Who Taught the Inca Stonemasons Their Skills?

A Comparison of Tiahuanaco and Inca Cut-Stone Masonry

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The use of dressed stone in architectural construction in pre-Colombian South America has a long history of development [*Figure 1*]. One of its early manifestations appears, for example, at Cerro Sechín, in construction from sometime before c. 1000 B.C. There it takes the form of an enclosure wall composed of large dressed granite stones engraved with bas-reliefs depicting grisly war or sacrifice scenes and forming a kind of frieze. If at Cerro Sechín dressed stones are still loosely fitted, well-joined cut-stone masonry emerges in the northern Andes at Chavín de Huantar between about 900 and 400 B.C. In the southern Andes, elaborate cut-stone masonry and carved stelae from the beginning of the Early Intermediate Period are found at Pukara.[1] It was left to the Tiahuanacans to raise the art and techniques of cut-stone construction to unequaled maturity and perfection at Tiahuanaco between c. 200 B.C and A.D. 1000, an era stretching from the Early Intermediate into the beginning of the Late Intermediate Period. In the Late Intermediate Period there appears to have been a lull in this kind of construction; no major new centers were built, nor were there any architectural or technological innovations. In the Late Horizon, however, the art and techniques of cut-stone construction experienced a revival and attained new heights under the Incas.

There is a persistent argument that the astounding Inca stonework was not an indigenous invention, but rather a derivative of Tiahuanaco masonry, and that to build their monuments the Incas did not use their own artisans, but imported Qollasuyu stoneworkers from the Lake Titicaca area. This argument rests, in part, on two sixteenth-century sources. The first, Pedro de Cieza de León, recorded:

> . . . I have heard Indians state that the Incas made the great buildings of Cuzco in the form they had seen in the rampart or wall one can see in this village [of Tiaguanaco].[2]

Pedro Sarmiento de Gamboa wrote:

> . . . he [the Inca ruler Pachacuti] went down the valley and river of Yucay to a place that now they call Tambo, . . . where he made some most lavish buildings. The construction and *stonemasonry* [italics ours] of these were made by captives, the sons of Chuchi Capac, the great sinchi of Collao, whom . . . he had defeated and killed in the Collao.[3]

There is little question that the Incas conquered the area around Lake Titicaca and visited the site of Tiahuanaco [*Figure 2*] some time before 1470, nor is there any doubt that they enlisted men from the Lake Titicaca area to serve as construction workers. However, the role these workers played in the development of Inca construction techniques is questionable. Garci Diez de San Miguel, who in 1567 inspected the Chucuito province for the Spanish crown, reported that the Incas had recruited Lupaqa *mit'ayoq* (impressed laborers) from the Qollasuyu (the southeastern quarter of the Inca Empire, wherein lay Tiahuanaco) in large numbers to build houses in Cuzco.[4] Presumably, the Qollasuyu stonemasons had maintained a reputation as fine craftsmen. Given the scarcity of such inspection reports, however, it is not known how many *mit'ayoq* from other areas of the Inca Empire were enlisted for construction. Therefore, the percentage of *mit'ayoq* from Qollasuyu within the Inca construction forces could have been negligible. The evidence from Chucuito is hardly conclusive.

Even if the *mit'ayoq* from Qollasuyu were a major constituent of Inca construction labor, what skills they actually brought to Inca construction is not known. As noted above, there is a critical time lag between the collapse of Tiahuanaco and the rise of the Inca empire. Graziano Gasparini and Luise Margolies, who first raised this argument, stated that there was "a problem in demonstrating the continuity of stonemasonry even among the Lupaqa masons who went in such great numbers to Cuzco. In fact, between the Tiwanaku [Tiahuanaco] monuments and the Inca construction there lie several centuries without buildings of cut stone. Indeed there are no examples of that technique during the Late Intermediate Period."[5]

Is it possible that the technology used by the Tiahuanacans survived over the several hundred years after the demise of Tiahuanaco and before the growth of the Inca empire? And how much of Tiahuanaco itself was left for the Incas to see? The best answer to the latter question is that of Cieza de León,

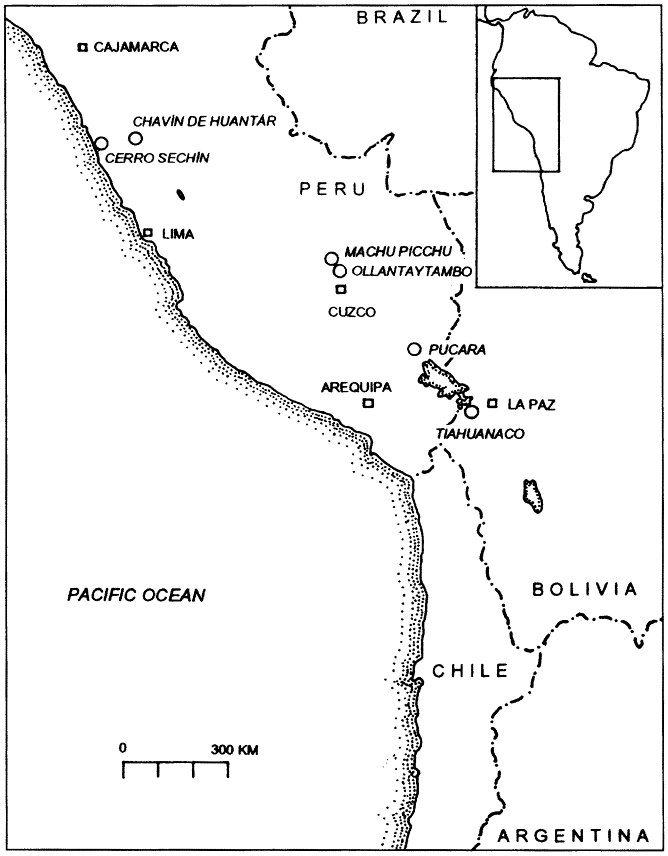


FIGURE 1: major ancient sites (italics) with cut-stone masonry in modern-day Peru and Bolivia

who visited the site in 1549, less than twenty years after the first Spaniards marched into Cuzco. His description leaves one with the impression of a site partially in ruins, wasted away by centuries of erosion, and partially in a state of abandoned construction.[6] What can be seen today does not seem to differ much from Cieza's account, yet it is known that since Cieza's visit the site has suffered enormous damage inflicted by treasure hunters, builders, and railroad construction. Thus, we can be confident that the Incas could have seen at least as much of Tiahuanaco's architecture and construction as we do today. With respect to the question of the technology's survival, several visitors to sites of both cultures have remarked on perceived similarities between Inca and Tiahuanaco architecture. Therefore, we turn to the architectural remains themselves for an answer.

Tiahuanaco influence in the stonework at the Inca site of Ollantaytambo has been noted by Heinrich Ubbelohde-Doering and by Alfons Stübel and Max Uhle, among others. Ubbelohde-Doering saw a similarity between construction at Ollantaytambo and the Temple of Pumapunku at Tiahuanaco. He based his argument on the T-shaped cramp sockets, the sharpness and straightness of the edges, and the precision of the angles he saw on blocks at both sites.[7] Stübel and Uhle likened Ollantaytambo's great upright monoliths to those of Tiahuanaco and found similarities in stones elaborated with what they believed to be right angles.[8] In his own work at Ollantaytambo, Jean-Pierre Protzen took issue with some of Ubbelohde-Doering's observations, and showed that the perfection he and the Stübel and Uhle team saw is not what it seems to be. He, too, questioned Tiahuanaco influences on Inca stonework.[9]

The position of Gasparini and Margolies, and Protzen's skepticism regarding a Tiahuanaco derivation of Inca stonework and architecture may well be justified, but it should be noted that they made their arguments in the absence of a thorough study of Tiahuanaco construction practices. Many researchers, from Alcide d'Orbigny to Javier Escalante, have described various architectural features or construction details at Tiahuanaco, but to date there has been no comprehensive treatment of the subject.[10]

The many building stones strewn about the site and recent excavations at Tiahuanaco yield a wealth of interesting details regarding the cutting and dressing of stones, as well as their fitting, laying, and handling.[11] Preliminary investigations of these details and observations made during the 1993 and 1994 field seasons lead us to argue that Tiahuanaco masonry differs significantly from Inca masonry, that Tiahuanaco construction techniques are radically different from those of the Incas, and that at Tiahuanaco itself, more than one technique was used.

MASONRY BONDS

The Incas used an amazing diversity of joint patterns, or masonry bonds, in the construction of their walls. Although many authors have attempted to classify the various bonds, there is no agreed-upon nomenclature. An examination of four types—cyclopean, convex polygonal, concave-convex polygonal, and scutiform—reveals that all are executed with beveled, often deep-seated joints which give the walls the pleasing chiaroscuro effect under sunlight that is so characteristic of Inca architecture [*Figure 3*]. There is no correspondence between these Inca masonry bonds and masonry bonds found at Tiahuanaco.

Similarities between Inca and Tiahuanaco masonry, if they

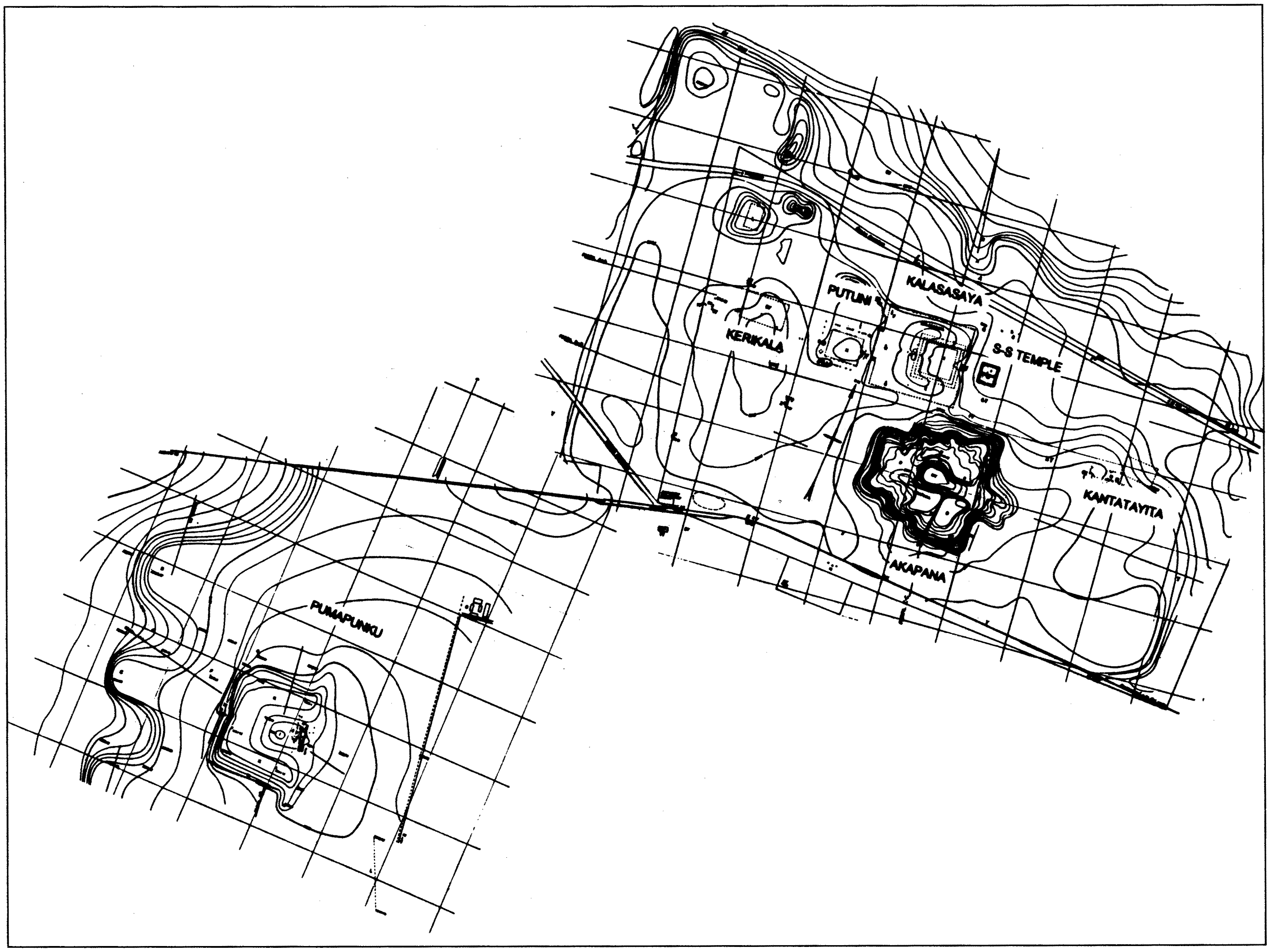


FIGURE 2: Tiahuanaco, site plan

FIGURE 3: Palace of Inca Roca, Cuzco: chiaroscuro effect in Inca masonry

exist, come into view only when we look at the Inca masonry of the Qorikancha, the Hatunkancha in Cuzco, or the Incamisana at Ollantaytambo, for example (See Figure 7). This masonry appears to be regularly coursed ashlar masonry. But on close inspection, it never is: the stones are not rectangular prismatic stones, nor are the stones in one course exactly the same height. As a result, the horizontal joints form not a straight, but a wavy line. Yet if the strict definition of "ashlar" as a squared building stone is expanded to include roughly rectangular, prismatic stones, this masonry can be described as ashlar masonry, and so can all of Tiahuanaco's cut-stone masonry. As we shall show, however, Tiahuanaco ashlar masonry—which is found in various guises—differs in significant ways from Inca ashlar masonry.

Random-Range Work Between Orthostats

Random-range work is "masonry of rectangular stones not laid in regular courses but broken up by the use of stones of different heights and widths."[12] At Tiahuanaco, this masonry is seen in the Semi-subterranean Temple and the Kalasasaya, with the exception of the latter's so-called balcony wall [*Figure 4*]. It is set between orthostats spaced from 1 to as many as 4 meters apart. The notion of infill masonry between structural elements is foreign to Inca construction practices, and so is random-range work, which, to our knowledge, was never used by the Inca stonemasons.

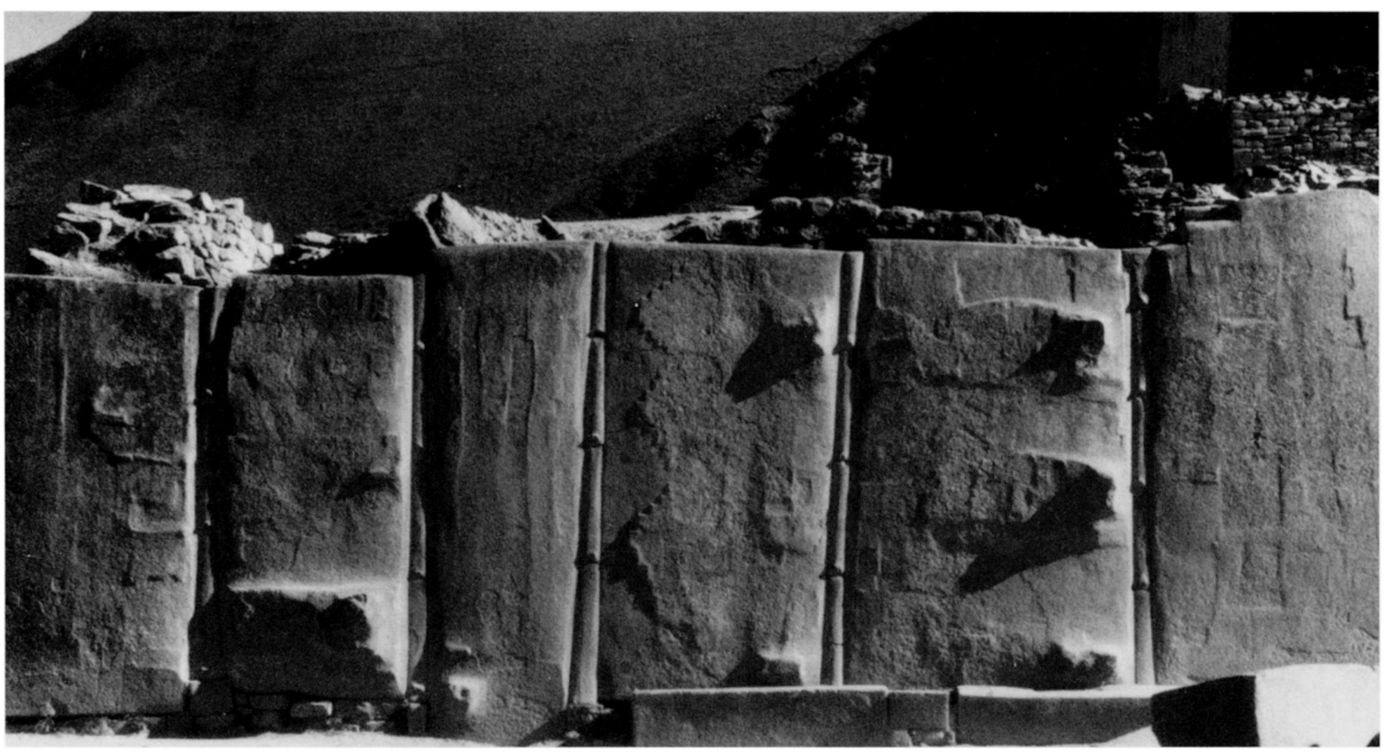
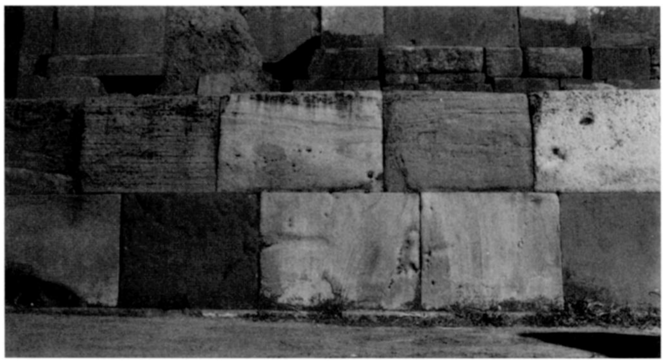


FIGURE 4: Semi-subterranean Temple, Tiahuanaco: random-range work

FIGURE 5: Wall of Six Monoliths, Ollantaytambo

Stübel and Uhle saw a similarity between the Kalasasaya and the Wall of Six Monoliths at Ollantaytambo with its fine fillet stones closing the gap between the monoliths [*Figure 5*]. The proportions of the monoliths at Ollantaytambo do not match those of the orthostats of the Kalasasaya. On average the space between the blocks at Ollantaytambo measures less than 15 centimeters. The fillet stones between the monoliths at Ollantaytambo do not fit the description of infill masonry, but rather that of "wedge" stones, to be discussed below.



Opus Quadratum, or Coursed Ashlar Masonry between Large Blocks

Opus quadratum, or coursed ashlar masonry, is "masonry of squared stones in regular courses," where the height of the courses may vary from course to course, and the ashlars are not all of the same size.[13] At Tiahuanaco, this bond is found, set between large blocks, in the base wall, a now freestanding wall right above another retaining wall on the east side of Akapana mound, and in the so-called balcony wall of the Kalasasaya [*Figure 6*]. This masonry has courses with level, perfectly even beds and its vertical joints perpendicular to the bedding joint. This makes stones in a course interchangeable, suggesting that stones could have been prefabricated.

One may see some affinity between the coursed ashlar infill of Tiahuanaco and the masonry of an Inca structure at Ollantaytambo's Incamisana [*Figure 7*]. But as mentioned before, in Inca ashlar masonry, the height of a single course is never perfectly uniform; one can always detect variations which result in wavy joints between courses. There is no Inca equivalent to the Tiahuanaco *opus quadratum* infill masonry.

FIGURE 6: Akapana, Tiahuanaco: *opus quadratum* masonry in wall on the east side

FIGURE 7: Incamisana, Ollantaytambo: Inca masonry showing "wavy" bedding joint

FIGURE 8: Akapana, Tiahuanaco: random-range work of small stones between large blocks on the west side

FIGURE 9: Machu Picchu: quasi-coursed masonry in "Beautiful Wall"

FIGURE 10: Akapana, Tiahuanaco: quasi-coursed masonry, second wall, east side

Masonry of Small Stones between Large Blocks

At Tiahuanaco, in the structure of Putuni and some parts of the Akapana, large blocks were placed at variable intervals to delimit the structure, and smaller stones fitted into the space between them in either random-range or coursed masonry [*Figure 8*]. Again, there is no comparable Inca masonry. One may on occasion find smaller stones fitted between larger stones, but the latter, with one exception at Ollantaytambo, were not used to outline a structure. The southwest and northeast walls of the so-called Sun Temple at Ollantaytambo are built on the model of large stones set apart, outlining the structure, with small-stone rubble infill masonry closing the gaps. These walls are built of reused stones, and the structure is evidently unfinished. It is thus difficult to guess

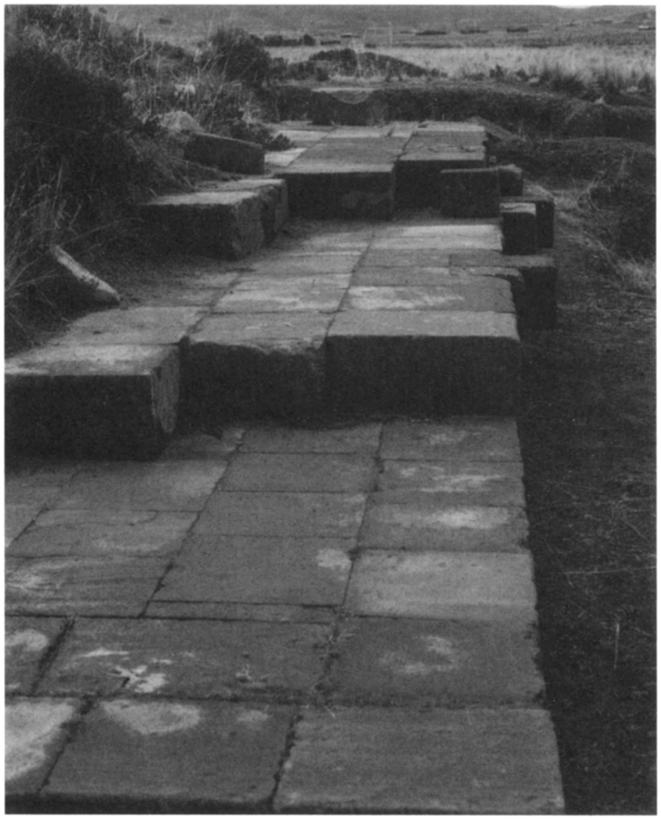


FIGURE 11: Pumapunku, Tiahuanaco: near-isodomic masonry on the southeast corner

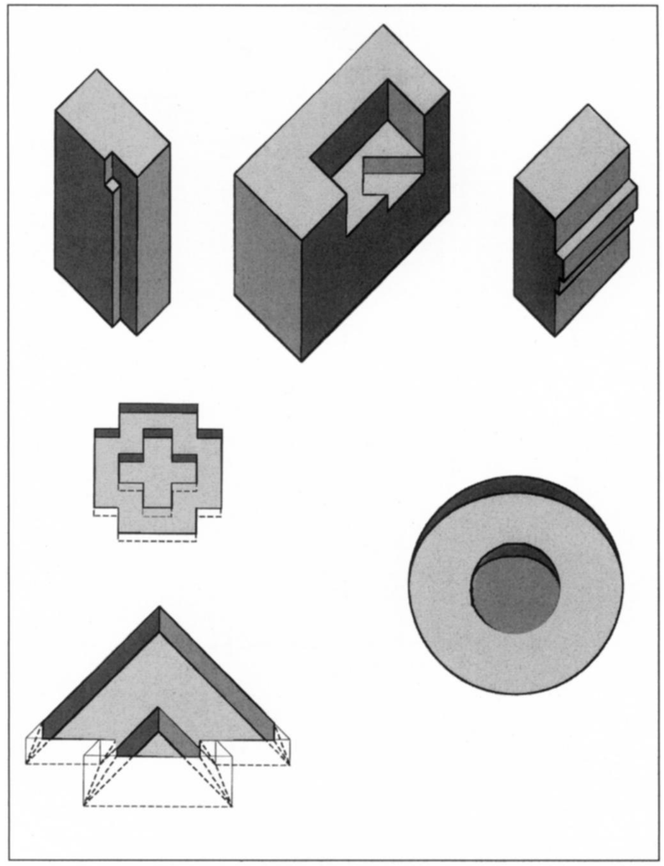
what the builder's intent may have been. Furthermore, the walls are a unique example and do not represent standard Inca practice. The similarity here with Tiahuanaco seems incidental.

Quasi-Coursed Ashlar Masonry

Quasi-coursed masonry is masonry with the appearance of coursed masonry, but in which some horizontal joints are discontinuous—some courses are offset against others—and the courses' bedding often is not planar. Quasi-coursed masonry was extensively practiced by the Incas. It is found, for example, in what Hiram Bingham called the Beautiful Wall at Machu Picchu and the Qorikancha in Cuzco [*Figure 9*]. At Tiahuanaco this masonry is found in the second wall on Akapana's east side [*Figure 10*]. The distinction between Inca and Tiahuanaco quasi-coursed masonry is that the former has beveled, or sunken, joints and the latter does not.

Near-Isodomic Masonry

Opus isodomum is a "masonry pattern in which stones of uniform length and uniform height are set so that each vertical joint is centered over the block beneath. Horizontal joints are continuous and the vertical joints form discontinuous straight lines."[14] At Tiahuanaco, in the mound of Pumapunku, one finds "near-isodomic" masonry [*Figure 11*]. We call it so because it fails to meet the *isodomum* definition only with regard to the uniform length of the blocks and thus the position of the vertical joints. Otherwise, this masonry is remarkable for its precision: perfectly rectangular, prismatic blocks in courses of uniform height. This method of construction is unknown in, and almost antithetical to, Inca masonry. Even in the finest of Inca ashlar masonry, the blocks, while perfectly fitted to each other, do not have planar faces and do not join at right angles. In the near-isodomic masonry at Tiahuanaco, one stone could be exchanged for another



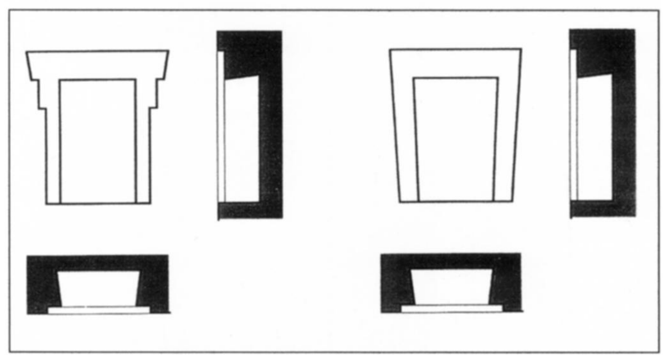
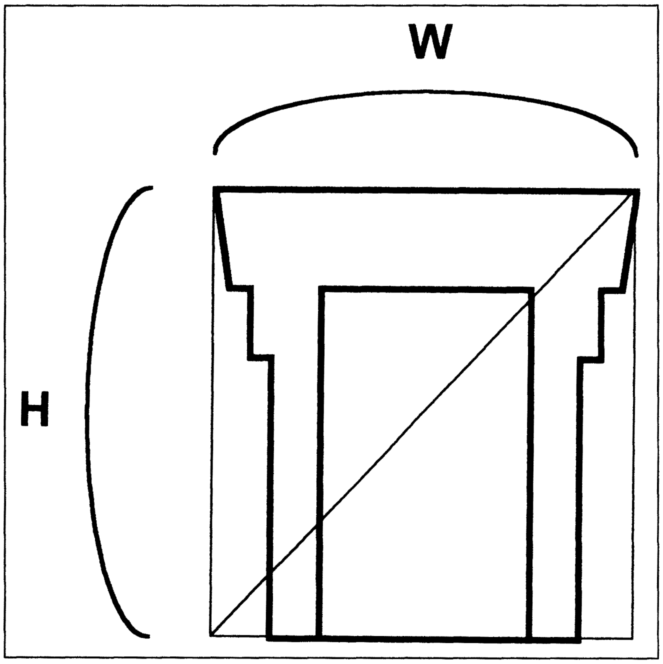


FIGURE 12: A sample of motifs found at Tiahuanaco. Clockwise from upper left: stepped rabbet, lozenge, step molding, circle, arrow, cross

FIGURE 13: Tiahuanaco, two types of niches: type 1 on the right, type 2 on the left, each in front view and section at top, in plan below



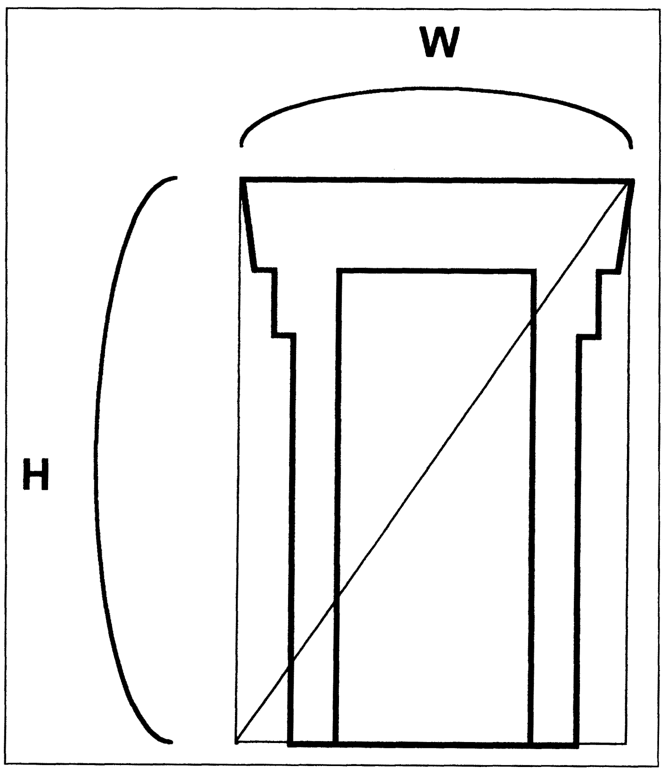


FIGURE 14: Type 2*a* niche inscribed in rectangle, height/width 1:1.0399

FIGURE 15: Type 2*b* niche inscribed in rectangle, height/width 1:1.4499

with even more ease than in the coursed ashlar masonry discussed above. This raises not only the possibility of prefabrication, but even of mass production. The latter, if it could be shown to have been the case at Tiahuanaco, would represent a major innovation in Andean cut-stone construction technology.

Near-Isodomic Masonry with In-and-Out Bond

A variant of the above, the near-isodomic with in-and-out bond, is found on the second tier of Pumapunku. The wall's face is not in a single plane; some stones jut in or out of the wall's general plane, giving the wall a rugged appearance. There is no comparable bond in Inca masonry.

DESIGN DETAILS

In addition to differences in joint patterns, or masonry bonds, and their implications for construction, there are other significant distinctions between Tiahuanaco and Inca walls. As a rule, Inca walls are built with a batter of 3° to 5°. In contrast, Tiahuanaco walls are generally vertical.[15] With the exception of a few instances, the Incas shunned ornament in their cut-stone masonry. Or perhaps one could argue that the joint pattern with its chiaroscuro effect has enough sculptural qualities so that no further carvings were deemed desirable. At Tiahuanaco, however, elaborate carvings adorn some stones in the Kantatayita, the stones and gate fragments at Pumapunku, and the gates of the Sun and the Moon.

Ornamental Motifs

The carvings are compositions incorporating a number of recurrent motifs, or geometric design elements: crosses, arrows, circles, lozenges, rabbets (straight and stepped), step moldings, dentils, niches, niche icons, and representational friezes [*Figure 12*]. This inventory of motifs is limited to what can still be observed at Tiahuanaco and is not meant to be exhaustive. Several additional motifs, which we will not describe here, can be found in old drawings and photographs of Tiahuanaco and in the Museo al aire libre (Museo Miraflores) in La Paz.

The niches are of two types [*Figure 13*]. The first, type 1, is set within an inverse trapezoidal, recessed frame. The niche itself has beveled reveals that flare out toward the back, or inside, and is higher at the back than the front. The second, type 2, is set within a stepped, recessed frame, and it too has beveled reveals flaring out toward the back and is higher at the back than the front. Type 2 niches further assume two distinct shapes: Type 2*a* is small and compact; type 2*b* is large, elongated, and gate-like in appearance [*Figures 14, 15*].

The jambs and lintels of the gates we investigated are all beveled in ways similar to the niches. Since the bevels in the niches flare open to the back, we reasoned that the bevels of the gates would also, thus giving us a clue as to which side of a gate was its front, or outside. If the gate has a frieze, it is invariably on the outside.[16]

There are two basic cross designs: the simple cross and the stepped, or so-called Andean, cross. The simple cross motif

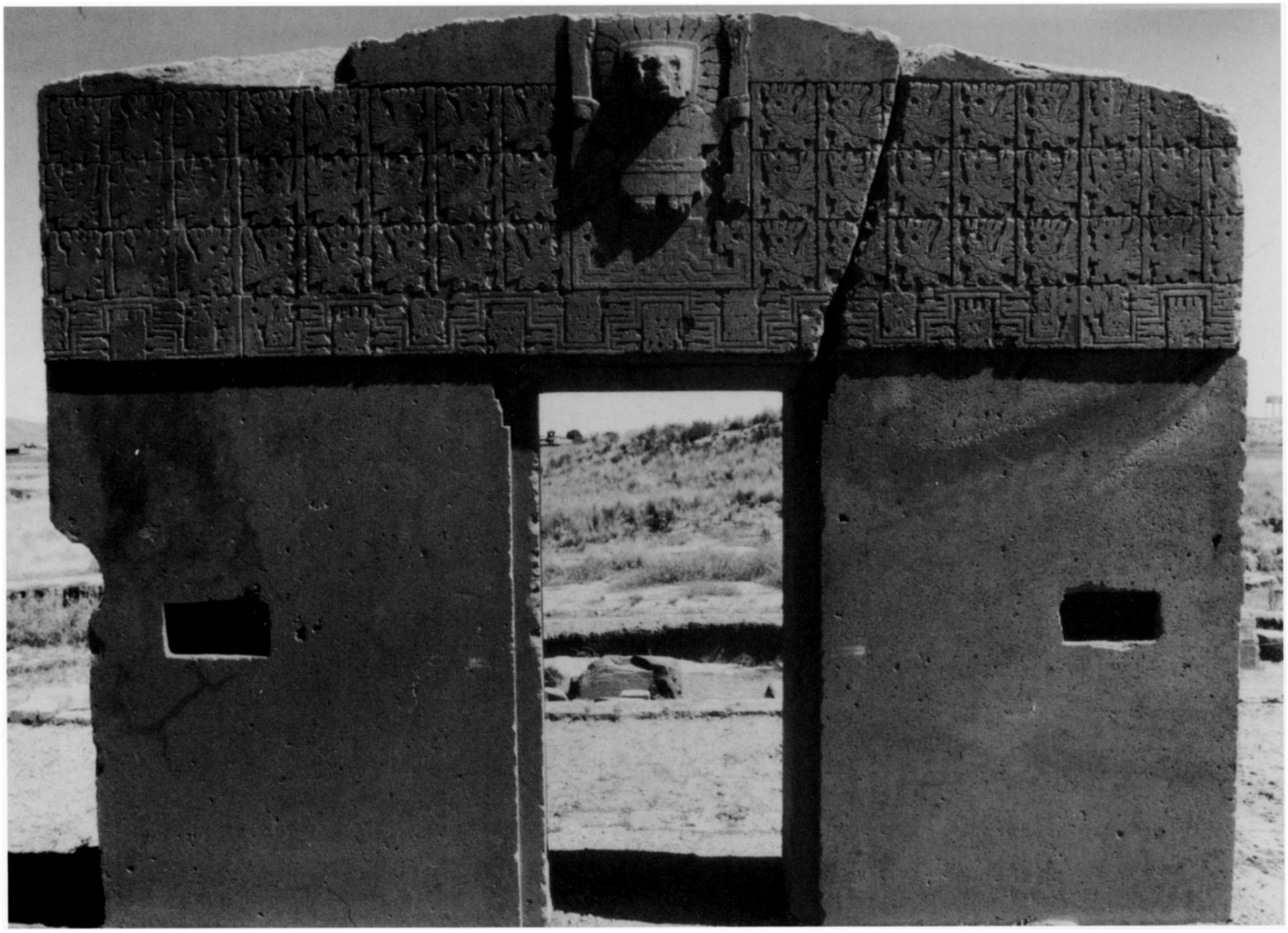


FIGURE 16: Tiahuanaco, Gate of the Sun, front side

always appears as a small, recessed simple cross within a larger, recessed simple cross. The stones with the stepped cross motif found in the structures known as Kantatayita and Kerikala and in the storage yard near the museum are unfinished. It is thus not known how the completed form would have looked. The motifs were not always carved from a single block, but were often assembled, puzzle-like, from two or more blocks, each having a part of the motif. Examples are the crosses on a stone known as El Escritorio del Inca, or on the cross stones (see Figure 26).

Compositions

When more than one motif is used in a composition, or if the same motif is repeated, there is consistency in the respective arrangements. Thus, for example, if the two niche types or niche icons are present, type 2 is always placed above type 1. Simple crosses, when repeated, are always organized vertically, one above the other. Niches of type 2*a*, when repeated, form horizontal rows. We suspect that there may be other typical arrangements, but to date we lack the proper evidence to assert their configurations.

The gates at Pumapunku, or, rather, their fragments, reveal on either side a design that is not unlike that of the Gate of the Sun.[17] They are plain on their outer side, with the gateway set within a double-stepped, recessed frame, surmounted by a frieze or frieze-like ornamentation, and flanked by rectangular "pockets" (the purpose of which is discussed below). On the inside the gates are divided by a step molding which wraps around the upper half of the gateway in two or three steps. The gate itself is set in a double-stepped, recessed frame. On either side of the jambs the gateway is flanked by type 2*b* niches below the step molding and by type 2*a* niches above. This regularity in design notwithstanding, the gates do not represent complete compositions; they were parts of larger compositions. The half niche on the upper left side of the Gate of the Sun and indentations with T-cramp sockets on the fragments of Gates I, II, and III at Pumapunku bespeak the addition of other elements to the gates [*Figures 16, 17*].[18]

Two stone fragments attest to the existence of a miniature gate with an opening about 93 centimeters in height, of a design very similar to that of the full-sized gates. It is surmounted by stepped step molding and is flanked by elongated niches on its inner side and two pockets on its front side. Two more fragments attest to the presence of a blind miniature gate of about the same dimensions cut from a single stone. The remarkable feature of this gate is its now broken back wall measuring only 8 centimeters in thickness.

Dimensions and Proportions

We are impressed with the apparent regularity and similarity of like elements. As have many researchers before us, we suspect that the Tiahuanacans used a system of preferred measurements, even a system of proportions. To elucidate these questions, we were very careful to measure everything with a precision of ±1 millimeter (thus allowing a maximum error of 2 millimeters). A millimeter may be lost because not all arrises are crisp and clean, or because the point to be measured does not fall exactly on a millimeter mark. Errors may also be due to unfavorable lighting conditions, difficulties in reaching the point to be measured, etc. On the basis of the measurements taken thus far we have not yet been able to determine a unit of measurement, and have found only limited evidence of a proportional system. Niches of type 2*a* can be inscribed in rectangles with the average proportion of 1:1.0399. Our sample of twenty niches yields a standard deviation of 0.013 for this ratio. The rectangle is just a touch higher than it is wide (see Figure 14). Type 2*a* niches cluster according to size [*Figure 18*]. Niches of type 2*b* can be inscribed in rectangles with the average proportion of 1:1.4495 (see Figure 15). Our sample of ten niches yields a standard deviation of 0.043 for this proportion. Type 2*b* niches also form two clusters of different sizes [*Figure 19*].

There are well-known and easy methods to construct, for example, the golden ratio (1:1.61803) with a straightedge and a compass. We know of no such simple methods to construct either of the ratios found above. The best we can do thus far is

FIGURE 17: Tiahuanaco, Gate of the Sun, back side

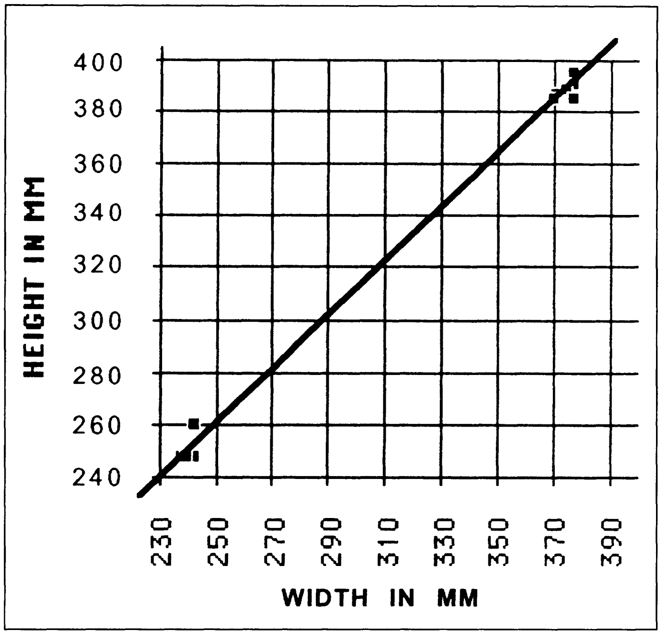


FIGURE 18: Regression line on proportions of type 2*a* niches showing two clusters

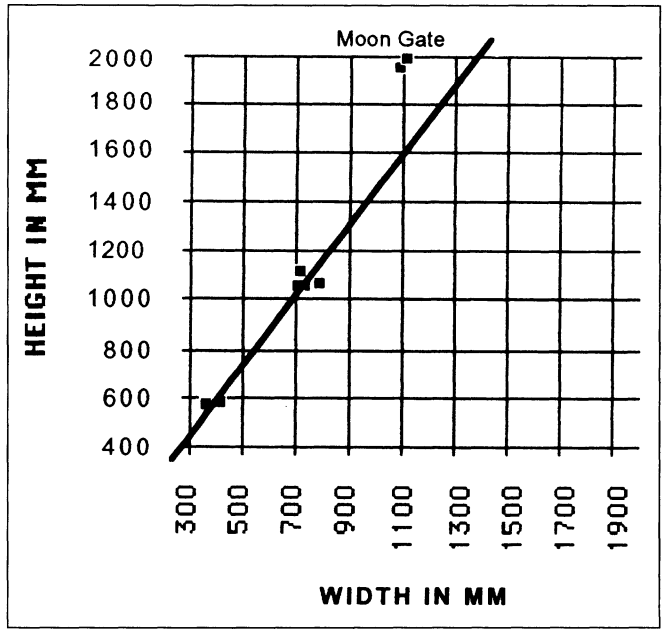


FIGURE 19: Regression line on proportions of type 2*b* niches showing two clusters

to offer ratios of natural numbers that approximate the observed width-to-height proportions: 25:26 = 0.9615 as compared to 1:1.0394 = 0.9616 for type 2*a* and 18:26 = 0.6923 as compared to 1:1.4495 = 0.6899 for type 2*b*. Although the natural number approximations in the first case fall below and in the second above the median and mean of the respective observed proportions, their values fit comfortably within the 90 percent confidence intervals around either mean. We are painfully aware that our samples are very small, and that therefore the statistical analysis of our data set is not very powerful. But our samples cannot be improved upon much, since there are very few visible and accessible niches at the site that we have not measured at this writing.

CONSTRUCTION TECHNIQUES

The fine stonework of Tiahuanaco has daunted every visitor to the site and induced early scholars, including Léonce Angrand in 1848 and Alfons Stübel in 1877 (31 December 1876 to 8 January 1877), to create highly accurate and exquisite measured drawings of the various gates and many carved stones found there.[19] From their close inspection of the stones and study of recesses of various kinds, of the precise arrises and exact right angles of recesses within recesses, and of the perfectly planar surfaces, Stübel and Uhle reasoned that

1. The Tiahuanacan stonecutters had a means of producing right angles with consistency
2. The stonecutters knew of several techniques to grind (*schleifen*) and smooth (*glätten*) stones
3. The perfectly executed interior corners required the use of sharp instruments.[20]

To these observations we add that the Tiahuanacan stonemasons had a means of controlling the planarity of extended, smoothed or ground surfaces.

Over the last two years we have inspected and recorded some seventy building blocks, among them many of the same stones that were drawn by our earlier colleagues. Here is what we have learned from this study of Tiahuanaco masonry techniques.

STONECUTTING

To rough out, shape, and finish building blocks, the Inca stonemasons pounded or crushed the work piece with hammerstones. On roughed-out stones the technique leaves diagnostic pit scars made by the impact of the hammers and patterns of cup-or trough-like depressions reflecting work in progress. On finished, or finely dressed stones, it also leaves pit scars: large scars in the center of a stone's face from large hammers, small scars along its arrises from small hammers. The particular technique for drafting edges on a block results in dihedral angles that are typically in excess of 90°, making the stone's faces bulge out, pillow-like.[21]

Pit scars and patterns of cup- or trough-like depressions are found on several roughly hewn and shaped stones at Tiahuanaco [*Figure 20*].[22] Although we have yet to find the actual hammerstones, the marks suggest that the Tiahuanacan stonemasons, to do the coarse work, used a technique quite similar to that of the Incas.[23] But to obtain the smooth finishes, the perfectly planar faces, and exact right interior and exterior angles on the finely dressed stones, they resorted to techniques unknown to the Incas and to us at this time.

The Incas, on occasion, polished their building stones, not in the visible face of the wall, but in the joints to improve the fit of stone on stone. Replicative experiments suggested that this polish was possibly obtained with a slurry of water and soil rich in clay, and a flat stone slab used in a linear or rotary movement to abrade the surface.[24] With this technique, and a good eye, it is possible to obtain an approximately planar surface, but not a perfect one as observed at Tiahuanaco.

Stonemasons today use a straightedge, preferably two, to check the planarity of a surface. They use the first straightedge set on a building block's clean edge to take a sighting at the second located anywhere on the surface to be cut. Ancient Egyptian stonemasons used a device called boning rods, consisting of three rods and a string. Two rods of equal length are connected to each other at their tops by a string. The third rod, also of the same length, is used to move over the surface against the taut string.[25] What the Tiahuanacans used is not known.

The sharp and precise 90° interior angles observed on building blocks and in various decorative motifs most likely were not made with hammerstones. No matter how fine the hammerstone's point, it could never produce the crisp right interior angles seen on Tiahuanaco stonework. Comparable cuts in Inca masonry all have rounded interior angles, typical of the pounding technique.

Perhaps the most remarkable stone carving feat at Tiahuanaco is seen on what we call arrow stones. The apexes at the base of the arrow project into the stone and under the surface design, with four planes perfectly planar, three of them meeting pair-wise at right angles, and eventually joining the fourth in one point [*Figure 21*]. Close examination of some interior angles of the precisely wrought stones reveals, even to the naked eye, a fine groove in the very apex of the angles. We suggest that these grooves result from the blade of a chisel-like tool, and that the point in which the four planes meet was made with a punch-like tool. No such tools have been recovered or recorded, but other details at Tiahuanaco suggest the use of chisels or punch-like tools. Several recessed pockets with T-shaped cramp sockets (discussed in more detail below) carved into them allow one to determine the tool's angle of attack and its minimum length [*Figure 22*].

Several building blocks and gates bear evidence that rough and finishing work were performed simultaneously on a work piece. Finely polished or carved surfaces adjoin surfaces that are still being roughed out [*Figure 23*]. Where recesses were

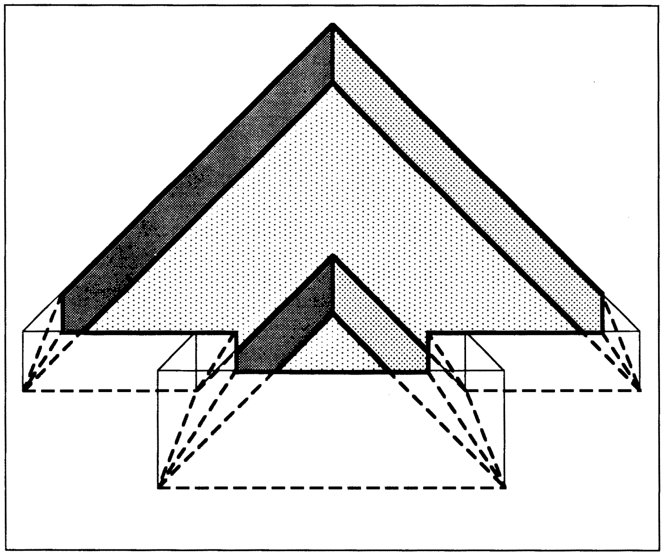
FIGURE 20: Trough-like depressions are found on several roughly hewn and shaped stones at Tiahuanaco.

to be carved into a stone, the outer surface was finished before the recess was attacked. Evidence of this is provided by the stepped cross stones at the Kantatayita. Their outer surface is planar and polished, while the recessed parts are only roughed out. The edges outlining the cross design, however, are clean and sharp and appear to have been made with a saw or file-like tool. The technique makes good sense: the prepared outer surface provided the reference plane necessary to position and outline the planned recesses and to control their depth.

Fitting Stones

The Incas, when building a wall, typically left the apparent upper faces of already set stones uncut until the next stone was ready for laying. This next stone was first carved on at least two faces, its bedding face and one lateral face. The shapes of these faces were then cut out of the already set stones to receive the new one. Thus, each stone was individually fitted to its immediate neighbors. On dismantled Inca walls one can always find the unique footprints of stones that once occupied these spots.[26]

At Tiahuanaco such footprints are not common, and are noticeably absent from all coursed ashlar and near-isodomic masonry. The fact that stones meet at right angles, have planar faces, and are all of the same height obviates the individual fitting of stone on stone. Fitting could be replaced by the control of dimensions, angles, and planarity of each stone,



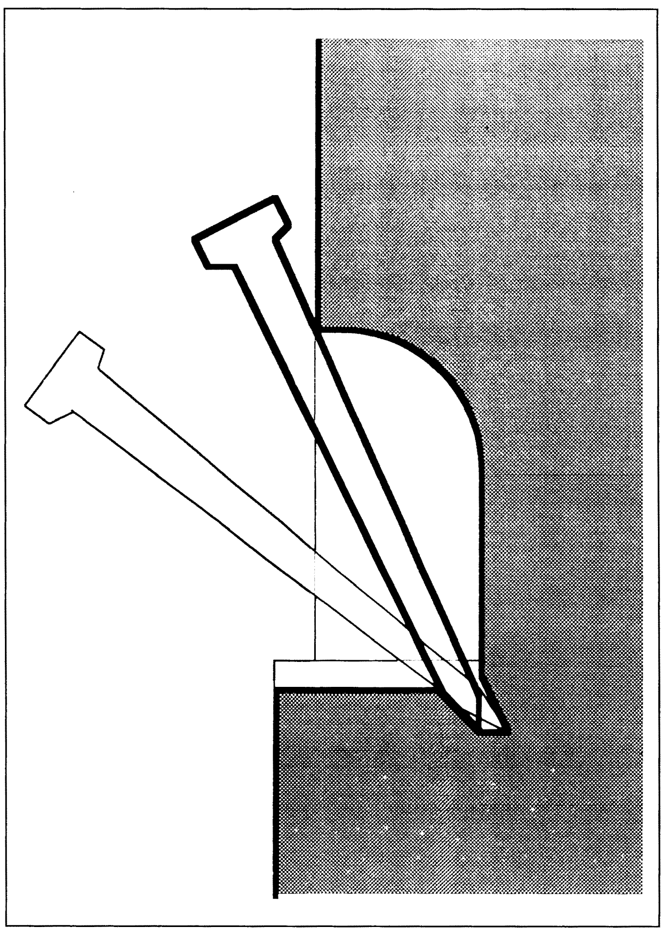


FIGURE 21: Diagram of carving on arrow stone

FIGURE 22: Diagram of recessed pockets with T-shaped cramp socket

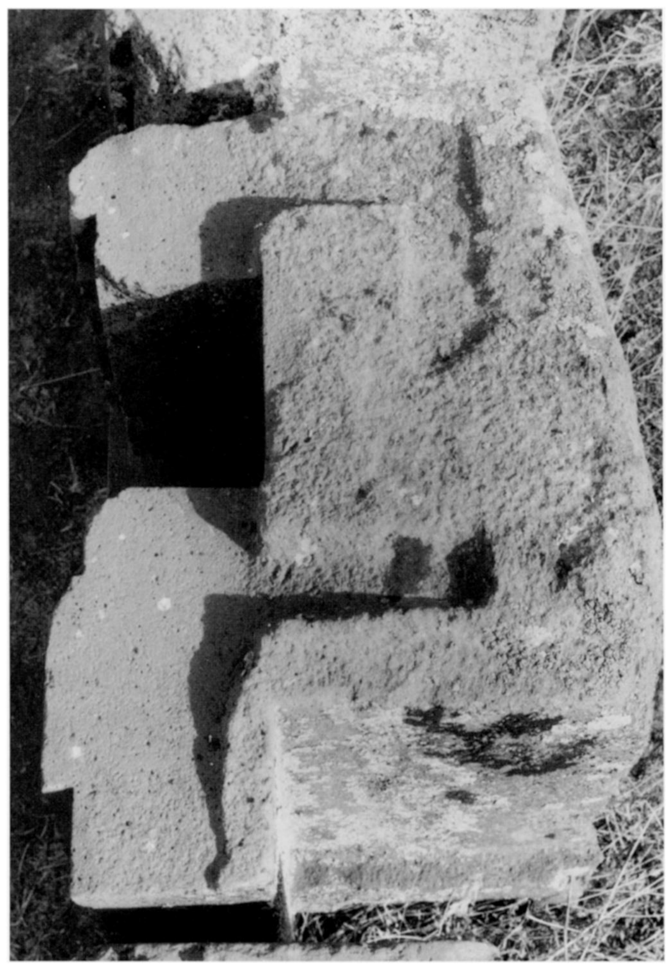


FIGURE 23: Building block showing surfaces in different states of finishing

FIGURE 24: Pumapunku, Tiahuanaco: second terrace wall on south side showing a residual bulge

carried out on the ground or even in a stonecutters' yard or workshop removed from the oeuvre. So prepared, the stones could be delivered to the site and assembled without further fitting work. In other words, building stones could have been prefabricated, even mass produced. Such a process presupposes the existence of appropriate tools to execute the control functions: a standard of measurement, squares, and straightedges, or their equivalents.

While prefabrication and mass production of stones are distinct possibilities, there is evidence that not all coursed ashlar and near-isodomic masonry was built that way. For example, in the second-tier wall of Pumapunku, with its in-and-out bond, where one stone projects from under another, one finds residual bulges at the front edges of the stones, suggesting that the tops of the stones were left uncut and the courses leveled to their height in situ [*Figure 24*]. The last course of the first tier on the south side provides further evidence, since its top has been left uncut. (On the north side, the corresponding course is evened out, suggesting that indeed the south side is unfinished.) And on the last step of the first tier, also on the south side, one can actually observe progress made in carving out the step; there are still unfinished sections. If the Incas fitted each stone individually to the course below by carving out an appropriate bed, the Tiahuanacans seem to have leveled the entire course, and then laid a new course of rectangular cut stones onto it.

Standardization of Building Blocks

Many blocks lying around the platform of Pumapunku show a striking similarity to one another, both in design and in dimensions, further supporting the idea of prefabrication. We are tempted to argue that the Tiahuanacans had a kit of standard building blocks from which they assembled the structures at Pumapunku. Unfortunately, many stones are so badly mutilated that they cannot be measured with any accuracy, or not enough stones of a certain type are left to substantiate the existence of a kit. Furthermore, some building blocks that appear identical in design show significant dimensional variations. Such blocks are not interchangeable, as would be the case in a true kit of building blocks, but the strong similarities indicate repetitive features in the architecture. The following inventory gives a partial overview of the types of building blocks found at Pumapunku [*Figures 25–29*]:

Type 1. H-stones with step molding and cross on backside (Figure 25)

Type 2. H-stones with step molding without cross on backside

Type 3. Sawtooth stones

Type 4. Step molding stones

Type 5. Architrave stones (Figure 29)

Type 6. Cross stones (Figure 26)

Type 7. Arrow stones (Figure 27)

Type 8. Lozenge stones

Type 9. Slabs with niche

Type 10. Circle stones

Type 11. E-stones.

Several standard building blocks were executed in lefthanded and righthanded versions (types 3, 4, 6, 7, 8, and 10), suggesting that the structures of which they were, or were to be, a part of had a high degree of symmetry (see Figure 27).

The design details and the puzzle-like partitioning of motifs discussed above, and the cramp sockets, discussed below, provide clues to a block's orientation and position in an assembly, and to the shape and dimensions of immediately adjacent stones. For example, stones with step moldings were positioned so that the molding ran horizontally with the wider step above the narrower, and stones with sawteeth were positioned with the prominent edges of the teeth lying horizontal and on the upper side. The U-shaped cramp socket and the outline of a step molding on what we call the Five Niches stone suggest that a stone of type 4 was connected to it (Figure 28).

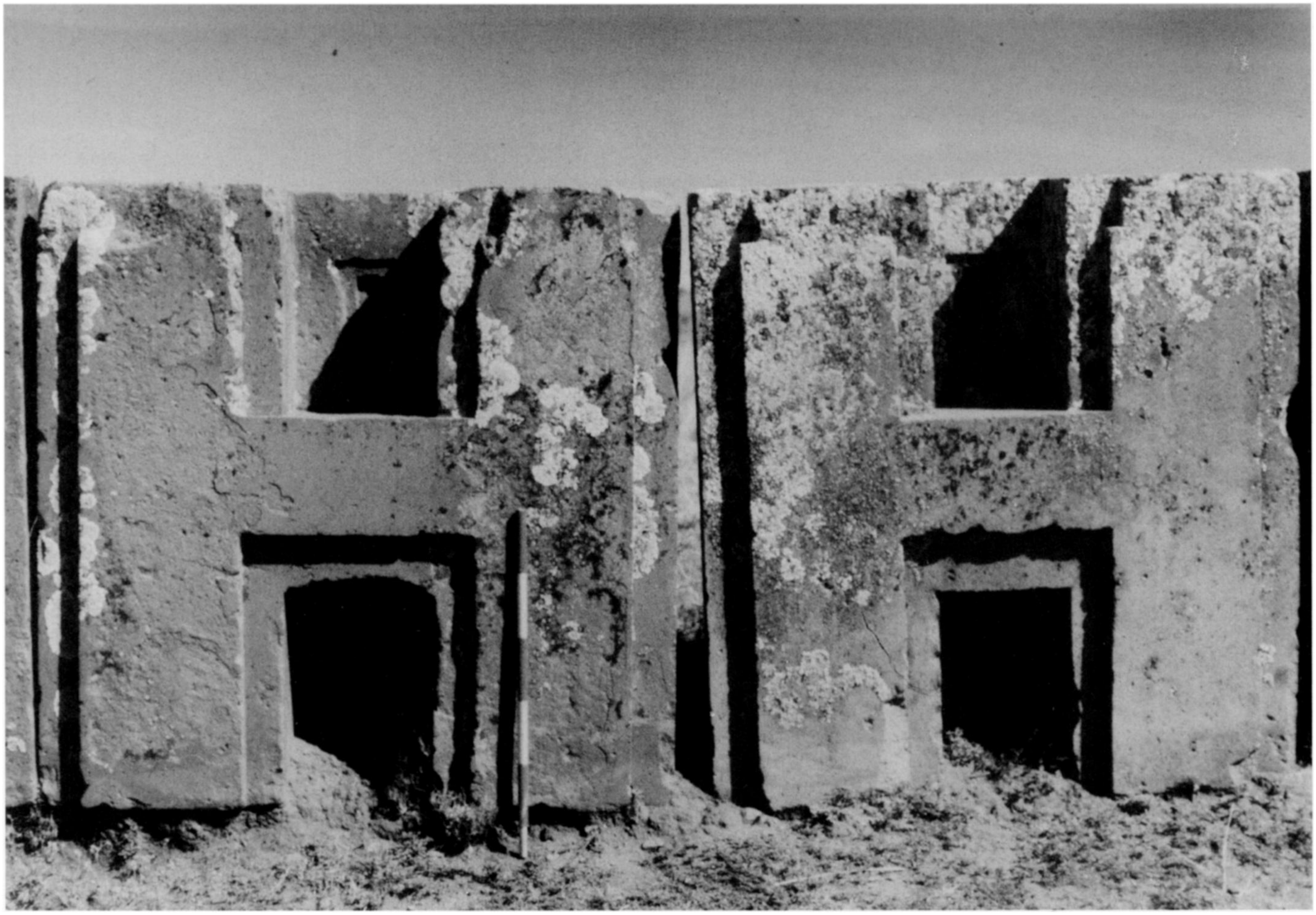


FIGURE 25: Types 1 and 2, or H-stones

Type 5 stones, because of the hoisting grips (described below), lay flat with the carved side on the underside, and served as "lids" on stones similar to type 1 or 2 stones, thus completing a niche (Figure 29).

Laying Stones

The erection of walls raises several issues: foundations (how a wall meets the ground); logistics (how and in what order the various courses are laid up); and structural integrity (how stones are joined to each other).

Foundations: To assure the stability of their structures, the Incas, as a rule, built very careful foundations. Where conditions were favorable, cut stones were fitted directly to bedrock. In other circumstances, builders dug trenches, some 50 to 80 centimeters deep, which they filled with mortared fieldstones. In the top layers, fieldstones were replaced by cut stones to accommodate the walls to be set on top. Foundations were generally wider than the walls they supported in order to distribute the load.

We are not yet certain about any general principles the Tiahuanacans applied to their foundations. But at Pumapunku they resorted to a rather unusual technique. As reported by Escalante, in setting down the base level of the first tier of the structure at Pumapunku, the Tiahuanacans used a kind of "leveling stone," that is, cobbles cut and flattened on one end, set in the ground and at the four corners of the base stones.[27] Several such stones can be observed in the area immediately west of the second platform, suggesting, of course, that some structure extended from the platform to this spot. It is possible that these stones are what Stübel and Uhle believed to be the remains of paving.[28]

Walls: The Incas often had several construction crews working side by side to build a wall. Where two crews met in a course the final gap in the wall was closed with a "wedge" stone introduced into the masonry bond from the front of the wall.[29] Because in the last gap there is not enough room to maneuver the stones for the usual one-on-one fitting, the Inca stonemasons hit on the ingenious idea of a wedge stone fitted to its neighbors only along a very narrow band near the face of the wall. Once one knows what to look for, it is relatively easy to spot wedge stones in an Inca cut-stone wall and to determine its construction sequences. At Tiahuanaco wedge stones seem to be absent, and there may not be any. In regularly coursed masonry, with perfectly rectangular blocks, there is no need for them.

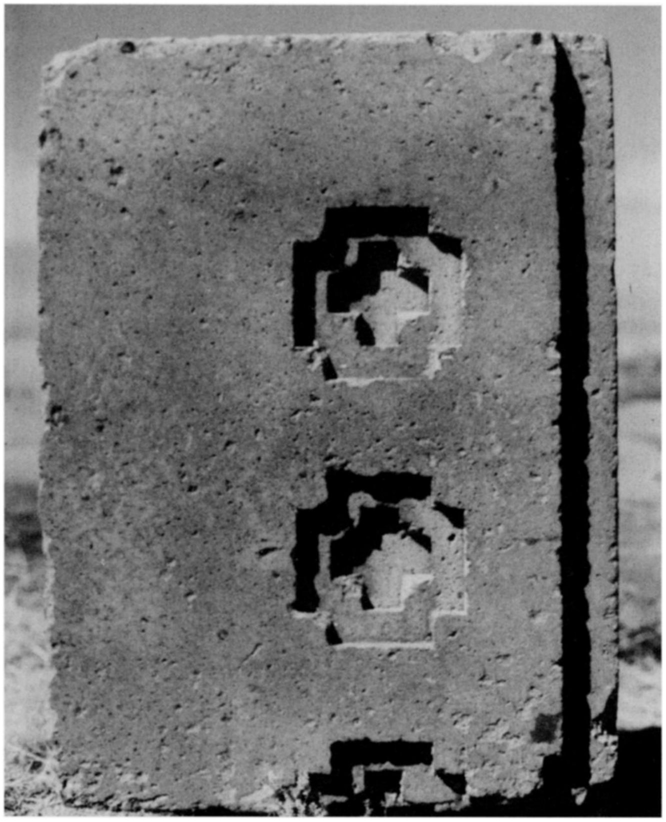
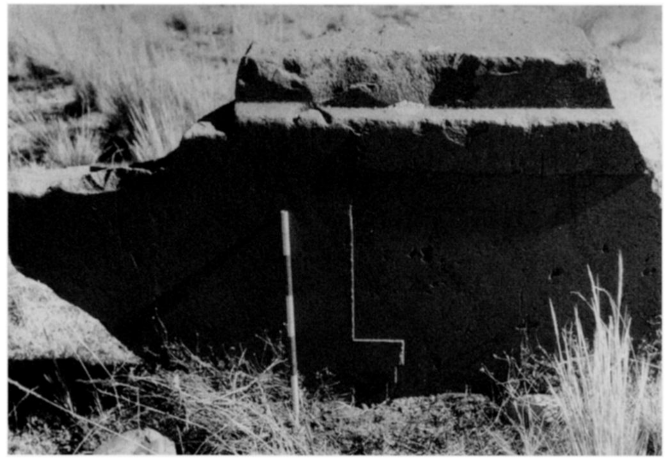


FIGURE 26: Type 6, or cross stone

FIGURE 27: Righthanded version of Type 7, or arrow stone



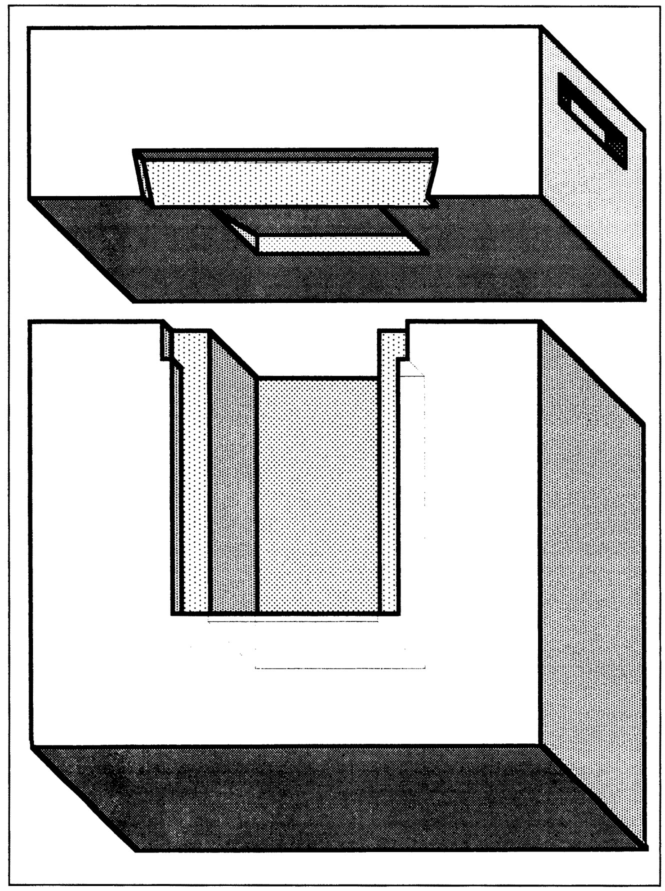


FIGURE 28: Building block showing the outline of a step molding and a U-shaped cramp socket

FIGURE 29: Diagram of a niche with type 5, or architrave stone, at the top

Cramp sockets: The ancient builders of the Old World often used cramps to join building blocks which they thought subject to special stresses. The Greeks, for example, systematically cramped or doweled together ashlars and other building elements to give continuity and structural integrity to their masonry. The cramps were of iron packed in lead; the lead protected the iron from rusting and thus prevented rust stains from marring the masonry.[30]

The Egyptians cramped together most of their ashlar masonry. They favored the dovetail shape and chose the wood from acacias or sycamores to make their cramps. Much less frequently, the cramps were of bronze, some of which were cast in situ.[31] Jean-Claude Golvin, the head of the Centre Franco-Egyptien des Temples de Karnak, wondered about the usefulness of wooden cramps in perfectly executed and seated ashlar masonry and was puzzled by the fact that in several monuments the cramp sockets were empty, even in undisturbed masonry. He eventually concluded that the wooden cramps had no structural function, but rather were used

FIGURE 30: Pumapunku: side wall of water channel with T-shaped cramp socket

during construction. Building blocks were set in place on a thin film of wet clay. The wooden cramps kept the blocks from sliding out of position until the clay had dried. The cramps were then removed and reused on the next course.[32]

Unlike these Old World examples, Tiahuanaco cramps were not universally applied; they are noticeably absent from the near-isodomic construction of the tiers at Pumapunku, as well as from the ashlar masonry at Akapana. The Tiahuanacans seem to have used cramps very selectively and for special purposes. In both Akapana and Pumapunku, there are carefully crafted and covered water channels, some 40 centimeters in width and 70 centimeters in depth. The side walls of these channels are built with upright stone slabs held together with T-shaped cramps [*Figure 30*]. The cramps' function here appears to be to hold the slabs in the proper alignment.

Substantial cramps of various shapes once pieced together the enormous sandstone slabs used in the construction of the four platforms at Pumapunku [*Figure 31*]. Presumably, the platforms served as a base for other structures, and possibly some gates. The cramps, then, lent the platforms structural continuity.

The lintel fragments of Gate II at Pumapunku and of an unidentified gate bear tiny T-shaped sockets with pinholes at both extremes of the bars of the *T*. These sockets, about 3.5 cm on the side, are found on what was the gates' front sides, where other gates at Tiahuanaco are decorated with a frieze. It seems reasonable to assume that the tiny T-cramps were used to attach the ornamental equivalent of a frieze to these lintels.

Recessed cramping: Most gates, or remnants of gates, including miniature gates, at Tiahuanaco feature rectangular "pockets" on their front sides, one on either side of the doorway, just as they can be observed on the celebrated Gate of the Sun (Figure 16). Most of these pockets feature one or two T-cramp sockets, pointing in one or two directions, suggesting that other building blocks were connected to the gates, either parallel or perpendicular to the gates [*Figure 32, C*]. Several gates have, in addition to such "pockets," niches with recessed cramp sockets [*Figure 32, B*]. In several instances, the pockets and recessed cramp sockets on a gate line up vertically, indicating that several blocks were stacked and attached to the gates. The spacing of the pockets and recesses is a measure of the height of each block or course. Each subsequent block would have hidden the pocket or cramping niche of the previously laid block. Recessed, or hidden, cramping in one or even two directions is, to our knowledge, unique in the world and bespeaks an innovative construction technique.

Cramp material: The Tiahuanacan cramps were of copper, or an arsenic-copper alloy, and were made in an astonishing variety of sizes and shapes.[33] Excavations conducted by the Instituto Nacional de Arqueología (INAR) in 1989 at Pumapunku uncovered cramps in situ in the side walls of two water channels. The channel walls and the cramp sockets are at a slope of about 12°, but the cramps are level, indicating that they were cast directly into the sockets. The casting suggests that the masons were moving around the site with crucibles and were capable of producing temperatures high enough to melt the copper or copper alloy.[34]

The use of cramps in masonry is not an obvious solution, especially if there are no precedents such as those that wood construction sometimes provides. It presupposes not only some experience with failed structures or unsuccessful construction efforts but also an understanding of the reasons for the failures. Unquestionably, the introduction of cramps represents a major innovation in construction technology. As noted above, the use of cramps at Tiahuanaco is not universal. Further investigation may show under what conditions and for what kind of construction the Tiahuanacans used cramps. Also, if it were possible to associate the introduction of cramps with a known time frame, this would help us understand the development of Tiahuanaco construction technology.

As mentioned at the beginning, cramp sockets are not unknown in the Inca heartland. Sockets of various shapes are found on blocks uncovered at the Qorikancha, and T-shaped sockets are well documented at Ollantaytambo. Unfortunately, and unlike the examples at Tiahuanaco, sockets on Inca sites cannot be observed in their original setting, since they are found only on displaced or reused blocks, and no cramps have been recovered in situ or elsewhere. To our knowledge there is no positive association of cramp sockets with Inca masonry. It is our hope that further study of cramps and their use at Tiahuanaco will help to clear up this vexing issue.

Mortar: An alternative or adjunct to cramping ashlars together is the use of an adhesive, such as mortar. To our knowledge, the Incas never used mortar in their fine cut-stone masonry, but there are indications that the Tiahuanacans may have applied mortar in the construction of Pumapunku. A thin coat (1 to 1.5 millimeters thick) of whiteish material covering some of the stones on the first and second tiers of the south side of Pumapunku was identified as a layer of mortar. Bolivian archaeologists Pareja and Escalante analyzed the material and concluded that it was composed of clay, lime, and

FIGURE 31: Pumapunku: sandstone slab with cramp socket. Scale in 10-centimeter units

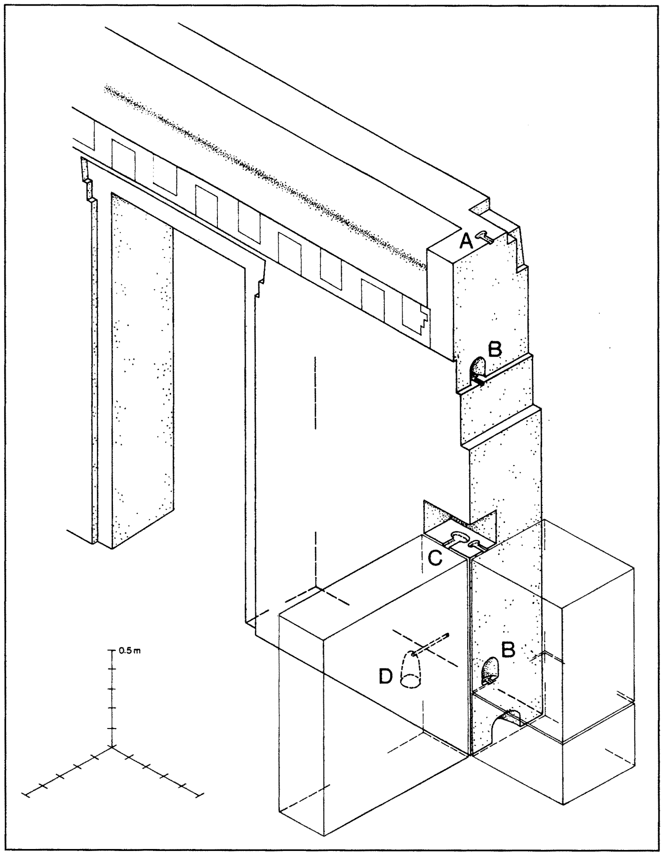


FIGURE 32: Pumapunku: righthand jamb of Gate III showing a variety of connecting features. *A*: simple T-cramp socket; *B*: recessed T-cramp socket in small niche; *C*: rectangular pocket with T-cramp sockets pointing in two different directions, suggesting the addition of building blocks parallel and perpendicular to the gates; *D*: cone

fine sand in the proportions of 3:1:1.[35] Workers of the Instituto Nacional de Arqueología have informed us that it was extremely hard to remove stones that were bonded with this material. What puzzles us is that even uncut and apparently unfinished areas are blanketed with the stuff. What was mortared to these areas? Given their unevenness, the mortar must have been applied in very thick layers, but only traces thereof remain. Even more puzzling is the fact that what looks like the same material is found on bedrock in the Quimsachata Range, some ten kilometers southeast of Tiahuanaco. An analysis of this material is currently underway.

Cones: The Gate of the Sun and the jamb fragments of Gates I, II, and III at Pumapunku exhibit sugarloaf- or cone-shaped recesses [*Figure 32, D*]. The cones are carved into the bottom of the jambs on either side of the gates with an additional cone, vertically aligned and similarly oriented, in the upper, inner corner of the type 2*b* niches flanking the gates. In each case, a small hole is drilled from the face of the gates into the cone near its apex. We have not yet been able to elucidate the purpose of these cones, but one could imagine, for example, that some object was inserted into a cone and held in place by a pin pushed through the drill hole. Similar cones are found on one big block atop the Akapana, and miniature cones can be seen on at least one small block in the Kalsasaya. The large cones were pounded out, as revealed by the pit marks inside. Given the depth of these cones (18 to 22 centimeters), it appears likely that the pounders, or hammerstones, were hafted.

Transportation and Handling

It has always been a subject of speculation how ancient civilizations which did not know the wheel transported stones weighing a hundred metric tons or more over long distances. In most instances, however, the solutions to the problem were deceptively simple. At Ollantaytambo the Incas dragged the large monoliths from the quarry to the construction site.[36] There is little doubt that the Tiahuanacans did the same; many blocks have telltale drag marks on at least one of their broad faces.

Bosses and leverage notches: Historic records suggest that to elevate building blocks onto a rising wall the Incas built embankments or ramps. One such ramp can still be seen at Sillustani near Puno on Lake Titicaca. But to handle the stones and set them into their final position the Incas also resorted to handling bosses and levering notches. Many Inca walls are still adorned with bosses of many shapes at the bottom edges of building blocks. The various shapes served different purposes.[37]

At Tiahuanaco there are only a few blocks with bosses, and levering notches do not abound. However, several building blocks at Tiahuanaco have grooves 2 to 3 centimeters in width and depth, on two adjacent faces [*Figure 33*]. These grooves most likely held ropes used to position the blocks. In addition to these narrow groves, one finds at Pumapunku, in particular, a variety of channels of different shapes, some up to 15 to 18 centimeters wide and deep, the function of which is not

FIGURE 33: Grooves 2–3 centimeters in width and depth on two adjacent faces of a stone may have served to position building blocks with ropes.

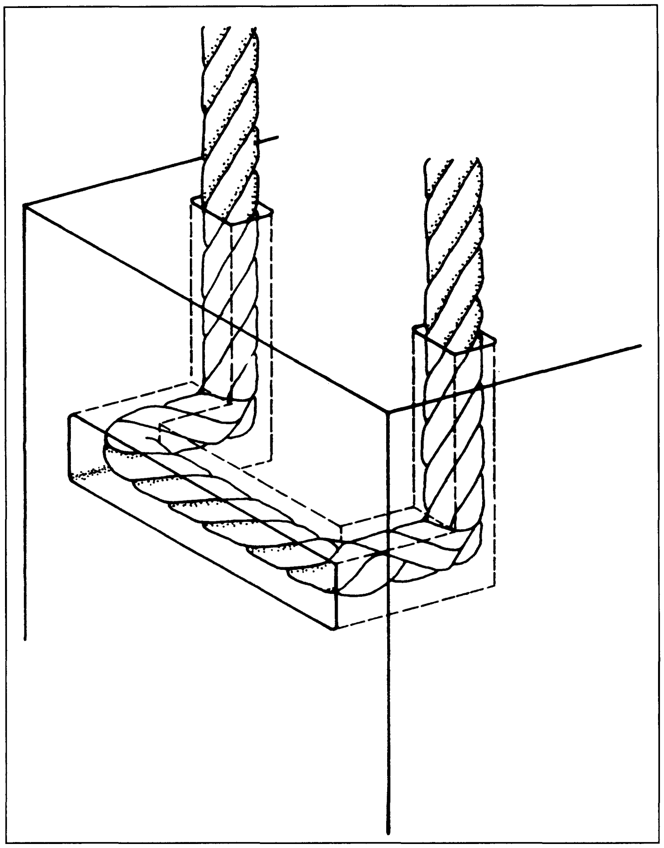


FIGURE 34: Hoisting grip

obvious and is in need of investigation. The position of some of these channels diagonally across the corners of large slabs suggests that logs were slid through them to lift the slabs.

Hoisting grips: Some blocks feature elaborate cutouts of grooves and communicating drill holes [*Figure 34*]. For lack of a better term, we call such cutouts "hoisting grips" because ropes could be threaded through the holes and used to lift blocks. These grips are ingenious, for in contrast to bosses, which must be removed when between two stones, hoisting grips allow the tight joining of neighboring stones with the ropes in place. Not many remaining blocks are equipped with hoisting grips, suggesting that the Tiahuanacans made only sparing use of these grips. One might argue that carving a hoisting grip is a lot of work for a small advantage. However, Protzen's experiments in setting down finely wrought stones without damaging the edges showed that this is one of the most difficult aspects of assembling an Inca-like wall. The task requires precise control over the stone's movements, something that is not easily achieved with levers. Suspending the block above and gradually lowering it into position would have resolved most of the difficulties encountered in the experiment. Thus, hoisting grips fulfill a very definite function. An analysis of the types of blocks with grips may yield clues to where and under what cricumstances grips were used.

The noted differences between Inca and Tiahuanaco stones suggest that the Tiahuanacan had a broader repertoire of lifting and handling techniques than the Incas. The Tiahuanacan techniques are more akin to those observed in the Old World, where grooves and drill holes for holding ropes were well known.[38] In its form, however, the Tiahuanaco hoisting grip is probably unique in the world.

Tool Kits

The known and documented tools of the Inca construction trade are hammerstones, bronze pry bars, plumb bobs, and ropes. Although several exemplars of chisels are held in Peruvian museums, judging by the tool marks on building stones, chisels were not used to cut or shape them. Evidence in the field points to the occasional use of some sort of saws or files, and of grinders.[39] The Inca builders probably used some kind of measuring device. Some chronicles mention the use of (measuring?) cords to lay out buildings, and John Rowe suggested a kind of sliding ruler.[40] The names of several Inca units of measurements are well known, among them are the *rikra*, the *sikya*, and the *'kapa*. Rowe gives their respective metric equivalents as 162, 81, and 20 centimeters.[41] From his experience at Ollantaytambo, Protzen was not able to relate these units of measure directly and unequivocally to construction. Most dimensions of buildings and building elements show too wide a spread. For example, there is no significant gap in wall thicknesses from 58 to 90 centimeters; every measurement in between is represented, and no distinctive plateaus appear in the distribution [*Figure 35*].

The construction tools of the Tiahuanacans, with perhaps the possible exception of hammerstones, remain essentially unknown and have yet to be discovered. To the extent that the

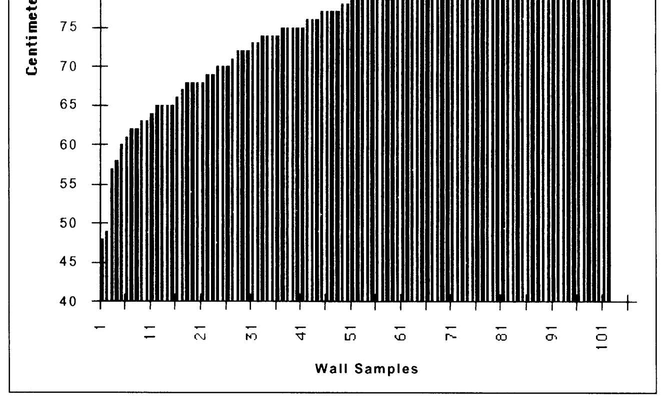


FIGURE 35: Frequency distribution of Inca wall thicknesses at Ollantaytambo

Tiahuanacans roughed out stone as the Incas did, it is reasonable to assume that the Inca tool kit was at least a proper subset of the Tiahuanaco tool kit. But to finish their stones the Tiahuacans must have had the use of other kinds of tools.

Postulated tools in the Tiahuanaco tool kit not found in the Inca kit are chisel- and punch-like tools, the square, and the straightedge, or their equivalents. Drills were also part of the Tiahuanaco kit, as evidenced by the many fine holes drilled into the friezes of Gate III of Pumapunku, the curved architrave of the Kantatayita, and other stones. The consistency of proportions over a range of niche sizes, the precision with which layouts follow given patterns, and the frequent repetition of certain dimensions suggests that the Tiahuanacans possessed an accurate measuring device with a standard unit of measure.

CONCLUSION

The Inca and Tiahuanaco builders created some of the most precise and most beautiful stonework ever made. Yet, as noted, some striking differences distinguish the two, in both technique and style. The Incas' play with endless variations in bond patterns and their use of mostly irregularly shaped stones with pillowed faces are in sharp contrast to the Tiahuanacans' severe symmetrical arrangements of standardized geometric patterns and elements and the planarity and orthogonality of their building stones. The Incas' one-on-one stone-fitting technique and their reliance on gravity and friction alone to join the building blocks are in contraposition to the Tiahuanacans' propensity for standardized building stones requiring little or no individual fitting work and their joining of building stones with cramps. The observable distinctions in design and technology between Inca and Tiahuanaco architecture and stonework suggest that the respective builders had very different conceptions of architecture and aesthetic sensibilities.

This comparison could be extended to formal elements and spatial organization. The formal elements that distinguish and characterize Inca buildings are battered walls; trapezoidal doorways, windows, and niches; and steep-pitched gable walls in buildings with gable roofs. Furthermore, most Inca buildings consist of a single room and are rectangular in plan and one story high. Either buildings are strung out in rows, or two, three, or four (rarely more) buildings are arranged to face on a common court.[42] At Tiahuanaco there are no standing buildings from which a similar list of diagnostic features can be derived. Yet the various platform mounds and sunken courts at the site bespeak a conception of spatial organization that has no correlate in Inca architecture. The strict treatment of planar surfaces modulated by sharp geometric figures and moldings encountered at Tiahuanaco betrays an aesthetic that is preoccupied with the precise relationship of elements to each other and an overall order to which the individual stonemason submitted. The formal elements defining Inca architecture, too, represent a certain order, but one that is not concerned with the treatment of details. There is a great variety in both dimensions and proportions in Inca buildings, and the individual stonemason appears to have had considerable freedom in laying out a building and in treating its surfaces. The purported derivation of Inca stonemasonry from Tiahuanaco is thus hardly defensible.

The passage from Cieza de León quoted at the beginning of this article and the following, from Bernabé Cobo, suggest that the Incas were well aware of Tiahuanaco.

> Pachacutic came to see the superb buildings of Tiaguanaco, of which he greatly admired the fabric of cut stone, for he had never seen buildings like these, and he ordered his people to observe and carefully notice this manner of construction, because he wanted the works to be built in Cuzco to be of the same kind of masonry.[43]

Because of this awareness, and the sudden appearence of fine stonemasonry in the Cuzco region—there are indeed no known examples of such masonry preceding the ascendancy of the Incas—Gasparini and Margolies argued: " . . . we may certainly consider the transmission of the experience of Tiwanaku to the ambitious work of the renovator Pachakuti."[44] While these researchers concede "that the excellent stone finishing [of Tiahuanaco] may have made more of an impression than the building techniques," they do suggest that the stoneworking technique "could have contributed to improving the coursing of the Cuzco walls," and that "it is possible that some Tiwanaku formal elements may have served as 'inspiration' in the formation and proliferation of the formal elements we now identify as Inca."[45] At this stage of our research, however, we find that whatever it was the Incas saw when they first came upon Tiahuanaco, and whatever they borrowed from there, if anything, they thoroughly reinterpreted and made their own. Our findings to date constitute at least a strong prima facie case in favor of the hypothesis that Inca architecture and stonemasonry are authentic inventions and not Tiahuanaco derivatives.

Notes

This article is based on papers read by the authors at the 34th and 35th annual meetings of the Institute of Andean Studies at Berkeley, in January 1994 and 1995. Research for this article has been supported in part by a Stahl Grant from the Archaeological Research Facility at the University of California at Berkeley. In addition, Stella Nair has been awarded a Chester Miller Fellowship and a Tinker Travel Grant from the Center of Latin American Studies, University of California at Berkeley. We express our gratitude to the various institutions for their support. The authors specifically wish to thank Oswaldo Rivera Sundt, Director of the Instituto Nacional de Arqueología (INAR), for granting us the necessary permits, for lending his logistical assistance to our project, and for his unflagging confidence in our research.

1 Archaeologists and historians divide Andean prehistory into periods and horizons: Preceramic Period, before 1800 B.C.; Initial, c. 1800–900 B.C.; Early Horizon, c. 900–200 B.C.; Early Intermediate, c. 200 B.C.–A.D. 550; Middle Horizon, c. 550–900 A.D.; Late Intermediate, c. 900–1438 A.D.; and Late Horizon, c. A.D. 1438–1532.

2 ". . . [Y]o he oído afirmar á indios que los ingas hicieron los edificios grandes del Cuzco por la forma que vieron tener la muralla ó pared que se ve en este pueblo. . . ." Pedro Cieza de León, *La Crónica General del Perú* [1553]. Anotada y concordada con las crónicas de indias por Horacio H. Urtega, vol. 1; Colección Urtega, Historiadores clásicos del Perú, vol. 7 (Lima, 1924): cap. cv, 301.

3 ". . . [F]ué [Pachacuti] por el mesmo valle y río de Yucay abajo á un asiento que agora llaman Tambo . . . adonde hacía unos suntuosísimos edificios. Y la obra y albañería de los cuales andaban trabajando como captivos los hijos de Chuchi Capac, el grand cin[che] del Collao, á quien . . . venció y mató el inga en el Collao." Pedro Sarmiento de Gamboa, *Historia de los Incas* [1572], 2nd ed., Colección Horréo (Buenos Aires, 1943), cap. 40, 81.

Pachacuti (c. 1438–1471) is believed to be the Inca ruler who first embarked on an empire-building enterprise which led to the Tawantinsuyu (the Four Quarters), the largest empire the New World has ever seen. He is also credited by the Spanish chroniclers with having introduced finely worked stonemasonry to Cuzco, the empire's capital.

4 Garci Diez de San Miguel, *Visita hecha a la provincia de Chucuito por Garci Diez de San Miguel en el año 1567*, Documentos Regionales para la Etnología y Etnohistoria Andinas, vol. 1 (Lima, 1964). In Spanish times Chucuito Province included the territories around Lake Titicaca. *Mit'ayoc* designated people carrying out their period of obligatory labor, the *mit'a*, for the Inca state.

5 Graziano Gasparini and Luise Margolies, *Inca Architecture*, trans. Patricia Lyon (Bloomington, Ind., 1980), 11.

6 Cieza de León, *La Crónica General*, cap. cv, 300–301.

7 Heinrich Ubbelohde-Doering, *Auf den Königsstrassen der Inka, Reisen und Forschungen in Peru* (Berlin, 1941), 36–37.

8 Alfons Stübel and Max Uhle, *Die Ruinenstätte von Tiahuanaco im Hochlande des alten Perú: Eine kulturgeschichtliche Studie auf Grund selbstständiger Aufnahmen* (Breslau, 1892), part 2, 48.

9 Jean-Pierre Protzen, *Inca Architecture and Construction at Ollantaytambo* (New York, 1993), 257–260.

10 Alcide d'Orbigny, *Viaje a la América Meridional*, vol. 4 (Buenos Aires, 1945), 1533–1542; Javier Escalante, *Arquitectura prehispánica en los Andes bolivianos* (La Paz, 1993), 93–298.

11 We refer here to the excavations at Pumapunku carried out by the Instituto Nacional de Arqueología in 1989 under the direction of Carlos Urquizo Sossa.

12 Cyril M. Harris, ed., *Dictionary of Architecture and Construction* (New York, 1975), 396.

13 Ibid, 339. Although in general we do not use terms from ancient Greek or Roman architecture to describe pre-Colombian Andean architectural features, we borrow such terms if they convey the desired precision and distinctions.

14 Ibid., 270.

15 A perfectly preserved section of the base wall of Akapana, excavated on its south side by Osawldo Rivera in 1995–1996, shows a precise and constant batter of 2°.

16 Arthur Posnansky, who also noted that the opening of the Gate of the Sun was larger on one side than the other, interpreted what we call the back side as the front or entry side. See Arthur Posnansky, *Tihuanacu: La cuna del hombre americano / Tihuanacu: The Cradle of American Man.* 4 vols., bilingual edition (New York, 1945), 2: 39. Léonce Angrand was the first to note the beveled jambs; see Heiko Prümers, "Die Ruinen von Tiahuanaco im Jahre 1848. Zeichnungen von Léonce Angrand," *Beiträge zur allgemeinen und vergleichenden Archäologie* 13 (1993): 385–478.

17 Like Stübel and Uhle, we see the remains of at least three gates near the platforms of Pumapunku. Stübel and Uhle, *Die Ruinenstätte*, part 1, plate 24. It is possible that there was a fourth, as Posnansky suggested. Gate III has been broken into several more pieces since Stübel and Uhle made their investigation. We identified at least three more pieces of Gate II. We have established that the left side jamb piece at the south end of the fourth platform belongs to Gate I, or one exactly like it. The Type 2*b* niche on this jamb has the exact same dimensions and position as the one on the right jamb. A fragment of a lintel which we cannot attribute to any of the three gates suggests the former existence of yet another gate.

18 The numbering of the gates is that of Posnansky.

19 Léonce Angrand (see n. 16).

20 Stübel and Uhle, *Ruinenstätte*, part 2, 44.

21 Jean-Pierre Protzen, "Inca Quarrying and Stonecutting," *JSAH* 44 (1985): 174, and "Inca Stonemasonry," *Scientific American* 254 (1986): 94–105.

22 Stübel and Uhle thought these marks resulted from fire. *Ruinenstätte*, part 2, 45.

23 We have found one hammerstone of hematite that shows wear marks. Unfortunately, the stone was found out of context, near the railroad tracks a couple of hundred meters west of the train station. The valley floor around Tiahuanaco is strewn with quartzite cobbles which would make excellent hammerstones, but their use as such has yet to be established.

24 Protzen, *Inca Architecture*, 194.

25 Sommers Clarke and Reginald Engelbach, *Ancient Egyptian Construction and Architecture* (New York, 1990), 105–106; Dieter Arnold, Building in Egypt: Pharaonic Stone Masonry (New York, 1991), 256–257.

26 Protzen, "Inca Quarrying," 177–178, and *Inca Architecture*, 193–195.

27 Escalante, *Arquitectura prehispánica*, 214–215.

28 Stübel and Uhle, *Ruinenstätte*, part 1, plate 24.

29 Protzen, *Inca Architecture*, 195–199.

30 Wolfgang Müller-Wiener, *Griechisches Bauwesen in der Antike*, Becks Archäologische Bibliothek (Munich, 1988), 82–93.

31 Arnold, *Building in Egypt*, 124–128.

32 Jean-Claude Golvin, personal communication, 1987.

33 Carlos Ponce Sanginés, "Análysis espectográfico y patrón de impurezas en el cobre de las grapas tiwanacotas," *Revista Pumapunku* (1994): 12–14. More recent analyses carried out by Professor Heather Lechtman of samples of cramps in situ at Pumapunku reveal a ternary alloy of copper, arsenic, and nickel. For a detailed discussion see Heather Lechtman, "Middle Horizon Metallurgy in the Titicaca Basin: A Preliminary Assessment," in *Tiwanaku and Its Hinterland: Archaeological and Paleoecological Investigations of an Andean Civilization, Vol. II: Rural and Urban Archaeology*, ed. Alan Kolata and John Janusek, in press. To our knowledge, only double T-shaped cramps measuring about 12–18 centimeters have been recovered; thus the shape and size of the other cramps are inferred from the empty sockets.

34 The melting point of pure copper at sea level is 1083° C. What exact temperatures the Tiahuanacans needed to melt their copper alloys remains to be determined.

35 Escalante, *Arquitectura prehispánica*, 218.

36 Protzen, "Inca Stonemasonry," 102–103, and *Inca Architecture*, 176–178.

37 Protzen, "Inca Stonemasonry." 102–103.

38 Dieter Arnold, *Building in Egypt*, 75; Müller-Wiener, *Griechisches Bauwesen in der Antike*, 81.

39 Protzen, *Inca Architecture*, 188–189.

40 Juan de Betanzos, *Summa y narración de los Incas* [1551], Transcripción, notas y prólogo por María del Carmen Martín Rubio (Madrid, 1987), 170; John Rowe, "Inca Culture at the Time of the Spanish Conquest," in *Handbook of South American Indians*, vol. 2, ed. Julian H. Steward; Bureau of American Ethnology, Bulletin 143 (Washington, D.C., 1946), 323–324.

41 Rowe, "Inca Culture," 323–324.

42 For a more elborate discussion of Inca architecture see Jean-Pierre Protzen, "Architettura Inca," in *I regni preincaici e il mondo Inca*, ed. L. Laurencich Minelli (Milan, 1992), 193–217.

43 "Llegó *Pachacutic* a ver los soberbios edificios de Tiaguanaco, de cuya fábrica de piedra labrada quedó muy admirado por no haber visto jamás tal modo de edificios, y mandó los suyos que advertiesen y notesen bien aquella manera de edificar, porque quería que las obras que se labrasen en el Cuzco fuesen de aquel género de labor." Bernabé Cobo, *Historia del Nuevo Mundo*, 1653, ed. P. F. Mateos, *Biblioteca de autores españoles desde la formación del lenguaje hasta nuestros días*, tomos 91, 92, *Obras del P. Bernanbé Cobo* (Madrid, 1964), 2: 168.

44 Gasparini and Margolies, *Inca Architecture* (see n. 1), 12.

45 Ibid., 12, 13.

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Figure 2. After Arthur Posnansky, *Tihuanacu: La cuna del hombre americano / Tihuanacu: The Cradle of American Man* (New York, 1945)
All others by Jean-Pierre Protzen