decade have expanded our understanding of multiple technologies and knowledge systems in use during the Classic period (Goguitchaichvili et al. 2020; Seligson et al. 2017a, 2017b, 2017c, 2019). Lime is produced by heating small pieces of limestone to high temperatures, transforming them into quicklime (calcium oxide). When water is added, quicklime turns into a multifunctional white powder called hydrated or slaked lime (calcium hydroxide). Lime was the key ingredient in the mortars and plasters that held Classic Maya architecture together, as well as in the nixtamalization process that converted maize kernels into a nutritious and viable dietary staple. It also served as a desiccant, preservative, fertilizer, sanitizing agent, and a potential enhancer of psychoactive reactions. The earliest evidence for architectural lime use in the Maya lowlands comes from northern Belize and dates to around 1100 B.C. (Hammond 1991; Hammond and Gerhardt 1990; Healy et al. 2004), though the incorporation of lime into various aspects of daily life likely began at an earlier date.

Archaeologists and ethnographers have studied the use of aboveground pyres or *caleras* to produce lime in the Maya lowlands since at least the 1930s (Abrams and Freter 1996;

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Morris et al. 1931; Russell and Dahlin 2007; Schreiner 2002). Typically, this method involves building a large circular or rectangular pyre out of freshly cut wooden logs of various diameters and placing a pile of *chich* (fist-sized pieces of limestone) on top (Figure 6). The *calera* is then lit from the center so that it burns slowly outward, eventually collapsing in on itself and forming an aboveground oven. Some *caleras* are built directly on the surface, while others are built within pits excavated into the earth that provide a measure of heat retention and protection from the wind. These expedient earthen pits are different from the annular pit-kilns excavated directly into the bedrock and built up with large boulders—a technology that appears to have been centered in the northwestern Yucatan and most frequently used in the Puuc region.

A 240 km^2 lidar flyover of the eastern Puuc region in 2017 led to the identification of over 1,200 annular pit-kilns (Ringle et al. 2021). Subsequent flyovers expanded the lidar coverage to more than 400 km^2, revealing over 2,000 annular pit-kilns. These data suggest that the eastern Puuc has the highest concentration of lime pit-kilns identified to date in the Maya lowlands. The kilns are generally distributed relatively evenly across the sites, with the most important factor influencing their location appearing to be a balance between proximity to outcrops of the best grades of limestone for lime production and residential clusters where the lime would eventually be used. Investigations of intra-site pit-kiln distribution at the Tier 2 site of Muluchtzekel, Tier 3 site of Kiuic, and Tier 5 site of Xanab Chak suggest that lime production was primarily a decentralized, household-based occupation, with approximately 33 percent to 50 percent of residential groups having access to an annular pit-kiln within Late and Terminal Classic Puuc communities (Ringle et al. 2021; Seligson and Parker 2026; Seligson and Ringle, this issue). Recent work in the Ichkaantijoo region and its surroundings resulted in the identification of several dozen additional lime pit-kilns, with 37 excavated so far (Ortiz Ruiz 2019). Although geographically dispersed, several of these kilns are strategically located near quarries, water sources, and *chich* mounds.

The annular pit-kilns of northern Yucatan varied in form and size, with a few identifiable regional idiosyncrasies. They appear in the archaeological record as low mounds, generally 1–2 m high, capped by a ring of rough boulders that surround a central depression. The rings vary in diameter from 1.5 to 3.5 m (Figure 7), and the mounds can have diameters of up to 10 m (with some kilns in the Ichkaantijoo region consisting of only a ring, without the mound). Excavations of annular structures at the eastern Puuc site of Kiuic revealed that they likely started as small silo-shaped stone rings. Over time, excess *chich* was added to the walls for structural integrity and greater heat/wind protection, resulting in sloping exterior walls (Seligson et al. 2017a). Unlike eastern Puuc kilns, which appear to be exclusively associated with Classic period sites, the Ichkaantijoo pit-kilns were used from the Classic period until historic times, from A.D. 700 to 1896 (Ortiz Ruiz et al. 2015; Ortiz et al. 2021b). Interestingly, some Classic period kilns show evidence of reuse during the Postclassic and colonial periods, suggesting technological continuity even after the Spanish arrival. Some kilns are associated with early colonial settlements, including Chacxulubchen,



Figure 6. A traditional *calera* created and fired by Ortiz Ruiz and colleagues at Uayma, Yucatan. Photograph by S. Ortiz Ruiz.

Maxtunil, and Site 161 of the *Atlas Arqueológico del Estado de Yucatán* (Garza and Kurjack 1980; Góngora Salas 2017). Changes in lime-production technology appear to coincide with the emergence of Henequen haciendas and the adoption of European practices.

The Puuc region, while not as geologically old as the Río Bec area to the south, still represents an Eocene-epoch uplift that predates much of the Plains region to the north (López Ramos 1973; SGM 2007b). Just like in the Río Bec region, the bedrock consists of a *laja* caprock overlaying pockets of softer *sascab*. However, ethnographic accounts reveal a repertoire of locally recognized limestones more varied than the seemingly uniform landscape might suggest. For instance, potters from Ticul identify at least twenty limestone types, each with distinct names and uses (Arnold 2018:77–78; Seligson

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Figure 7. Classic period lime pit-kilns excavated at the Puuc site of Kiuic by Seligson and colleagues (top), and in the Ichkaantijoo region near Mérida, Yucatan by Ortiz Ruiz and colleagues (bottom). Photographs by K. Seligson and S. Ortiz Ruiz.

2016:203). While several of these rocks could theoretically be converted into lime, their suitability for high-quality lime production varies based on their physical and mineralogical properties. For locals who retain knowledge of traditional lime burning, *sakel baach tunich* (or "white birds' egg rock") is the most suitable (Seligson et al. 2017a). Compared to harder limestones preferred for kiln construction, such as *tok' tunich*, or limestones rich in impurities, such as *chak tunich*, this white hard-medium stone is easier to extract, crush into *chich* of roughly equal size, and transform into lime without undesirable chemical reactions. Its relative porosity also facilitates heat diffusion during combustion, while its compactness prevents rapid disintegration at high temperatures.

Paleotemperature estimations using attenuated total reflectance with Fourier-transform infrared (ATR-FTIR) spectroscopy reveal that the temperatures reached during lime combustion in the Ichkaantijoo kilns ranged from 750°C to 809°C. These findings are consistent with data from the Tamanché region and recent experiments (Ortiz Ruiz et al. 2021a, 2023). At Kiuic, experimental calcination of limestone indicates that a few hours after fuel ignition, the temperature in an underground structure could reach 950°C, then slightly decrease to stabilize at 800°C (Seligson et al. 2017b). These temperatures indicate that pit-kilns could have been at least 20 percent more fuel-efficient than aboveground *caleras*, suggesting that fuel management was an important factor behind their widespread construction and use in the region. This would, in turn, suggest that the use of alternative production methods, such as aboveground pyres, was likely discouraged. With only half or fewer households producing a product that all community members needed for architectural and dietary purposes, intra-site distribution or exchange mechanisms would have been necessary (Seligson and Parker 2026).

Limestone tool manufacture at Mayapan and nearby sites

In Maya archaeology, lithic procurement and toolmaking strategies have long served as entry points for examining trade networks and domestic economies. Studies of artifacts made from chert and other "exotic" stones have illuminated, for instance, how lithic trade contributed to elite wealth and authority or how lithic production was integrated into both elite and non-elite craft practices (Aoyama 2007; Braswell and Glascock 2011; Horowitz 2022; Inomata 2007; Masson et al. 2016; Widmer 2009). Yet, as Horowitz (2018) notes, lithic research has tended to marginalize the role of locally available materials in shaping procurement and production strategies. As a result, little is known about how Maya toolmakers perceived and engaged with local limestone materials.

The assemblage of tools recovered in the Mayapan region as part of Carlos Peraza Lope's Salvamento Arqueológico Mérida Chetumal 2015 project provides a unique window into these underexplored aspects. This assemblage was analyzed (morphologically, functionally, and according to basic macroscopic properties) by Masson and a team of students. The results demonstrate that locally sourced materials were integral to Mayapan's lithic practices, calling into question the idea that their use resulted solely from a lack of higher-quality stone (Hearth and Fedick 2011; Rovner 1976; but see Cap 2021; Horowitz et al. 2019). The petrographic analysis of 592 stone artifacts from Terminal Classic and Postclassic residential contexts shows that the inhabitants of the Mérida-Teabo region had access to limestone materials with varying properties and selectively employed them to produce different types of tools. Geoarchaeological examination of selected tools, limestone sources, and outcrops exposed by highway construction revealed the use of diverse calcareous materials, including coquina, calcarenite, *piedra dura*, calcrete, dolostone, speleothem, and fracture fill, alongside chert and "Ticul" stones likely imported from the Puuc (Glumac et al. 2017, 2019; Howard et al. 2017).

These artifacts are conventionally categorized as "ground stone" in lithic typologies, though this catch-all term may be misleading and fails to capture the variety of techniques employed in their production. For instance, tools used for grinding and crushing (*metates, manos*, mortars, pestles, and bark beaters), as well as stone containers (bowls, dishes, and plates), were likely shaped through multi-step processes involving both percussive and abrasive actions (Hayden 1987; Searcy 2011). In some cases, limestone boulders and cobbles

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Figure 8. An example of a cylindrical grinding tool from Mayapan made of coarse-grained shelly coquina limestone. Photograph by B. Glumac.

were also knapped into bifacial or unifacial chipped disks (Paris et al. 2018:9–10) or minimally retouched to create expedient tools such as hammers and tools presumably utilized for pounding, chopping, cutting, scraping, smoothing, and polishing. Plaster residues on the edges and working surfaces of many of these tools suggest frequent reuse in plaster and stucco work (Proskouriakoff 1962:341).

Several considerations likely influenced the choice of specific limestone materials for tool production, including their perceived workability and functional affordances. Some were likely appreciated for their ease of shaping, while others were chosen for their performance characteristics like abrasiveness, grinding effectiveness, and resistance to abrasion and fracturing. Importantly, the underlying variable might not have been the stone type *per se* but its texture. Based on textural properties, the limestones used to produce the tools analyzed can be grouped into three main categories, each linked to distinct functional uses, as detailed below.

(1) Coarse- to medium-grained limestones: grinding, abrading, polishing. The most common limestone types employed in the local ground-stone industry were coquina and calcarenite, sourced from the Carillo Puerto and Chichén Itzá Formations (Rebolledo-Vieyra et al. 2000; SGM 2007b). While the exact provenance of these materials is uncertain, the lack of large quarries in the study area suggests they were obtained from surface outcrops like those exposed on the top of the *altillos* or small hills that dot the region. Unlike the microcrystalline limestones quarried at Río Bec, coquina and calcarenite are fossiliferous limestones. Coquina, rich in marine skeletal remains, is easily recognizable by its shelly, coarse-grained, and rough texture. Its abrasive qualities made it ideal for grinding and abrading tools (Figure 8). Its weak cementation and porous nature allowed toolmakers to shape it with ease, although its friability likely posed challenges for controlled flaking. Nonetheless, coquina was apparently favored for producing small chipped-stone disks, possibly for its lightness or some symbolic load. Calcarenite, rich in detrital sand-sized carbonate grains, shares coquina's soft and porous nature. However, it differs in texture, with a more homogeneous and slightly denser fabric, enhancing its resistance to abrasion and ability to be shaped into complex forms. This made it particularly suitable for fine-grinding and polishing tasks.

(2) Fine-grained limestones: fine-grinding and abrading, pounding, pulverizing, and smoothing. Although less prevalent, *piedra dura* and dolostone are well-represented in the assemblage. *Piedra dura*, found as cobble-sized pseudoclasts in weathered, chalky deposits (*sascab*), consists of skeletal debris and peloidal grains. In contrast to coquina and calcarenite, these grains are well-cemented together by microcrystalline calcareous mud, making *piedra dura* harder and more resistant to abrasion. The cobbles' rounded to subrounded shapes facilitated their processing into various grinding, pounding, and pulverizing tools, as well as smoothing and flattening tools (including plaster smoothers and bark beaters) (Figure 9). Dolostone, a dolomite-rich carbonate rockwith minimal fossil content, is characterized by a uniform, crystalline, sugar-like texture, which is hardly visible to the naked eye but makes it particularly dense and hard. Like calcarenite, dolostone was primarily used for fine-grinding and abrading implements.

(3) Very fine-grained limestones and secondary mineral formations: pounding, pecking, cutting, scraping. The third category includes materials from secondary mineral formations like petrocalcic horizons or calcrete, speleothems or fracture fills, and siliceous rocks. Calcrete, or the lithified caliche crust that developed on carbonate-rich soils and *sascab* deposits, consists of very fine-crystalline or micritic mud, often rich in Fe-oxide. Thinner (up to 5–6 cm) and harder than the caliche crust found in the Río Bec region, it provided naturally flat stones suitable for expedient hammerstones and other pounding stones (Figure 10). Speleothems and fracture fills, resulting from the precipitation of large calcite crystals within fractures, dissolution voids, and caves, were occasionally used in tool production, although they cannot be linked to specific tool types. Nodular chert, found locally in *sascab* deposits, served for producing cutting and scraping tools. However, most formal chert implements were likely made from nodules sourced elsewhere, possibly in the nearby Puuc Hills (Masson and Peraza Lope 2014; Rovner 1981).

Far from being a substitute material for toolmaking, limestone was a versatile material, valued for its workability, abrasive properties, and other potentialities. However, this does not imply that its affordances were the sole driving force behind its selection. As discussed elsewhere, toolmakers' material choices could have been influenced by various nonpractical concerns, including cultural values (Andrieu 2009, 2013; Horowitz 2022; Kovacevich 2017) or conceptual associations with the sacred and potentially dangerous underworld (Brady et al. 1997; Brady and Rissolo 2006). Still, the correlation between specific limestone types and specific tool types reflects deliberate and informed choices. As in other contexts, the evidence suggests that Mayapan toolmakers "did not indiscriminately choose any rock type, or even any rock within a rock type, to use as a tool" (Hayden 1987:13).

Learning with limestone

Taken together, these case studies demonstrate that, for those who worked with it, limestone was not one, but many stones, each with its own properties and possibilities. These properties emerged through specific actions and interactions: the strike of a pick against the bedrock sending vibrations through a human body; the slow combustion of wooden logs gradually heating *chich* stones and altering their chemical and physical structure; or the attentive eye

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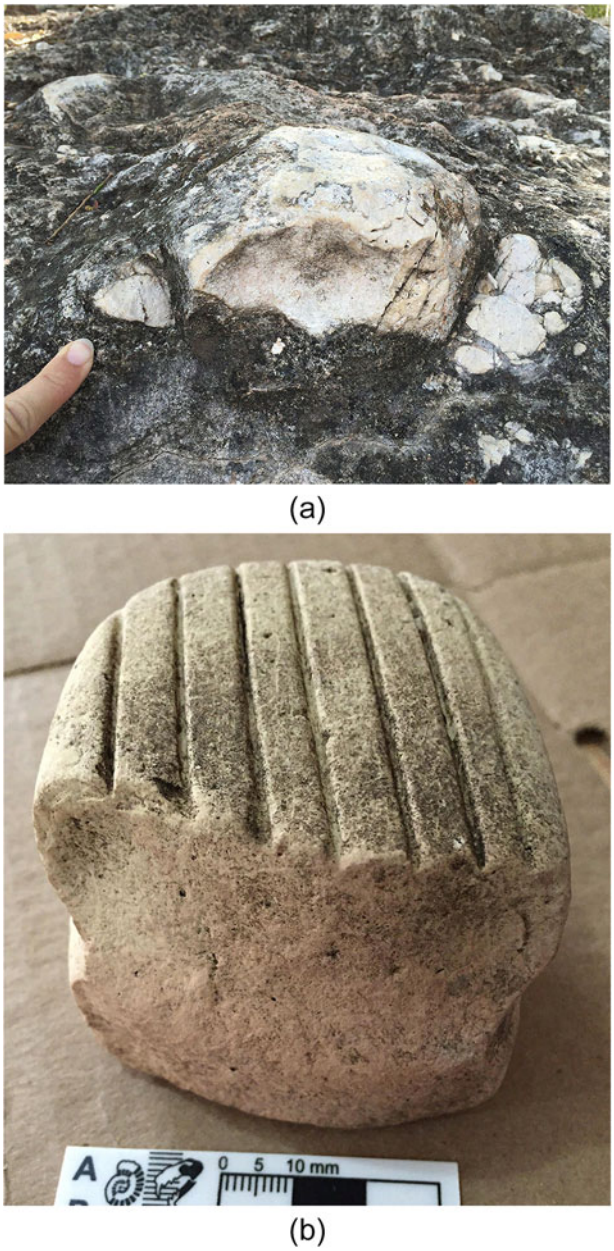


Figure 9. (a) Subrounded pseudoclasts of *piedra dura* from an extensively weathered outcrop in the vicinity of Mayapan; and (b) an example of a smoothing/flattening tool made from this type of fine-grained limestone. Photographs by B. Glumac.

and hand perceiving the countless small grains that make up a boulder. It was through such interactions that people came to recognize the properties and affordances of a stone: its hardness and ability to be cut into square blocks; its purity and ability to decompose into high-quality lime; or its graininess and ability to grind and withstand abrasion. Tracing the emergence of these properties through acts of working and sensing illuminates not only the choices that guided the selection of specific stones and technologies but also the practical, perceptual, and relational knowledge necessary for efficiently sourcing, extracting, and processing limestone materials.

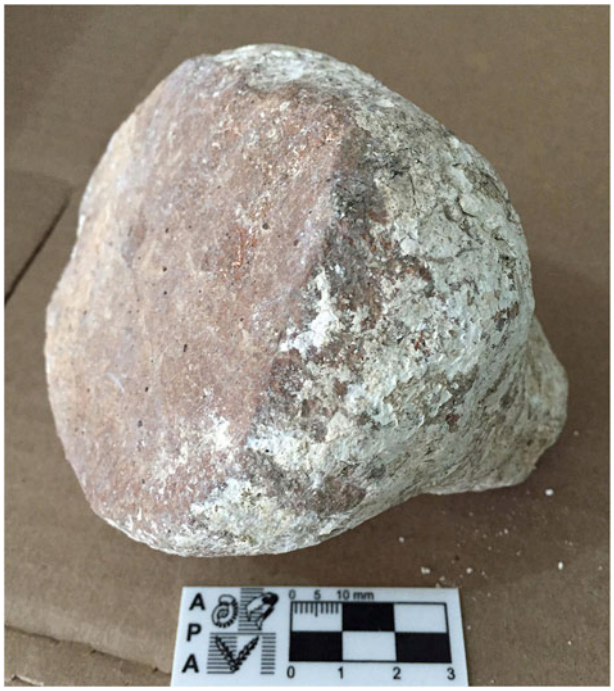


Figure 10. A pounding tool from Mayapan made of well indurated caliche crust. Photograph by B. Glumac.

In studies of ancient stone technologies, the relational properties of stones and the ways in which people came to perceive and skillfully respond to them rarely come into consideration. Studies of *chaînes opératoires* provide valuable insights into production sequences and the specific choices that guided them (Lemonnier 1992; Schlanger 2005). By examining the materials, techniques, tools, gestures, and contexts of a particular technology, they also have the potential to reveal how these choices were materially, socially, and culturally informed and effective (Dobres and Hoffman 1999; Porqueddu et al. 2023; Sillar and Tite 2000). But they rarely shed light on how people came to know how to locate source areas, identify suitable materials, select appropriate techniques and tools, and perform the right gestures at the right moment. In addition, evidence pointing to past craft-learning experiences remains elusive, especially within Maya and Mesoamerican contexts (see, however, De Lucia 2010; Knight 2017). Yet, by mapping production spaces and tracing the movements of individuals within and between them, we can gain a clearer view of craft-learning contexts. Combined with ethnographic data and practitioners' accounts, these insights allow for a more articulated discussion of how people learned their craft.

Becoming attuned to limestone

One key element emerging from these case studies is that limestone procurement depended on the ability to read the land, its geomorphological features, and what they revealed about the bedrock variability. Even in landscapes dominated by calcareous formations, suitable outcrops were not uniformly distributed. The location of many quarries at Río Bec—atop interfluves, where the caprock was hard and thick

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enough to support large-scale block production—and the location of many kilns in the Puuc—near hillsides, alongside or directly on top of outcrops rich in *sakel bach tuunich* (the highest grade of lime-quality limestone)—reveal a deep familiarity with the geological environment. In both contexts, there is also evidence of strategic use of natural features. Río Bec quarry workers, for example, exploited pre-existing fractures to facilitate stone extraction. In the Puuc, kilns were often excavated into the slopes of bedrock outcrops, taking advantage of the stability and heat retention provided by the bedrock walls. Such choices, however, reflect more than technical know-how.

Choosing where to extract stone or burn lime was not just about locating suitable outcrops. It also involved a range of considerations, including territorial dynamics (e.g., land control and use), cost-efficiency (e.g., proximity to construction sites, consumption centers, or sources of wood and water), and practical concerns (e.g., quarry reuse potential or risk mitigation with regard to smoke pollution and bonfire-related injuries; see Seligson et al. 2017c for further discussion of the trade-offs and dangers associated with lime production). Similar factors likely guided the selection of limestone boulders for toolmaking (Dahlin et al. 2011; Pujol Pizà 2022). In terms of knowledge, this implies that obtaining stones for building houses, producing lime, or making tools was not just about knowing the land and its lithological heterogeneity but also about understanding how to navigate inhabited, socially constructed landscapes. Moreover, given the animated and active nature of the landscape and its components in Maya worldviews (Grauer 2020; Henderson and Woodfill 2024), extractive and potentially disruptive activities likely necessitated ritual negotiations and the ability to perform appropriate ceremonies and offerings.

Engaging with limestone involved two-way relationships not only with the landscape and the other-than-human beings that animated it but also with the material itself. As each case study illustrates, especially the analysis of Mayapan's limestone tool repertoire, Maya communities had access to a variety of limestones and recognized variations between them. While we cannot know all the criteria that made a specific type of limestone suitable for a given task, its perceptible attributes played a role in determining what it could do, or afford. Recognizing, making sense of, and working with material properties is fundamentally a perceptual process—one grounded in bodily and sensory experience (Ingold 2010; Malafouris 2013; Marchand 2010; Sennett 2008). This process is also bi-directional. Materials like stones do more than vary in their visual, tactile, and other observable qualities; they also provoke different ways of thinking and acting (see, e.g., Weedman Arthur 2021). By *feeling* stones and *thinking through* their embodied minds, skilled practitioners do not just recognize material qualities and affordances; they also develop taxonomies that capture their sensations and perceptions.

Ticul potters' taxonomy of locally available limestones (Arnold 2018), for instance, reflects more than an awareness of limestone's versatility. Names such as *chak tok' tunich* (red hard rock), *hi' tunich* (crystalline rock), or *tunichil' aktun* (rocks in natural caves) speak of a multisensory familiarity cultivated through repeated, embodied engagement. Similarly, Mayapan toolmakers' use of limestones with varying textures likely reflects more than abstract representations passively transmitted across generations. Textural variations could be physically experienced through touching more-or-less grainy surfaces, observing slightly nuanced colors (from gray or white to tan and pale brown), or noticing the presence of inclusions. Weight, sound, and vibrations may also have played a key role in determining porosity and detecting potential flaws and impurities. Likewise, Río Bec quarriers and northwestern Yucatan lime producers probably distinguished between stones that exhibited crystalline or non-crystalline textures, possessed distinct colors, felt hard or soft when struck, or sounded clear or dull. Rather than being intrinsic, such characteristics emerged through task-specific interactions and within specific contexts.

Developing a "sense" of stone and acquiring the sensorimotor abilities needed to perceive its qualities and possibilities take time and practice (Leitch 1996; Paton 2015; Sciuto 2023; Stout 2002; Weedman Arthur 2018). People learn to work with stone not just by observing and imitating others but also by doing, and doing again. Drawing on ethnographic fieldwork in the limestone quarries of Aramel (Syria), Bessac et al. (1997) describe the several-year process through which individuals transitioned from novice to proficient quarry workers. While these observations cannot be directly transposed to other historical or cultural contexts, they vividly illustrate what many studies have shown: perceptual and gestural knowledge has to be learned by both the body and the mind. This requires training, often with the support of "scaffolding" strategies (Ferguson 2008) or "legitimate peripheral participation" (Lave and Wenger 1991). Bessac's work further shows that quarries were not simply places where novice practitioners progressively acquired task-specific skills but also important arenas for social participation and identity formation (see also Leitch 1996; Stout 2002; Talib 2010).

Working and learning together

Quarries, as learning environments, offered ample opportunities for novices to progressively master the skills needed to become competent limestone workers. It is likely, however, that their learning journey began before participation in quarrying activities and extended beyond the confines of quarries or other limestone-working locales. In places such as Río Bec, where limestone was extracted primarily for house-building activities, quarries were not isolated but formed part of the daily landscape, or "taskscape" (Ingold 1993), of rural dwellings and their residents. Without a clear division between the domestic and productive spheres, it can be assumed that learning was embedded within the rhythms of everyday life and often began through observing ongoing activities in and around the household, including in quarries. Río Bec's quarries can thus be envisioned as lively, bustling places where skilled stone-workers labored alongside and guided less-experienced kin, while intermittently engaging with family members and relatives working nearby. As sources of materials essential to various activities, quarries likely also functioned as "boundary objects" (Wenger 1998:106), or spaces that connected distinct experiences and promoted reciprocal learning.

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Likewise, constructing or attending lime kilns on the hilly peripheries of the settled and cultivated lands of the Puuc fostered interactions among individuals pursuing varied tasks. During the Late and Terminal Classic periods, much of the arable land would have been cleared for agriculture, making hillsides the primary source of wood fuel for lime production and activities such as cooking and pottery firing. The hillsides were likely familiar landscapes for many individuals gathering wood fuel, possibly coordinating their efforts, and exchanging information about the wood they used—which species, sizes, and levels of maturity burned the hottest for the longest, or the effects of weather on fire-related tasks. Developing such knowledge was crucial for those who produced lime since, as experimental studies demonstrate (Seligson et al. 2017b), selecting the right fuel and ensuring dry conditions were critical for successful burns. With lime production demanding at least 20 hours of sustained high-temperature burning, even a brief downpour could compromise the process. Although it remains unclear whether lime production was a seasonal or year-round activity, the need for dry conditions during burning suggests that lime kilns were mainly used during the dry season.

Becoming attuned to seasonal and environmental cycles was central to the organization of household work, but so too was the ability to navigate the intersecting and overlapping rhythms of the multiple domestic and economic activities in which households engaged, and with which limestone extraction, lime preparation, and tool production were intertwined. In the three regions considered, these practices appear to have been integrated into household-based economies, without strict elite oversight. They allowed households to meet their own needs and possibly engage in part-time and small-scale production of goods for exchange. Although it cannot be excluded that local elites received some of this production, and further evidence is needed to assess its scale, one can imagine a "lime person" (Martin 2012) at the local marketplaces, trading various textural and aesthetic grades of lime for a range of dietary, craft, and other purposes (Seligson and Parker 2026). Similarly, local markets may have provided a way for households around Mayapan to trade limestone boulders, either pre-shaped or already worked into tools. Evidence from Late Classic Buenavista del Cayo, in Belize, further suggests that part of this production may have taken place in marketplaces (Cap 2020, 2021).

The unstable nature of lime, the weight of stone objects, and challenges associated with their storage and transport may have limited the distances over which these products circulated. Nevertheless, producing and exchanging surplus limestone products would have enabled some households to maintain economic stability and strengthen social ties within local networks (Dahlin et al. 2011:86; Horowitz 2022). Such practices were likely incorporated into the broader set of productive activities in which Maya households engaged as part of multi-crafting strategies (Alonso Olvera 2013; Inomata 2007; Masson et al. 2016, 2020; Widmer 2009). Multi-crafting strategies also reinforced intrahousehold cohesion, since it required the collective mobilization and coordination of labor and expertise among household members. Within such contexts, where the boundaries between practices were more porous than generally assumed (Gillot and Halperin 2019), novice producers could learn from individuals with varied expertise, experiment with different materials and techniques, and develop cross-task abilities. This, in turn, suggests that limestone-working knowledge could move across domains of practice, with individuals proficient in multiple crafts potentially acting as "brokers" (Wenger 1998:108), or agents facilitating connections between distinct forms of making and knowing.

Conclusion

This paper explored how the inhabitants of the precolonial Yucatan Peninsula engaged with calcareous substances. While craft studies often center on the relational configurations from which a specific category of product or producer emerged, we instead examined the connections woven around a specific substance and how these connections enabled the emergence of diverse categories of materials and producers. By following limestone through multiple production processes and individuals through varied learning experiences, we showed that (1) materials commonly labeled as "limestone" in archaeological literature might not have been perceived as a singular, undifferentiated entity, and (2) activities traditionally considered as "unspecialized" occupations involved specific knowledge and skills, which required not only time and practice to be acquired but also repeated interactions with both material elements and social actors.

Focusing on the relationships forged with and around limestone also illuminates aspects often overlooked in craft-specific studies, notably the sociomaterial dynamics through which knowledge moved within and across communities of practice. While such studies typically frame knowledge transmission as a top-down process, where knowledge is passed on between generations, from skilled practitioners to less-experienced learners, we suggest that learning also unfolded through more horizontal and reciprocal interactions, particularly in domestic settings. Thinking of learning as a process that occurred at the interface of distinct but interrelated practices offers a glimpse into how practice-specific perceptions and understandings converged and transformed into shared, collective knowledge. This does not imply that the transmission of limestone-related knowledge did not contribute to hierarchical relationships and social differentiation within and among households or categories of producers. However, the specific ways in which these dynamics operated and shaped past identities and lives remain poorly understood, offering fertile ground for future exploration.

Data Availability Statement. The data that supports the findings of this study can be provided by the authors upon reasonable request.

Competing Interests. The authors declare none.

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