Extraction strategies and technological tradition at late pre-Hispanic quarries, southern Peru (ca. 1000–1532 CE)

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Abstract
Studies of Inka quarry operations have focused on large-scale quarries in the Inka imperial heartland, with emphasis on finishing techniques and geochemical sourcing. To assess diachronic variation in the technological organization of late pre-Hispanic building stone extraction, we compare survey data from the Chuquibamba District (Arequipa Region) – an Inka provincial context – and the Sacred Valley, a vital part of the Inka imperial heartland. Our sample (n=41) includes small- and large-scale quarries that supplied material for Inka state and elite projects as well as local vernacular construction during the Late Intermediate Period and Late Horizon (ca. 1000–1532 CE). To chronologically contextualize quarry sites, we assess use periods based on scale, diagnostic technology, and building stone provenance. We deploy a multilinear approach using archaeological data, colonial chronicles and dictionaries, and analogies to ethnographic and modern cases to analyze the knowledge, decision-making process, and mechanics that facilitated material extraction. The results demonstrate that Inka building stone quarrying techniques developed out of widely shared local vernacular knowledge and practice. This study articulates a new approach to late pre-Hispanic Andean architecture while providing a case study to evaluate the relationship between political organization and technological systems.

Keywords: late pre-Hispanic Andes; regional archaeology; quarries; raw material procurement; construction; logistics; technology; labor; monumentality; vernacular architecture

1. Introduction

Changes in political organization have recurrently accompanied the emergence of novel technologies. This is expected in state societies to the extent that *how* distinctive technologies are developed, or where they come from, is often left unexamined. Technological experimentation and innovation may occur during times of rapid change as a response to stress, such as during intermittent periods following state collapse (Schiffer and Skibo 1987:598; Lane 2009; Lechtman 1993:249). Equally, technological change can catalyze economic intensification and political centralization or be developed to support these shifts (Childe 1929; Pauketat and Alt 2005; Wittfogel 1957; Xie et al. 2015, 2021). Given the pivotal role that technologies have played in the maintenance or transformation of social order, aggrandizers have depended on and sought to control technologies for the legitimization of authority and the functioning of institutions (Carter 2007; Costin 1989; Swenson and Warner 2012). Rather than transforming an entire system to accommodate increases in scale and complexity, technological change and innovation are necessarily built upon existing practices, knowledge, and traditions that can be more resistant to change (Lechtman 1993; Schiffer and Skibo 1987).

Political centralization is often associated with changes in construction practices to produce monumental architecture and large-scale infrastructural systems (e.g., McCurdy and Abrams 2019; Murakami 2014; Moore 2021; Sinopoli 1994; Trigger 1990). An activity foundational to all construction operations regardless of scale, material procurement provides a case to examine diachronic change in the organization of technological systems under shifting political conditions. To this end, we evaluate building stone extraction in the late pre-Hispanic Andes (ca. 1000–1532 CE). Specifically, we compare survey data collected from two regions of the southern Peruvian highlands: the Chuquibamba District (Arequipa Region) – located in the former Kuntisuyu province of the Inka Empire – and the Sacred Valley, a vital part of the Inka heartland. Our sample (n=41) includes data from surveyed sites and published data encompassing small- and large-scale quarries[3] that supplied stone for Inka state administrative and

[3] Whereas the modern usage of the term "quarry" generally refers to a place where subterranean rock is mined, this study takes a broader definition of quarry sites "as the material remains from the various processes involved in the exploitation of [a stone resource]" (Heldal and Bloxam 2008:6). Indeed, "quarry" is the closest translation

royal projects as well as vernacular construction in local (non-Inka) villages during the Late Intermediate Period (LIP, ca. 1000–1400 CE) and Late Horizon (1400–1532).

Herein, we posit a new account of the development of Inka construction technology by testing the existing model of Inka quarrying as labor-intensive and highly centralized, oriented toward elite consumption, and divergent from non-state construction practices. Foundational to this study is a view of technology as the ways in which humans solve practical problems through collaborative effort and embodied knowledge that accumulates with intergenerational transmission (Dobres and Hoffman 1994; Ingold 2013; Lemonnier 1992; Moore 2021; Schiffer and Skibo 1987). Rather than simply comparing the products of technological acts, we focus on the *process* of material extraction. This approach allows us to isolate and analyze the gestures, knowledge, and logistics implicated in diverse production contexts.

2. Background

Where did Inka architecture come from? Given the apparent dissimilarity between the Inkas' cut-stone walls and the "rustic" masonry of neighboring non-Inka groups, scholars have commonly attributed the development of Inka architecture to the continuity of antecedent state traditions (Hyslop 1990:20–25; Gasparini and Margolies 1980:7; McEwan 2006:98; Protzen and Nair 1997:166; Rowe 1946:229) and the creative genius and personal tastes of elite actors (Nair 2015; Niles 1999). This stems partly from a tacit acceptance of ethnohistoric accounts that credit the ninth Inka sovereign, Pachakutiq, with the invention of Inka architectural canons when he purportedly razed and rebuilt the capital Cusco (Farrington 2013; Hyslop 1990:25; ICOMOS 1982:2; Kendall 1985; Kubler 1952:2; Rowe 1946). According to this account, Pachakutiq emulated stonework at Tiwanaku, a ceremonial center in the Titicaca Basin that was abandoned long before his arrival (Cieza de León 1864[1553]; Sarmiento de Gamboa 2007[1572]). However, the possibility of direct technological transmission is unlikely given the centuries-long gap between the fall of the Middle Horizon states (ca. 900–1000 CE) and the consolidation of the Inka state (ca. 1300–1400) (cf. Hyslop 1990:21; Protzen and Nair 1997:147).

In comparison with the scholarly attention on elite and monumental architecture, relatively few studies have examined the relationship between Inka state construction practices and the vernacular architectural traditions of neighboring ethnic groups that lived alongside the Inkas (e.g., Kendall 1976, 1996; Rowe 1944:24). Where non-elite and vernacular masonry has been described, it is usually categorized as "rustic" and composed of fieldstones, naturally occurring loose rocks found on the ground (Agurto 1987; Farrington 2013; Gasparini and Margolies 1980; Hyslop 1990; Kendall 1976, 1996; Moore 2021; Niles 1980). This reflects an implicit perception that stone was only quarried for large-scale state-sponsored construction projects. In contrast, our research indicates that many late pre-Hispanic buildings traditionally classified as "rustic" are actually built of a combination of fieldstones and quarried stones (Cruz and Earle 2020; cf. DeMarrais 2001; Guengerich 2018). These materials were retouched to varying degrees to serve the desired purpose and improve fit within a wall.

The focus on elite Inka architectural styles has precluded a more robust anthropological understanding of architecture as part of a broader technological system. While the inspiration for Inka architectural forms may well have come from older aesthetic repertoires, this alone cannot account for the unique set of knowledge and practices that informed Inka construction technology (Protzen and Nair 1997). Instead, technologies develop gradually as a result of quotidian problem-solving, building on a foundation of intergenerational knowledge (Schiffer and Skibo 1987). In light of these observations, here we reframe late pre-Hispanic architecture as resulting from this dynamic process of tradition, experimentation, and innovation (cf. Moore 2021).

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of *cantera*, the word Spanish chroniclers used to refer to the Inkas' building stone sources (e.g., Betanzos 2004[1551–1557 Part I, Chapter XVI]:114).

In the same way, Inka architecture has tended to be viewed as an energetically intensive expression of elite power. Gasparini and Margolies exemplify this position where they explain fine Inka masonry as the pursuit of "the most difficult means of achieving an easily attainable result. *There is no worthwhile rational explanation when one suspects that they enjoyed difficulties*. … What appears absurd to us today may have had a mystical content. But to our understanding, *only the excess of human energy resulting from the mit'a* [corvée labor] *could explain the number of works that required great devotion of time and manpower for their execution*" (1980:324–325, italics added). The discourse around Inka architecture as "irrational" and energetically wasteful can be traced back to early colonial accounts (Dean 1998, 2011). While the first chroniclers marveled at Inka engineering feats and construction technology (Cieza de León 1864[1553]; Pizarro 1921[1571]; Sancho 1917[1534]), by the mid-1500s, Spaniards began to cast the expenditure of time and energy in the movement and fitting of stones as a product of cruel despotism, surplus labor, and the influence of "diabolic forces" (Acosta 1880[1590 Book VI, Chapter XIV]; Cobo 1990[1653]:228).

As the initial stage of construction, the quarrying of blocks for use in fitted stone masonry has been framed similarly. Existing studies tend to portray Inka quarrying as a labor-intensive expression of elite power without local precedent (deFrance and Olson 2013; Ogburn 2004; Outwater 1959). This is in part because the majority of published data on Inka quarrying derives from three quarries: Kachiqhata, Rumiqolqa, and Waq'oto. Each of these quarries is known to have supplied material for high-profile construction projects; is located several kilometers' distance from construction sites; and is equipped with infrastructure including stairways, ramps, platforms, and workers' lodges (Béjar 2003; Miranda and Zanabria 1994; Protzen 1983, 1985, 1993; Tovar 1996). Studies of these quarries have generated high-resolution, site-specific data, facilitating analyses of labor in the production of elite architecture and monuments at large quarry sites. This, in turn, has produced a model of Inka quarrying as generally large-scale, intensive, and centrally managed.

In contrast, the results of our fieldwork demonstrate that most quarries strongly deviate from this model. Even at quarries that supplied material for elite projects, such as Chinchero, Machu Picchu, and Saqsaywaman, quarry workers worked in an opportunistic manner by sporadically exploiting numerous outcrops within or in close proximity to the construction site, supported by minimal physical infrastructure. This way, the insights generated by site-specific quarry studies have likewise revealed a complementary need for comparison and contextualization within a broader regional and temporal context. How standardized was Inka quarrying practice? Did non-state groups quarry for vernacular construction? How did quarrying technology change over time? Responding to these questions, this study takes a macro-scale analysis of multi-regional, diachronic data to develop a new model of late pre-Hispanic building stone extraction in the southern Peruvian highlands.

3. Geology

The quarries discussed in this paper are located in two regions of the southern Peruvian highlands (Figure 1). Those of the Chuquibamba District (Arequipa Region) are found in the Chuquibamba and Cotahuasi Basins, where Triassic and Quaternary volcanic activity created vast tablelands broken by deep canyons and valleys. Eruptions from the Firura, Solimana, and Coropuna volcanoes formed volcanic cones belonging to the Barroso Formation that extends over the tablelands of the upper Chuquibamba and Cotahuasi Basins. Other sources of igneous rock are present in the upper valleys of Chuquibamba and Pampacolca, where the Huaylillas Formation harbors tuff, rhyolite, and dacite (Olchauski and Davila 1994).

While volcanic deposits dominate the Chuquibamba District, the Cusco Region is more varied. Particularly to the north and southwest of Cusco, extensive sedimentary and metamorphic deposits of alluvial and fluvial origin contain conglomerates, sandstone, and quartzite (Carlloto et al. 1996). Along the hills and slopes of the Sacred Valley, these materials overlap with the wine-colored igneous rock of the Pachatusán Formation, including andesite, dacite, ignimbrite, basalt, and tuff. The Pachatusán Formation exhibits vertical geological strata between volcanic and sedimentary deposits caused by basin inversion, uplift, and contraction (Carlotto et al. 1996:65). Basin inversion results in advantageous conditions for quarrying by creating linear fractures in deposits that can be exploited to easily extract rock in slab or block form.

The Rumicolca Formation occurs sporadically throughout the Cusco Region's valleys and alluvial terraces as small discontinuous bodies of lava produced by linear volcanic fissure vents (Mendivil and Davila 1994). Rumicolca deposits are composed of shoshonite, a potassium-rich variety of andesite that is particularly suitable as building material owing to its porphyritic texture (Carlotto and Cardenas 2003). Extrusive deposits of the Rumicolca Formation are readily identifiable as small patches of wrinkled outcrops ranging from 0.5 to 5 km^2. These deposits frequently exhibit a distinctive structure known as columnar jointing, which forms prismatic blocks or columns and intersecting fractures as lava cools and contracts. Columnar jointing also occurs in sedimentary formations heated by volcanic events. Like basin inversion, columnar jointing produces favorable conditions for extraction. Extrusive deposits of the Rumicolca Formation in the Cusco-Huacarpay Basin are found at Oropesa, Raqchi, Rumiqolqa, Tipón, and Waq'oto (Carlloto and Cardenas 2003). In the Urubamba Valley, Rumicolca deposits occur along the geological fault delimiting the Altiplano and eastern Cordillera at Qaqaqollo, Huarocondo, Huch'uy Qosqo, Maras, Moray, Pisaq, and Qoriqocha (Carlloto et al. 1996). There is evidence of pre-Hispanic quarrying activity at nearly all of these sites, attesting to the favorability of Rumicolca andesite for extraction and construction.

4. Methods

4.1 Survey and reconnaissance

This research integrates evidence compiled over the course of three field projects carried out in 2017, 2019, and 2022, respectively. In spite of the differing research methods and objectives deployed by each project, the resultant data on quarry sites are mutually compatible for the purposes of this study. For the first project, we reconnoitered the Chuquibamba District to identify the sources of construction material used at Maucallacta. Maucallacta is the largest of numerous Inka ceremonial centers and shrines built to propitiate Mt. Coropuna, the principal *apu* (mountain deity) of the Kuntisuyu peoples (Cieza de León 1864[1553]; Guaman Poma 2009[1615]; Ziółkowski 2008). We designed our research to test the hypothesis that the Inkas transported exotic (non-local) stone to build Maucallacta, given the religious significance of the regional geology (cf. Ogburn 2004).

For reconnaissance, we targeted geological formations expected to harbor materials suitable for Inka construction, namely igneous rock, based on the Inkas' purported preference for andesite in the imperial heartland (Hunt 1990). We also limited reconnaissance to areas accessible via paved roads. Using these parameters, we created a predictive model in ESRI ArcMap to identify areas of high potential, which were primarily located in the *puna* (high-altitude grasslands). The *puna* of the Chuquibamba District is occupied ephemerally by transient herders and has experienced no significant urban development throughout its history. At 3,700 to 4,000 masl, the Chuquibamba quarries (n=8) are in nearly pristine condition compared with the Cusco Region, where urban development and modern extraction have damaged and cleared many pre-Hispanic quarry sites. This well-preserved provincial sample allows us to reconstruct patterns of extraction activity outside of the imperial heartland.

In 2019, we executed the second project, involving a survey of Late Intermediate Period and Late Horizon sites identified during regional surveys of the Sacred Valley (Covey 2003, 2014; Kendall et al. 1994). The Sacred Valley encompasses a stretch of the Urubamba-Vilcanota River Valley running roughly from Ollantaytambo to Pisac, arguably the most important region of the Inka heartland after the Cusco Basin (cf. Garcilaso de la Vega 1989[1609]:303). It is the site of the highest concentration of Inka royal estates and monuments in the empire, where thousands of *mitmaqkuna* (colonists) were settled to work on state projects involving landscape engineering and intensive maize agriculture (Covey and Amado 2008). The Sacred Valley was occupied ephemerally until the beginning of the LIP when migrant groups established villages on hilltops and ridges; they continued to live there during the Inka occupation of their territories (Covey 2006, 2014; Kosiba 2010). This region remained vital to the Inka political economy and sovereign ideology leading up to the Spanish invasion.

The 2019 project measured variation in late pre-Hispanic buildings, terraces, tombs, and quarries at LIP and Late Horizon sites previously registered by systematic regional surveys (Covey 2003, 2014). In addition to conducting site surveys, we reconnoitered the Chongo Basin and the Sacred Valley floor between the towns of Calca and Pisac, resulting in the identification of 12 quarry sites. A subsequent phase of the project was carried out in 2022, expanding the study area west toward Yanahuara; this work registered 11 additional quarry sites. For the present analysis, we present data gathered during the 2017, 2019, and 2022 survey projects in addition to evidence from the royal Inka estates of Ch'eqoq and Chinchero to the south of the Sacred Valley, which we reconnoitered outside of the formal survey work. Cumulatively, this work presents evidence from 31 quarries that had not been reported by previous investigations.

4.2 Chronological and cultural affiliation

Quarries are zones containing contiguous or related evidence of stone extraction and reduction activities, which can be either dispersed or localized depending on the geology and topography. They contain the following components: geological source (e.g., outcrop); artifacts and refuse (i.e., débitage, products, tools); and work areas and associated infrastructure (cf. Heldal and Bloxam 2008:6–7). As the leftover byproducts of a continuous sequence of on-site activities, it is difficult to separate quarries into discrete, identifiable events (Bloxam 2011:149–150; Ericson 1984:2). Evidence of extraction is typically overlapping and contiguous, as more recent extraction events destroy and obscure traces of antecedent events, preventing the formulation of fine-grained quarry chronologies (cf. Ericson 1984:2).

To deal with this methodologically challenging feature class, we isolated extraction from the material source as the object of analysis. This is in contrast to existing studies that focused on describing block finishing techniques, infrastructure and spatial organization, and provenance. As quarrying is a subtractive process, outcrop scarring (e.g., expanded fissures, ventral scarring, stepped fractures) constitutes reliable evidence of pre-Hispanic quarrying and facilitates the reconstruction of extraction sequences. Spoil piles, including débitage and pre-form blocks, index quarry activities but are inherently incomplete registers, as technicians continually disposed of refuse and removed products for use in construction. Moreover, this evidence is sometimes absent due to local site formation processes, including erosion along steep slopes and the removal of materials in later periods.

Even in this palimpsestic context, it is possible to distinguish extraction events associated with cultural groups or periods. The most readily apparent correlates of pre-Hispanic extraction include immediate proximity to pre-Hispanic sites or features and the absence of diagnostic technologies introduced during the colonial and modern periods, including metal chisels and hammers, mechanical tools, and dynamite (cf. Hollowell 1987). Nevertheless, it is notable that masons working at Waq'oto purportedly continued to use hammerstones into the early 20th century when metal tools became more widely available (Tovar 1996:24). This fact problematizes the automatic attribution of lithic tool use in quarrying and stonework to the pre-Hispanic era (cf. Nair 2007:51). On the other hand, the association between quarry and construction site is complicated where quarries are located at a distance from construction sites or were used continuously from pre-Hispanic to modern times. The latter is true at many important pre-Hispanic quarries named in historical documents. At Waq'oto, Ch'eqoq, and Rumiqolqa, in particular, the destruction caused by modern activities has prevented an accurate reconstruction of pre-Hispanic quarrying operations.

This way, multiple lines of evidence must be evaluated to identify and interpret pre-Hispanic quarry sites. We rely on situational evidence such as scale, spatial association with archaeological features and artifacts, diagnostic technology; outcrop scarring; and how these variables relate to one another. While we cannot directly date quarries, the presence of weathering, oxidation, and lichen on an outcrop or detached piece serve as indications that fractures are not immediately recent. As for provenance, archaeologists have used petrographic and geochemical analyses to source materials used in pre-Hispanic structures (Hunt 1990; Janusek et al. 2013; Ogburn 2004; Ogburn et al. 2013). For our purposes here, the macroscopic comparison of materials has been sufficient to identify the primary destination of quarried materials.

4.3 Determination of use

Recurrent similarities in quarry form, organization, and distribution allowed us to discern patterns of late pre-Hispanic building stone extraction. Through comparison between contexts, such patterns facilitate the identification and interpretation of quarry sites in the field. Typically, Inka state quarries are distinguished from vernacular quarries by the scale of extraction. The Inkas organized large-scale quarry operations throughout their empire to supply materials for administrative buildings, roads, and other infrastructural works. For these projects, rather than procuring a small amount of material from many dispersed sources, it would have been more efficient to plan the extraction of large volumes from a smaller number of sources. Although sources close to construction sites were preferred, the location of large-scale quarry sites ultimately depended on topographic and geological conditions. In contrast, vernacular quarrying tends to be lower intensity, dispersed, and located immediately proximal to the construction site. Non-Inka villagers in the Sacred Valley coordinated to construct infrastructural works such as canals and defensive walls, but they did not build monumental architecture (Covey 2006:91). Nevertheless, it is significant that quarries exploited by non-state groups often closely resemble quarries used for smaller-scale Inka projects.

We deploy a heuristic typology based on the determined use of the building material (see Supplementary Materials), comprising vernacular (n=9), state (n=11), and elite quarries (n=14). While larger quarries likely served multiple projects over the course of their use lives, types are generalized to reflect the most prolific use of extracted material. Vernacular quarries are those exploited for local vernacular construction, including houses, tombs, and terraces. State quarries are typically small and localized, providing material for the construction of state infrastructure, including waystations, storehouses, roads, and outposts. Lastly, elite quarries are associated with royal building projects, namely estates and monumental works. We reference this typology to contextualize the data presented below.

4.4 Analogy and linguistic evidence

In this study, we draw analogies between the archaeological record and modern quarrying activity to reconstruct the activities carried out at pre-Hispanic quarry sites. Rather than seeking to use modern cases to reconstruct an entire technological system, we follow Roux's approach, which is founded on the recognition that material constraints are constant and independent of historical context (2007:171). Comparing archaeological remains with outcrop morphologies at modern quarries allows us to extrapolate some of the knowledge, procedures, and techniques deployed by pre-Hispanic quarry workers.

Our sources of analogy come from first-hand observations at three modern quarries in the Cusco Region, in addition to published work, including interviews with quarry workers at the Waq'oto quarry (Miranda and Zanabria 1994; Tovar 1996). Benavides' (2018) documentary video entitled *Los cortadores de sillar* provides a particularly useful source for analogy, illustrating how modern quarry workers extract volcanic tuff at the Añaswayq'o quarry (Arequipa Region). These sources show that despite their use of metal tools, modern quarry workers' extraction techniques still rely on some of the knowledge and practices evidenced at pre-Hispanic quarry sites.

We also integrate modern and archaeological evidence with historical and linguistic data to build an ethnoscience (after Marcus and Flannery 2001) of late pre-Hispanic quarrying technology based on an emic conceptualization of geology. Our linguistic data are drawn from historical Quechua vocabulary from Santo Tomás' (1560) and Gonçález's (1952[1608]) colonial lexica. According to Mannheim (1991), these lexica recognize the formal linguistic variation in their original spoken contexts. To contextualize semantic categories, we cross-referenced vocabulary using QichwaDic (dic.qichwa.net), an online database that integrates dialects from 36 digitized Quechua dictionaries.

5. Results

5.1 Late pre-Hispanic perspectives on lithic technology

Technologies are embedded within cultural systems such that technological choices are culturally determined (Gosselain 2011; Lemonnier 1992; Sillar 2000). We follow a holistic technological approach to reconstruct late pre-Hispanic quarrying activity as a technological system (*sensu* Shimada and Craig 2013). This approach contextualizes activities in relation to the cultural framework that structured interactions between humans, materials, and the environment. Rather than assume a default of modern extractivism, colonial historical documents and dictionaries help us conceptualize how emic understandings of geology shaped late pre-Hispanic quarrying technology. Specifically, historical and ethnographic evidence attests to a recognition among many Andean peoples that matter intrinsically harbors burgeoning life and vitality, whether dormant or actively manifest (Arriaga 1968[1621]; Cummins and Mannheim 2011; Sillar 2009). In this context, technology is not simply "action upon matter" (Lemonnier 1992:1) but rather an exchange or transaction between materials and technicians that results in their mutual transformation (Allen 2015; Janusek and Williams 2016).

In Quechua, a language used by the Inkas and their contemporaries, quarry worker or mason is translated as *ch'eqoq* or *ch'eqoqkamayoq*, and architect as *perqakamayoq* (Gonçalez 1952[1608]; Santo Tomás 1560). The suffix *-kamayoq* demarcates individuals occupying positions of authority or specialized ability and knowledge as possessing the creative vitality (*kamana*) of an action or object, such as walls (*perqa*) (Allen 2015; Salomon 1991, 1998). By accessing *kamana*, the technician manifested a transformation of matter that resulted in an enduring bond between the technician and the product (cf. Bray 2009). This transformation process is likewise indicated by Quechua's division of lithic materials according to their relation to humans. *Rumi* typically refers to a worked or individuated stone, as opposed to *qaqa*, which is the raw material in its natural state as a landscape feature (Gonçález 1952[1608]). This distinction and its relationship to the *kamayoq* implies that quarrying and stoneworking was a process of material conversion (Dean 2010), analogous to the Inkas' taming of "wild" (*purum*) lands by creating irrigated fields and terrace systems (Covey 2011).

Terminology describing the initial stages of extraction include *horqoy* or *horqonakuy* and *lliqquioi* (lit. to break or cut), while *ch'eqoy* and *kaninakuy* refer to the finishing stages of block fitting and joining (Gonçález 1952[1608]). The reciprocal suffix *-naku* in the words *horqonakuy* (lit. to extract or excavate) and *kaninakuy* (lit. to bite) suggests that both the technician and material were jointly implicated in the production process (cf. Allen 2015:29; Dean 2010; Swenson and Warner 2012). The requirement that rock actively participate – or be complicit – in the stoneworking process is illustrated in the story of the tired stone that wept tears of blood and refused to move farther while being dragged from the quarry to the construction site (Guaman Poma 2009[1615]:161; Murúa 1590, folio 7v). In the story, workers responded by respecting the stone's agency and leaving it in its place to be revered as a *wak'a*, a numinal agent corresponding to an object, person, or place.

Pre-Hispanic quarries were volatile places that demanded ongoing negotiation and transaction between humans and non-humans, where stone extraction could provoke encounters with numina.

Terms for "quarry" include *rumi mama* (lit. mother of stone) and *rumi chakra* (lit. agricultural field of stone) (Gonçález 1952[1608]), both having a generative, organic connotation related to biological reproduction. The Spanish chronicler Bernabé Cobo described four *wak'a* that were quarries or quarry débitage situated along the *siq'i* (ritual paths) surrounding Cusco (1956[1653 Book 13]). The quarry Curovilca was worshiped and offered sacrifices so that it would not be exhausted and the structures built from it would not collapse (Cobo 1956[1653 Book 13, Chapter 14]), suggesting that material extracted from a quarry retained an agentive bond with its source. Meanwhile, the *wak'a* Cugiguaman and Viracocha were zoomorphic and anthropomorphic pieces of quarry débitage that emerged during the extraction of stone for Inka construction projects (Cobo 1956[1653 Book 13, Chapters 13 and 14]). In the following sections, we explore how this recognition of stone as an active, lively material informed the development of lithic technologies and quarrying strategies.

5.2 Tools

To account for Inka stonework, Spanish chroniclers explained that Indigenous masons had used dark-colored river cobbles to pound stone into blocks (Cobo 1956[1653 Book 14, Chapter 12], 1990:229; Garcilaso de la Vega 1989[1609]:131; Polo de Ondegardo 1916[1571]:106). This claim is supported by the widespread presence of hammerstones at quarry sites and by Protzen's experimental work (1983, 1985). It is also corroborated by linguistic evidence: the only words listed as stoneworking tools in Gonçález's lexicon (1952[1608]) are hammerstones, defined as strong, hard, or heavy stones, sometimes siliceous and black in color. These include *salluq rumi* (lit. hard stone), *qollota*, *hiwaya*[4], and *wini*. *Wini* or *winininiq hiwaya rumi* is a stone "as hard as steel," an apparent acknowledgment that it matched the strength of metal tools (Gonçález 1952[1608]).

Despite their simplicity, hammerstones are remarkably efficient tools. The impact of a hammerstone generates shearing forces that detach flakes; the technician can control this force by increasing or decreasing the striking angle (Protzen 1985:173). While large, heavy hammerstones were ideal for extraction, splitting, and roughing out blocks, technicians used smaller stones (*qollota*) to finish blocks by gently pecking the edges (Protzen 1985:189). In accordance with this toolkit, we identified hammerstones of two size categories at quarries: 7 to 10 cm in diameter to be held in one hand and 18 to 24 cm in diameter to be gripped with two hands (Figure 2). Based on the stone extraction and reduction techniques observed in both Inka and local contexts, hammerstones were ubiquitous regardless of cultural or chronological affiliation.

For a cobble to serve as an effective hammerstone, its hardness must match or exceed that of the material to be worked. All hammerstones we recovered at quarry sites were either igneous rock (andesite or basalt) or quartzite (Mohs scale 7). Protzen notes that the morphology of a hammerstone is directly related to its efficacy, such that irregularly shaped hammerstones are ineffective at channeling energy and perform unpredictably in comparison with more balanced cobbles (Protzen 1983, 1985). For this reason, technicians preferred round river cobbles, but where river cobbles were scarce – as in the Chuquibamba *puna* – fieldstones were supplemented. In some cases, technicians modified hammerstones to accommodate their grip by flaking the tool as needed.

We recovered wedge-shaped pieces of reworked débitage at several quarries, similar to a tool Miranda and Zanabria (1994) reported at Waq'oto. Technicians likely inserted these angular shards (known in some parts of the Andes as *chilete*) into fractures to aid in separating material from an outcrop or splitting blocks (Benavides 2018). A wooden pole would have also helped dislodge large chunks of

[4] *Hiwaya* could refer to hematite, a nonmagnetic iron ore (Mohs scale 5.5 to 6.5) (Protzen 1993:173). Protzen reported two hematite hammerstones at Kachiqhata (1993:172), but we have not recovered this material at surveyed quarries. While pre-Hispanic quarry workers used hematite, it was not the predominant hammerstone material, given its relative rarity and comparable performance to more common quartzite cobbles.

stone during this process (cf. Ogburn 2013:50; Rowe 1946:225). Some modern quarry workers use this same combination of lever, *chilete*, and hammer to extract material longitudinally, working from the top of the outcrop (Benavides 2018). This constitutes one of the most common extraction strategies that we find at pre-Hispanic quarries, where technicians applied percussion to the top of the outcrop to detach material vertically from the rock face.

Contrary to some claims, channels found in blocks at some Inka quarries were not produced by pre-Hispanic workers to split rock but were created later using metal chisels introduced by Spaniards (Agurto 1987:121; Hollowell 1987:15). Instead, percussion marks bruised out around fractures are evidence that technicians split rock by applying direct percussion at a right angle to the striking platform (Protzen 1993:169). Other lithic tools with traces of use have been identified at quarries, including picks and polishing stones (Miranda and Zanabria 1994). This auxiliary toolkit would have been adaptively used in combination with hammerstones whenever deemed necessary or advantageous. Experiments using replicas of bronze tools from Machu Picchu show they are less effective than cobble hammerstones at producing Inka-style stereotomy (Gordon 1985; Gordon and Knopf 2006; Hollowell 1987). Thus, although the Inkas may have been experimenting with novel tools for stonework, these were not found to be effective enough to warrant the high cost of mass production.

5.3 Extraction techniques

Building stone extraction has not been examined in-depth by previous studies of Inka quarries, which have focused more on material sourcing, transportation, labor, and block reduction and finishing techniques (Béjar 2003; Bengtsson 1998; Harth-Terré 1964; Hollowell 1987; Hunt 1990; Miranda and Zanabria 1994; Ogburn 2013; Ogburn et al. 2013; Protzen 1983, 1985, 1993; Tovar 1996). Reorienting our focus to extraction techniques reveals the foundation of knowledge and skill shared by late pre-Hispanic lithic technologies. It also shifts the narrative away from reinforcing assumptions about state technology and toward understanding technology as part of a cultural system (cf. Flannery 1968). As Protzen observed of block reduction (1983, 1985), building stone procurement did not require large work crews to incessantly hammer away at unyielding material[5]. Rather, material extraction involved individuals or small groups strategically applying percussive force using a restricted tool kit in accordance with the unique morphology and physical properties of each geological deposit (Figure 3).

We identified four techniques that represent the repertoire of Inka and local vernacular quarrying: spalling, columnar extraction, induced rockfall, and boulder splitting. There also exist several variants, reflecting how these techniques were applied to distinct geological conditions and selection criteria (Table 1).

Spalling entails the direct and repeated application of percussive force using a hammerstone. To identify the internal structure and more effectively strategize extraction, this technique is first used to remove the cortex of the outcrop (Figure 4). Then, the technician would strategically spall the exposed rock to detach conchoidal or truncated pieces. In the final stages, spalling is used to split, reduce, and retouch detached material. Spalling involves striking at calculated angles and locations with the appropriate intensities and rhythms according to the geometry, hardness, porosity, and cleavage of the source material (cf. Protzen 1983, 1985). All other pre-Hispanic quarrying techniques are based on these same principles and gestures.[6]

[5] "*Thousands of stonecutters, alternating with one another uninterruptedly in pounding stones with other harder stones*, pulverizing the rock, achieved a great amount of work in less time and with greater ease than may be imagined" (Gasparini and Margolies 1980:321–324, italics added).

[6] Pit quarrying uses the same gestures and tools as spalling, so we consider it to be an application of the spalling technique to extract subterranean rock in massive and intrusive deposits. We did not register evidence of pit

A particularly effective application of spalling entails the direct application of percussion to the top of an outcrop to detach material longitudinally from the rock face, what we call vertical extraction. The resultant detached piece is a large truncated spall with a smooth ventral surface that can then be split into smaller pieces. This approach treats the outcrop as a lithic core from which flakes are systematically detached by striking the platform at the top of the outcrop and from platforms created by the removal of flakes.

Columnar extraction occurs at stratified deposits characterized by basin inversion or columnar jointing, the latter being particularly advantageous for material extraction because it contains regularly spaced parallel fractures (joints) that can be exploited to extract stone in blocks or sheets. Where massive outcrops with a vertical structure are quarried using this technique, the resulting outcrop can take on a stepped appearance (cf. Horowitz et al. 2021). In stepped columnar extraction, technicians extract blocks from the top of the outcrop and progressively down the face of the outcrop as cleavable platforms are created through the removal of material. The Inkas deployed this form of extraction for large-scale construction operations at Calca – a royal Inka settlement – and at the Challwane quarry in the Arequipa Region to build a waystation (Figure 5). Using modern tools, quarry workers continue to use this approach of working from the top down at the Añaswayq'o quarry (Benavides 2018) and in the Cusco Region, producing an outcrop morphology similar to that found at pre-Hispanic quarry sites (Figure 6).

Induced rockfall occurs where an outcrop positioned on a steep hillside or hilltop is intentionally fractured, causing detached material to cascade down the hill (Figure 7). In turn, gravity performs the work of transporting and breaking detached material into smaller, more manageable pieces that accumulate along the slope or at the base of the hill to be reduced further or used as-is. These quarries may appear to be the result of natural mass wasting (Bengtsson 1998; Kendall et al. 1992; Protzen 1993). However, given the local geological conditions, distribution of scree, and patterned appearance of these features near Inka sites, it is clear that these are not natural features and are instead the result of human intervention. Like columnar extraction, this technique produces a high volume of material suitable for large-scale works such as agricultural terraces.

The simplest extraction method is boulder splitting. In this case, the material is already detached due to natural processes, so the technician can proceed to reduce loose material into smaller pieces using the same procedures and toolkit described above. Builders also used boulders in their natural form and modified them where necessary to improve fit in a wall, as in the local village of Chupani (Figure 8).

The patterns described above demonstrate how late pre-Hispanic technicians quarried according to the same technological principles in spite of their variable cultural, geographic, and temporal contexts. For example, spalling from the rock face and vertical extraction were commonly employed in both Inka and local vernacular contexts. These are foundational techniques such that other techniques represent variations applied to different outcrop types and topographies at an augmented scale. These "scaled-up" intensive variations of spalling and vertical extraction produce high volumes of material, namely induced rock fall, stepped columnar extraction, and pit mining, and are only found in Inka elite and state contexts.

Because pre-Hispanic quarry workers did not create incisions or channels in rock (Agurto 1987; Hollowell 1987), technicians had to adeptly read the source geometry to successfully exploit inherent irregularities, including cleavage, fractures, shearing, and vesicles. Technicians continuously evaluated and adjusted their strategies according to the ongoing feedback received throughout the quarrying process. As efficiency in this context depends on the amenability of source lithology and morphology,

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quarrying, but it has been documented at Waq'oto and Rumiqolqa (Protzen 1983, 1985; Tovar 1996), and thus appears to be associated with large-scale quarrying operations.

we observed a preference for geological deposits that were most compatible with the predominant techniques and tools employed by technicians. This foundation of intuition and experiential knowledge allowed technicians to reliably predict the results of each successive action and plan their strategies according to changing outcrop geometry and quarry topography.

5.4 Material selection

Most Inka construction targeted igneous rock (n=24) – including andesite, basalt, dacite, tuff, and ignimbrite – favoring visually homogeneous materials from a single deposit. To build Cusco, the Inkas favored a fine-grained dark blue andesite from the Rumiqolqa quarry 35 km from the city and, to a lesser extent, the closer Waq'oto quarry (Hunt 1990). Other materials used in notable monumental works include diorite at the palace of Inka Ruq'a in Cusco, limestone at Chinchero, Saqsaywaman, and Urquillos, and granite at Machu Picchu, Qispiwanka, and Ollantaytambo. In addition to igneous rock, vernacular and Inka state construction utilized more limestone (n=8) and metamorphic rock (quartzite and conglomerates, n=6).

Our fieldwork in the Sacred Valley recorded extensive evidence of quarrying and stoneworking in non-Inka villages and mortuary complexes[7]. As vernacular construction practices have routinely been characterized as using unworked fieldstones (for exceptions, see DeMarrais 2001; Guengerich 2018), this finding draws attention to the existing knowledge and skill sets wielded by local groups and provides a context in which to situate the development of Inka technology. Vernacular buildings are generally built using the closest material source, typically combined with lesser quantities of other local rocks. We also found that the construction of tombs in rock shelters and cliffs ubiquitously involved cutting the rock face to spatially accommodate the tomb and produce construction material.

In both local vernacular and Inka buildings, the aesthetic qualities of stone were usually not a significant determinant of material selection because most walls were covered with a thick layer of clay plaster, except in the case of Inka cut-stone masonry. More influential in affecting material selection is the presence of irregularities, such as fractures and joints, that could be readily exploited for extraction. To evaluate deposits for fissility, technicians could have assessed outcrops visually as well as sonically by gently tapping the material and interpreting the resonant sound. Using this method, modern quarry workers deduce whether a source will fracture favorably or are more likely to break unpredictably (Benavides 2018). Only deposits with well-defined cleavage planes would produce large chunks of material that could be worked into ashlar blocks for Inka cut-stone masonry.

Conversely, ostensibly suboptimal materials were sometimes preferred in state and vernacular contexts, such as a brittle metamorphic rock that occurs in small sheared outcrops at the local village of Markasunay. This material fractures unpredictably and degrades easily. Quartzite was also quarried from the western part of Markasunay, where it could be extracted vertically as large blocks. However, the brittle metamorphic rock was still preferred in the eastern part of the site, where it is immediately available. Similarly, the Inkas used sheared basalt to build storehouses at Patallaqta (CY-147), Yawarmaki, and Yukay. While facilitating extraction, the friability of these materials would make regular-sized blocks difficult to produce. As such, the masonry at these sites is predominantly composed of irregular-sized, angular shards. This example demonstrates how different material properties may have been preferred depending on the particular requirements of the project. It also evidences a correlation between deposit types and masonry style, reflecting both selectivity and flexible adaptation (Figure 8).

5.5 Size and distribution

[7] These sites were primarily occupied during the Late Intermediate Period and Late Horizon, based on relative and absolute chronological data (Covey 2006, 2014; Covey and Amado 2008; Kendall 1976, 1985, 1996).

Quarry size is correlated with the scale and sequence of operations, as well as the resulting need for infrastructure and discrete activity areas (Table 2). The largest quarries – Kachiqhata, Rumiqolqa, and Waq'oto – are equipped with infrastructure and discrete activity areas where workers extracted material and prepared blocks for transportation (Bengtsson 1998; Protzen 1993; Tovar 1996). The only quarries with an extension of >1 hectare provided material for elite construction projects (n=9). Unlike these large-scale quarries, where more material was extracted than necessary for construction (cf. Bengtsson 1998; Hollowell 1987), quarries for vernacular construction are associated with minimal spoils. In this case, the quantity of detached material appears to have been proportional to the needs of the construction project. Whatever material was left over could have been recycled for other purposes, including expedient stone tools and fill for terrace construction.

Among the most decisive factors affecting modern builders' decision-making process are the accessibility and proximity of geological sources to construction sites (Schilman and Reisner 2011). Likewise, pre-Hispanic quarries tend to be located within immediate proximity to construction sites. Of 33 quarries for which the approximate extension and distance to the construction site are known, 82% (n=27) are located at a distance of ≤1 km, where builders extracted stone in immediate proximity to where it was intended to be used. Quarrying was generally opportunistic in the sense that technicians chose the closest source that met the minimum requirements for exploitation. This does not imply an absence of planning but rather the prioritization of proximity. Other factors were afforded higher priority than source proximity in the case of quarries such as Rumiqolqa and Kachiqhata where materials were transported over longer distances.

We used Spearman's rank correlation to test whether the maximum linear distance that stone was transported determines the size of the quarry (see Supplementary Materials). The results of this test observe a moderately positive correlation between quarry size and distance from the construction site ($R_{32}=0.593$, $p=0.001$). Thus, larger quarries reflect higher investment, more intensive extraction, and a preference towards localized, massive deposits of special materials that would justify transportation over long distances. Conversely, most vernacular and state construction projects utilized immediately available materials found in dispersed pockets over a large area.

In the Cusco Region, the Inkas recurrently extracted from outcrops of the Rumicolca Formation, while the *puna* of the Chuquibamba District also features a high concentration of volcanic outcrops with columnar structures amenable to extraction. For the Inkas, these materials' high quality and ease of extraction justified their transportation over long distances. Meanwhile, the limestone used to face the monumental terraces at Urquillos with fine pillowed masonry was likely brought from Chinchero, the closest source of this material at a distance of six kilometers (Arroyo Abarca 2010). Both estates belonged to Thupa Inka Yupanki (Ravines 2008:46), suggesting that Inka sovereigns and their *panaqa* (dynastic lineages) may have retained rights to particular quarries, which could be another factor influencing material selection.

As for larger quarries, topography was also an important factor. Large-scale quarries were preferably positioned on hilltops or flat terrain with ample room to work, else significant energy had to be invested in accommodating the terrain by building platforms and ramps. At Kachiqhata, for example, workers moved 40,000 m^3 of earth and rocks to construct a series of platforms and ramps to adapt the steep slope where block reduction was taking place (Protzen 1993:140). Site planners and architects could only afford to build at locations far from building stone sources in the case of high-profile projects. Otherwise, proximity to sources appears to be a determinant of site location.

5.6 Infrastructure

As part of a holistic approach to technology, assembling the infrastructure that supported quarrying activity facilitates an appraisal of logistics in relation to topographic challenges and labor requirements (Heldal and Bloxam 2008:7). Quarry infrastructure – encompassing physical features that structure and support extraction activities – can be classified into three categories: transportation, topography, and accommodation (cf. Tovar 1996; Table 3). Transportation infrastructure includes ramps and roads that facilitate the movement of material through the quarry and to the construction site (Protzen 1993). Topographic infrastructure such as platforms and retaining walls would accommodate uneven terrain so workers could safely and efficiently carry out quarry work. Accommodation includes rectangular buildings interpreted as workers' lodges and storehouses; canals to supply drinking water; and corrals for camelids that could have been used to transport provisions for workers (Béjar 2003; Harth-Terré 1964; Kendall et al. 1992; Miranda and Zanabria 1994; Protzen 1993; Tovar 1996).

While we can only describe permanent physical features preserved at quarry sites, other impermanent structures may well have supported quarry operations in the past. At the Ch'eqoq quarry, which has been continually exploited from pre-Hispanic to modern times, we observed a simple thatch-roofed shelter next to a set of newly finished andesite ashlars (Figure 9). A contemporary mason built this structure to provide shade from the sun. It is perhaps more likely that workers rested in such ephemeral shelters in the past rather than in buildings interpreted as "workers' lodges" (cf. Harth-Terré 1964; Protzen 1993).

While the large-scale quarries of Kachiqhata, Rumiqolqa, and Waq'oto are equipped with each type of feature, the majority of quarries we documented exhibited minimal to no physical infrastructure. The most common feature was a small platform (<5 m^2) installed at the foot of an outcrop to facilitate extraction where uneven topography and steep slopes made work difficult. We find such platforms at early and later Inka quarries as well as at a local vernacular quarry in Pukara Pantilliklla. The platforms in these contexts leveled terrain to provide workers with enough room to extract and reduce material at the foot of the outcrop. This lack of infrastructure is partly due to the smaller scale of these quarries, where material was extracted periodically and sporadically. But even the quarry at Wimin that supplied andesite for Pisaq's royal buildings was only equipped with a road and a large clearing for the final stages of preparation preceding exportation to the construction site. This way, infrastructure reflects not only the scale of operations but also the adaptation of quarrying operations to local topographic conditions.

6. Discussion

6.1 Labor organization

To discuss the organization of labor in quarrying operations, we must first distinguish between domestic and state projects, where quarry workers either procured material for their personal use or someone else's. In the case of small-scale domestic projects such as house construction, individuals or households could have conducted extraction intermittently for their immediate needs. It is also possible that there were local specialists within communities who were enlisted to assist in domestic quarrying and construction projects. Quarrying would be expected to invoke more asymmetrical power relations when it was conducted to meet external demand. The demands of Inka elites and state institutions shifted the relations of work, where workers were supervised and directed by state-employed specialists.

Drawing on ethnohistoric accounts, scholars have weighed inconclusively on whether the Inka state directly managed and controlled quarry operations (Bengtsson 1998; Ogburn 2013; Protzen 1993; Tovar 1994). We identified many of the same extraction techniques at the provincial quarries of the Chuquibamba District that were present in the imperial heartland (Figure 5). This uniformity could support chroniclers' claims that the Inkas sent specialists trained and employed by the state to direct and work on provincial construction projects per the Inkas' technological and aesthetic conventions (Cobo 1990[1653]:227). The degree to which planning and execution of this work were top-down or resulted from collaboration among quarry workers could have depended on the specificity of building material selection criteria (i.e., block dimensions).

To address labor organization at quarry sites, it is necessary to model the expected material correlates of centralized production and specialization (cf. Costin 1991). Based on evidence from ancient Roman and Egyptian state quarries, centrally managed quarries often include well-defined work areas and refuse piles, as well as infrastructural systems to support workers and facilitate the processing and transportation of materials over long distances (Coli et al. 2011; De Laet et al. 2015; Harrell et al. 2022; Heldal and Bloxam 2008; Shaw 1994). States may favor the systematic extraction of massive deposits, demanding the collaboration of large workgroups to increase the volume and efficiency of production while necessitating prior logistical planning and coordination. Another indication of centralized management is specialized tools that would be provisioned by the government or patron (cf. Xie et al. 2015).

As we have seen, most Inka quarries do not match the model of centrally managed production outlined above. Exceptions include Kachiqhata, Rumiqolqa, and Waq'oto. Each of these quarries is equipped with infrastructural systems; well-defined activity areas; and has an extension of >50 hectares, reflecting the ongoing and intensive nature of material extraction. At Kachiqhata, for example, the construction of its extensive ramp and road system would have required centralized planning and direction (Protzen 1993:140). Still, extraction and construction activities could have been subjected to differential systems of organization, as suggested by Tovar's division of quarry work into principal and auxiliary tasks (1996:266–268). Other quarries present minimal to no physical infrastructure, while quarrying tools were relatively commonplace and did not have to be provided by the state.

The uneven topography at most quarry sites would have accommodated a limited number of workers focusing on different tasks. Certain techniques required coordinated efforts, while others could have been accomplished independently. The frequent occurrence of small-scale opportunistic extraction suggests that quarrying operations were likely more decentralized, even while quarrying remained part of a centrally managed operational sequence (cf. Murakami 2019). That is, quarrying likely relied upon autonomous decision-making and coordination among small groups rather than requiring direct oversight and planning at every stage (Bengtsson 1998). Decentralized operations might reflect the independent operation of specialists who supplied material for the state but were not always directly supervised and managed by higher-level authorities (cf. Horowitz et al. 2021).

This scenario is comparable to current quarrying activities in the Andes, where workers tend to operate alone or in small groups (Benavides 2018). At Ch'eqoq and Qaqaqollo, modern masons produce ashlars for lintels and ornamental stone that they sell at small workshops nearby. In industrial operations, workgroups employed by companies use dynamite to expose subterranean deposits and create fractures that can be targeted with mechanical tools to extract high volumes of material. Likewise, the organization of Inka state quarry operations would have varied according to factors including lithology and topography, as well as the particular goals of each construction project (Ogburn 2013:46). Overall, this is not entirely different from state quarries in other global contexts, which demonstrate variable degrees of centralized management according to political and economic factors, as well as geological conditions (Coli et al. 2011; De Laet et al. 2015; Harrell et al. 2022; Horowitz et al. 2021; Janusek et al. 2015; Kokkorou-Alevras et al. 2009; Maschek 2016; Shaw 1994; Verhoeven et al. 2012).

6.2 Technological continuity and innovation

Technological change can occur as the result of top-down imposition as aggrandizers and institutions seek to control production or by bottom-up processes when commoners develop solutions to mitigate emergent environmental stressors and adapt to novel social conditions (Costin et al. 1989; Schiffer and Skibo 1987). As discussed above, studies of Inka quarrying and stonework have tended to take an actor-based historical approach that follows a literal reading of ethnohistoric narratives by accepting top-down explanations of technologies as the inventions of elite personages (cf. Bauer and

Smit 2015). While acknowledging the elite interests responsible for designing distinctive architectural styles, we trace the development of technology in relation to regional vernacular traditions to account for the mechanisms of origin, transmission, and change (cf. Browman 1998). Rather than following an actor-based approach, we embrace a view of technology as a culturally embedded system of knowledge, practice, and gestures (Lemonnier 1992:5–6; Miller 2007:4).

Throughout the LIP and Late Horizon, local village communities extracted material from outcrops and reworked loose fieldstones to build their houses, terraces, corrals, and tombs (cf. Guengerich 2018). Villagers' techniques drew on geological knowledge accumulated from ongoing interactions with the surrounding environment and know-how passed down by senior community members (cf. Schiffer and Skibo 1987). The resultant knowledge system would have served villagers' individual and immediate needs while remaining flexible to different sociopolitical contexts, providing a foundation for innovation and experimentation (cf. Guengerich 2014). Basic principles must be understood to perform a given technique, even if implicit or explained within a cultural framework. These physical principles that account for a technology's efficacy correspond to what Schiffer and Skibo call techno-science (1987:597). The techno-science that underlies quarrying and stoneworking encompasses how lithic materials' fracture mechanics and responses to percussive force. This techno-science informed pre-Hispanic technicians how to distinguish materials amenable to extraction, how to strike material, and how materials were likely to fracture.

Like other groups occupying the Cusco Region during the LIP, the Inkas would have wielded this knowledge prior to developing their distinctive stereotomy style. Individual kin groups built their own dwellings by drawing on shared architectural conventions and perhaps by enlisting the guidance of local specialists, such that quarrying and construction knowledge could have been widely shared among villagers (cf. Moore 2021:110). The architecture that supported the initial Inka expansion into the Sacred Valley demonstrates a foundation of knowledge, gesture, and practice shared with local vernacular traditions. In local vernacular and Inka construction, technicians flexibly invoked this shared know-how that supported experimentation and adapted extraction strategies to new circumstances.

This scenario conforms with Lechtman's observation that Andean technologies are characterized foremost by practitioners' knowledge and the accommodation of natural properties (1993:246). In the same way, Inka extraction techniques remained closely related to local vernacular traditions over the course of the LIP and Late Horizon, in spite of the increasing scale of construction projects and shifting labor relations. Quarrying technology was not transformed to support increased state demands, in part because existing techniques were already capable of extracting high volumes of material with relatively low energetic input. The Inkas innovated principally in the aesthetics and structure of the finished product, while their extraction techniques remained rooted in a widely shared technological tradition. That is, the Inkas' novel block-finishing and construction techniques still operated using the basic toolkit, gestures, and geological knowledge that were foundational to contemporaneous lithic technologies.

The quarrying technology that the Inkas deployed was extremely effective at extracting material from deposits with regular fractures and joints. This specialization limited the Inkas to outcrops with regular cleavage and flow structure, while non-fractured deposits were avoided (cf. Hunt 1990). Notably, the Inkas did not develop new tools or techniques to extract from non-fractured deposits, which they might have if the aesthetic or symbolic value of stone was paramount in determining material selection. Thus, we argue that geological conditions were the most influential factor affecting pre-Hispanic material selection and extraction strategies. In this sense, materials' perceived value derived partly from their amenability to extraction, as framed within an ontological perspective that appreciated the agency and involvement of non-humans in production activities (cf. Allen 2015; Salomon 1991, 1998; Sillar 2009). That is, while some deposits could have been perceived as dormant and inert in refusing to yield to percussion, technicians would have favored outcrops that were more receptive to extraction, regarding them as dynamic and lively participants in human activities. In interpreting how geological deposits react to percussive force, technicians were informed by an appreciation of the active – rather than passive – state of materials. It was this perspective that enabled the creative flexibility of lithic technologies under changing political conditions.

7. Conclusions

The common framing of Inka architecture, masonry, and quarrying as energetically wasteful and elite-oriented has obscured the creative ways that Andean peoples have harnessed geological deposits' unique properties to their advantage. The data presented herein do not support the model of Inka quarrying activity as uniformly labor-intensive and centrally managed. Instead, opportunistic material extraction was the norm in the heartland and provinces, as demonstrated in both Inka and non-Inka contexts. Most quarries' sporadic distribution and limited associated infrastructure suggest that production was intermittent and decentralized, undertaken by small teams working semi-independently and adapting their strategies to local topographic and geological conditions. The Inkas developed new techniques of extraction to increase production and block size, but these techniques ultimately relied on the same principles and procedures prevalent in vernacular contexts.

Rather than attributing responsibility for technological innovation to elite personages, we foreground the role of technicians as they drew upon embodied knowledge that accumulated through intergenerational transmission and practical experimentation. As evidence of this long-running tradition, the same principles that informed Inka quarrying techniques were also deployed at non-Inka villages in the Sacred Valley, where villagers built domestic structures by expediently extracting and fitting stone. The continuity between these practices indicates that Inka quarrying technology was founded on a tradition shared by neighboring societies throughout the Cusco Region during the LIP. This tradition was rooted in an economical use of gestures and an adept reading of source geometry and material properties. That is, while the Inkas shifted the relations of labor and elaborated block finishing and wall construction techniques, the knowledge, toolkit, and gestures that formed the basis of this process were flexibly adjusted to the demands of the state. The case of Inka building stone extraction demonstrates how states may appropriate and build upon vernacular traditions and how a technological system rooted in non-state practices can be transposed into a state context.

Acknowledgments.

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Figures

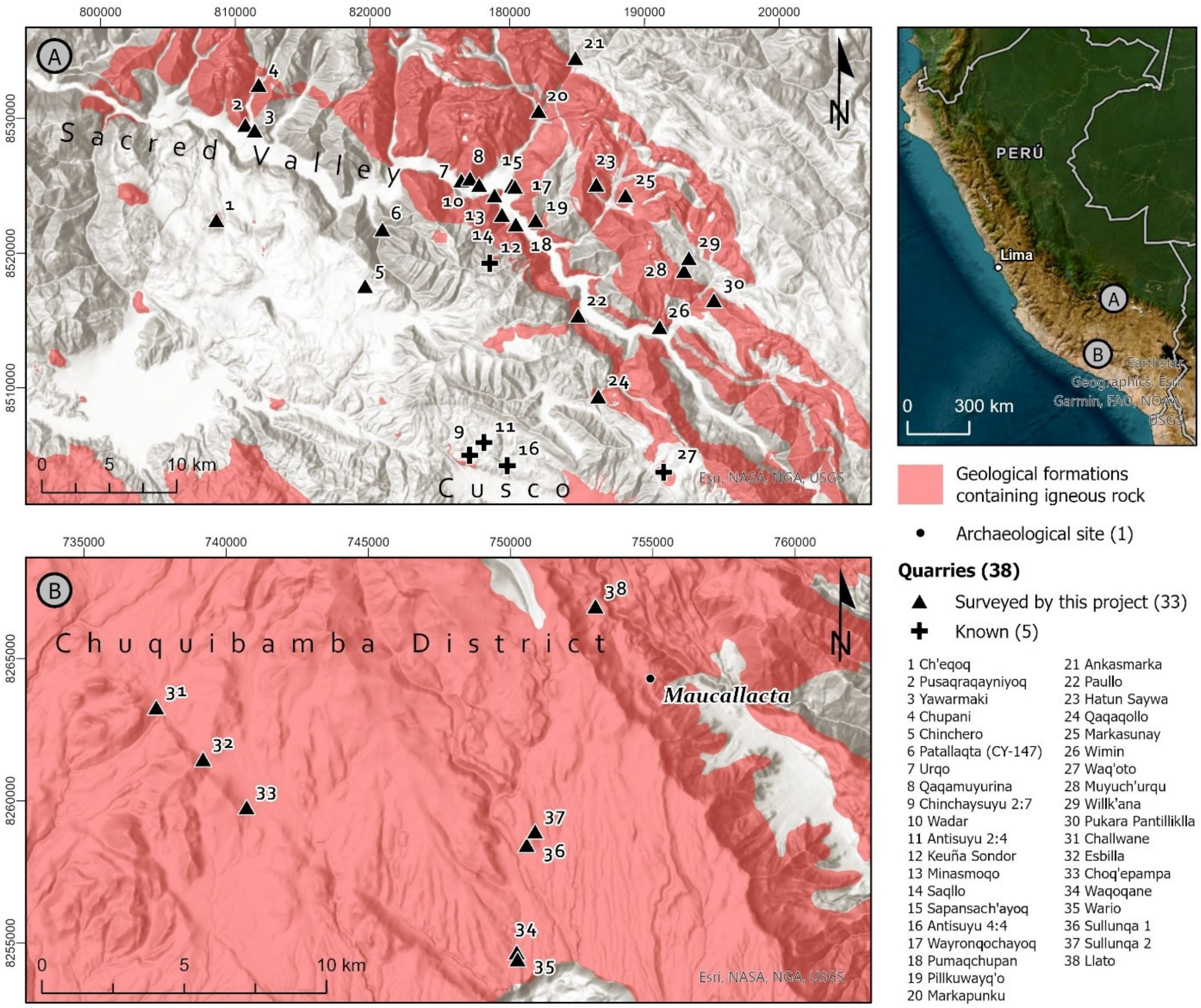

Figure 1. The distribution of known (n=5) and surveyed (n=33) late pre-Hispanic building stone quarries in (A) the Cusco Region (Machu Picchu, Kachiqhata, and Rumiqolqa not pictured) and (B) the Chuquibamba District relative to geological formations, which are generalized for better visualization. The shaded area corresponds to formations containing high volumes of igneous rock alongside other rock types, while the unshaded area is composed of primarily sedimentary and metamorphic rock. Previously unidentified quarries were named according to local toponyms or geography. The locations of the quarry *wak'a* on the Antisuyu and Chinchaysuyu *siq'i* (ritual paths) are reported by Bauer (1998). Geological data source: Instituto Geológico Minero y Metalúrgico de Perú (INGEMMET).

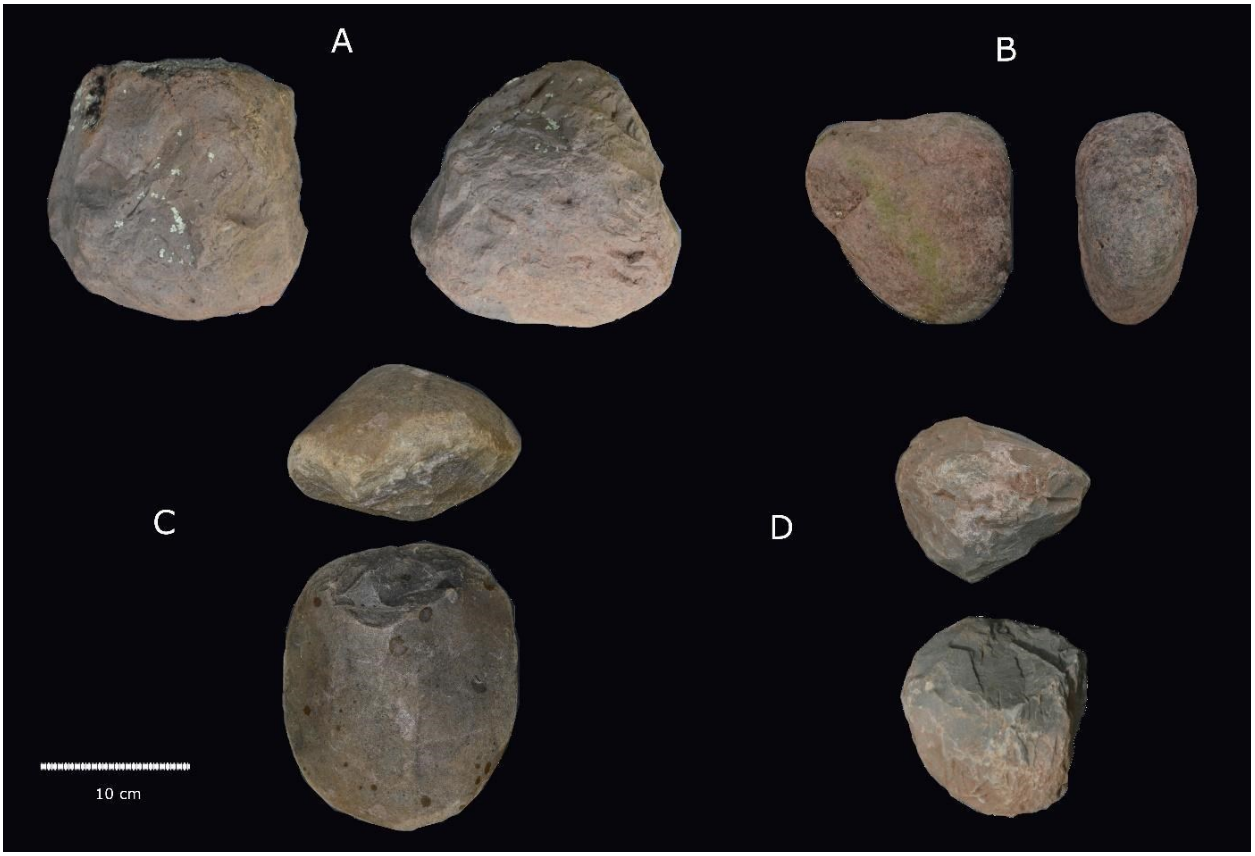

Figure 2. A set of four hammerstones recovered from the Wimin quarry at Pisaq, representing two size categories. A (andesite) and C (quartzite) were used for the initial stages of splitting detached material, and were held in two hands. B (andesite) and D (quartzite) were to be held in one hand for finer grained retouching and flaking. While B has a naturally ergonomic morphology, D was intentionally flaked to fit in its user's left hand.

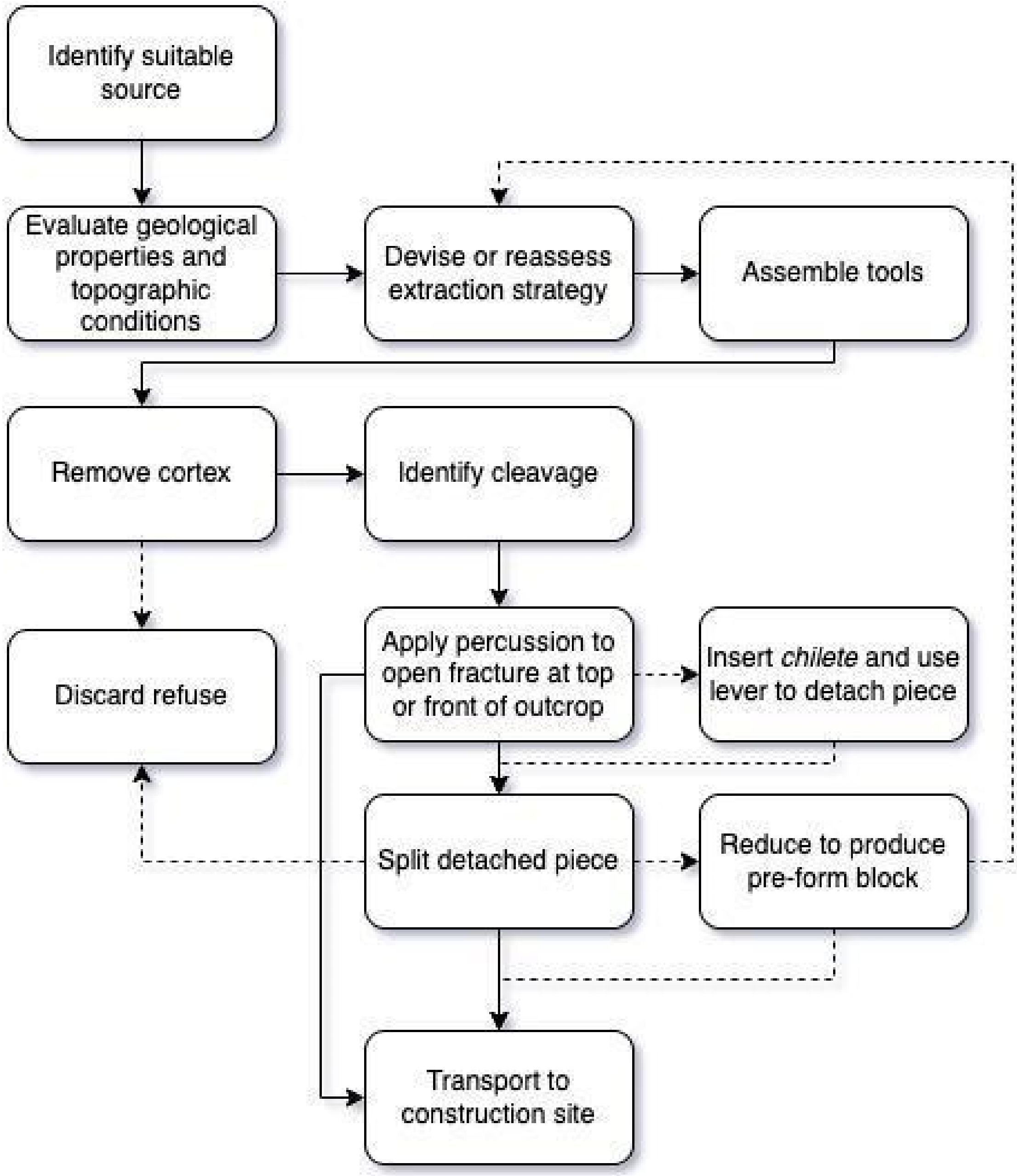

Figure 3. The technical sequence (*chaîne opératoire*) of late pre-Hispanic building stone extraction from an outcrop. The dotted lines represent optional choices, dependent on the geological conditions and intended use of the material.

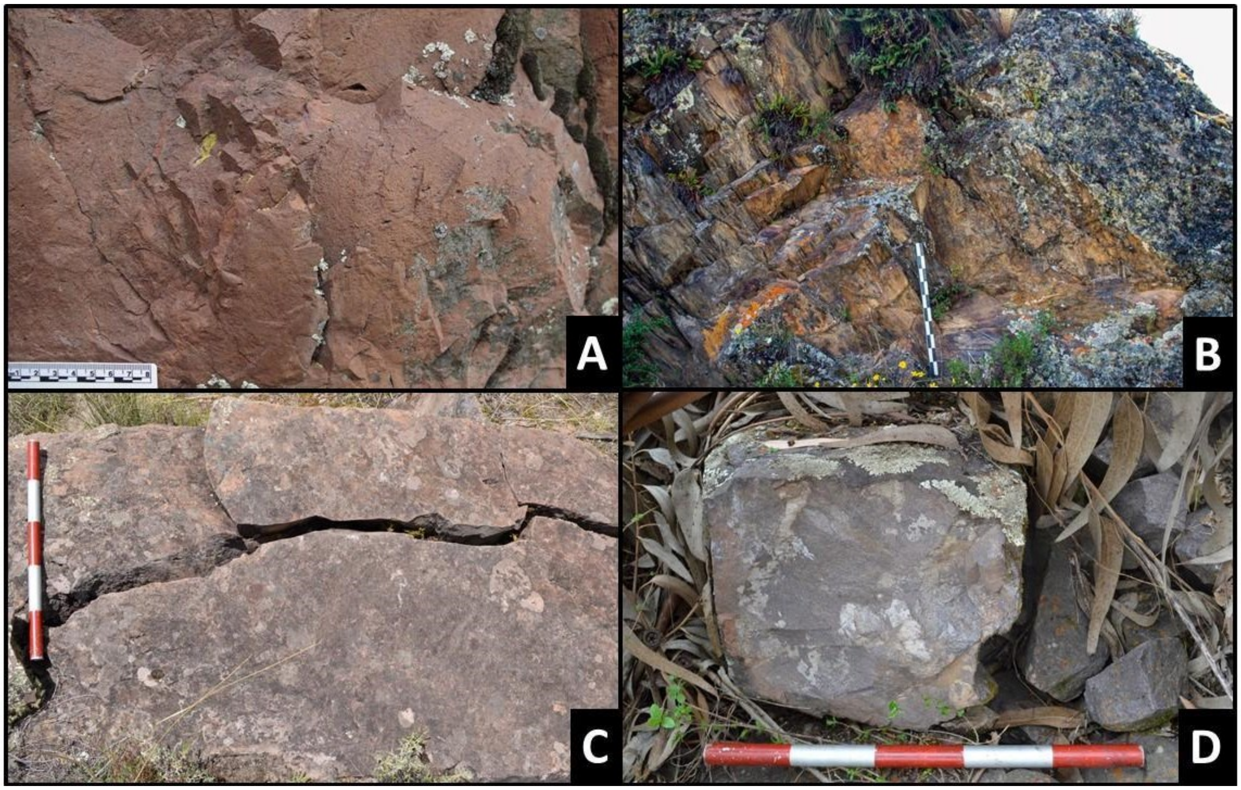

Figure 4. The sequential stages of building stone procurement.
A) The technician removes the outer cortex to reveal hidden fractures that could be then struck to extract chunks of material. This activity is evidenced here by scarring resulting from repeated application of percussive force to the face of an andesite outcrop at Pukara Pantilliklla (a local village). Scale 8 cm.
B) The technician "reads" the internal structure of the outcrop to strategically target fractures or irregularities and create a geometry ideal for producing blocks of a desired size and shape. Here, a technician used spalling to target the columnar structure of a quartzite outcrop and extract blocks of regular size and shape at Ankasmarka (a local village). Note the unmodified cortex on the right side of the photo. Scale 1 m.
C) Large detached pieces of the outcrop may be subsequently split using a hammerstone. Here, a large andesite slab was longitudinally detached from a nodular outcrop using vertical extraction at Wimin, the quarry at Pisaq (an Inka royal estate), likely intended for further reduction to be used as ashlars. Scale 50 cm.
D) Using a smaller hammerstone, the technician gives form to the material until they reach the finished product or a pre-form block to be finished on-site. A roughly finished andesite block in the spoil pile at Saqllo (an elite Inka terrace complex) is shown here. Scale 50 cm.

Figure 5. Exploitation of fractures in igneous columnar outcrops to extract blocks at A) the Challwane quarry and B) at Sapansach'ayoq near Calca. Scale 1 m.

Figure 6. Modern workers quarry material from a subterranean limestone deposit near Coya. The workers first used explosives to “open” the deposit before subsequently extracting larger pieces of material by fracturing the top of the deposit with mechanical tools. The resulting morphology closely resembles pre-Hispanic quarries.

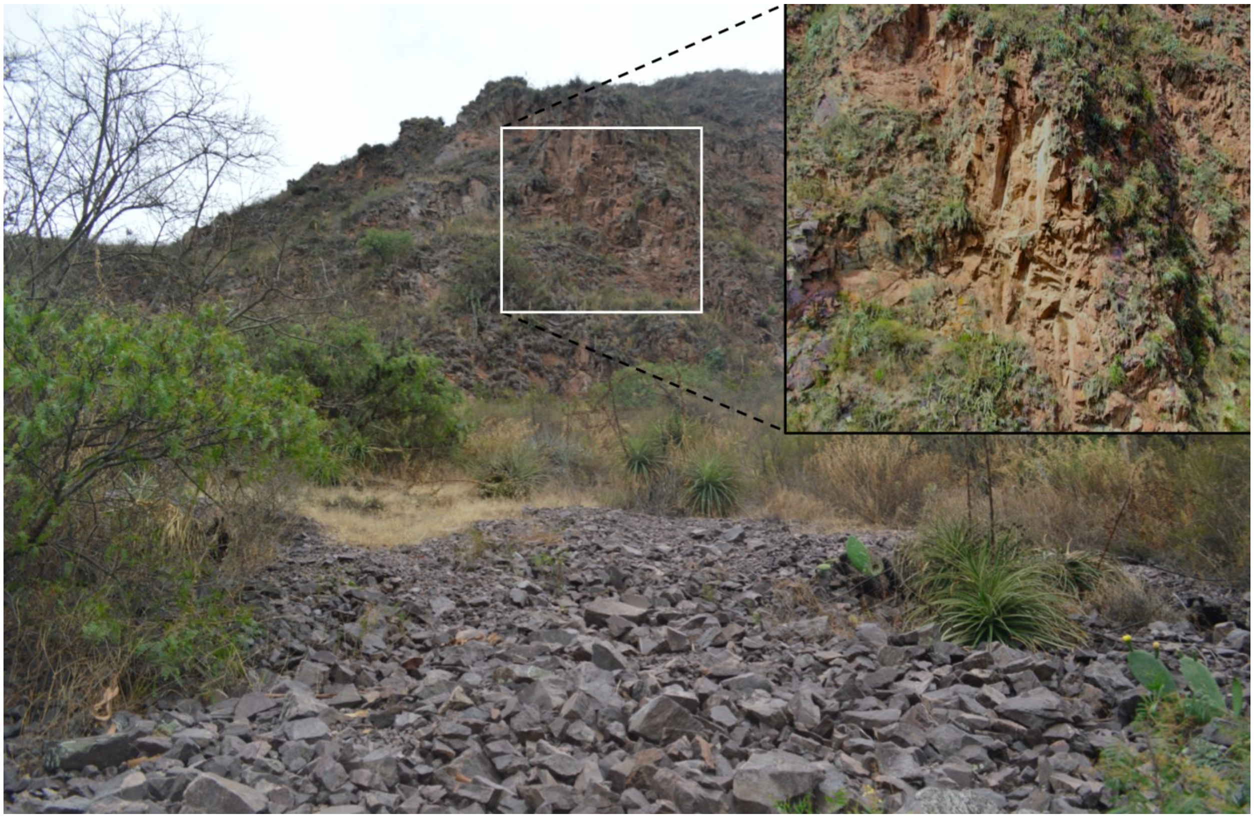

Figure 7. An induced rock fall quarry at Saqllo, where an outcrop (shown in the inset) on a steep hillslope was strategically fractured, causing scree to collect in piles at the base of the hill for use as building stone.

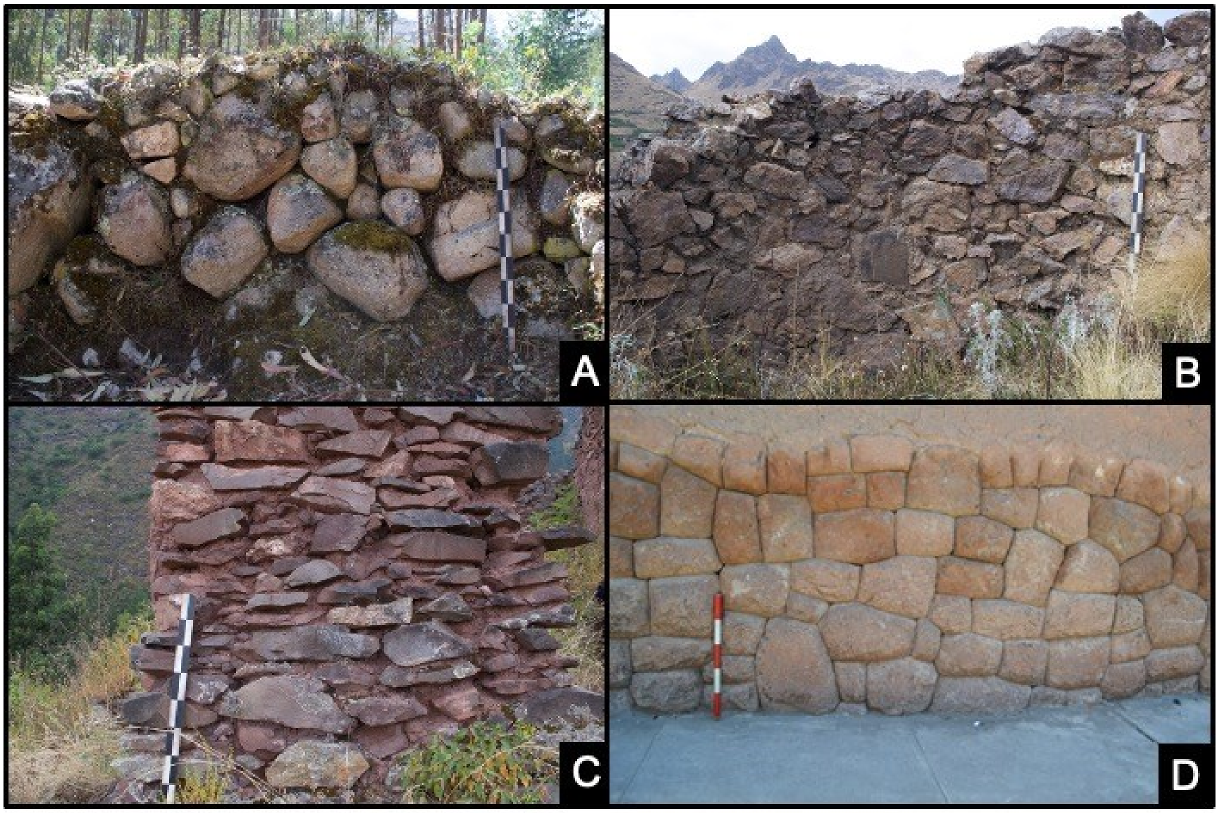

Figure 8. A sample of "finished products" registered during the 2019 and 2022 field projects.
A) The granite boulders used at Chupani (a local village) were minimally worked while retaining much of their natural form. Builders generally collected boulders that met selection criteria from alluvial deposits within the site. Scale 1 m.
B) At Markasunay (a local village), builders opportunistically used blocks of varying sizes and shapes, filling the gaps between blocks with flake byproducts of the quarrying and stoneworking process. The faces of the blocks were made smooth to help clay plaster adhere evenly to the surface of the wall. Scale 1 m.
C) At a small Inka complex behind the royal estate of Yukay, builders used angular slabs and shards to build walls from sheared basalt in conformance with the material's inherent fracture mechanics. Scale 1 m.
D) A polygonal-style wall at Calca, a royal Inka settlement. The ignimbrite used here was likely quarried from Sapansach'ayoq, a columnar deposit that allows for the extraction of material in blocks. Scale 50 cm.

Figure 9. This temporary structure at the Ch’eqoq quarry was built by a mason to provide shelter. The set of finished ashlars and distribution of débitage in front of the structure offer an impression of how pre-Hispanic masons may have organized their workspace. This quarry has been continuously exploited from colonial to modern times, which has destroyed most evidence of pre-Hispanic extraction.

Extraction technique	Source type	Material	Quarries by primary construction product		
			Elite architecture	**State architecture**	**Local vernacular architecture**
Columnar extraction	Columnar outcrop, massive deposit	Andesite, limestone, quartzite	None	Sullunqa, Waqoqane, Wario	Muyuch'urqu
Induced rock fall	Cliff outcrop	Andesite, dacite, granite, limestone	Kachiqhata*, Saqllo, Urqo, Wimin	None	None
Pit mining	Massive intrusive deposit	Andesite	Rumiqolqa*, Waq'oto*	None	None
Spalling and vertical extraction	Nodular, sheared, or vesicular outcrop; massive deposit	Andesite, basalt, dacite, granite, limestone	Ch'eqoq, Chinchero, Keuña Sondor*, Machu Picchu*, Paullo, Rumiqolqa*, Waq'oto*, Wimin	Llato, Markapunku, Minasmoqo, Patallaqta, Pusaqraqayniyoq, Qaqaqollo, Wayronqochayoq, Willk'ana, Yawarmaki	Ankasmarka, Markasunay, Pukara Pantilliklla
Splitting	Boulder	Andesite, tuff	None	Choq'epampa	Chupani, Esbilla
Stepped columnar extraction	Columnar outcrop, massive deposit	Andesite, ignimbrite	Sapansach'ayoq, Wadar	Challwane	None
Vertical extraction	Cliff outcrop	Andesite, basalt, dacite, conglomerates, limestone, quartzite	Minasmoqo, Pumaqchupan, Qaqamuyurina, Wayronqochayoq	None	Ankasmarka, Hatun Saywa, Markasunay, Pillkuwayq'o, Pukara Pantilliklla

Table 1. Extraction techniques were strategized according to source, material type, and primary construction product. We list each extraction type alongside the source types and materials amenable to each extraction technique based on our survey data and literature review. We include the names of quarry sites where each extraction technique was documented. Definitions of source types are included in the supplementary materials. Quarries marked with an asterisk (*) were not surveyed by this project. Sources: Béjar 2003; Bengtsson 1998; Hollowell 1987; Kendall et al. 1992; Miranda and Zanabria 1994; Protzen 1983, 1985, 1993; Sillar et al. 2019; Tovar 1996.

Extension (ha)	Linear distance from construction site (km)	Quarries by primary construction product			Total quarries
		Inka elite architecture	Inka state architecture	Local vernacular architecture	
≤1	≤0.5	Machu Picchu, Paullo, Sanapsach'ayoq, Saqllo, Urqo	Challwane, Choq'epampa, Esbilla, Minasmoqo, Markapunku, Patallaqta, Pumaqchupan, Pusaqraqayniyoq, Qaqamuyurina, Qaqaqollo, Wayronqochayoq, Willk'ana, Yawarmaki	Ankasmarka, Chupani, Hatun Saywa, Markasunay, Muyuch'urqu, Pillkuwayq'o, Pukara Pantilliklla	23
1.1 to 6	0.6 to 3	Wadar, Wimin	None	None	3
33 to 125	>3	Kachiqhata, Keuña Sondor, Rumiqolqa, Waq'oto	None	None	4

Table 2. Correlation between quarry extension and distance from construction site, according to primary construction product. Extensions and distances were measured using Google Earth Pro.

Infrastructural features	Quarry sites where infrastructure was identified								
	Chin-chero	Kachiqhata (Ollantay-tambo)	Keuña Sondor (Huch'uy Qosqo)	Minas-moqo	Paullo	Pukara Pantilliklla	Rumiqolqa	Waq'oto	Wimin (Pisaq)
Canals		X						X	
Corrals			X					X	
Platforms, contention walls, leveled terrain	X	X	X	X	X	X		X	
Ramps		X					X	X	
Roads and paths		X	X	X			X	X	X
Storage yards		X						X	
Water reservoirs								X	
Work areas, clearings		X				X	X	X	X
Worker's lodges, administrative buildings		X					X	X	

Table 3. Presence of associated infrastructure at quarry sites. Only sites with identified infrastructural features are included (n=9). Sources: Béjar 2003; Bengtsson 1998; Harth-Terré 1964; Hollowell 1987; Kendall et al. 1992; Miranda and Zanabria 1994; Protzen 1983, 1985, 1993; Tovar 1996.

Bibliography

Agurto Calvo, S., 1987. Estudios acerca de la construcción, arquitectura y planeamiento Incas. Cámara Peruana de Construcción, Lima, Peru.

Allen, C., 2015. The whole world is watching: new perspectives on Andean animism. In: Bray, T. (Ed.), The Archaeology of Wak'as: Explorations of the sacred in the pre-Columbian Andes. University Press of Colorado, Boulder, CO, pp. 23–46.

Arroyo Abarca, P., 2010. Informe final del proyecto de evaluación arqueológica con excavaciones en el sector de Jantu Pata, Urquillos. Final report presented to the Instituto Nacional de Cultura, Cusco, Peru.

Bauer, B., 1998. The Sacred Landscape of the Inca: The Cusco Ceque System. University of Texas Press, Austin, TX.

Bauer, B., Smit, D., 2015. Separating the Wheat from the Chaff: Inka myths, Inka legends, and the archaeological evidence for state development. In: Shimada, I. (Ed.), The Inka Empire: A multidisciplinary approach. University of Texas Press, Austin, TX, pp. 67–80.

Béjar, I., 2003. La cantera inca de Rumiqolca, Cusco. Boletín de Arqueología PUCP 7, 407–417.

Benavides Watmough, A. (Director), 2018. Los cortadores de sillar [Documentary film]. ABENA Producciones.

Bengtsson, L., 1998. Prehistoric Stonework in the Peruvian Andes: A case study at Ollantaytambo. GOTARC Series B No. 10. Goteborg University, Goteborg, Sweden.

Betanzos, J., 2004[1551–1557]. Suma y narración de los incas (M. del Carmen Martín Rubio, Ed). Ediciones Polifemo, Madrid, Spain.

Bloxam, E., 2011. Ancient Quarries in Mind: Pathways to a more accessible significance. World Archaeol. 43 (2), 149–166.

Bray, T., 2009. An Archaeological Perspective on the Andean Concept of Camaquen: thinking through late pre-Columbian ofrendas and huacas. Cambridge Archaeol. J. 19(3), 357–366.

Bray, T. (Ed.), 2015. The Archaeology of Wak'as: Explorations of the sacred in the pre-Columbian Andes. University Press of Colorado, Boulder, CO.

Browman, D., 1998. Lithic provenience analysis and emerging material complexity at Formative Period Chiripa, Bolivia. Andean Past 5 (17), 301–324.

Carlotto, V., Cardenas, J., 2003. Revisión y actualización del Cuadrángulo de Cusco (28- s). Escala 1:50 000 INGEMMET.

Carlotto, V., Gil, W., Cárdenas, J., Chávez, R., 1996. Geología de los cuadrángulos de Urubamba y Calca. INGEMMET, Boletín, Serie A: Carta Geológica Nacional 65.

Carter, T., 2007. The Theatrics of Technology: consuming obsidian in the early Cycladic burial arena. Archeol. Papers Am. Anthropol. Association 17, 88–107.

Childe, V., 1929. The Most Ancient East: The oriental prelude to European prehistory. Alfred and Knopf, New York, NY.

Cieza de León, P., 1864[1553]. The Travels of Pedro de Cieza de León (C. Markham, Trans., Ed.). Hakluyt Society, London, UK.

Cobo, B., 1956. Historia del Nuevo Mundo. In: Francisco Mateos, P. (Ed.), Obras del P. Bernabé Cobo de la Compañía de Jesús, Vol. II. Ediciones Atlas, Madrid, Spain.

Cobo, B. 1990[1653]. Inca Religion and Customs (R. Hamilton, Trans., Ed.). University of Texas Press, Austin, TX.

Coli, M., Rosati, G., Pini, G., Baldi, M., 2011. The Roman quarries at Antinoopolis (Egypt): development and techniques. J. Archaeol. Sci. 38, 2696–2707.

Costin, C., 1991. Craft Specialization: Issues in defining, documenting, and explaining the organization of production. Archaeol. Method Theory 3, 1–56.

Costin, C., Earle, T., Owen, B., Russell, G., 1989. The impact of Inca conquest on local technology in the Upper Mantaro Valley, Peru. In: van der Leeuw, S., Torrence, R. (Eds.), What's New? A closer look at the process of innovation. Unwin Hyman, London, UK, pp. 107–139.

Covey, R., 2006. How the Incas Built Their Heartland: State formation and the innovation of imperial strategies in the Sacred Valley, Peru. University of Michigan Press, Ann Arbor, MI.

Covey, R. (2003). The Sacred Valley (Peru): Inka state formation and the evolution of imperial strategies (Unpublished doctoral dissertation). University of Michigan, Ann Arbor, MI.

Covey, R., 2011. Landscapes and languages of power in the Inca imperial heartland (Cuzco, Peru). SAA Archaeol. Rec. 11 (4), 29–32.

Covey, R. (Ed.), 2014. Regional Archaeology in the Inca Heartland: The Hanan Cuzco surveys. University of Michigan Press, Ann Arbor, MI.

Covey, R., Amado González, D., (Eds., Trans.), 2008. Imperial Transformations in Sixteenth-Century Yucay, Peru. University of Michigan Press, Ann Arbor, MI.

Cruz Quiñones, J., Earle, J., 2020. Orígenes de la tecnología de construcción Inka en la cuenca del río Vilcanota. Final report presented to the Ministerio de Cultura del Perú. Dirección Desconcentrada de Cultura Cusco, Cusco, Perú.

Cummins, T., Mannheim, B., 2011. Editorial: The river around us, the stream within us: the traces of the sun and Inka kinetics. RES: Anthropol. Aesthetics 59 (60), 5–21.

Acosta, J. de, 1880[1590]. The Natural and Moral History of the Indies, Vol. II (E. Grimston, Trans., and C. Markham., Ed.). Hakluyt Society, London, UK.

Arriaga, P. de, 1968[1621]. The Extirpation of Idolatry in Peru (L. Keating, Trans., Ed.). University Press of Kentucky, Lexington, KY.

De Laet, V., van Loon, G., Van der Perre, A., Deliever, I., Willems, H., 2015. Integrated remote sensing investigations of ancient quarries and road systems in the Greater Dayr al-Barsha Region, Middle Egypt: a study of logistics. J. Archaeol. Sci. 55, 286–300.

Murúa, M. de, 1590. Historia del Origen y Genealogía Real de los Reyes del Piru, de sus hechos, costumbres, trajes, maneras de gobierno. Private collection.

Dean, C., 1998. Creating a Ruin in Colonial Cusco: Sacsahuaman and what was made of it. Andean Past 5, 161–183.

Dean, C., 2010. A Culture of Stone: Inka Perspectives on Rock. Duke University Press, Durham, NC.

Dean, C., 2011. Inka ruins and the discourse of mystery. Third Text 25 (6), 737–749.

deFrance, S., Olson, E., 2013. Late Prehispanic coquina quarrying and tomb construction in coastal Southern Peru. J. Island Coastal Archaeol. 8, 3–16.

DeMarrais, E., 2001. The architecture and organization of Xauxa settlements. In: D'Altroy, T., Hastorf, C. (Eds.), Empire and Domestic Economy. Kluwer Academic Publishers, New York City, NY, pp. 115–153.

Dobres, M., Hoffman, C., 1994. Social agency and the dynamics of prehistoric technology. J. Archaeol. Method Theory 1 (3), 211–258.

Ericson, J., 1984. Toward the analysis of lithic production systems. In: Ericson, J., Purdy, B. (Eds.), Prehistoric Quarries and Lithic Production. Cambridge University Press, Cambridge, UK, pp. 1–9.

Farrington, I., 2013. Cusco: Urbanism and Archaeology in the Inka World. University of Florida Press, Gainesville, FL.

Flannery, K., 1968. Archaeological systems theory and early Mesoamerica. In: Meggers, B. (Ed.), Anthropological Archaeology in the Americas. Anthropological Society of Washington, Washington, D.C., pp. 67–87.

Garcilaso de la Vega, "El Inca", 1989[1609]. Royal Commentaries of the Incas and General History of Peru (H. Livermore, Trans., Ed.). University of Texas Press, Austin, TX.

Gasparini, G., Margolies, L., 1980. Inca Architecture (P. Lyon, Trans.). Indiana University Press, Bloomington, IN.

Germinario, L., Zara, A., Maritan, L., Bonetto, J., Hanchar, J., Sassi, R., Siegesmund, S., Mazzoli, C., 2018. Tracking trachyte on the Roman routes: provenance study of Roman infrastructure and insights into ancient trades in northern Italy. Geoarchaeology 33, 417–429.

Gonçalez Holguín, D., 2007[1608]. Vocabvlario de la Lengva General de todo el Perv llamada Lengua Qquichua, o del Inca. Digitized by Runasimipi Qespisqa Software (http://www.runasimipi.org) for Internet publication.

Gordon, R., 1985. Laboratory evidence of the use of metal tools at Machu Picchu (Peru) and environs. J. Archaeol. Sci. 12 (4), 311–327.

Gordon, R., Knopf, R., 2006. Metallurgy of bronze used in tools from Machu Picchu, Peru. Archaeometry 48 (1), 57–76.

Gosselain, O., 2012. Technology. In: Insoll, T. (Ed.), The Oxford Handbook of the Archaeology of Ritual and Religion. University of Oxford Press, Oxford, UK, pp. 243–260.

Guengerich, A., 2014. The Architect's Signature: The social production of a residential landscape at Monte Viudo, Chachapoyas, Peru. J. Anthropol. Archaeol. 34, 1–16.

Guengerich, A., 2018. The View from the Top: The materiality of mountainscapes and the re-creation of society in the Andean Late Intermediate Period. In: Jennings, J., Swenson, E. (Eds.), Powerful Places in the Ancient Andes. University of New Mexico Press, Albuquerque, NM, pp. 361–397.

Harrell, J., Ali Mohamed, A., 2021. Exploitation of Geological Resources: Ancient mines and quarries in Nubia. In: Emberling, G., Beyer Williams, B. (Eds.), The Oxford Handbook of Ancient Nubia. Oxford University Press, Oxford, UK, pp. 956–974.

Harth-Terré, E., 1964. Técnica y arte de la cantería incaica. Editorial "Garcilaso", Cusco, Peru.

Hegmon, M., 1998. Technology, style, and social practices: archaeological approaches. In: Stark, M. (Ed.), The Archaeology of Social Boundaries. Smithsonian Institution Press, Washington, DC, pp. 264–279.

Heldal, T., Bloxam, E., 2008. QuarryScapes Guide to Ancient Stone Quarry Landscapes: Documentation, interpretation, and statement of significance. Geological Survey of Norway (NGU), Trondheim, Norway.

Hollowell, L., 1987. Precision cutting and fitting of stone in prehistoric Andean walls. Unpublished Research Report #2832–84. Submitted to the National Geographic Society, Washington, D.C.

Horowitz, R., Clarke, M., Seligson, K., 2021. Querying Quarries: Stone extraction practices and socioeconomic organization in three sub-regions of the Maya lowlands. J. Field Archaeol. 46 (8), 551–570.

Hunt, P., 1990. Inca volcanic stone provenance in the Cuzco province. Papers Inst. Archaeol. 1, 24–36.

Hyslop, J., 1990. Inca Settlement Planning. University of Texas Press, Austin, TX.

ICOMOS (International Council on Monuments and Sites), 1982. World Heritage List No. 273 nomination. UNESCO. Available from: <http://whc.unesco.org/en/list/273>.

Ingold, T., 2013. Making: Anthropology, Archaeology, Art and Architecture. Routledge, New York, NY.

Janusek, J., Williams, P., 2016. Telluric techne and the lithic production of Tiwanaku. In: Costin, C. (Ed.), Making Value, Making Meaning: Techne in the pre-Columbian world. Dumbarton Oaks Research Library, Washington, D.C., pp. 95–128

Janusek, J., Williams, P., Golitko, M., Lemuz Aguirre, C., 2013. Building Taypikala: telluric transformations in the lithic production of Tiwanaku. In: Tripcevich, N., Vaughn, K. (Eds.), Mining and Quarrying in the Ancient Andes: Sociopolitical, Economic, and Symbolic Dimensions. Springer, New York, NY, pp. 65–97.

Kendall, A., Early, R., Sillar, B., 1992. Report on archaeological field season investigating early Inca architecture at Juchuy Coscco (Q'aqya Qhawana) and Warq'ana, Province of Calca, Dept. of Cuzco,

Peru. In: Saunders, N. (Ed.), Ancient America: Contributions to New World Archaeology. Oxbow Monograph No. 24, Oxbow Books, Oxford, UK, pp. 189–256.
Kendall, A., 1976. Preliminary report on ceramic data and the pre-Inca architectural remains of the (lower) Sacred Valley, Cuzco. Baessler-Archiv, Neue Folge, Band XXIV, 41–159.
Kendall, A., 1985. Aspects of Inca Architecture: Description, Function and Technology. BAR Publishing, Oxford, UK.
Kendall, A., 1996. An archaeological perspective for Late Intermediate Period Inca development in the Cuzco region. J. Steward Archaeol. Soc. 24, 121–156.
Kokkorou-Alevras, G., Chatziconstantinou, A., Efstathopoulos, A., Zavvou, E., Themos, N., Kopanias, K., Poupaki, E., 2009. Ancient quarries in Laconia. British School Athens Studies 16, 169–179.
Kosiba, S., 2010. Becoming Inka: The transformation of political place and practice during Inka state formation (Cusco, Peru) (Unpublished doctoral dissertation). University of Chicago, Chicago, IL.
Kubler, G., 1952. Cuzco: Reconstruction of the town and Restoration of Its Monuments. UNESCO, Paris, France.
Lane, K., 2009. Engineered Highlands: The social organization of water in the ancient north-central Andes (AD 1000–1480). World Archaeol. 41 (1), 169–190.
Lechtman, H., 1993. Technologies of power: the Andean case. In: Henderson, J., Netherly, P. (Eds.), Configurations of Power: Holistic anthropology in theory and practice. Cornell University Press, Ithaca, NY, pp. 244–280.
Lemonnier, P., 1992. Elements for an Anthropology of Technology. Museum of Anthropology, Ann Arbor, MI.
Mannheim, B., 1991. The language of the Inka since the European invasion. University of Texas Press, Austin, TX.
Marcus, J., Flannery, K., 2001. La clasificación de animales y plantas entre los zapotecos del siglo XVI. Un estudio preliminar. Cuadernos del Sur 7 (16), 5–20.
Maschek, D., 2016. The Marble Stoa at Hierapolis: Materials, labour force, and building costs. In: Ismaelli, T., Scardozzi, G. (Eds.), Ancient Quarries and Building Sites in Asia Minor, Research on Hierapolis in Phrygia and Other Cities in South-Western Anatolia: Archaeology, archaeometry, conservation. Edipuglia, Bari, Italy, pp. 393–402.
McCurdy, L., Abrams, E. (Eds.), 2019. Architectural Energetics in Archaeology: Analytical expansions and global explorations. Routledge, Oxon, UK.
McEwan, G., 2006. Inca state origins: collapse and regeneration in the southern Peruvian Andes. In: Schwartz, G., Nichols, J. (Eds.), After Collapse: The regeneration of complex societies. The University of Arizona Press, Tucson, AZ, pp. 85–98.
Mendívil, S., Dávila, D., 1994. Geología de los cuadrángulos de Cuzco y Livitaca. INGEMMET, Boletín, Serie A: Carta Geológica Nacional, 52.
Miller, H., 2007. Archaeological Approaches to Technology. Elsevier Academic Press, Burlington, MA.
Miranda Ayerbe, A., Zanabria Alegría, W., 1994. La Cantera de Huaq'oto: Una introducción a su estudio tecnológico. Licentiate thesis, Facultad de Ciencias Sociales, Universidad Nacional San Antonio de Abad del Cusco, Cusco, Peru.
Moore, J., 2021. Ancient Andean Houses: Making, inhabiting, studying. University of Florida Press, Gainesville, FL.
Murakami, T., 2014. Social identities, power relations, and urban transformations: politics of plaza construction at Teotihuacan. In: Tsukamoto, K., Inomata, T. (Eds.), Mesoamerican Plazas: Arenas of Community and Power. University of Arizona Press, Tucson, AZ, pp. 34–49.
Murakami, T., 2019. Labor Mobilization and Cooperation for Urban Construction: Building apartment compounds at Teotihuacan. Latin American Antiquity 30 (4), 741–759.

Nair, S., 2007. Witnessing the in-visibility of Inca architecture in Colonial Peru. Build. Landscapes J. Vernacular Archit. Forum 14, 50–65.

Nair, S., 2015. At Home with the Sapa Inca: Architecture, Space, and Legacy at Chinchero. University of Texas Press, Austin, TX.

Niles, S., 1980. Pumamarca: A Late Intermediate Period site near Ollantaytambo. Nawpa Pacha 18, 49–62.

Niles, S., 1999. The Shape of Inca History: Narrative and architecture in an Andean empire. University of Iowa Press, Iowa City, IA.

Ogburn, D., 2004. Power in stone: the long-distance movement of building blocks in the Inca Empire. Ethnohistory 51 (1), 101–135.

Ogburn, D., 2013. Variation in Inca building stone quarry operations in Peru and Ecuador. In: Tripcevich, N., Vaughn, K. (Eds.), Mining and Quarrying in the Ancient Andes: Sociopolitical, Economic, and Symbolic Dimensions. Springer Science + Business Media, New York, NY, pp. 45–64.

Ogburn, D., Sillar, B., Sierra, J., 2013. Evaluating effects of chemical weathering and surface contamination on the in-situ provenance analysis of building stones in the Cuzco region of Peru with portable XRF. J. Archaeol. Sci. 40, 1823–1837.

Olchuski, L., Davila, D., 1994. Geología de los cuadrángulos de Chuquibamba y Cotahuasi. INGEMMET, Boletín, Serie A: Carta Geológica Nacional, Boletín No. 50.

Outwater, J., 1959. Building the fortress of Ollantaytambo. Archaeology 12 (1), 26–32.

Pauketat, T., Alt, S., 2005. Agency in a Postmold? Physicality and the archaeology of culture-making. J. Archaeol. Method Theory 12 (3), 213–236.

Pizarro, P. (1921[1571]). Relation of the Discovery and Conquest of the Kingdoms of Peru (P. Means, Trans., Ed.). Cortes Society, New York City, NY.

Polo de Ondegardo, J., 1916. Relación de los fundamentos acerca del notable daño que resulta de no guardar a los indios sus fueros. In: Informaciones acerca de la religión y gobierno de los Incas. Imprenta y Liberia Sanmarti, Lima, Peru, pp. 45–188.

Guaman Poma de Ayala, F. (2009[1615]). The First New Chronicle and Good Government: On the history of the world and the Incas up to 1615 (R. Hamilton, Trans., Ed.). Austin, TX: University of Texas Press.

Protzen, J.-P., 1983. Inca quarrying and stonecutting. ˜Nawpa Pacha: J. Andean Archaeol. 21, 183–214.

Protzen, J.-P., 1985. Inca quarrying and stonecutting. J. Soc. Archit. Historians 44 (2), 161–182.

Protzen, J.-P., 1993. Inca Architecture and Construction at Ollantaytambo. Oxford University Press, Oxford, UK.

Protzen, J.-P., Nair, S., 1997. Who Taught the Inca Stonemasons Their Skills? A comparison of Tiahuanaco and Inca cut-stone masonry. J. Soc. Archit. Historians 56(2), 146–167.

Ravines, R., 2008. Informe final proyecto de evaluación arqueológica en el fundo Salabella: Sector Silvayoc, Urquillos, Cusco. Final report presented to the Instituto Nacional de Cultura, Cusco, Peru.

Roux, V., 2007. Ethnoarchaeology: a non-historical science of reference necessary for interpreting the past. J. Archaeol. Method Theory 14 (2), 153–178.

Rowe, J., 1944. An introduction to the archaeology of Cuzco. Papers of the Peabody Museum of American Archaeology and Ethnology 27(2).

Rowe, J. 1946. Inca culture at the time of Spanish conquest. In: Steward, J. (Ed.), Handbook of South American Indians, Vol. II: The Andean civilizations. US Government Printing Office, Washington, DC, pp. 183–330.

Salomon, F., 1991. Introductory essay. In: Salomon, F., Urioste, G. (Eds.), The Huarochirí Manuscript: A Testament of Ancient and Colonial Andean Religion. University of Texas Press, Austin, TX, pp. 1–38.

Sancho, P., 1917[1534]. Relación de la conquista del Perú [An Account of the Conquest of Peru] (P. Ainsworth Means, Trans.). The Cortes Society, New York City, NY.
Santo Tomás, D., 1560. Lexicón, o Vocabulario de la Lengua General del Perú. Impreso en Valladolid, por Francisco Fernández de Córdova, impresor de la M.R. Digitized by John Carter Brown Library for Internet publication. Available from: <https:// archive.org/details/lexiconovocabula00domi>.
Sarmiento de Gamboa, P., 2007[1572]. The History of the Incas (B. Bauer & V. Smith, Trans., Eds.). University of Texas Press, Austin, TX.
Salomon, F., 1998. How the Huacas Were: The language of substance and transformation in the Huarochirí Quechua manuscript. RES: Anthropol. Aesthetics 33, 7–17.
Schiffer, M., Skibo, J., 1987. Theory and experiment in the study of technological change. Curr. Anthropol. 28 (5), 595–622.
Schilman, M., Reisner, D., 2011. Pircando con piedras en Susques y Rinconada. Usos y funciones, conocimientos y saberes a través de la experiencia. In: Tomasi, J., Rivet, C. (Eds.), Puna y arquitectura. Las formas locales de la construcción. Centro de Documentación de Arte y Arquitectura Latinoamericana, Buenos Aires, Argentina, pp. 57–70.
Shaw, I., 1994. Pharaonic Quarrying and Mining: Settlement and procurement in Egypt's marginal regions. Antiquity 68, 108–119.
Shimada, I., Craig, A., 2013. The Style, Technology and Organization of Sic´an Mining and Metallurgy, Northern Peru: insights from holistic study. Chungara, Revista de Antropología Chilena 45 (1), 3–31.
Sillar, B., 2000. Dung by Preference: the choice of fuel as an example of how Andean pottery production is embedded within wider technical, social, and economic practices. Archaeometry 42, 43–60.
Sillar, B., Vranich, A., Ogburn, D., 2019. Prior to Pachacuti: A Pre-Imperial Phase for Monumental Construction in Cuzco? Presented at the 84th Annual Meeting of the Society for American Archaeology, Albuquerque, NM.
Sillar, B., 2009. The social agency of things? Animism and materiality in the Andes. Cambridge Archaeol. J. 19 (3), 367–377.
Sinopoli, C., 1994. The archaeology of empires. Annu. Rev. Anthropol. 23, 159–180.
Smith, A., 2000. Rendering the political aesthetic: political legitimacy in Urartian representations of the built environment. J. Anthropol. Archaeol. 19, 131–163.
Smith, A., 2015. The Political Machine: Assembling sovereignty in the Bronze Age Caucasus. Princeton University Press, Princeton, NJ.
Swenson, E., Warner, J., 2012. Crucibles of Power: forging copper and forging subjects at the Moche ceremonial center of Huaca Colorada. J. Anthropol. Archaeol. 31, 314–333.
Tovar Cayo, J., 1996. Cantería Inka en Waqoto-Cusco. Licentiate thesis, Facultad de Ciencias Sociales, Universidad Nacional de San Antonio Abad del Cusco, Cusco, Peru.
Trigger, B., 1990. Monumental Architecture: a thermodynamic explanation of symbolic behaviour. World Archaeol. 22 (2), 119–132.
Verhoeven, G., Taelman, D., Vermeulen, F., 2012. Computer vision-based orthophoto mapping of complex archaeological sites: the ancient quarry of Pitaranha (Portugal–Spain). Archaeometry 54 (6), 1114–1129.
Wittfogel, K., 1957. Oriental Despotism: A comparative study of total power. Yale University Press, New Haven, CT.
Xie, L., Kuhn, S., Sun, G., Olsen, J., Zheng, Y., Ding, P., Zhao, Y., 2015. Labor costs for prehistoric earthwork construction: experimental and archaeological insights from the Lower Yangzi Basin, China. Am. Antiquity 80 (1), 67–88.

Xie, L., Wang, D., Zhao, H., Gao, J., Gallo, T., 2021. Architectural energetics for rammed earth compaction in the context of Neolithic to early Bronze Age urban sites in Middle Yellow River Valley, China. J. Archaeol. Sci. 126, 105303.

Ziołkowski, M., 2008. Coropuna y Solimana: los oráculos de Condesuyos. In: Curatola Petrocchi, M., Ziołkowski, M. (Eds.), Adivinación y oráculos en el mundo andino antiguo. Pontificia Universidad Católica del Perú, Fondo Editorial, Lima, Peru, pp. 121–159.