# Inca Quarrying and Stonecutting*

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*Inca construction techniques have long been the subject of wild speculation. Investigations of ancient quarry sites and of numerous cut-stone walls reveal that the amazing Inca constructions were built with very simple means. Stones were selected out of rock falls or just broken out of a rock face with pry-bars. If the blocks needed to be parted, big hammerstones were used to split them. To dress the stones smaller hammerstones were used to pound them until they had the desired shape. The fitting of one stone to another was done by cutting the already laid stones to receive the next ones in a trial-and-error fashion. Experiments show that with this process stones can be mined, cut, dressed, and fit with little effort and in a short time.*

WHEN PACHAKUTI, the ninth Inca, acceded to power in (or around) 1438, he ordered Cuzco, the capital of his emerging empire, be rebuilt in stone. The stonemasons he put to work, and those who worked for his successors, created a style of masonry, which—if not without parallels—is unique throughout the world.

The achievements and the ingenuity of the Inca stonemasons have deeply impressed every traveler to the highlands of south central Peru since the Spanish conquest in 1532. Of the most impressive of the Inca monuments, the "fortress" of Saqsaywaman near Cuzco, Pedro Sancho wrote in 1534, "neither the bridge of Segovia nor any buildings that Hercules or the Romans built are so worthy of being seen as this."[1] And 450 years later, the tens of thousands of tourists who flock to the Inca ruins every year are filled with awe, amazement, and wonder. From Cuzco to Pisac, from Ollantaytambo to Machu Picchu, they marvel at the stark beauty of Inca stonemasonry, are stupefied by the sheer size of the stones, and are stunned by the exacting precision with which each stone is fitted to the next.

Inca culture had its origins in the Cuzco valley around A.D. 1200. For some 200 years the Incas remained within their confines, governing over an agricultural state of minor importance. But under Pachakuti they broke out of their territory to embark on an empire-building enterprise many have compared to that of the Romans.[2]

At its peak—at the time of the Spanish conquest—the Inca empire reached from Chile to Ecuador, from the river Maule in the south to the river Angasmayo in the north, from the Pacific Coast in the west to the highlands of the Andes and the fringes of the Amazon basin in the east.[3]

The comparison of the Incas with the Romans is not an idle one. It rests not merely on the size of their empire and the military exploits by which they conquered it, but also on the massive construction program they carried out, which was quite similar to that of the Romans. The Incas built a road network whose total length has been estimated at some 10,000 miles. Two trunk lines ran the length of the empire, one along the Pacific Coast, the other through the central highlands. Both were connected by numerous transverse highways wherever the topography permitted. Most of the roads were paved and were tunneled or stepped wherever the terrain required it. Rivers were spanned by daring suspension bridges made of bunchgrass cables.[4]

The extent of the road network was equaled, if not surpassed, by the thousands of miles of agricultural terraces that still lace the Andean landscape from Bolivia to Ecuador. The terraces protected the soil against erosion from the torrential summer

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Elsbeth and Maurice Protzen have actively participated in all phases of the fieldwork. They have helped me in mapping out the various sites, measuring and drawing numerous walls, inspecting and recording innumerable blocks, and taking notes and slides. Their help was instrumental in the completion of this research. I am deeply indebted to them for their contribution, their support, and their companionship on the long hikes and camping trips to the remote quarries.

I owe very special thanks to John H. Rowe. Not only has he encouraged me to pursue the study of Inca stonemasonry, but he has been very generous with suggestions and criticism and has reviewed earlier versions of this paper. Without his interest in my project and his support, I never would have dared to embark on this enterprise.

1. Graziano Gasparini and Luise Margolies, *Inca Architecture*, transl. Patricia J. Lyon, Bloomington and London, 1980, 282.
2. José Antonio del Busto D., *Perú Incaico*, 4th ed., Lima, 1982, 19ff.
3. Busto, *Perú Incaico*, 179.
4. Busto, *Perú Incaico*, 235ff.

rains and provided level terrain for cultivation. The fields were irrigated by an extensive and intricate system of water canals, many of which are still in use today.

One might assume that the construction of an infrastructure of such magnitude, combined with the enormous military effort, would have exhausted the Inca state of its resources, yet the Incas also built strongholds, temples, palaces, rest stops along their highways, warehouses for food, clothing, and arms, and waterworks for ceremonial and (possibly) recreational uses.

The Inca builders used a variety of means in the edification of their architecture. They were well versed in the construction and use of adobe walls, walls of mud-bonded stones, and dry walls of field stones and cut stones. It is in the latter, however, that they excelled and achieved levels of incomparable perfection. The walls of cut stones were often of cyclopean dimensions and were put together not only without cement but with a precision that often came within fractions of a millimeter. The Inca stonemasons' craft was not limited to the technical aspects. The aesthetic appeal of their work is evident in the manyfold bonds, the associated geometries of joints, and the variety of wall textures achieved through differentiated surface treatments and juxtapositions.

How did the Inca stonemasons, who did not have the use of iron tools and did not know of the wheel, cut and fit the stones and erect the walls that have been the object of so much admiration? As an architect interested in construction technology, I have been intrigued for some time with the beauty and perfection of Inca stonemasonry.

The technological issue is, of course, the question of how the Incas managed to build such masonry. This problem may be formulated more succinctly with questions about the following operations:

a) The quarrying. What kind of stone did the Incas select? How, and with what tools, did they extract it and break it up?

b) The cutting and dressing. How, and with what tools, were these operations performed and where?

c) The fitting and laying. With what technique and what devices did the Incas achieve the proverbial fit between stones?

d) The handling and transportation. How, and with what devices, did the Incas transport and lift the building stones?

On the basis of my research in the Cuzco area in 1982 and 1983, I can provide answers to the questions about the first three operations. The research involved analyzing numerous Inca walls in and around Cuzco and visiting several ancient quarry sites. Special attention was paid to two quarries: Kachiqhata, from which the Inca mined the red granite used in part in the construction of Ollantaytambo, and Rumiqolqa, which supplied much of the andesite used in the construction of Cuzco.

## QUARRYING

### *Organization of quarry sites*

The quarries of Kachiqhata lie on the other side of the Urubamba River from Ollantaytambo at about 4 km to the southwest and between 700 to 900 m above the valley floor. They are located in two giant rockfalls just below the cliffs of a granitic outcrop, called Negra Buena or Yana Orqu, which has penetrated through an environment of metamorphosed sedimentary rocks.

The quarries of Rumiqolqa are 35 km southeast of Cuzco, past the site of Pikillakta, on the left bank of the river Vilcanota, just off the Inca highway leading from Cuzco to the Qollasuyu. They are situated in a volcanic outcrop of andesite which in geological times has intruded the surrounding sandstone formation.

The choice of a particular rock type must have been of utmost importance to the Incas, or they would not have quarried sites so difficult of access and so far away. The high degree of organization manifested in the layout of these and other quarry sites that I visited is a further indication that quarrying was a very important operation to the Incas and not simply a routine matter.

The quarries of Kachiqhata have probably not changed very much since they were visited by George Squier in 1863. His descriptions match my own observations very closely.[5] The quarries are reached, as they were in Inca times, by a ramp that leads down from the site of Ollantaytambo to the river and up the mountain on the south bank to the rockfalls. Along the whole length of the ramp there are some 80 abandoned blocks. Most of the access road is fairly well preserved and easily traced. The map (Fig. 1), constructed from my on-site survey, shows the south-bank portion of the road and its ramifications to, and at, the three quarrying locations—the north, south, and west quarries. The connections between Ñawinpata and the north quarry and between the north and west quarries have been obliterated by erosion.

The roads have a gentle slope of between 8 to 12 degrees and are from 4 to 8 m wide. They are cut into the mountainside and filled in behind retaining walls on the valley side. These walls are from 1 to 3 m high, with occasional sections of over 10 m. Where the terrain permitted, the ramps were replaced by slides, the longest of which is at the northern end leading down to the river. It is an awesome drop of some 250 m down a slope of about 40 degrees, at the bottom of which there are four abandoned blocks. This slide may not always have been used, as there is clear evidence of a ramp immediately to the east of the slide (see Fig. 1).

5. Ephraim George Squier, *Peru; Incidents of Travel and Exploration in the Land of the Incas,* London, 1877, 505–510.

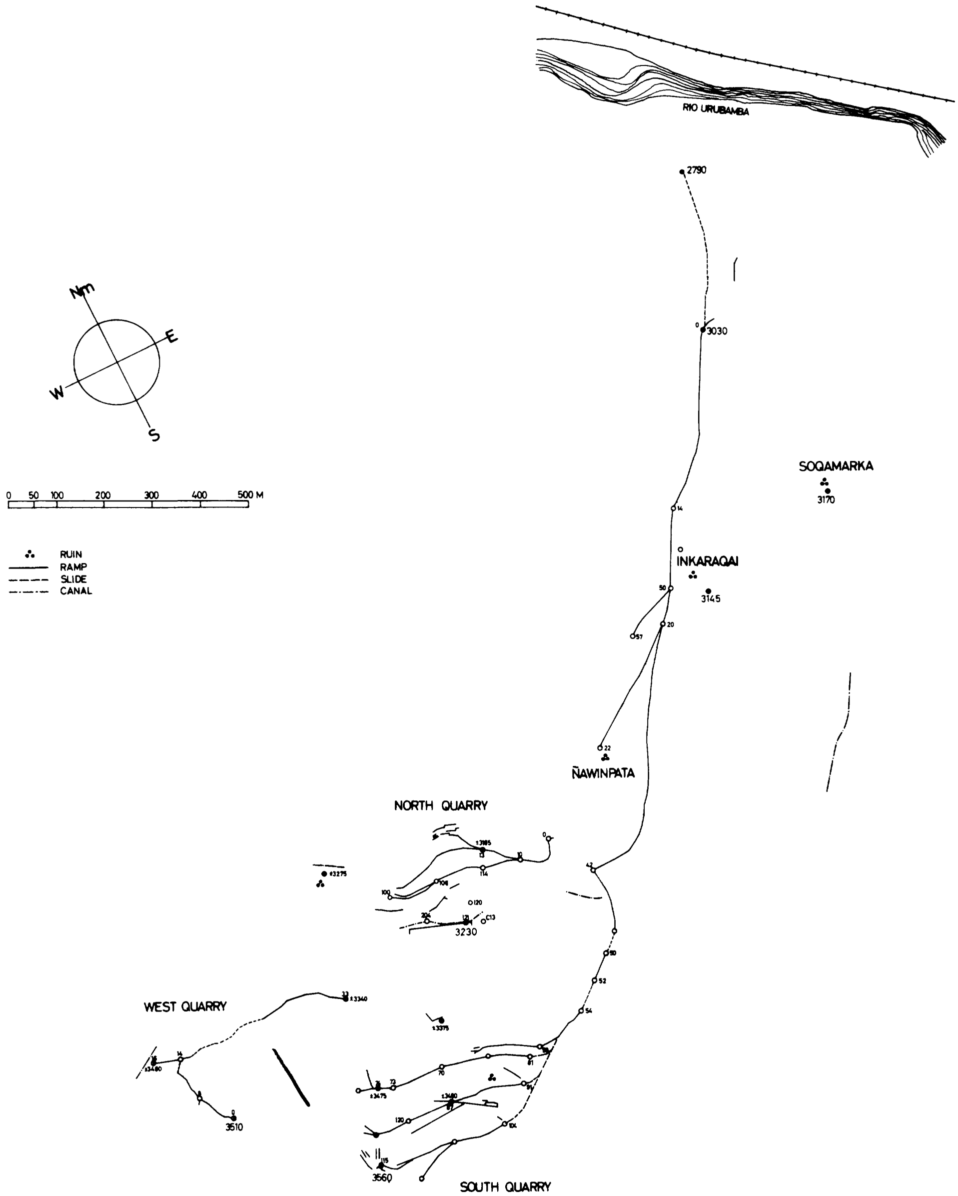


Fig. 1. Map of the quarries of Kachiqhata near Ollantaytambo.

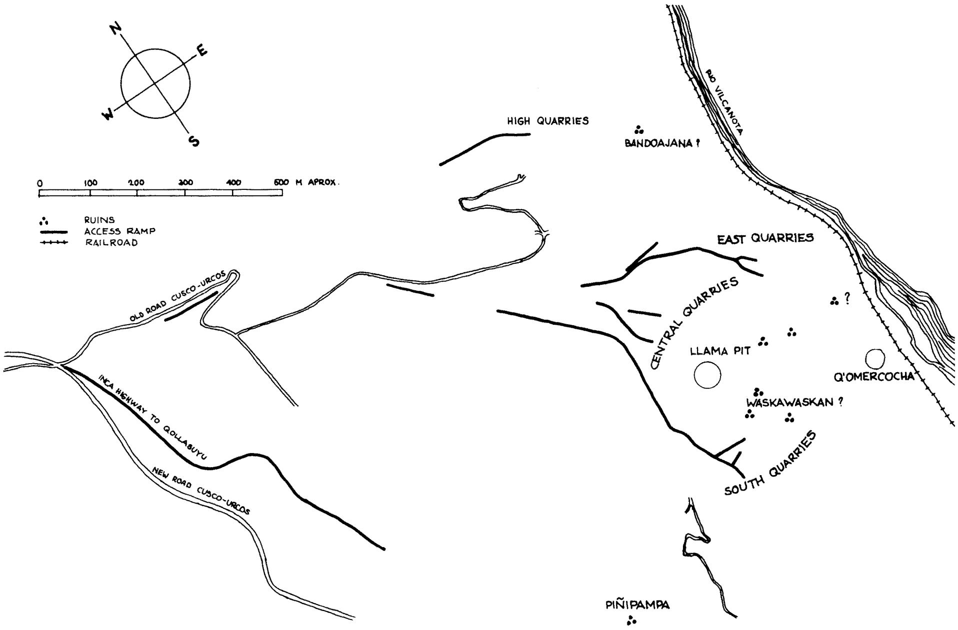


Fig. 2. Sketch map of the quarries of Rumiqolqa.

The sketch map of the quarries of Rumiqolqa (Fig. 2), made from an aerial photograph and from inspections on the ground, reveals a similar network of roads or ramps leading to different quarrying areas: the high, central, and south quarries.

In both quarries, the Incas complemented the access roads with additional works of infrastructure. At Kachiqhata they built great retaining walls to protect the quarries from rockfalls and (possibly) to stop big blocks sliding down from higher locations. Traces of water canals leading to the quarries and to nearby ruins are clearly visible. At both sites, Kachiqhata and Rumiqolqa, one finds ruins which the local lore identifies as residences of the "supervisors" or "administrators" (Soqamarka, Bandoajana?), and quarters for the quarrymen (Inkaraqai, Ñawinpata; Waskawaskan?). No excavations have been made at either of these sites, so there is no evidence available that would support or contradict the alleged use of these ruins.

In an article on Inca stonemasonry, the Peruvian architect Emilio Harth-terré described and mapped what he called the quarrymen's quarters of Kachiqhata.[6] I was not able to locate these houses. The ruins that come closest to resembling Harth-terré's description are houses A and B at Soqamarka (Fig. 3), but otherwise the Soqamarka ruins do not quite match Harth-terré's plans and sections (Fig. 4). The general layout and the orientation of the complex deviate significantly from Harth-terré's sketches.

What Harth-terré failed to mention about Kachiqhata—although they were observed by Squier—are the many burial towers, or "chullpas," that dot the sites of Inkaraqai and the north quarry. These structures are either circular or square, between 1.5 and 2 m in diameter or width, and about the same height. What special significance can be attributed to the presence of these structures remains to be established. There are no chullpas at any of the other quarries I visited.

A feature that appears to be unique to the quarries of Kachiqhata is the existence of stonecutting and temporary storage yards that are distinct from the extraction areas. I found at least three such yards: one in the west quarry near survey point 14; one in the south quarry near survey point 54; and another near Inkaraqai. These are strategically located just below the point where the access ramps to the north and south quarries merge. This last is the largest of the three yards. It is built on a terrace on the valley side of the main access ramp and is connected to it by a short inclined plane (Fig. 5). Numerous large and small blocks of red granite are still deposited there. Is this perhaps the place where the blocks coming from the quarries were checked for suitability and further dressed or cut up according to some schedule?

### *Rock qualities*

In both quarries, the different quarrying areas correspond to specific rock types or rock qualities. The north and south quar-

6. Emilio Harth-terré, "Téchnica y arte de la cantería incaica," *Revista Universitaria,* 51–52 (1962–1963), nos. 122–123, 124–125; número extraordinario, 152–168, Universidad Nacional del Cuzco, 1965, 162, 168.

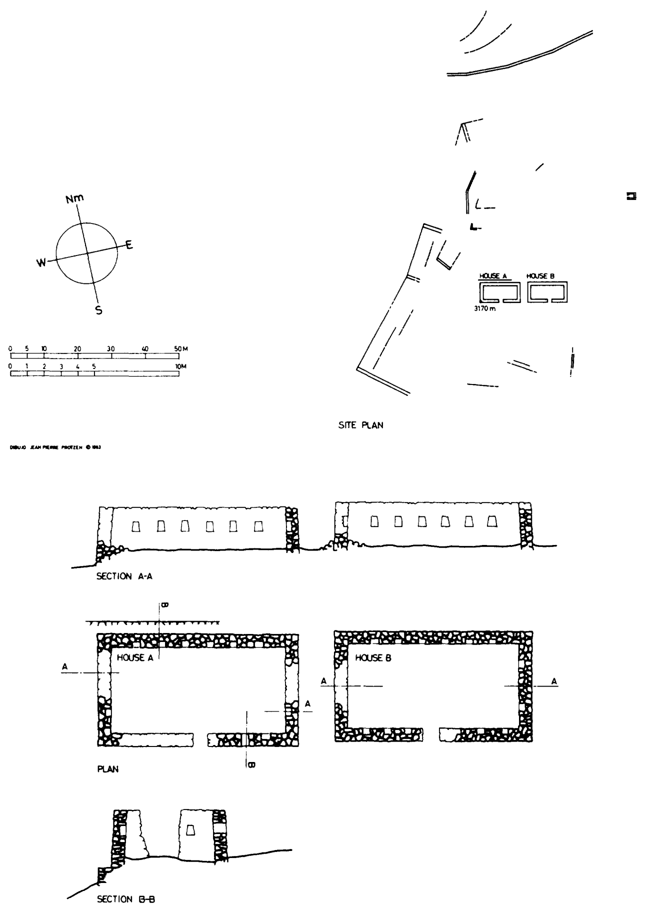


Fig. 3. Site plan of Soqamarka and plans and sections of houses A and B.

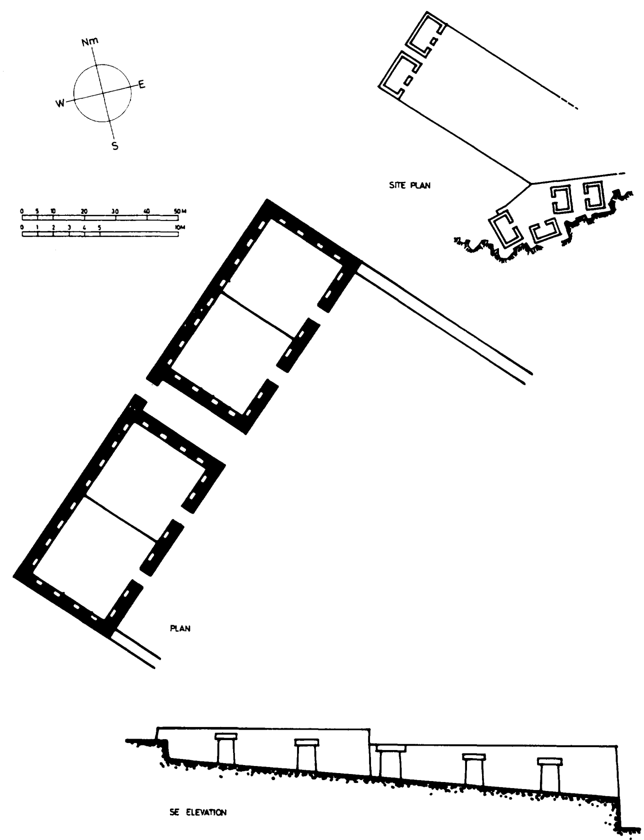


Fig. 4. Site plan, plan, and elevation of the quarrymen's houses of Kachiqhata (after Harth-terré).

ries of Kachiqhata are the ones that provided the coarse-grained red granite that was used in the great structures of what is called the "religious sector" of Ollantaytambo. Most of the abandoned blocks along the access roads are of that type, with a few exceptions. The exceptions are of a grayish and much finer-grained granite, the principal source of which is the west quarry.

At Rumiqolqa, the high quarry provides a distinctly flow-banded andesite, which lends itself to extraction in thin slabs. Most of the sidewalks in Cuzco are still paved with tiles from this quarry. In the east quarry the rock is columnar, and in the central quarries it is boulder-like, with an occasional flowbanded outcrop. The flowbanded and the boulder-like rocks are also found in the south quarries.

*Extraction*

At Kachiqhata, the Incas did not practice quarrying in the proper sense. They neither cut stone off a rock face nor detached it from bedrock by undercutting. The quarrymen simply went through a giant rockfall, carefully selecting blocks that met their specifications. As far as I can ascertain, once an appropriate block had been located, it was dressed only minimally before it was sent on its way to the construction site. The fine work and the adjustments for the final fitting appear to have been made later at the construction site. Often work had been started on a block before the ramp to it had been finished. Evidence of this is particularly obvious at the end of the highest ramp in the south quarry (survey point 115 in Fig. 1), where two blocks (one 4.5 × 2.5 × 1.7 m, the other 6.5 × 2.7 × 2.1 m), raised on working platforms not yet connected to the ramp, are in a state of partial dressing.

The cutting marks on these and other blocks are intriguing. They are very similar to those found on the unfinished obelisk at Aswan, and the technique involved must not have been very different from the one used by the Egyptians, who used balls of dolerite to pound away at the workpiece until it had the desired shape (Figs. 6, 7).[7] In 1959, Outwater reported, "[v]ery few tools are in evidence at the site [Kachiqhata]. There were

7. R. Engelbach, *The Problem of the Obelisks, from a study of the unfinished obelisk at Aswan,* London, 1923.

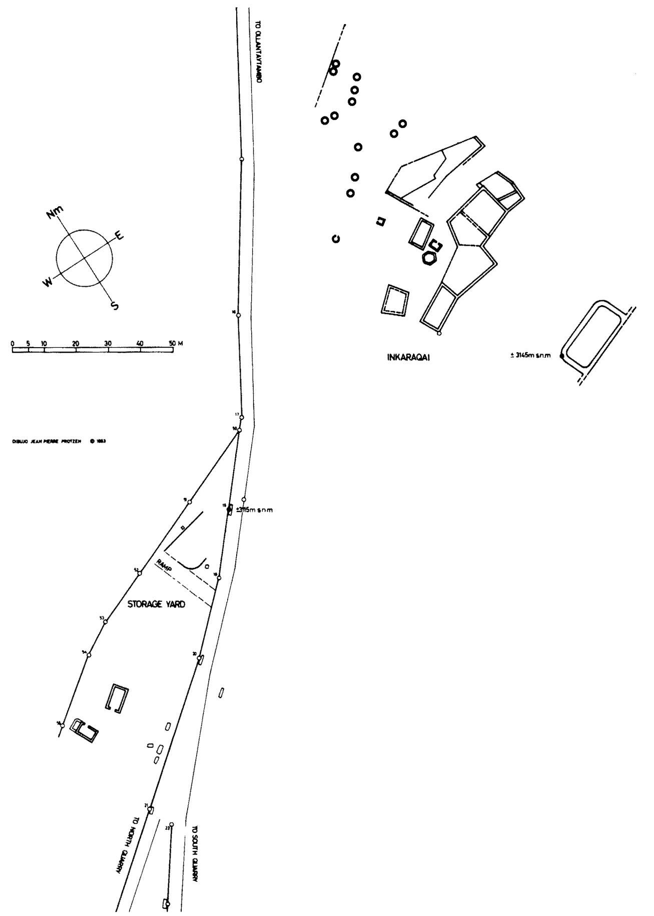


Fig. 5. Site plan of Inkaraqai and of storage yard just below the junction of the access ramps leading to the north and south quarries of Kachiqhata.

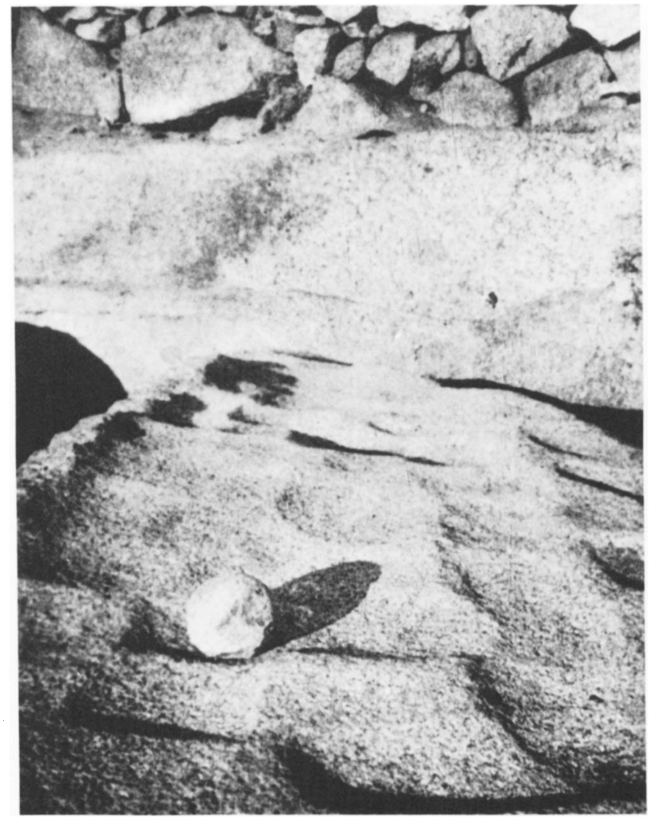

Fig. 7. Pounding marks and hammerstones on obelisk at Aswan (illustration from Reginald Engelbach, *The Problem of the Obelisks, from a study of the unfinished obelisk at Aswan,* London, 1923).

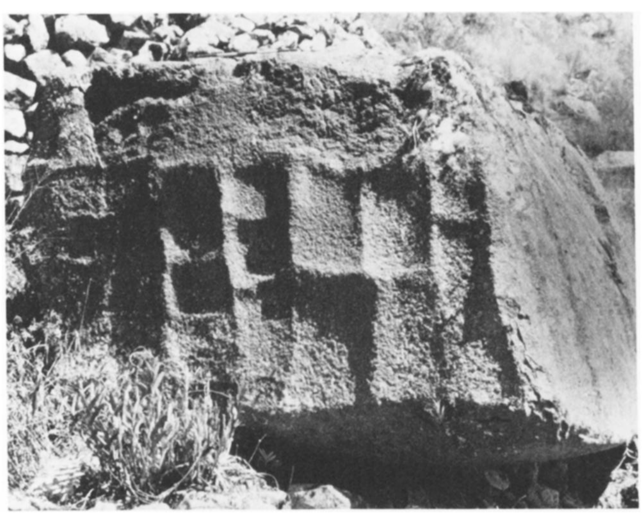

Fig. 6. Pounding marks on block of red granite in the south quarry of Kachiqhata.

some hammerstones of diorite but very few picks or wedges."[8] And, indeed, tools are rare at this site. It was not until a subsequent visit to Kachiqhata in 1983 that I discovered three hammerstones—two of quartzite and one unidentified to date—at the storage yard near Inkaraqai. Since there is only very scant evidence that the Incas split rocks with the aid of wedges, I am rather skeptical about Outwater's claim that he found picks and wedges.

As mentioned above, the rock found at the west quarry is of a grayish and fine-grained granite. Very few of the large blocks abandoned on either the ramps or the construction site are of that material. Nevertheless, the local lore maintains today, as it did in Squier's time, that this is the real quarry of Ollantaytambo. Two millstones—one almost finished, the other roughly hewn—would indicate that the quarry had been worked in colonial times. But other aspects, in particular the construction of the ramps, associate the west quarry with the other two. The one

8. J. Ogden Outwater, Jr., "Building the Fortress of Ollantaytambo," *Archaeology,* 12 (1959), 28.


Fig. 8. Site plan of Llama Pit in the quarries of Rumiqolqa.

surprising feature at this quarry, lying just off the main ramp, is the presence of many long, thin blocks in various stages of production. Some of them are almost 7 m long and have a cross section of only 40 × 40 cm. How these stone "needles" were extracted remains somewhat of a puzzle. From the way some of them are strewn about, it is evident that long blocks with large cross sections had been split up repeatedly into blocks with ever smaller cross sections. But how? There are no identifiable tool marks on the work pieces, no traces of wedge holes, and only faint traces of channeling. The needles had not been pounded upon as had the big blocks in the north and south quarries.

What were these needles used for? I was told by local informants, as was Squier before me, that they served in the construction of the bridge over the river Urubamba. This explanation is doubtful, since the respective spans from either bank to the still-existing pier in the river are about 20 m and 30 m wide. Curiously, there are no abandoned needles on the ramps leading from the quarries to the construction site. The only blocks at Ollantaytambo that fit that description at all are the lintels over the doorways in the walls of Manyaraqai at the entrance to the "fortress."

At all of the sites at Rumiqolqa, in contrast to Kachiqhata, one encounters quarrying in the proper sense: the rock is broken off a face or extracted from pits. The area is still extensively worked today, so that much of the evidence of ancient activity has now been obliterated. I did succeed in finding one well-

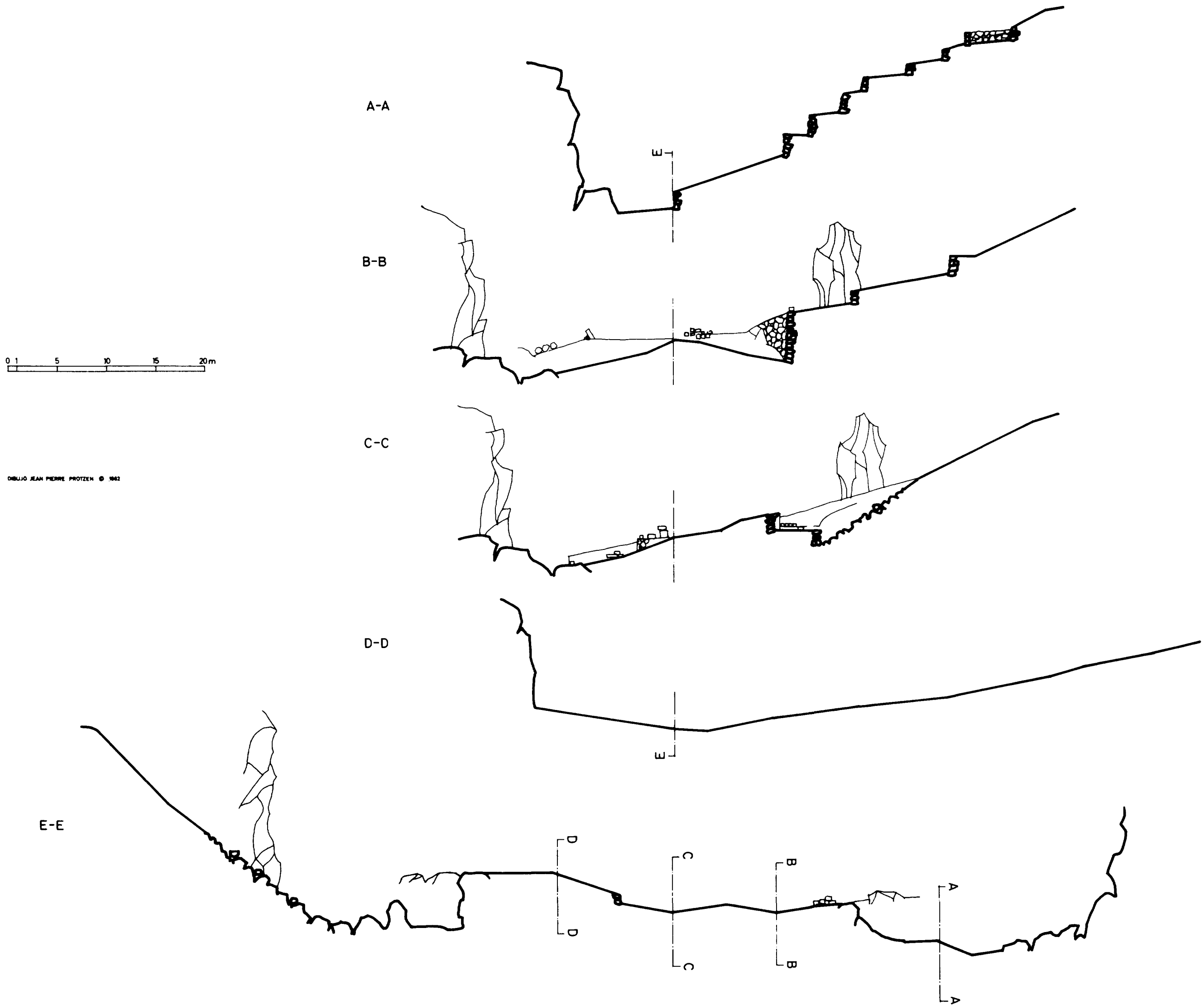


Fig. 9. Profiles through Llama Pit in the quarries of Rumiqolqa.

preserved quarry pit in an inaccessible area of the central quarries. It shows hardly any evidence of modern quarrying activity, although contemporary quarrymen are closing in fast.

I named this pit "the Llama Pit" for two petroglyphs of llamas that I found on a rock face in the pit. The pit is about 100 m long, 60 m wide, and between 15 to 20 m deep (Figs. 8, 9). The outstanding feature of the Llama pit is the 250 or so cut stones, finished and ready to be shipped, lying around four major extraction areas (Fig. 10).

Under an overburden of very porous, loose, and small-size material, the Llama Pit yields three distinct rock qualities. First, there is a stratum of still porous and loose but larger rocks, a material that seems to correspond to the one used in the small-scale, regular bond masonry in Cuzco. Directly below this comes a layer of somewhat larger rocks of a light gray or brown color; this rock is considerably denser and not really loose but very fractured. The bottom stratum comprises the best stone: dense, in large pieces, and of a beautiful sparkling dark gray color. The various strata are most likely the result of the more or less rapid cooling of the andesite mass during its extrusion. The more porous the rock, the faster the cooling had been.

The quarrying of this stone does not pose any major problems. Even the densest quality is still sufficiently fractured that it can easily be broken out of the face of the rock. To break it out, the Inca quarrymen may have used pry-bars of bronze, of the kind exhibited in the museums at Cuzco and Lima, or they may simply have used wooden sticks, as I have observed contemporary quarrymen do.

Fig. 10. Ancient cut stones abandoned in Llama Pit.

Squier wrote about Rumiqolqa:

> Of the manner in which the stones were separated from the natural rock there are here, as in other places, abundant illustrations. Excavations were made, where possible, under the masses of rock, so as to leave some portions of them impending. A groove was then cut in the upper surface on the line of desired fracture, on which oblong holes were worked to a considerable depth, precisely in the manner now practiced. The presumption is strong that wedges of dry wood were driven into these holes, and water turned into the groove.[9]

Neither at Rumiqolqa nor at Kachiqhata did I encounter evidence conclusive enough to confirm the use of this technique by the Inca quarrymen. The only positive indications I found of the use of this technique were on a single block of red granite on the ramp up to the site of Ollantaytambo. A short channel, 145 cm long, 4 cm wide, and 2 cm deep, traverses the top face of this block. In the channel are three holes, from 10 to 13 cm long, 4 cm wide, 6 cm deep, and from 32 to 34 cm apart. Ten more such holes are to be found in the block, three of which are curiously staggered across the top face. The irregular shape of the holes, their rounded edges and bottoms, the sinuous tracing of the channel, and the pit marks in it strongly suggest that the channel and holes had been pounded out rather than cut with a chisel (Fig. 11). This is in sharp contrast to the one split rock in the quarries at Machu Picchu, which features clean-cut wedge-holes, regular in shape and size, but no channel. There can be little doubt that these holes had been cut with a metallic chisel (Fig. 12). I am led to believe that the rock at Machu Picchu was split in more recent times. The lack of traces of channeling and of the use of wedges does not, of course, rule out the application of this technique by the Inca quarrymen to mine stone or to break up large blocks. However, contrary to most accounts in the literature, it does suggest that the technique was not in common use.

## CUTTING AND DRESSING

At Rumiqolqa, in contrast to Kachiqhata, the stones had generally been finished, or nearly finished, on five of six sides in the quarry. Once broken out of the quarry face, how had these stones been hewn and dressed? Among the many blocks in the Llama Pit, one can observe blocks in all stages of production, from the raw, to the roughly cut, to the partially hewn, to the finely dressed. One can easily imagine what the process may have been.

9. Squier, *Peru*, 419.

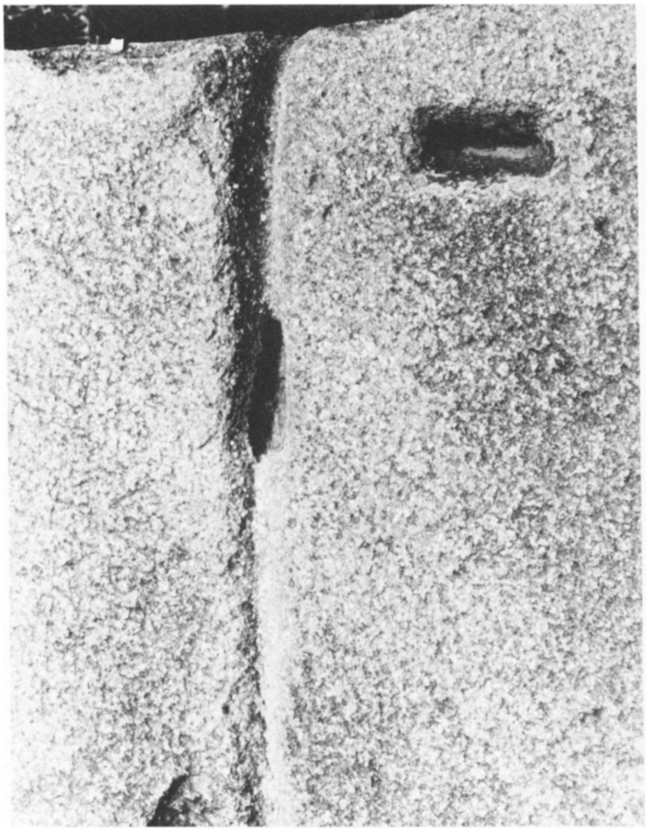

Fig. 11. Channel and wedge-holes on block of red granite on access ramp to Ollantaytambo. Pit marks and oval wedge-holes suggest that holes were bruised out.

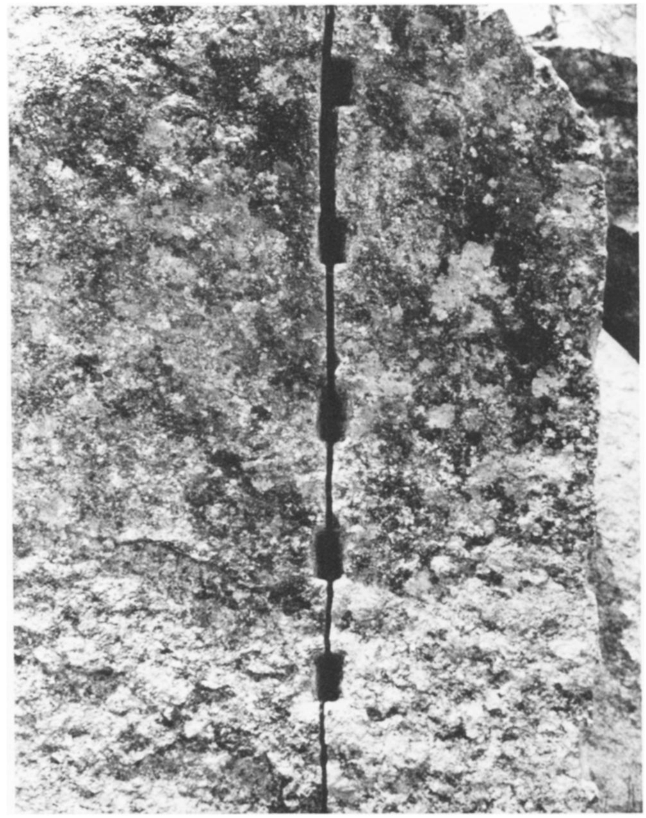

Fig. 12. Wedge-holes on split rock at Machu Picchu. Sharp rectangular shape of wedge-holes suggests sharp cutting tool.

*Tools*

I have found enough tools at this site to be quite certain about the techniques involved in the process of cutting and dressing. The tools were simple river cobbles used as hammerstones. They were found loosely strewn about the chippings of andesite or partially buried in them (Fig. 13). The map indicates the location of each of the 68 lithic implements found in the Llama Pit (Fig. 14).

The hammers were easily identified since they are foreign to the site, both as to their shape and their petrological characteristics. Most hammers are quartzo-felspathic sandstones that have metamorphosed to various degrees. A few are pure quartzite; others are granite; and some are olivine basalt. They range in weight from a couple of hundred grams to 8 kg, with two groups in between that range between 2 and 3 kg and between 4 and 5 kg. All types of hammerstones have a hardness of at least 5.5 on Mohs' scale. This is comparable to the hardness of the andesite on which the hammers were used, but the hammers are tougher than andesite, which, due to differential cooling during its formation, is easily shattered on impact. The provenance of the hammerstones is most likely the nearby Vilcanota River. Large quantities of river cobbles can be found also on the northwest side of the quarries, away from the river, all the way up to the high quarry. It appears that the upthrust of volcanic rock had cut off the Huatany River from joining the Vilcanota at Rumiqolqa and dislodged its old bed. Outwater must have overlooked these facts when he wrote, "I found two hammer-stones of quartzite which must have been brought to the site from considerable distance, as there is no evidence of such material near the site."[10]

The largest of the hammers was used to break up and square off, by flaking, the blocks broken out of the quarry face. The fact that the technique of flaking was used for shaping is clear when one looks at the scars on actual blocks (Fig. 15). The scars are similar to ones on flaked stone tools, such as arrowheads, but much larger.

The dressing was done using medium-weight hammers to cut the surfaces and smaller ones of 200 to 600 gr to draft and finish the edges.

10. Outwater, "Ollantaytambo," 28.

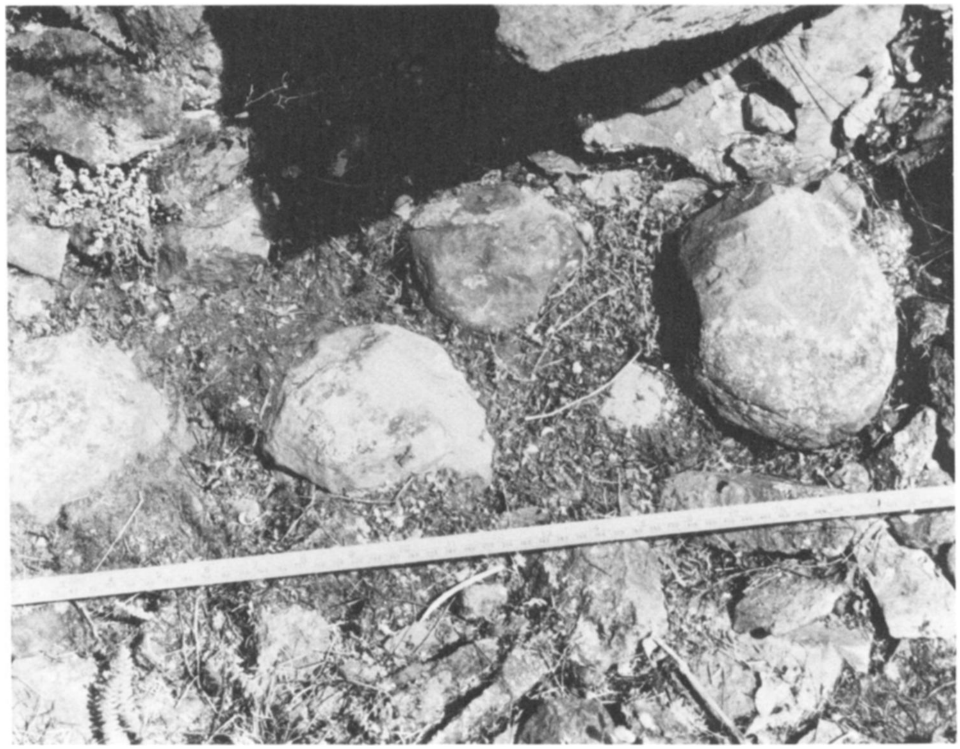

Fig. 13. Half-buried hammerstones in Llama Pit.


Fig. 14. Distribution of lithic finds in Llama Pit.

Fig. 15. Flaking scars on block in Llama Pit.

Fig. 16. Raw block of andesite used in stone-cutting experiment.

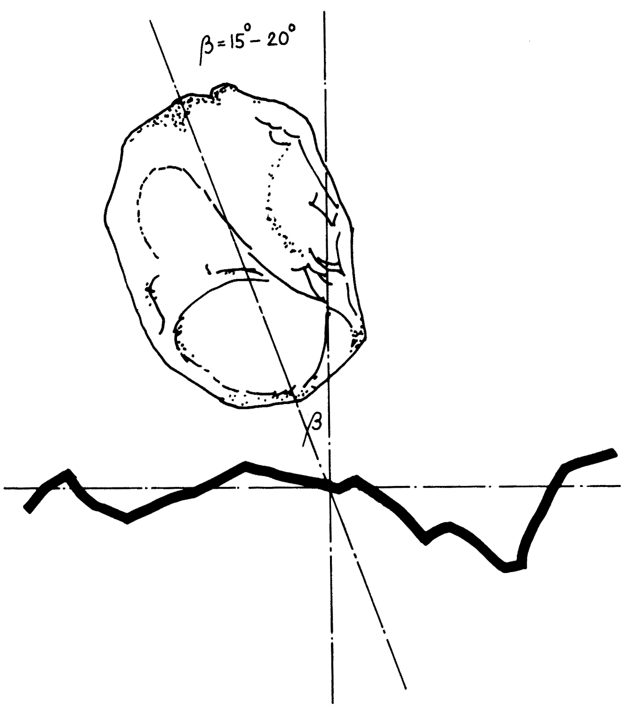


Fig. 17a. Directing the hammerstone at an angle of 15 to 20 degrees to the surface to be worked increases the efficacy of the strike.

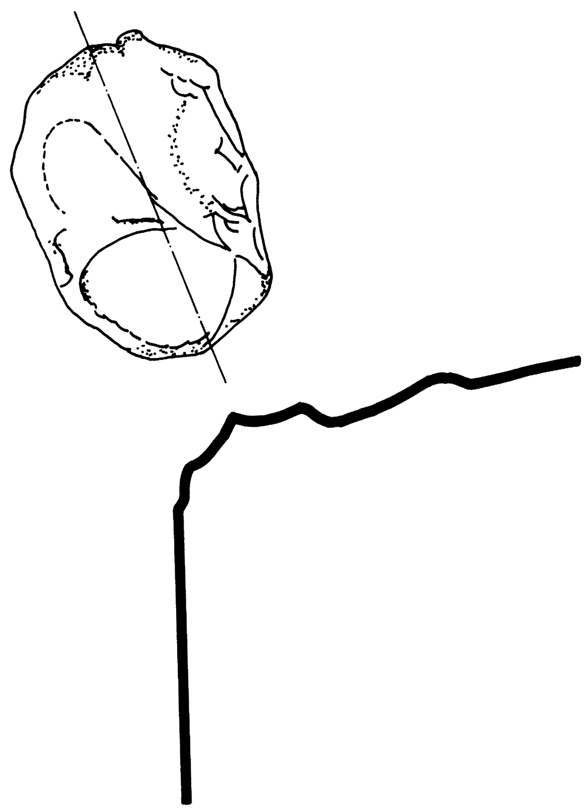

Fig. 17b. Once a face has been cut, one cannot simply turn over the workpiece to continue on another face. The big hammerstone would chip off large flakes at the edge.

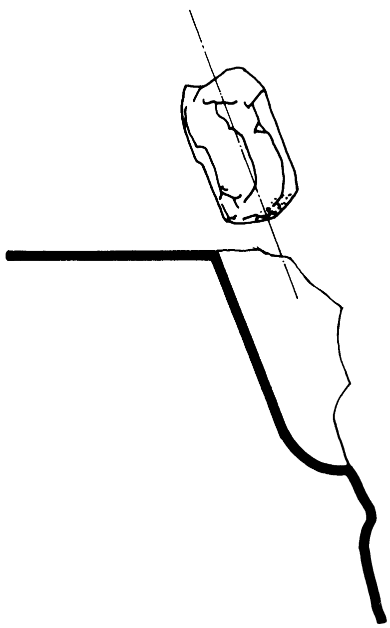

Fig. 17c. Before a new face is cut, one must draft the edges with a small hammerstone and with grazing blows away from the edge.

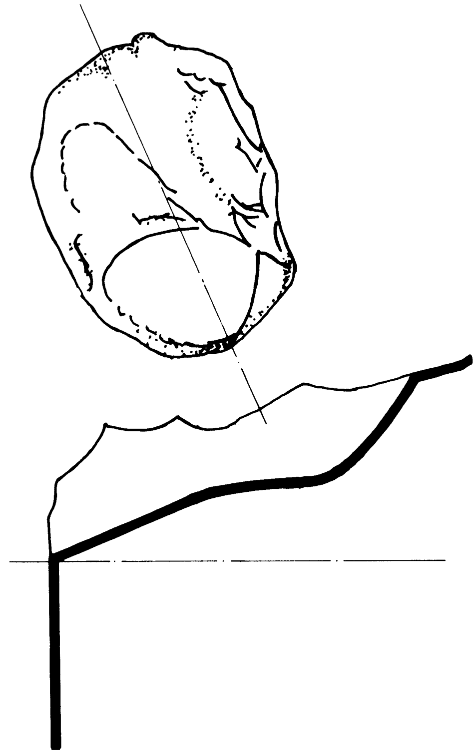

Fig. 17d. Once the edge is drafted, the workpiece can be turned over and the dressing of the next face may be started.

*Experiments*

To test my assertions, I proceeded from observation to experiment. Starting with a raw block of andesite, about 25 × 25 × 30 cm (Fig. 16), I first knocked off the largest protrusions, using a hammer of metamorphosed sandstone weighing about 4 kg to achieve a rough parallelipiped. Six blows were enough to achieve this step. The next objective was to cut a face. Using another hammer of the same material of about 4 kg, and holding the hammer between my hands, I then started pounding at a face of the block (see Fig. 19). Cutting stone in this fashion is essentially a process of crushing the rock. However, if one directs the hammer at an angle of between 15 to 20 degrees off the normal to the surface to be worked, tiny flakes will chip off and the cutting is accelerated considerably (Fig. 17a). The efficacy of each strike is further enhanced by increasing the angle of impact to about 40 to 45 degrees just before the hammer hits the surface. This is accomplished with a twist of the wrists at the last moment. The mechanics of this process are easily explained. When the hammer is directed vertically at the surface the whole force of the strike is converted into compression which crushes the rock (or at the worst may even split it). As soon as the direction of the strike deviates from the vertical, the force of the strike is diffused into a compression and a shear component. The larger the angle of impact, the larger the shear component becomes. It is the shear component of the force that tears off the small flakes.

One might think that wielding a 4-kg hammer for an extended period of time would be very tiring work. However, it is not necessary to support the hammer while using it. By taking advantage of gravity and the hammer's own mass, one can simply drop it on the surface to be worked while following with both hands. On andesite, the hammer bounces back 15 to 25 cm and can be caught again in the hands. The stonemason can then direct the hammer at the next spot he wants to hit, drop it, catch it again, and so forth. If he feels like working faster, he may at every catch impart a new impulse to the hammer. Even in this case, the effort involved in drop-pounding is quite small. The work from rough block to the stage with one face dressed took me only 20 minutes.

When a face of a block has been cut, the block cannot simply be turned over for cutting the next face (Fig. 17b). The big hammer would most likely chip off large flakes near the edges. To avoid this danger, the edge must be drafted first with a small hammer, and with grazing strikes away from the edge (Fig. 17c). Only after the edge is drafted can one return to the technique of dressing a face (Fig. 17d).

Fig. 18. Drafting of an edge with a small hammerstone of metamorphosed sandstone.

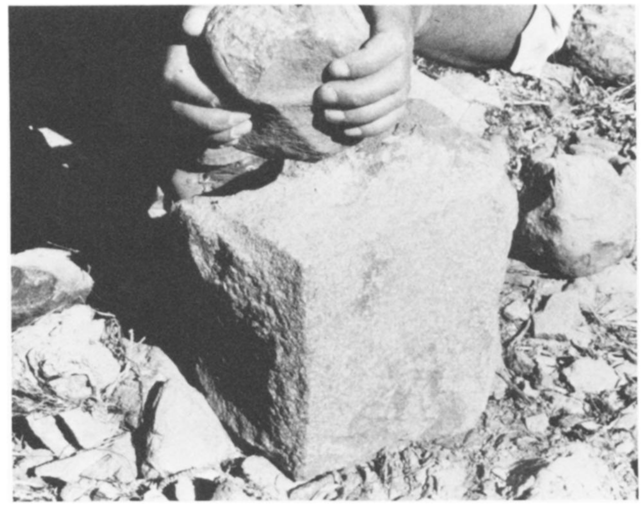

Fig. 19. Dressing of a face with hammerstone of metamorphosed sandstone.

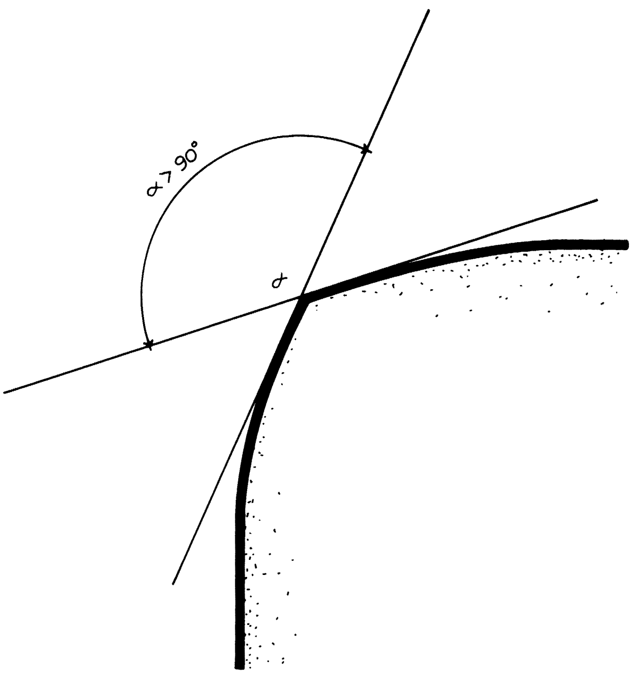


Fig. 20. As a result of the technique used to draft edges, the dihedral angle between two cut faces generally exceeds 90 degrees.

To draft the edges of the experimental block, I used a hammer of about 560 gr (Fig. 18). With hammers of that weight, gravity cannot be put to use effectively, and the nature of the strike does not have the advantage of the rebound. The hammer needs to be held tightly while pounding, and the force of the blow is the force with which the mason drives the hammer. To avoid pain and possible later injury, the hammer has to be held with the palm of the hand parallel to the direction of the strike. Attempts at holding the hammer with the palm of the hand perpendicular to the direction of strike proved to transmit the shock of percussion directly to the bones of the wrist and lower arm.

After drafting the edges, I dressed two more faces, trying out a few more hammers weighing between 3.5 and 4 kg (Fig. 19). Not all the hammers I used yielded the same results. One that was badly balanced bounced back at unpredictable angles and was very difficult to control. Others did not bounce high enough to be used without effort. Nevertheless, the dressing of three sides and the cutting of five edges took no longer than 90 minutes.

I noticed that, on most blocks, the dihedral angles between two adjacent faces, measured at the edge, seemed greater than 90 degrees (Fig. 20). Verification on a group of 31 blocks yielded an average dihedral of 117 degrees, with a range from exactly 90 degrees to an extreme of 132 degrees. This dihedral appears to be a direct consequence of the technique of drafting edges. The resulting protruding faces have the advantage of protecting the edges during transportation and handling. This technical detail of stonecutting accounts for the sunken joints that produce the chiaroscuro in Inca masonry.

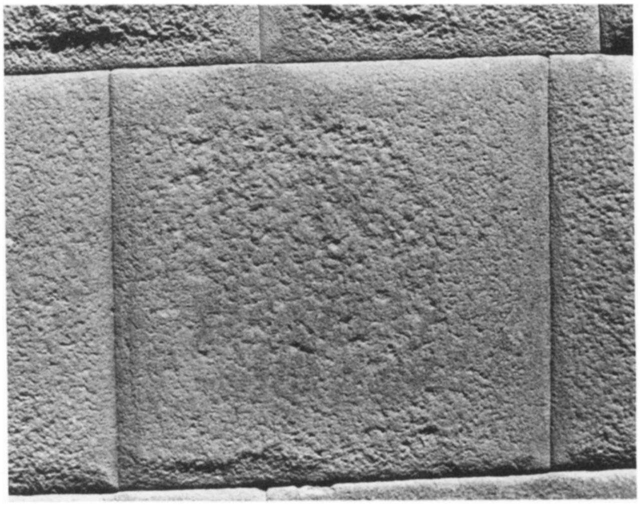

Fig. 21. Pit marks from pounding on andesite block in wall of Aqllawasi. Notice how pit marks get finer around the edges of block.

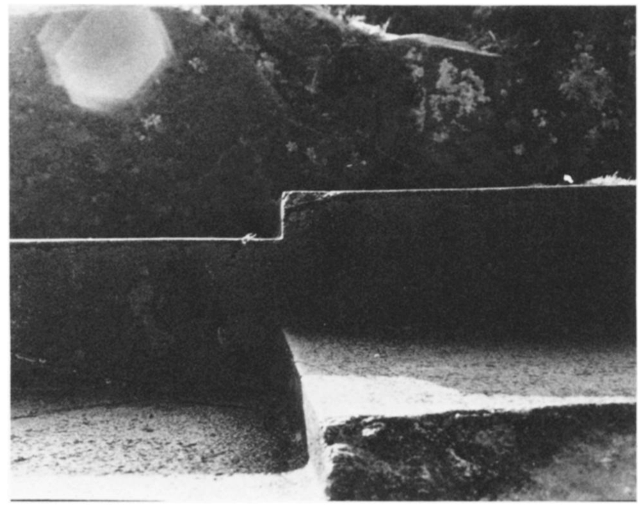

Fig. 23. Sharp concave corner on steps of "Throne of the Inca" at Saqsaywaman.

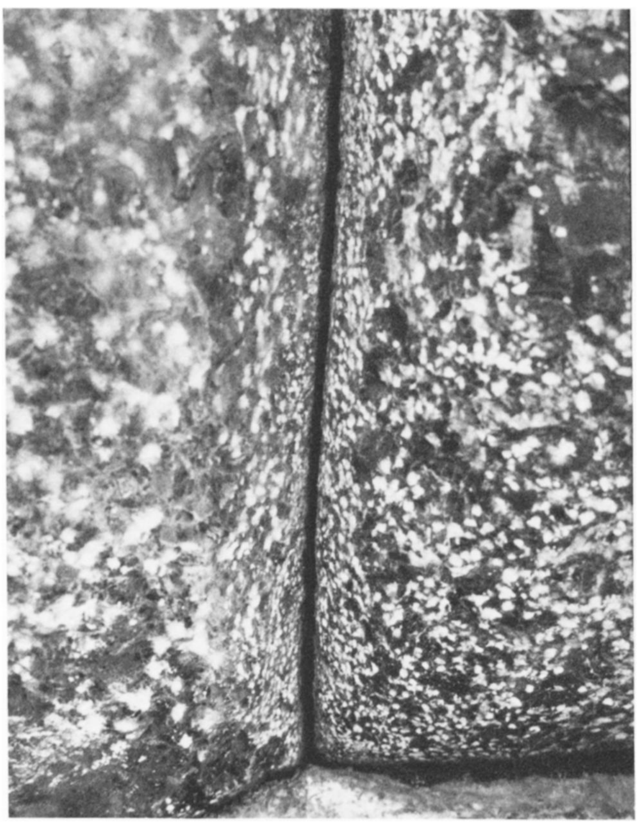

Fig. 22. Pit marks on limestone. Whitish spots are result of partial metamorphosis of limestone produced by the heat of impact of the hammerstone. The finer pit marks toward the joint suggest the use of smaller hammerstones.

The experiments show that stones can be mined, cut, and dressed with simple tools yet with little effort and in a very short time. Is that the way the Inca stonemasons worked? The physical evidence that they used techniques close to those developed in the experiment is abundant. Pit scars similar to those obtained on the andesite block at Rumiqolqa are found on all Inca walls, regardless of rock type (Fig. 21). On limestone, the pit scars show a whitish discoloration of the stone. These white spots are the result of a partial metamorphosis of the limestone produced by the heat generated by the impact of the hammerstone (Fig. 22). In each case, the pitmarks are finer toward the edge or joint than in the center of the face of the stone, suggesting the use of smaller hammers to work the edges.

If the exotic stones I found were indeed used as hammers, there should be indications of wear not only on the hammers themselves but also on the ground, in the form of chips or slivers. To check this, I marked off an area of 1.8 × 1.8 m near four partially buried hammerstones and combed through the surface rubble of andesite flakes. Limiting myself to chips that I could pick up with my fingers, I found 43 slivers, all of which petrologically match the hammerstones found.

My only doubt about the technique of pounding had to do with sharp concave edges, such as those observed in the steps at the "Throne of the Inca" at Saqsaywaman (Fig. 23). How could one pound out concave angles? At Rumiqolqa I found a small, elongated tool that dispelled my reservations. This tool, made of quartzite, could have been used as either a hammer or a chisel, since it shows wear on both the pointed and the blunt ends (Fig. 24).

At many Inca sites one finds eye-holes cut into stones: eye-bonders to tie down roofs at Machu Picchu; eye-holes of unknown use at the Inkawatana in Ollantaytambo and at the Qorikancha

Fig. 24. Lithic tool of quartzite from Llama Pit which could have served as hammerstone, chisel, or wedge.

Fig. 25. Groove made of two cuts at Inkamisana. Cuts are result of abrasion and not of pounding.

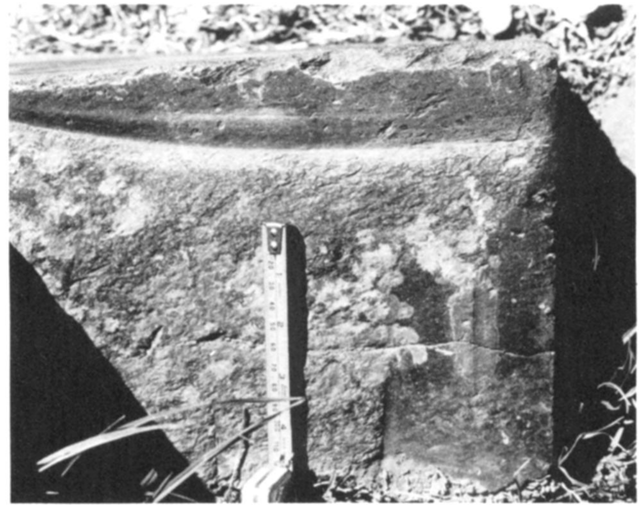

Fig. 26. Cuts made by abrasion with unknown tool on "fountain" stone at Ollantaytambo.

in Cuzco. All of the holes that I investigated are pounded out. They show the characteristic pit marks and exhibit a conical shape on either side of the perforated stone. This suggests that the pounding had been started from both sides until there remained only a thin membrane to be punched out. I know of only one eye-hole (in a stone in the courtyard of the museum of Cuzco) that could possibly support Bingham's suggestion that eye-holes had been bored "probably by means of pieces of bamboo rapidly revolved between the palms of the hands, assisted by the liberal use of water and sand."[11]

The technique of pounding is reported by at least one documentary source. Garcilaso de la Vega wrote, "They had no other tools to work the stones than some black stones they called hihuana with which they dress [the stone] by pounding rather than cutting."[12]

### *Alternative techniques*

Although there is no doubt that the technique of pounding was the predominant method of dressing stone, there is evidence in the area that I investigated that the Inca stonemasons had knowledge of other techniques for working stone.

Many of the building blocks at Ollantaytambo exhibit highly polished sections of faces and edges, while the rest of the faces show the familiar pit marks. This polish may have been achieved with bars of pumice, of which I found a few fragments.

Close to the "religious sector" of Ollantaytambo, there is a stone block that appears to have been sawed into. In fact, this

11. Hiram Bingham, *Machu Picchu: A Citadel of the Incas,* New Haven, 1930, 68.

12. Gasparini and Margolies, *Inca Architecture,* 306.

stone has not been cut at all. The alleged saw cut, which is shown to every tourist and is referred to by Ravines in an editorial footnote to Outwater's article "Edificacción de la fortaleza de Ollantaytambo," is only a quartz vein that has partially weathered out.[13] However, a few hundred meters from this stone, at the place known as Inkamisana, there are a number of genuine cuts forming a pattern of lozenges. These cuts are the result of abrasion, not of crushing or pounding. They may have been made with some kind of saw or file but clearly not with a wire or string, since the cuts abut onto a vertical wall through which no wire could have been pulled. The cuts are in fact made of two smaller channels with a fine ridge between them that has been broken off (Fig. 25). Similar cuts forming similar patterns can be found on stones, labeled "paving stones," in the museum at Cuzco.

At some 20 m to the north northeast of the Sun Temple, in the religious section of Ollantaytambo, there is a purplish fountain-like stone of meta-arkose that features interesting abrasion marks (Fig. 26). Ravines suggested that this stone is in a state of a *roca a medio pulimentar.*[14] At Ollantaytambo, there are some good examples of polished blocks. As mentioned before, most blocks of red granite lying around show areas of almost mirror-like polish. This indicates that the marks on the stone in question result not from polishing but from some form of sawing. But again, the cuts could not have been made with a string or wire; the curvature of the cut is contrary to what one would obtain with a string. There is more evidence throughout the territory that I explored to show that the Incas did on occasion saw into stones. What tools they used for this I do not yet know.

## FITTING AND LAYING

The next and the most intriguing questions about Inca stone masonry concern the unbelievably precise fitting of the blocks. For the purpose of the discussion, a distinction will be made between the bedding joints, that is, the joints through which most of the weight of a block is transmitted to the course below, and the lateral or rising joints.

### *Bedding joints*

With regard to the bedding joints, I have made an observation that can be formulated as a general rule: *the bedding joint of every new course is cut into the top face of the course already laid below it.* The rule is manifest, for example, at Saqsaywaman (see Fig. 35) and gives a simple explanation for the wall section at Machu Picchu that so attracted Bingham's attention (Fig. 27). Of this wall he wrote:

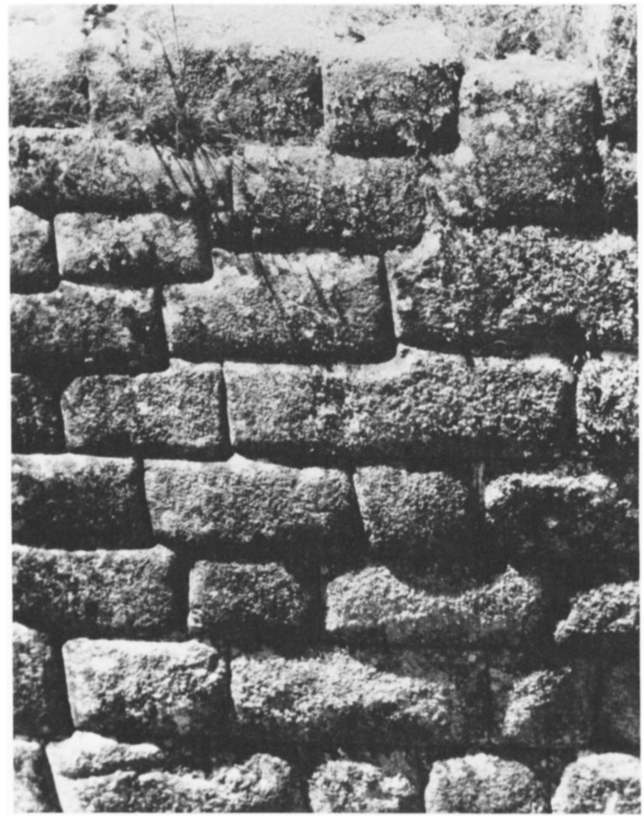

Fig. 27. "Hookstones" in Bingham's "Beautiful Wall" at Machu Picchu are a good illustration of the bedding-joint rule.

> In the course of time such a house, whose attic was entirely above the level of the Beautiful Wall, would tend to lean away from the wall, and the seams would open. Consequently the stone mason ingeniously keyed the ashlars together at a point where the greatest strain would occur, by altering the pattern from one which is virtually rectangular to one containing hookstones, thus making a series of braces which would prevent the ashlars from slipping and keep the house from leaning away from the ornamental wall.[15]

If indeed the two-story house were to lean away from the Beautiful Wall, this would create an uplift, rather than a slip motion, against which the "hooks" would be useless. The particular configuration is better explained by the bedding-joint rule, and may be interpreted as a "seam" where wall sections started from opposite ends meet.

13. Rogger Ravines, comp., *Tecnologia Andina,* Lima, 1978, 584 n. 6a.

14. Ravines, *Tecnologia,* 548 n. 6b.

15. Bingham, *Machu Picchu,* 92.

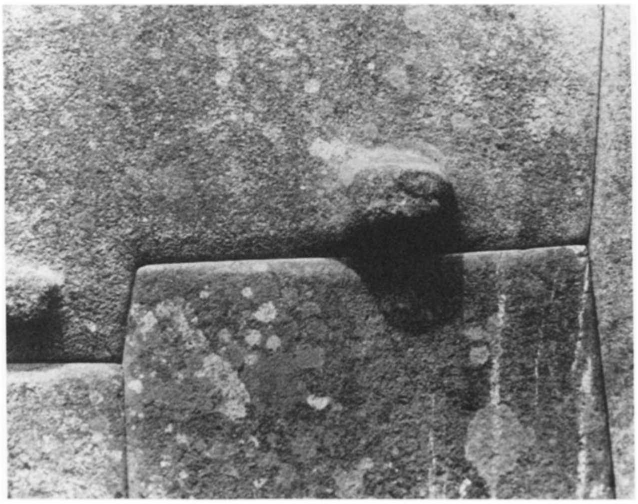

Fig. 28. Exception to bedding-joint rule at Ollantaytambo.

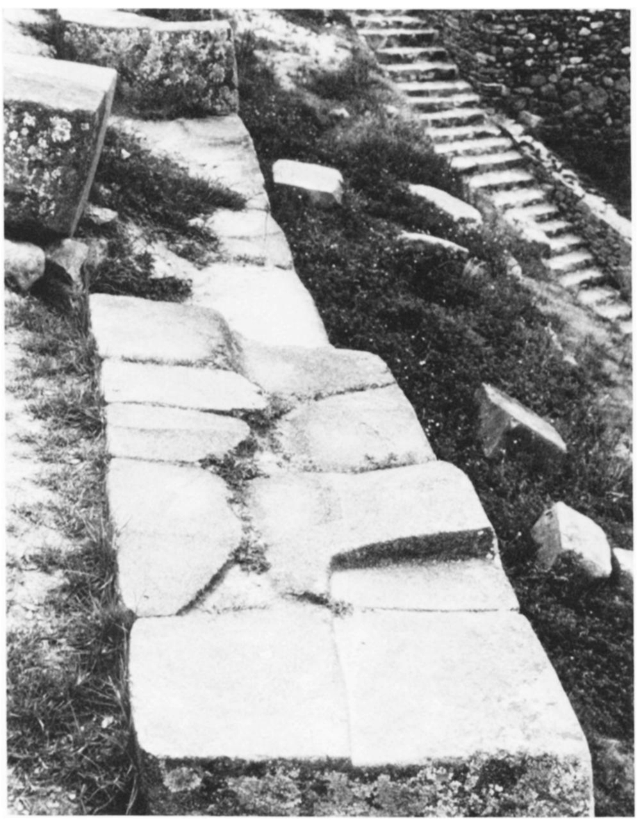

Fig. 29. Bedding joints cut to receive next course of stones. Such cuts were not obtained by grinding stone against stone, but were pounded out.

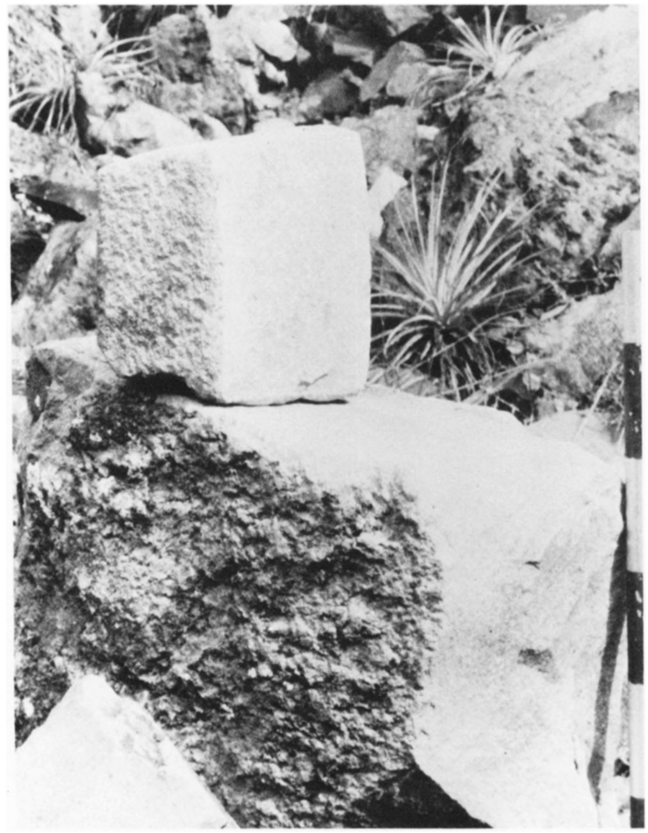

Fig. 30. Two blocks of andesite to be fitted in experiment.

The rule (according to which the upper courses project into the lower course) does, like any good rule, have its occasional exceptions, for example at Ollantaytambo (Fig. 28). But even exceptions like this do not preclude that it is primarily the lower course that is cut to adapt to the upper course.

Wherever walls have been dismantled, one can clearly see the cuts made into the top face to receive the next course of blocks (Fig. 29). Cuts like these are the manifest refutation of the often advanced hypothesis that neighboring stones were ground against each other to achieve the perfect fit.[16] Obviously, grinding would not have left marks like these. How then was the fit achieved?

Again, to get a better understanding of the technique involved, I tried to do it myself. The experiment required two blocks of andesite, the one used in the dressing experiment and a larger one into which the bedding joint was to be cut. The face of the small stone shown in Figure 30 is the one for which the bedding joint was to be cut.

I started by putting down the face to be fitted onto the lower block and outlining its contours. (Modern quarrymen dig up the root of an ubiquitous bush, named "llawlli," and use its deep yellow sap as a marker in the manufacture of paving tiles.)

16. Ravines, *Tecnologia,* 559.

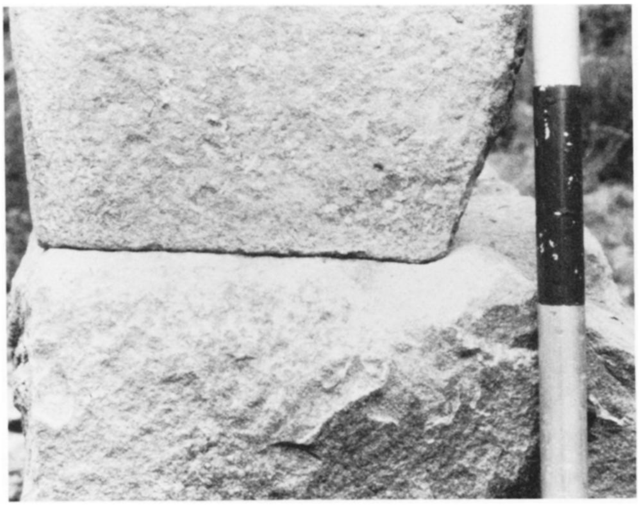

Fig. 31. Fit of two blocks obtained in experiment.

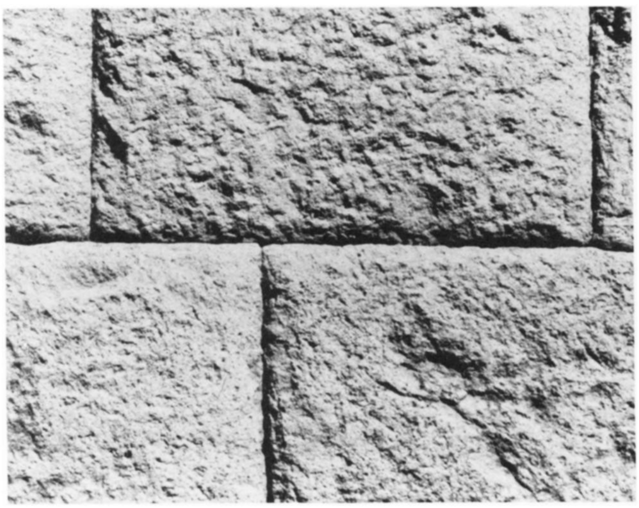

Fig. 32. Fit of blocks of andesite in Inca wall of Amarukancha.

Fig. 33. Sometimes the building blocks were fitted only along a shallow band close to the visible face of the wall, while the interior of the joints was filled with rubble.

After outlining the bedding joint, I pounded it out. In the process a lot of dust is produced that proves quite useful, for when one puts back the upper block to check the fit, the dust compresses where the two faces of the joint touch, while it remains loose elsewhere. Where it is compressed is where one has to continue the pounding. Through repeated fitting and pounding, one can achieve a fit as close as one wishes. Figures 31 and 32 compare the fit achieved in this fashion with an actual fit in the Inca wall of the Amarukancha in Cuzco. It took me 90 minutes to complete the fit.

The technique for fitting two stones is thus one of trial and error. I concede that this technique appears to be tedious and laborious, especially if one thinks of the cyclopean blocks at Saqsaywaman or Ollantaytambo. It should be remembered, however, that to the Incas time and labor were probably of little concern. My experiments show that with some practice one develops a very keen eye for matching surfaces, so that the number of trials can be reduced considerably. The suggested method works and has the advantage of not postulating the use of tools and other implements of which no traces have been found. Finally, it has the support of at least one 16th-century observer. José de Acosta wrote in 1589:

> And what I admire most is that, although these [stones] in the wall I am talking about, are not regular but very different among themselves in size and shape, they fit together with incredible precision without mortar. All this was done with much manpower and much endurance in the work, for to adjust one stone to another until they fit together, it was necessary to try the fit many times, the stones not being even or full.[17]

The emphasis here should, of course, be on the phrase "it was necessary to try the fit many times."

17. Joseph de Acosta, *Historia natural y moral de las Indias,* ed. Edmundo O'Gorman, Biblioteca Americana, 38, 2nd ed., Mexico, 1962, bk. 6, chap. 14, 297:

> Y lo que más admira es que no siendo estas [piedras] que digo de la muralla, por regla, sino entre si muy desiguales en el tamaño y en la facción, encajan unas con otras con increíble juntura sin mescla. Todo esto se hacía a poder de mucha gente y gran sufrimiento en el labrar, porque para encajar una piedra con otra, según están ajustadas, era forzoso proballas muchas veces, no estando las más de ellas iguales ni llenas.

Fig. 34. Sometimes the building blocks were fitted carefully over the whole extent of the joining plane.

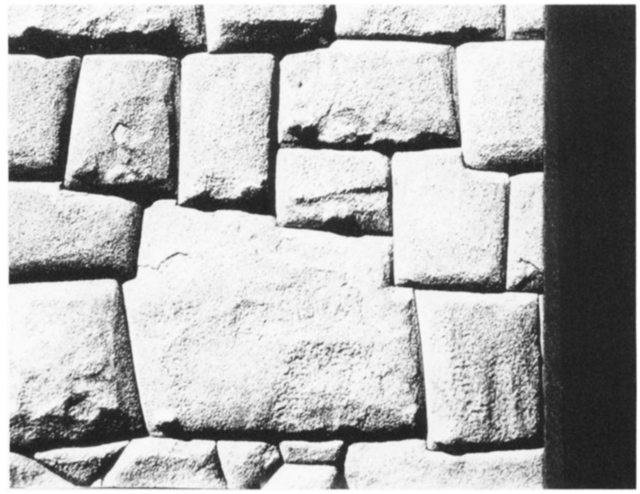

Fig. 36. "Twelve-angle" stone in a wall of the palace of Inca Roca is the simple result of the fitting technique.

Fig. 35. Illustration of the combined effect of the fitting of bedding joints and lateral joints at Saqsaywaman.

*Rising joints*

The lateral or rising joint differs from the bedding joint in that the fit observed from the front is often only a few centimeters deep, with the interior of the joint being filled with rubble (Fig. 33). Harth-terré hailed this method of fitting stones as the technical secret of the "wedge-stone" (*piedra-cuña*) which allowed the Inca stonemason to reduce the fitting work to only a thin band around the edges of the stones.[18] While this shallow fit is common, it rarely applies to bedding joints and is by no means the rule for rising joints. In many instances the blocks are fitted with the same care over the extent of the joining plane (Fig. 34). Nevertheless, as I will show below, wedge-stones do play an important role in Inca stonemasonry.

The technique for fitting lateral joints I assume to be similar to that used for the bedding joints: *the new block to be laid is fitted into, and the joint cut out of, the lateral block or blocks already in place.* The combined effect of the fitting of bedding joints and lateral ones is neatly illustrated at Saqsaywaman (Fig. 35), and it takes out some of the magic of the famous "twelve-angle stone" in the retaining wall of Inca Roca's palace (Fig. 36).

*Laying sequences*

The matter of lateral fitting raises some questions about the sequence in which the blocks were laid. The sequence may not matter so much for masonry with a regular bond, but it certainly becomes critical in masonry with an irregular bond. To investigate laying sequences, I surveyed one of the fortification walls at Saqsaywaman. The unfolded view of walls 26 and 27 of the

18. Harth-terré, "Cantería incaica," 155.

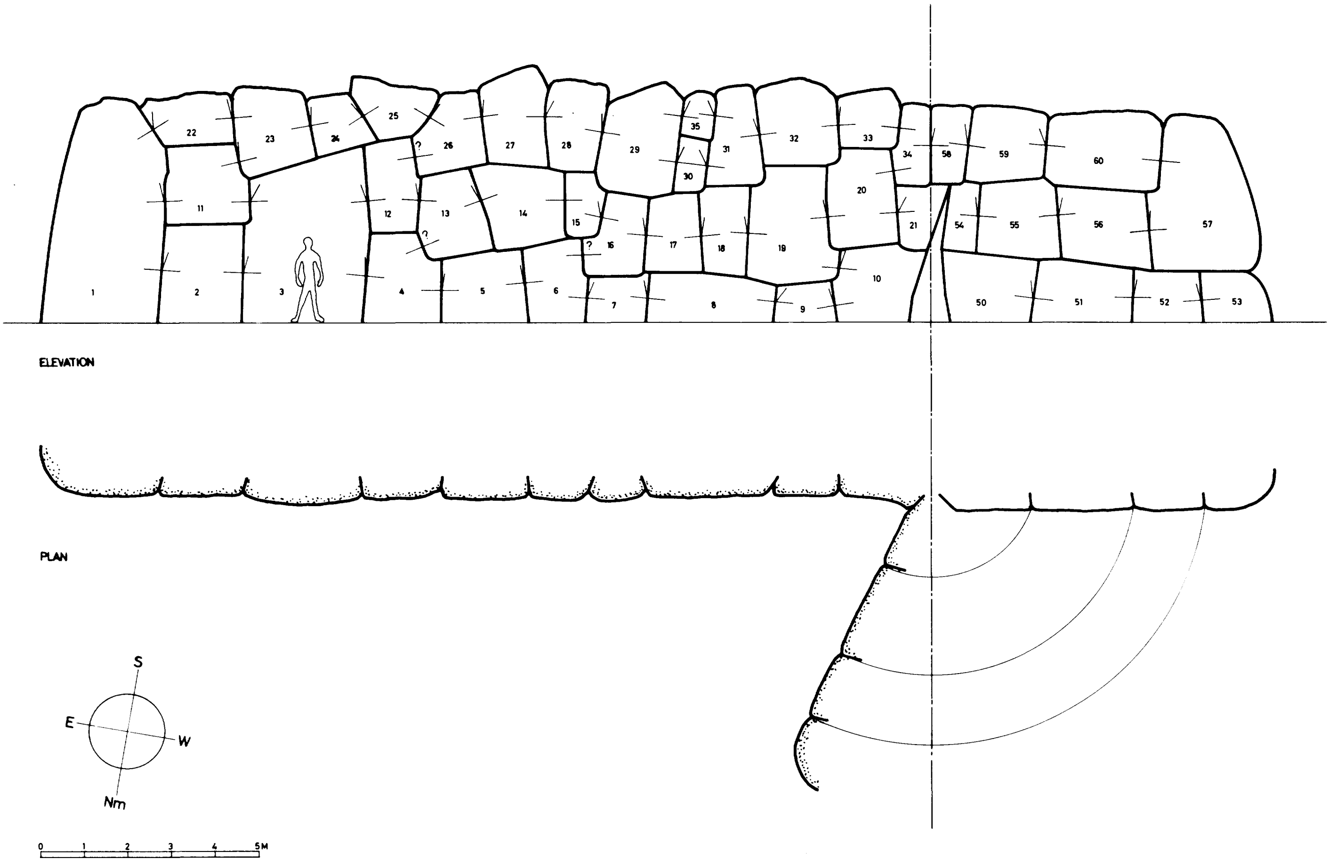


Fig. 37. Plan and unfolded elevation of wall sections 26 and 27 of the first rampart at Saqsaywaman showing the angles formed by the joining planes and the plane of the face of the wall.

first rampart shows the orientation and magnitude of the angles formed by the joining planes and the plane of the face of the wall (Fig. 37).[19]

Assuming that the laying of the first course—with the exception of block 1—was straightforward, one can reasonably assume that blocks 16 and 19 were laid before either 15 or 20; and that block 34 must have been in place before the laying of 33, and block 26 in place before the laying of 25.

Inspecting the second course (blocks 16 to 19) in detail, one notes again how the bedding joints are cut into the lower course and how rising joints are cut into the laterally adjoining blocks. The changing orientation of the angles of the joints between 19 and 10, and between 19 and 20, supports the argument that 19 was fitted to 10 first, and that 20 was cut into 19 later. As for the sequence in which blocks 16 to 19 were set, I would argue that this course was started from both ends, with block 18 as the last stone. Its shape would have allowed it to be lowered into position from the top, but more likely it has been pushed in from the front. Block 18 is wedge shaped and acts as a sort of a keystone, just as Harth-terré described it.[20]

The reason I think that some keystones were introduced from the front is manifest in a gap found in the second rampart at Saqsaywaman (Fig. 38). The tapering sides of the gap indicate that it held a keystone that has fallen out of the bond. Since the width is broader at the bottom of the gap than at the top, the keystone must have been introduced from the front. If, as I suspect, the Incas used earthen embankments to raise the building blocks into position, it would make sense to assume that keystones were always inserted from the front. Each of the courses in these walls proves to have a block that can reasonably be regarded as such a keystone: blocks 15, 58, 30, and 35, and possibly 28 and 25. The course formed by blocks 20 to 57 does not have a keystone because it does not need one. Block 57 is a cornerstone which could easily be put in place last. Cornerstone 1 was most likely erected after blocks 2 and 11 were in place.

19. The numbering of the walls of Saqsaywaman is that of the Instituto Nacional de Cultura of Cuzco.

20. Harth-terré, "Cantería incaica," 155.

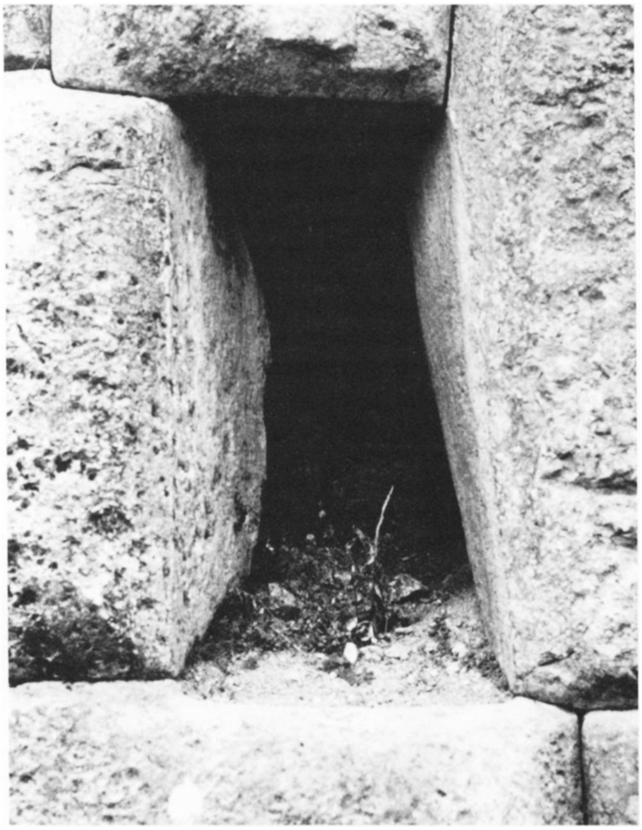

Fig. 38. Gap left by a keystone fallen out of bond. Notice taper of the sides of the gap leaving a wedge-like hole. Since the width of the hole is wider at the bottom than at the top, the keystone must have been introduced from the front.

For a number of reasons, these conclusions about laying sequences are not meant to be definitive. First, it is necessary to analyze more walls for sequence; one wall is simply not a sufficient sample. Second, because of the proverbial fit, which does not allow one to introduce even the blade of a knife into the joints, I was not able to measure all the internal angles, and in particular those of the bedding joints. Where I succeeded in making measurements, I often could do so only to a depth of about 5 cm. This depth is not sufficient, since the joining planes quite frequently are not flat but warped, with the result that further inward the direction to the joining plane might be different from what I measured on the surface. Third, and most important, firm conclusions about the laying sequences can be reached only after careful motion studies have been conducted about the available space and the degrees of freedom left to move the blocks around and into position.

The latter problem leads me to a set of questions regarding the handling and transportation of the stones, a subject that I have not yet taken up, having chosen to address first the questions of quarrying, cutting, and fitting the stones.