

Figure 1. Machu Picchu has endured for centuries because of the care taken in its construction. This National Geographic Society photograph was used for their AD 1530 reconstruction of Machu Picchu map that appeared in the May 2002 issue of the National Geographic magazine.

A Visit to a Prehistoric Construction Site

by Kenneth R. Wright, Andrew Earles and Eric A. Bikis

Ancient stonemasons are the friends of history scholars because it is the long-ago work of this noble profession that tells modern historians what prehistoric people were like, how they lived, and what standard of care they practiced.

The Inca of 500 years ago had no written language, no iron or steel, and they did not have the wheel. It is the stonemasonry at Machu Picchu that we can use to learn about these early talented Americans; people who had a great civilization long before Columbus sailed for America!

The Research of Wright Water Engineers, Inc. at Machu Picchu started in 1994. Since then, their engineers have answered many questions about how Machu Picchu was built and how it functioned. What we learned was that the Inca were good engineers and that their stonemasons practiced a high standard of care; no detail was overlooked.

The Machu Picchu we see today was never finished. It was still very much a work in progress when Inca workers packed up their tools in 1540 AD and went home. While working at Machu Picchu, we didn't realize, at first, how many buildings were still under construction. In fact, what we found was mind boggling and even surprised or colleague, Dr. Alfredo Valencia Zegarra, a veteran local archeologist who grew up with Machu Picchu and who we consider the world's leading expert on the site.

There is abundant evidence that work in progress had been interrupted. For instance, we found a temporary construction ramp near the Sacred Rock. Sloping 30-degrees, this ramp served to lever huge stones up onto a high wall. Nearby, a large stone has been left on the wall. It is tilted at a 45-degree angle so that the bottom could be shaped to make it nestle snugly onto the stone below.

The huge stones of the Principal Temple were still being shaped when work ceased. And the walls of the Temple of Three Windows still bear the centuries old stone-chipped instructions from the master stonemason to his workers. Further, what can be seen of the huge raised platform that Hiram Bingham, in 1913, called the Temple of the Jagged Rocks shows that it would have become a striking architectural addition to the site. We also found a haphazard group of partially carved stones. Even atop Huayna Picchu, we discovered evidence of monumental building. And several hundred yards up the Inca Trail towards Intipunku, we came upon examples of huge stones in the process of being shaped and placed.

Check out the evidence on your next trip to Machu Picchu. Imagine the busy stonemasons and civil engineers in AD 1540 working to bring this exquisite royal estate to completion. Just look for the clues.

The Inca royal estate of Machu Picchu (Figure 1) is clearly the most famous archaeological site in the Western Hemisphere. That it has endured for centuries is due to the skill of the nameless engineers who built it five centuries ago (Kendall 1973).

Little is known about the construction methods of the Inca. Scientists still argue about the methods the Inca used to move the huge stones into place and match them with others to form perfect joints. Engineers still disagree on what type of timber structures supported the thick, heavy thatched roofs of the buildings. While others marvel at the sophisticated drainage and flood control system that can handle nearly 2,000 millimeters (79 inches) that falls on Machu Picchu annually. The Inca engineers who met all these challenges had no written language, wheels, iron or steel (Von Hagen and Morris 1998). Even today, the mystery remains—how the Inca accomplished so much with so few visible resources.

Although lacking a written language, the well-preserved remains of Machu Picchu show that the Inca had an advanced understanding of urban planning, hydrology, hydraulics, drainage and impressive construction methods. By studying their engineering techniques, we are able to broaden our archeological knowledge of their building techniques and shed light on the significance of this world famous site.

Machu Picchu lies about 1,400 kilometers (870 miles) south of the Equator on the eastern slope of the Peruvian Andes at Longitude 72°32' and Latitude 13°9' near the headwaters of the Amazon River. Machu Picchu is laid out like a patchwork quilt on a mountain ridge between two prominent mountain peaks: Machu Picchu and Huayna Picchu (Wright 2001).

CONSTRUCTION METHODS

The precision achieved by Inca engineers is legendary. But until recently, what was known of their construction methods fills only a few pages in the ASCE Press publication *Machu Picchu: A Civil Engineering Marvel* (Wright and Zegarra 2000). Because of the paucity of data, we returned to the archaeological site on several different occasions during 2001. On these occasions, we set about to inventory, document and analyze what construction remained uncompleted. We used this information to provide advice to the artist as to what Machu Picchu looked like in AD 1530 for

the National Geographic Society's beautiful map supplement. This appeared in the May 2002 issue of the National Geographic magazine.

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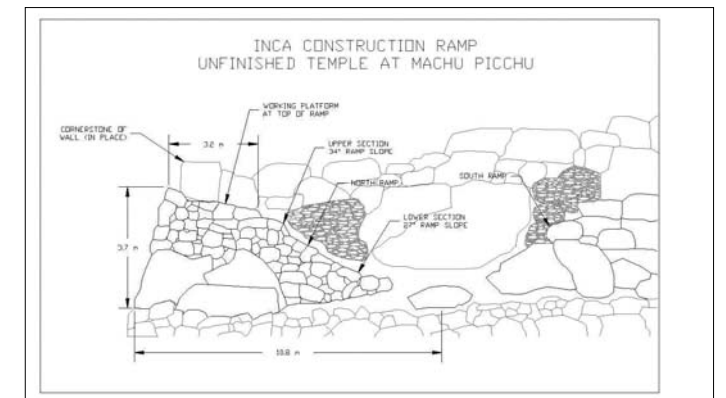


Figure 2. The Unfinished Temple's remarkable temporary construction ramp provides ample evidence of how the Inca moved huge stones into place and how they utilized stone platforms to reach in-place stones for final shaping.

Construction Ramps

Signs of the considerable construction taking place at The Unfinished Temple (a.k.a. Temple of the Jagged Rocks) are everywhere. One of the most visible indications of this activity can be seen from the construction ramps alongside the unfinished terrace walls on the west and northwest side. Years ago, Dr. Valencia took us to this ramp when we were studying types of Inca wall construction. The largest construction ramp is situated along the northern length of the west wall, adjacent to a secondary ramp. The largest ramp is illustrated in Figure 2.

This ramp has a slope of approximately 60 percent (30 degrees from horizontal). Along with the construction ramps, there are also several examples of temporary worker platforms along the west wall of the Unfinished Temple and on the northwest wall. Figure 2 also shows an example of an Inca platform used for wall finish work.



Figure 3. The stone in the eastern Urban Sector was in transit when Machu Picchu was abandoned. It would later have been shaped at its final destination.

ROCKS BEING MOVED AND AWAITING PLACEMENT

We found a number of rocks in the process of being transported and placed. Examples include the large stone in the middle of the Sacred Plaza near the Temple of the Three Windows. We surmised from the position, shape, and size of the rock that this rock was being moved into place to serve as a center support for a roof beam for the Unfinished Temple. Another is the stone in the eastern section, shown in Figure 3. The smaller stones beneath the large stone were used like rollers to reduce friction when moving the stone.

Other examples of rocks awaiting placement can be found along the west walls of the Unfinished Temple. A good illustration of a rock about to be placed is seen on the north end of the west wall. All that was needed for final placement was to lower the rock, tilted at 60 degrees, into position to the left of the cornerstone. Once in place, hammer stones were used to smooth the face the rock faces (Figure 4).

Scientists still argue about the methods the Inca used to move the huge stones into place...



Figure 4. Geologist Eric Bikis points to the underside of a tilted stone at the Unfinished Temple that was in the process of final shaping in AD 1540 so that it would fit snugly onto the stone below. The huge wall was nearly complete when the workers left.

TERRACE WALLS UNDER CONSTRUCTION

Two examples of megalithic stone terraces are the east and west walls of the Unfinished Temple. Figure 5 shows the west upper terrace wall. The construction ramp again serves to haul up stones and provide a platform to set them in place. Another unfinished terrace wall is seen along the west side of the Sacred Plaza. It may be that a fourth temple was planned for this location; the



Figure 5. The monolithic upper stone walls of the Unfinished Temple would have been completed in a few more years if the workers had not left the site. It likely would have been one of Machu Picchu's most impressive structures.

small circular wall is oriented to emulate the Coricancha in Cusco. The rocks nearby have been dressed and are ready for placing in the wall.

At the Unfinished Temple, on the top terrace, many cut stones abound. These stones provide insight into Inca practices—construction methods and the exact measurements that characterize Inca stonework. Before placing the stones in their final position, the builders first conducted a “dry run,” fitting the stones together on the ground. Once assured of a proper fit, the stones were placed in the wall.

In addition to the unfinished walls found in the Urban Sector, there is unfinished terrace construction and repair work in the Agricultural Sector. Figure 6 provides some examples of unfinished terraces.

ROOFS



Figure 10. Experts are still debating the types of Inca roof structures of Machu Picchu. This National Geographic magazine portrayal represents the most likely structure to have been able to support the heavy thatched roofs.

After conferring with Vince Lee, an expert on Inca design and construction, Ruth Wright, Dr. Valencia and Alfredo Mormontoy examined every building for roof structure and analyzed construction techniques. Some of these can be seen in Figure 6. At the Principal Temple, we found roof gables that were under construction, and others at the Temple of the Three Windows. The niches at the Principal Temple were being enlarged to support large beams at the time of abandonment.

ROUGH HEWN STONES

Stones in the process of being finished are seen around the Unfinished Temple, the Temple of Three Windows, the Principal Temple, the Sacristy and the Temple of the Moon. Work marks or unpolished/uneven rock faces indicate the work was ongoing. Figure 7 shows a wall of the Temple of Three Windows that is likewise unfinished. Under the watchful eye of Dr. Valencia, we carefully documented the abundance of evidence. Marks on the outer side of the wall showed how the rock was being cut back. A line chipped in the stone marked what would eventually be the finished surface. Many other walls in the Principal Temple were left unfinished. Many large stones are already in place but need further work before they exhibit the smooth meticulously fitted surface for which the Inca are known. Once you know what to look for, work marks on the stone abound and all over (especially the Sacristy) bumps and pits used to maneuver and position the stones have yet to be smoothed away.



Figure 7. Visitors to Machu Picchu can clearly see the work in progress at the Temple of the Three Windows that was never completed. The supervisor's vertical line on the west side of the building wall and the already finished wall surface show exactly what still remained to be finally shaped.

At the quarry at Machu Picchu you can see another dramatic example of work in progress. An unfinished stone stairway lies near the Rock of the Serpents. This stairway clearly fit into some overall design but its final destination is unknown.

UNCOMPLETED CANAL

You'll find a terrace just below the Inca Canal, as it crosses the Agricultural Sector. Here, there was to be a secondary canal. On this terrace, we encountered numerous stones, with a small trapezoidal cross section cut into them. After examining the stones, we concluded that the master stonemason cut the ends of the stones

and left them to be connected by the workers. Some, partially finished, were left when the workers abandoned the site (Figure 8). The secondary canal was meant to be smaller and narrower than the main canal, but it was never finished. Based on the location of these stones—too low to deliver water to Fountain 1—and given the small size of the canal, we deduced it was intended to lead water from the main canal, perhaps to supply another series of fountains. No one will ever know for sure.



Figure 8. The shape and character of unused channel stones that someday were to carry water to new fountains provides evidence of good civil engineering.

LANDSLIDE

Landslides damaged the agricultural sector but it has been estimated that 80 percent of this problem was corrected before construction crews left Machu Picchu. Our colleague, geologist Eric Bikis, carefully studied the prehistoric ground shifts and mapped them with a scientist's devotion to detail.

One ancient landslide, from scarp to toe, covered 140 m with a vertical drop of 66 m. This landslide damaged many terrace walls (Figure 9), displacing several by 1 to 2 meters. The full-length access stairway is intact, however, showing that it was either constructed at a later date or was completely repaired.

The landslide left a sizable section of steep slope without terraces, a relocated canal, a drainage channel to intercept runoff water, and ten partially completed terraces. By AD 1540, Inca engineers managed to stabilize the slope, but the terraces were still being repaired when the site was abandoned.

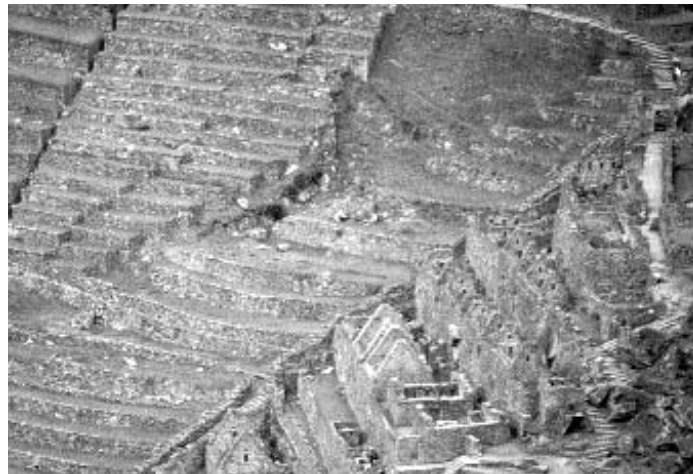


Figure 9. Evidence of the Inca landslide still remains on the agricultural terraces near the Dry Moat. The offset walls are founded on earth that slid 1 meter or more downhill. Correction of the landslide was nearly complete when the Inca left Machu Picchu.

IN A NUTSHELL

To build walls Inca engineers made use of ramps formed by stone walls filled with earth. Workers stood on platforms of stacked stone to shape and place the stones. As there is no evidence otherwise, we concluded that the Inca did not use ladders at Machu Picchu. This is why no ladders are shown in the National Geographic May 2002 map supplement. Larger stones were moved about using smaller stones underneath to reduce friction. It's our opinion that the engineers at Machu Picchu commonly employed the levering techniques described by Vince Lee (Lee 1999).

The Inca carefully fit the megalithic terrace walls to provide structural stability and present a fine appearance. Through excavations, we determined that unlike the visible front side of the terrace walls, the backside had not been smoothed but left in a rough state. Terrace walls tilt back at a 5- to 6-degree slant.

We found five Inca roof types: gable, hip, conical, shed and the wayrona (i.e., the elegant unbalanced gable form one finds on three-sided buildings) as seen in National Geographic. The Inca cut niches in the stones to support the beams. We came across several niches that were in the process of being enlarged presumably to accommodate a larger and stronger beam than called for in the original design. Throughout we found evidence of thoughtful design and crafting.

It seemed a common practice for Inca workmen to put stones in place before finally shaping the rock. Often they rotated stones upwards to allow final shaping of the bottom of the stone face. Smoothing and polishing the stones was accomplished with hammerstones of various sizes, ranging from 20- to 25-centimeter (cm) (8- to 10-inch) river cobbles down to 6-cm (2.5-inch) diameter cobbles (Figure 10). It is clear the Inca set the very large stones in place first then shaped them to predetermined building lines. Evidence for this can be found on the Temple of Three Windows and the Principal Temple. Stairways, on the other hand, seem

often to have been roughly hewn at the quarry and then moved to their final destination. And in some cases the Inca appear to have placed the lower rocks of a building temporarily in position to check the size and alignment. They were then moved away, shaped and returned for final placement.

Dozens of stones strung out in a row remain what was to have been a canal. Here, you can see a good example of the division of labor between worker and master mason—once the shape and position of the channel was established, the cutting and shaping of the individual channel stones was left to the workers.

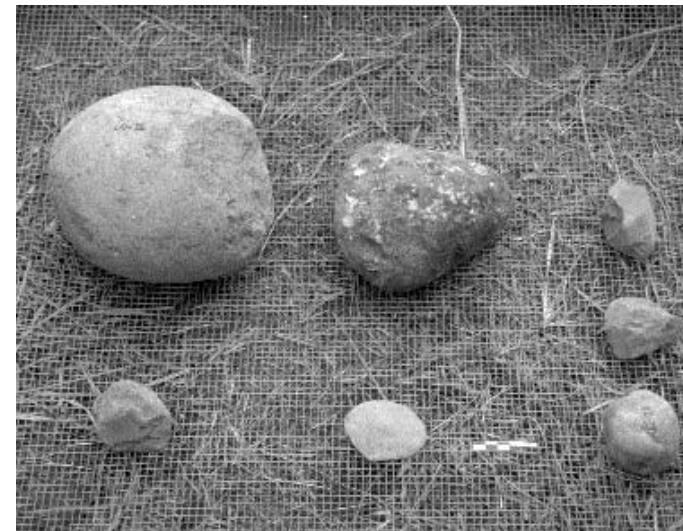
SUMMARY AND CONCLUSIONS

Our investigations convinced us that Machu Picchu was still very much a work in progress up until AD 1540, when the Inca Empire collapsed. There is no doubt that the Spanish conquest interrupted the work at Machu Picchu. Had the civil engineers finished their work, Machu Picchu would be even more attractive. Visitors would find an imposing temple, rising over the large central plaza just south of the Sacred Rock.

To achieve the vaunted precision and monumental design, Inca engineers relied heavily on building techniques seen in earlier civilizations throughout their far-flung empire. The willingness of the Inca to adopt technology from other cultures is a valuable lesson for modern engineers. The similarities in construction between Machu Picchu and other Inca projects all over the Empire provide evidence of a high level of control and coordination by a government bent on creating inspiring public works that would last for centuries.

When you next visit Machu Picchu, take time to look at the exceptional quality of the Inca engineering—you can almost see their fingerprints on their work.

Figure 10. A variety of workers' hammerstones was recovered from the 2002 wall excavation at the Unfinished Temple, the place that Hiram Bingham called the Temple of the Jagged Rocks.



References

- Kendall, A. 1973. *Everyday Life of the Incas*. New York, NY: Dorset Press.
- Lee, V. R. 1988. *The Lost Half of Inca Architecture*. A paper presented to the Annual Meeting of the Institute of Andean Studies in Berkeley, California on January 8, 1988.
- Lee, V. R. with N. G. Lee. 1999. *The Sisyphus Project: Moving Big Rocks Up Steep Hills and Into Small Places*. Paper presented to the 39th Annual Meeting of the Institute of Andean Studies, January 8, 1999, Berkeley, CA.
- Zegarra, A. Valencia. 2001. *Personal communication with author*.
- Von Hagen, A. and C. Morris. 1998. *The Cities of the Ancient Andes*. New York, NY: Thames and Hudson.
- Wright, K. R. and A. Valencia Zegarra. 2000. *Machu Picchu: A Civil Engineering Marvel*. Reston, VA: ASCE Press.
- Wright, R. M. 2001. *The Machu Picchu Guidebook*. Boulder, CO: Johnson Books.

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