Khufu and Kukulcán

Andy Ryan

The Great Pyramid of the Egyptian pharaoh Khufu, *above,* is a masterpiece of architecture and engineering—especially when one considers that the ancient Egyptians constructed it without benefit of the compass, the pulley, or the wheel. While not as celebrated as the Egyptian pyramids, those of the ancient Maya—the pyramid built in honor of Kukulcán among them, *opposite*—are testaments to their builders' remarkable skills.

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The pyramids built by the pharaohs of ancient Egypt—especially the magnificent tomb of the Fourth Dynasty's Khufu, or Cheops—have prompted extensive inquiry through the ages. Not so the pyramids erected by other ancient peoples—those of the Maya, for example. But the pyramids of the Maya—Kukulcán's among them—reveal much about the sophisticated skills of their builders. **By Craig B. Smith, P.E., and Kelly E. Parmenter**

The more than 100 pyramids that punctuate the west bank of the Nile have intrigued mankind for millennia. The earliest surviving descriptions of them were provided by the Greek historian Herodotus, who visited Egypt in the middle of the fifth century B.C. They were surveyed in detail more than 2,000 years later by the scientists and engineers who accompanied Napoleon in 1798 on his campaign in Egypt and were described in the 10-volume *La Description De L'Egypte,* published in Paris in 1809. Since then, numerous articles and books have discussed the pyramids of Egypt and the wondrous tombs, sculpture, jewelry, and artwork they secreted.

But pyramids are found in various locations in the world beyond Egypt—most notably in South America, Mesoamerica, Mesopotamia (ancient Sumer), India, and Cambodia. Is it possible that the ancient civilizations of Central America and South America, as an example, somehow came to be aware of the pyramids of the ancient Egyptians or did the Mesoamerican pyramids arise spontaneously from the culture

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A component of the restoration program of Kukulcán's pyramid—begun in the mid-1920s—was the removal of the trees and shrubs that had taken root in the nooks and crannies of the stonework.

of the Inca and subsequently from that of the Maya? We believe the latter to be the case. We have seen no convincing evidence that the methods of siting, designing, and constructing the pyramids built by the ancient Egyptians thousands of years earlier could have in any way been communicated to the Inca and the Maya. At the time the Egyptians were building their pyramids the Inca and the Maya were still nomadic hunter-gatherers who had not yet advanced to the point of establishing social and legal institutions and had not yet acquired and mastered the considerable skills necessary to erect such structures.

On the other hand, there *is* convincing evidence that communication occurred between the Inca and Maya civilizations—that wandering nomads traveled north from Peru to Central America and described to the Maya ancient pyramid mounds dating to 3500 B.C. These structures would have been contemporaneous with—or even have predated in some cases—the earliest Egyptian pyramids.

Although they are not nearly as celebrated as the Egyptian pyramids and have not received comparable scholarly attention, the extraordinary pyramids, temples, and other structures constructed by the Maya in what is now southern Mexico, Belize, Guatemala, and parts of El Salvador and Honduras are nonetheless significant from archaeological, historical, architectural, and engineering perspectives. Like the ancient Egyptians, the Maya—whose civilization dates from at least 3000 B.C. and who flourished from the fourth to the ninth century A.D.—produced extraordinary structures, had a superb command of mathematics, developed highly accurate calendars as well as an elaborate system of hieroglyphic writing, and established sophisticated and complex social and political orders.

The earliest Mesoamerican pyramids were built between 1000 and 400 B.C.—roughly 700 to 1,000 years after the pyramid-building era of the ancient Egyptians had drawn to a close. Even in their original glory, the largest Maya pyramids were dwarfed by the colossal Egyptian pyramids built at Giza and Saqqara, although some of the Maya pyramids were comparable in size to the smaller pyramids built by the Egyptian pharaohs of the Twelfth Dynasty and the Thirteenth Dynasty (1991–1650 B.C.).

Perhaps one reason why less is known about the Maya pyramids is that with the passage of time they became hidden from view. They are located in a tropical belt extending south from the Tropic of Cancer about 14 degrees in a region that, in contrast to Egypt's arid climate, enjoys abundant rainfall and sustains fast-growing jungles. Many of the Maya's structures vanished from sight as dense jungles engulfed them, and the jungles exacted a toll on the structures as seeds found their way into the nooks and crannies of the stonework and then grew as shrubs and trees. Over time, the plant growth not only concealed the structures; it also contributed greatly to their decay. Root masses dislodged large stones from the Maya's careful masonry and hastened the collapse of some portions of buildings. Further damage was inflicted by the Spanish conquistadores, who in their determination to subjugate the native population razed the temples and structures they found and burned ancient writings and other records of that civilization.

The pyramids of the ancient Egyptians and those of the Maya were constructed for entirely different purposes—another indicator that those of the Maya were not inspired by those of the Egyptians. The Egyptian pyramids were burial sites of religious significance. They were constructed to protect the mortal remains of the pharaohs, who were regarded as deities, and were designed to ensure the smooth passage of the pharaohs' spirits to the gods in the heavens. Because the Egyptians believed that the soul required nourishment in the afterlife, the design of a pyramid complex gave the pharaoh's soul access not only to food but also to clothing, a boat, and other possessions he might need. Since the pyramid was the pharaoh's tomb, completing it in advance of his death was of paramount importance. And since a number of priests and retainers remained at the complex to care for the needs of his soul, it was important for the pharaoh to make arrangements to endow his pyramid complex with a source of income.

The pyramids also stood as important symbols of the power and prestige of the pharaoh and, by extension, of the power of Egypt. The construction of Khufu's pyramid in particular was an enormous undertaking, one that required a national effort and no doubt brought unity and cohesion to the kingdom. As a large public works project, it also served to return some of the pharaoh's wealth to the economy.

The Maya pyramids, on the other hand, were constructed for ceremonial purposes, as evidenced by the placement of a temple at the top of the pyramid structure. Additionally, they were located in the center of town, often occupying a location that commanded a view of adjacent buildings and the surrounding countryside. It is clear from their location, as well as from carvings and other records, that the pyramids were used for ceremonies in which the general population took part or were at least observers.

The Great Pyramid at Giza is the best-known and largest of the pyramids constructed between the Third Dynasty and the Thirteenth Dynasty (2686–1650 B.C.) of Egypt's pharaonic age. The Great Pyramid of the pharaoh Khufu—or, as the Greeks referred to him, Cheops—was constructed during the Fourth Dynasty, about 2,550 years before the birth of Christ. Khufu reigned from 2551 to 2528 B.C.

The structural wonder that became this pharaoh's legacy to the world is nothing short of astonishing. The square base of the pyramid, which is approximately 230 m on a side, covers an area of 53,000 m^2; its volume is 2.59 million m^3. Originally the pyramid was 146.6 m high, but the topmost 8 m has been lost to time.

The interior of Khufu's great tomb is architecturally quite complex. The principal internal structures include the Descending Corridor, the Lower Chamber, the Ascending Corridor, the Queen's Chamber, the Grand Gallery, and the King's Chamber. Each of these structures posed considerable construction challenges. Upon entering the Descending Corridor, one can see the joints in the masonry used to frame the passageway, which is composed of blocks roughly 1.5 m long and 1.2 m high forming the walls and ceiling. The upper portion was clearly constructed as the pyramid was being built. The aboveground portion of the tunnel rises through the body of the pyramid and emerges from the north face at a vertical elevation of around 17 m, or at course 19 (see cross-sectional illustration on page 42). About one-third of the way down, the corridor branches upward, leading to the Queen's Chamber and the King's Chamber, high up in the center of the pyramid, while the passageway continues downward. Below the surface, the corridor becomes horizontal, terminating after a short distance in the Lower Chamber. This corridor—a little more than 1 m wide—is only 1.26 m high and is decidedly uncomfortable to descend. While the stonecutters labored underground, construction would have proceeded on the surface, allowing for the removal of the miners' debris from below.

The unfinished state of the Lower Chamber indicates that for some reason the construction plans changed. The chamber was hewn from bedrock in a rectangular shape, but one area is unfinished. Channels are evident in one corner, made in preparation for the hewing out of additional blocks of stone to enlarge the chamber. An Egyptian stonemason stood in this narrow channel, one foot in front of the other, and hacked at the limestone with a mattock or hammer and a copper chisel. After cutting a channel approximately 15 cm wide and 1 m deep on three sides of a block, the masons would insert levers and break out a piece of stone. This piece would then have to be further broken down to a size that could be laboriously maneuvered up the Descending Corridor. The most difficult part must have been the initial cut at the ceiling line. There, the mason had to lie on his stomach in a narrow groove, working his tools horizontally, chips and limestone dust dropping in front of his face. Looking at the tool marks and rough cuts that remain, one can only marvel at the fortitude of the stonecutters who performed this hard, dusty work in an area with little light and less ventilation.

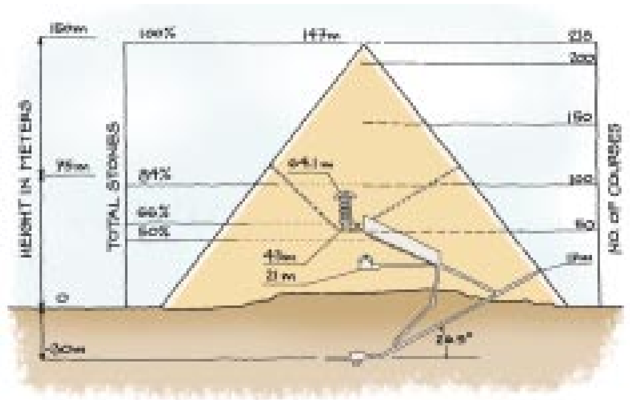
Some features of the Lower Chamber suggest it was planned to be somewhat complex. There is an unfinished recess in the west wall, as well as a pit in the floor. From the south wall a small, cramped tunnel extends some 5 or 6 m horizontally to a dead end. Was the Lower Chamber originally intended as the burial chamber? Or was it intended to serve some other purpose? The answer may never be known for certain. What is known is that the ancient stonecutters laboriously removed approximately 430 m^3 of rock to create the chamber. To minimize the removal of this rubble—or, more precisely, the backbreaking labor it required—the material was probably used as fill in the lower layers of the pyramid.

Above ground, the masons worked to complete and level the foundation platform and then began laying the first few courses of stone. At some point the Lower Chamber was abandoned, and the decision was made to build a chamber for the pharaoh's final resting place above ground in the upper portion of the pyramid. Using the Descending Corridor as a point of departure, the Ascending Corridor was constructed, rising to the center of the lower portion of the pyramid. As reported by I.E.S. Edwards in his book *The Pyramids of Egypt* (Penguin Books: Baltimore, 1993), a hole was cut in the roof of the Descending Corridor at a point about 28 m from the outside entrance, giving access to a corridor rising at an angle of 26.2 degrees. The lower portion of the Ascending Corridor is framed with special stones ("girdle stones") placed every 5.2 m. The 39 m long Ascending Corridor rises to a height of around 21 m (corresponding to course number 23) and then becomes horizontal before reaching a point midway between the north and south sides of the pyramid. Here another chamber was constructed, known today as the Queen's Chamber. Access to the Ascending Corridor is now obtained by means of a passageway constructed using the tunnel opened by the grave robbers who first gained access to the pyramid. Continuing down this passageway, one enters the Ascending Corridor at a point past the blocking plugs that once sealed the entrance to the tomb.

The Queen's Chamber is a misnomer; this chamber was most likely intended for Khufu. (It was mistakenly given its name centuries ago by Arab explorers.) The room itself is 5.75 by 5.23 m and features a vaulted ceiling that rises to a height of 6.22 m. The roof of the Queen's Chamber incorporates 6 large beams on each side, for a total of 12 beams that form a V-shaped ceiling—technically a pointed saddle roof. The walls and ceiling have tight joints and a fine finish. On the east wall is a recessed alcove with a corbeled ceiling, which might have been intended for a statue of Khufu. The alcove has a depth of about 1 m and is framed in blocks that are approximately 1 m in height. There are two such blocks, one on top of the other, forming the vertical sides of the alcove, the next four blocks being offset about 13 cm toward the center to form the corbeled ceiling. In this manner the width of the alcove, which is 1.6 m at the lower portion, decreases to approximately 0.5 m at the top. The floor is in a rough condition, indicating that this chamber was never finished.

Above the Queen's Chamber is a large gallery that is basically an extension of the Ascending Corridor but can be entered without stooping. This is called the Grand Gallery and is a truly spectacular example of stonemasonry. In cross section

Cross-sectional View of the Great Pyramid



it resembles the Queen's Chamber alcove, but on a much larger scale. The vertical walls rise about 2 m, while the width at the base is also about 2 m. It is noteworthy that this is close to 4 cubits by 4 cubits. (The cubit was a unit of measurement used by the ancient Egyptians that was the equivalent of 52.4 cm.) At the foot of each vertical wall is a stone curb that extends 50 cm, or roughly 1 cubit, into the passageway. Within the passageway is a series of regular notches—27 in all—cut into the stone. The purpose of these is not known, but their appearance suggests they once held some sort of scaffold or wooden support structure, possibly to aid in construction or to hoist the plug blocks. In the depressed center space between the two curbs, there is now a wooden walkway fitted with steps and handrails for the convenience of visitors. Above the vertical walls are seven steps to the corbeled ceiling. The overall height is 8.6 m and the total length of the gallery is 46.1 m. The corbeled ceiling does not meet at the top of the Grand Gallery. Instead, it is bridged by roofing slabs, with a clear span of 2 cubits, matching the distance between curbs on the floor.

The Grand Gallery features one of the most remarkable examples of the ancient Egyptians' skill with corbeled ceilings, but this space has several other interesting elements. In addition to the flat curbs or ramps running along each sidewall for the entire length, there are niches and slots cut into the walls. The exact purpose of these is not known, but one can surmise that in part they were cut so that the Ascending Corridor could be sealed after the pharaoh's body had been laid to rest. Various theories have been advanced to explain how the three granite plugs that seal the Ascending Corridor could have been pulled up into the Grand Gallery for storage. A wooden structure could have been placed over them so that the funeral procession could progress through the Grand Gallery. After the interment ceremony, workers could have released the plugs from behind, sealing the entrance. The workers would then have exited the pyramid through the vertical shaft that connects the end of the Ascending Corridor (just before the entrance to the Grand Gallery) to the Descending Corridor. Then, as the final step, the entrance to the Descending Corridor would have been sealed and the final casing stones put in place to cover and conceal the entrance.

Site Plan of Giza

Kurt Mueller, both

At the end of the Grand Gallery is a short horizontal passage leading into the King's Chamber that is entered through a small opening. A portion of this is constructed of red granite. Here we find an antechamber—or, more properly, a portcullis—that appears to have been designed in such a way that the chamber could be sealed by the blocks of granite that would have been slid into place following the pharaoh's burial. There are four sets of slots in the sidewalls of this room, and clearance overhead, so heavy slabs of granite could have been slid in from above (before the roof was placed) and propped up on supports in some manner. After the pharaoh's remains had been placed in the sarcophagus, the supports would have been removed and the slabs lowered by ropes, effectively blocking access to the King's Chamber.

The King's Chamber was intended as the final resting place for Pharaoh Khufu. Entrance is gained through a small opening, roughly 1 m wide by 1 m high. A granite sarcophagus is situated near the west wall. One corner is damaged, possibly by grave robbers who entered the pyramid and pried off the lid. The sarcophagus is wider than the Ascending Corridor, indicating that it was placed in the chamber and the walls erected around it. The chamber is constructed of red granite, its walls rough polished. Internally it is 5.23 m wide, 10.5 m long, and 5.8 m high. The walls are five courses high, a course being a little more than 1 m. The ceiling is flat and is constructed of nine massive granite beams, each weighing 40 Mg or more.

Above the roof is a structural feature unique to Khufu's pyramid that has not been observed in any of the earlier pyramids: a series of compartments, one above the other, that act to relieve the load on the roof of the King's Chamber. There are five in all, the uppermost distinguished by a pointed saddle roof. Exploration of these chambers shows that the rough limestone walls still bear the red ocher quarry marks that guided the masons who cut them. There are also graffiti left by gangs of workmen that make reference to Khufu.

Orientation was an important component of Egyptian pyramid design. The typical approach was to align the axes of the pyramid with the cardinal directions of east-west and north-south. Initially, the entrances were always on the north side. While various theories have been advanced as to the significance of the angle of inclination of the corridors that the pharaoh's soul would use to communicate with the gods, it is more likely that the angle was dictated by construction and ease of access for workers.

Chichén Itzá is one of the best-known Maya sites because of its proximity to Cancún and because of the extensive restoration work undertaken there by the Mexican government and various international groups (including the Carnegie Foundation) over the past 100 years. The site, illustrated on page 45, consists of Kukulcán's pyramid (also referred to by the name the Spaniards gave it: El Castillo, "The Castle"), as well as a large Maya sports arena, various temples, palaces, a market, and other structures.

In his book *An Overview of the Mayan World* (Mérida, Mexico: Estigia Press, 2002), Gualberto Zapata Alonzo reported that there are indications that the pyramid at Chichén Itzá was built during the reign of a chieftain by the name of Quetzalcóatl, which means "bird-serpent" or "plumed serpent" in the language of the Nahua, an early Maya people. The Maya translated the chieftain's name into their own language, calling him Kumkumcān. The name was misunderstood to be Cuculcān, and then over time became Kukulcán, the name used today.

Some ancient records refer to a leader called Itzamna—later deified—who is believed to have guided the Maya to Chichén Itzá. "Chichén" translates as "mouth of the well" and "Itzá" is the name of the ancient Maya who developed the site, so the name can be translated as "Mouth of the Well of Itzá." The real development of the site was begun by the Itzás around 500 A.D., but it is believed that the site was occupied earlier by nomadic tribes who were attracted to the site by the water supply.

The wells at Chichén Itzá are actually large limestone sinkholes—known in Spanish as *cenotes* (underground pools)—and they are one of the singular aspects of the site. The Yucatán peninsula is underlain by limestone and evidently rose from the sea in ancient times. There are few rivers, and the cenotes, which dot the countryside, are the principal sources of water.

There are two cenotes at Chichén Itzá—one on the north side of the site, the sacrificial cenote**,** and the other on the south side, known as the Xtoloc Cenote, which provided the city with water. The sacrificial cenote is about 60 m in diameter, with a distance from ground level down to the water surface of 15 to 20 m and a water depth about 20 m in the center. It is reputedly the site where young virgins were sacrificed to the rain god, Yum Chaac. Excavations begun in the early 1900s revealed numerous offerings—incense, ceramics, gold jewelry, gold and copper bells, human female and other skeletal remains, and other artifacts—that seem to confirm the sacrificial cenote's use.

The Itzás occupied the site during two periods. The first ended in 692 A.D., when for reasons unknown they abandoned the site. Around 950 A.D. they returned and stayed until 1200 A.D., when the site was again abandoned. (The Spanish conquistadores first visited the site in 1541 A.D.) During the second period of occupancy there is a notable difference in the architecture, the later structures decidedly influenced by the Toltecs.

The pyramid of Kukulcán is actually two pyramids—a large pyramid built over a smaller, earlier structure. In the early 1900s the pyramid was in a state of disrepair. Part of the roof of the temple at the top of the pyramid had collapsed; many of the exterior stones had fallen off; the exterior stairsteps were severely damaged; and sections of the masonry at the corners were eroded. The structure was covered with vegetation, including trees growing from the stonework (see photograph on page xx). Between 1924 and 1944 much of Chichén Itzá was cleared and the pyramid was partially reconstructed. In particular, the north and west sides were restored, making use of the stones that had fallen to the ground and were scattered about the base of the pyramid. The east and south faces have been only partially restored. The photograph on page 39 provides a view of the east face as it appears today.

Kukulcán's pyramid is essentially a nine-step structure culminating in a flat platform that supports a two-story temple. The height to the top platform is 24 m, the temple adding another 6 m. Therefore, Kukulcán's pyramid is roughly one-sixth the height of Khufu's. The orientation of the pyramid is approximately 17 degrees east of magnetic north, in an area where the declination is approximately 2 degrees east, so the actual orientation is around 19 degrees east of true north. Several other major structures on the site are oriented in approximately the same way.

Each of the four faces incorporates a broad, steep staircase consisting of 91 steps that ascends to the top platform. Counting the top platform as an additional step gives a total of 365 steps—1 for each day of the year. The staircases rise at an angle of 45 degrees to the horizontal, while the average inclination of the stepped pyramid itself is 53.3 degrees, slightly greater than that of Khufu's pyramid. The faces of the individual steps are sloped at a greater angle, approximately 73 degrees (see photograph on page 49). The temple at the top of the pyramid is 6 m high, 13.4 m wide, and 16.5 m long.

The exterior casing stones are irregular in size but are carefully cut and fitted. An important distinction between the Egyptian pyramids and Kukulcán's pyramid is that the corners of Kukulcán are rounded (see photograph on page 46). In general, the Maya used much smaller stones than the Egyptians. Typically their building blocks were 35 cm high, 45 cm long, and 20 cm thick, and many were even smaller, say, 25 by 25 by 20 cm. Behind the exterior casing stones the construction appears to consist of stones of an irregular shape that were not carefully cut or fitted, the crevices and interstitial spaces filled with rubble and a lime mortar (see photograph on page 47).

We developed a mathematical model to estimate the number of stones used in the construction of this pyramid. For the purposes of this model we first assumed that the pyramid is solid and, based on observations we made at the site, that the stones are uniform 30 cm cubes. This analysis indicated that the pyramid contains 1.3 million stones, not including the stones of the four staircases or the temple at the top of the pyramid. However, we know that it is not solid, as the pyramid contains hollow spaces owing to the internal temple on top of the smaller internal pyramid and the internal stairway leading up to the internal temple. When we deduct the void spaces and add the exterior staircases and temple, we arrive at a total of around 1.5 million stones. These are not packed uniformly, however, as the interstitial spaces are filled with rubble and mortar, as can be noted in the photograph. Estimating that the packing factor for these interstitial stones is 80 percent, the net number of stones needed to build the pyramid is on the order of 1.2 million, or about half that required for Khufu's pyramid, the difference being that the stones used by the Maya were much smaller.

Since El Castillo was constructed around an existing pyramid with an estimated volume of 9,000 m^3, the actual number of additional stones required was only about 78 percent of the above number, or around 940,000 stones.

Given the size of the stones (assuming limestone with a specific weight of 2,200 kg/m^3), the weight of the stones would be in the range of 50 to 100 kg. Since the interior stones are even smaller, it would appear that it was possible for laborers to carry them up the external staircase and place them on the course currently being constructed. The larger stones observed at the site are used as lintels over doorways or windows. The large blocks used for carving figures could weigh as much as 5 Mg.

The temple consists of several rooms supported by massive walls. The north face incorporates three openings framed by massive stone columns, and the east and west faces each have a single door. The roof of the temple includes the remains of a decorative roof comb.

Originally there were no external openings, and it was thought that the pyramid was solid. In 1931, however, archaeologists made an opening in the south side and discovered that Kukulcán had been constructed over an older, smaller pyramid. Subsequently a tunnel was dug under the north steps. It extended east about 6.5 m to the centerline of the pyramid and then turned south and continued an additional 6 or 7 m. Here a wide descending stairway was encountered. At its base, the archaeologists discovered a stone box containing jade jewelry, two flint daggers, and other artifacts, and nearby a human skeleton was found. A passageway up the old staircase was cleared and framed in stone to provide access. At the top of the staircase is a small temple that had been filled with stone at the time the larger pyramid was constructed on top of it. When the inner temple was cleared, it was found to contain two rooms. One was found to contain a *chacmol* (a type of reclining idol), and the other a statue of a jaguar. The latter is beautiful figure, about 1 m long, carved from solid stone and painted red. It is embellished with flint teeth and jade eyes, and the spots on its body are inlaid jade.

To reach the inner temple, one climbs a steep, narrow staircase barely large enough for the passage of a single person. At the top landing, the platform is equally confined, providing room for two or three persons to the left of the stairs and an equal number to the right to peer into the temple chambers. There are 62 stairs to the top platform, suggesting that the inner pyramid is approximately two-thirds the height of the finished pyramid.

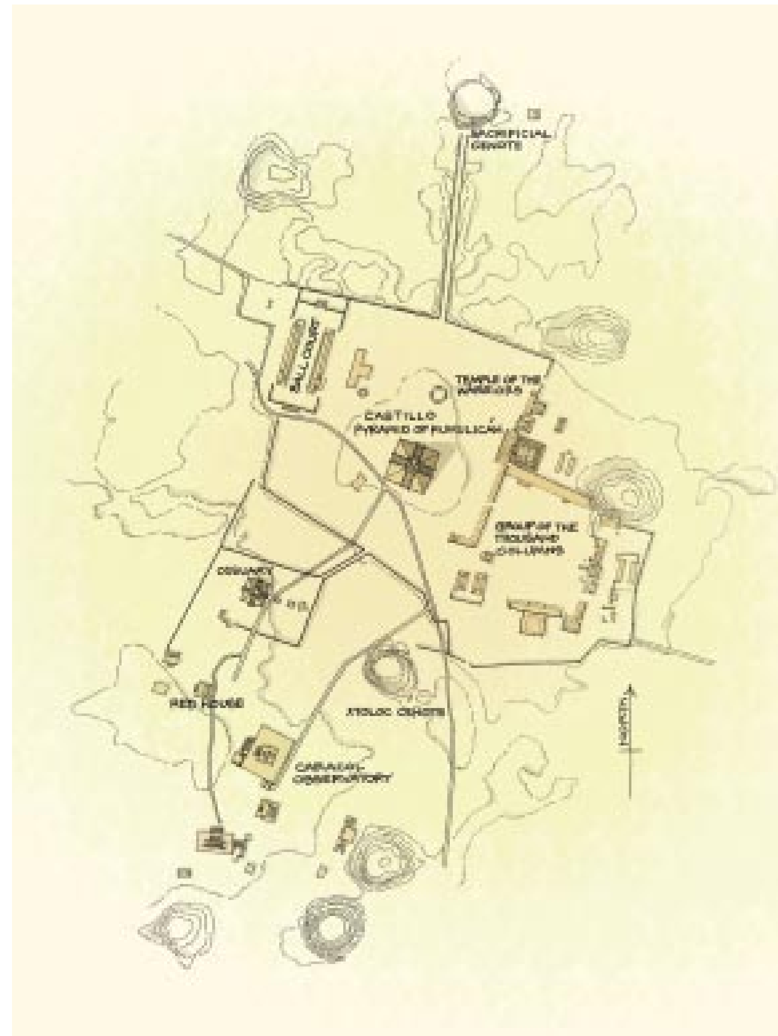
Initially it was thought that the Maya pyramids did not serve as tombs, but recent explorations have identified burial sites within some of them. It does not seem likely, however, that they were constructed solely for this purpose. Their location in villages suggests that they played a role in day-to-day life for ceremonies and other functions. Also, they appear to have had an astronomical purpose, possibly related to predicting the seasons for planting and harvesting crops and marking other important dates.

The orientation of the Maya pyramids seems to have assumed greater significance than that of the Egyptian pyramids. There is no uniform approach among the Maya pyramids, and they are not necessarily oriented in the cardinal directions. However, their orientation suggests an important astronomical significance in that they denote the summer and winter solstices and the equinox, as well as other planetary phenomena. Clearly the Maya were astute astronomers capable of predicting celestial events and keeping records of solar eclipses and other events.

It is evident from their calendars and other records of astronomical phenomenon that the Maya had studied the sky and the movements of planets and stars and that they used that information in deciding when to plant and when to harvest the crops on which they depended. Observations from beneath the leafy canopy of the jungle on the flat Yucatán peninsula must have been difficult, so it would have been logical to construct an observation post that would rise above the surrounding terrain. For these skilled builders, a stepped pyramid would be the easiest and most accessible structure to construct.

Kukulcán's pyramid is notable for the fact that at the spring and fall equinoxes (March 21 and September 22) the sun projects an undulating pattern of light on the northern stairway for a few hours in the late afternoon—a pattern caused by the angle of the sun and the edge of the nine steps that define the pyramid's construction. These triangles of light link up with the massive stone carvings of snake heads at the base of the stairs, suggesting a massive serpent snaking down the structure. Additionally, when one looks at the western face during the winter solstice, the sun appears to climb up the edge of the staircase until it rests momentarily directly above the temple before beginning its descent down the other side.

Site Plan of Chichén Itzá



Kurt Mueller

The Egyptians and the Maya both exhibited sophisticated design and construction skills. The Egyptians, in particular, possessed a highly developed ability to plan, design, and execute complex projects; it is otherwise inconceivable that a construction project on the scale of Khufu's pyramid could have been undertaken in the middle of the desert. However, little evidence has been discovered of the details underlying the design process; this evidence takes the form of some small-scale stone models of pyramids, some sketches on remnants of limestone, and a few drawings on papyrus.

The Egyptians well understood the concept of scale drawings, as evidenced by unfinished tomb paintings in which the artists have constructed a square grid pattern to help establish the scale of the work and to assist in laying out the figures portrayed in the drawings. Construction lines cut into the limestone at Giza that survive to this day indicate the dimensions of the blocks the stonemasons were to cut. There are also surviving construction lines produced with red paint. These indicate horizontal alignment, leveling, and centerlines for the builders.

Knowledge of mathematics in ancient Egypt was by no means superficial, and we know that the Egyptians could calculate areas, angles, and volumes. In fact, records of such calculations have survived from later periods. One example is the *Rhind Papyrus,* which describes a series of arithmetic and geometry calculations. The mathematical abilities of the Egyptians enabled them to carry out the accurate dimensioning and layout of large structures. They could calculate the weight of large objects and structures and determine the number of blocks required for a sloping embankment. They used a decimal system and had symbols denoting, for example, 1, 10, and 100 cubits, and they had developed methods for multiplying and dividing. Division was accomplished by breaking quotients into a series of sums of fractions, a method that was approximate but gave results accurate enough for practical purposes. The concepts of squaring and finding a square root were known to them. They had an approximate method of determining the area of a circle, which was to subtract one-ninth of the diameter and square the remainder, resulting in the formula $A = (8D/9)^2$. This is equivalent to giving p (pi) a value of 3.16 rather than 3.14. The Egyptians also knew how to calculate the volumes of cylinders and pyramids. Among the more sophisticated calculations within the ken of the ancient Egyptians that would have been of use to the pyramid builders was that for determining the volume of a truncated pyramid.

The Egyptians developed measuring instruments as early as the First Dynasty (3050 to 2890 B.C.). The basic measuring instrument was the cubit rod, the cubit being the length of the pharaoh's arm from his elbow to the tip of his fingers. During the Fourth Dynasty the cubit was approximately 52.4 cm. Cubit rods from various dynasties have been found, and the length of each varies slightly, so it would appear that there was no absolute standard.

The cubit is further subdivided into 7 palms, each having 4 digits—a digit being the width of the pharaoh's finger, about 1.88 cm. The digit was further subdivided into eighths, tenths, et cetera, to provide a very accurate smaller scale. For surveying and quarry work, longer rods were available, from 3 to 10 cubits. For still greater distances, a system of "rods and chains" was used, although the chain was actually a woven rope calibrated with knots or marks and cut to a precise length—probably 1 *khet,* the *khet* being equivalent to 100 cubits. One common unit of area, a *stat,* was equal to 100 by 100 cubits. Systems for measuring angles were known, since the slope of the pyramid was controlled very accurately, as were the rise and decline of the ascending and descending tunnels within the pyramid.

Measurement tools also included the square level, used for leveling horizontal surfaces. It was based on the shape of the English letter *A* and consisted of a plumb bob hanging down from the apex. When the surface was level, the plumb bob would be directly in the center of the cross bar on the *A*. A plumb bob could also be used to create a vertical level. We also know that the Egyptians had a square, or a means of making a right angle. Most likely this was developed from the principle of a "3-4-5" triangle. A triangle constructed with its sides in these proportions will contain a 90-degree angle.

Egyptian techniques for surveying were based on the use of the square level and a knotted cord for measuring length. It is also possible that the Egyptians used wooden rods 3 cubits in length or greater. The ancient Egyptians were able to level a site with precision and could lay out the base of a large structure quite accurately. There is very good evidence at Giza of the high level of skill possessed: the dimensioning and leveling of the site are perfectly comparable to what could be achieved by modern methods.

An important distinction between the Egyptian pyramids and Kukulcán's pyramid is that the corners of the structure built by the Maya are rounded.

Craig B. Smith

In addition to achieving precision in leveling, alignment, and measurement, the ancient Egyptians were skilled at accurate orientation. This is confirmed by the fact that the axes of the primary pyramids at Giza—those of Khufu, his son Khafre, and his grandson Menkaure—are closely aligned not only with one another but also with the points of the compass—that is, north-south and east-west. Since the compass had not yet been invented, there are two ways this could have been accomplished: by celestial sightings, using a circumpolar star, or by sighting on the sun.

By the Fourth Dynasty, which commenced in 2613 B.C., Egyptian stonemasons had perfected the art of cutting and finishing stone. While they worked with several different materials, they preferred limestone for the massive pyramid structures because it was readily available and was soft enough to work easily. By trial and error they came to understand the load-bearing capacity and strength limitations of limestone, and so they knew when it was necessary to use a stronger material, such as granite. They had also developed techniques for making mud bricks and gypsum mortar, although the mortar used at Giza does not appear to have been of a very high quality. Wood was another building material used but was not available in large quantities; special types of wood were imported from elsewhere. Skill at woodworking during the Fourth Dynasty is clearly evident from the boats found in Khufu's pyramid, as well as from other artifacts and tomb paintings. The ancient Egyptians also had the ability to make rope from local vegetation; this is evident from the rigging on the boats and from tomb paintings. Ropes of various diameters were made, some with a working strength of 11,000 N.

Metals were limited and consisted primarily of copper and gold. Copper could be worked into tools but was generally

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Behind the exterior casing stones the construction of Kukulcán appears to consist of stones of an irregular shape that were not carefully cut or fitted, the crevices and interstitial spaces filled with rubble and lime mortar.

relatively soft. While there is speculation that the Egyptians knew how to temper or harden copper by subjecting it to heating and hammering, no solid evidence has been found to confirm this. Modern excavations at Giza have found remnants of copper and even the hearths or kilns used to process the metal into tools.

The ancient Egyptians had a wide variety of tools at their disposal. Laborers used tools resembling mattocks or hoes for digging and used woven reed baskets for hauling dirt and debris. Stonemasons used saws, drills, wooden mallets, wedges, wooden rollers, stone hammers, copper chisels, and smooth round balls of diorite, a very hard stone used to cut blocks of granite by chipping it away, one flake at a time. Carpenters had mallets, hammers, drills, chisels, scrapers, planes, and copper saws at their disposal. Many tools have been found at pyramid sites, and they are now on display in Cairo at the Egyptian Museum and in other institutions around the world.

To transport stone they used sailing vessels and barges—some with capacities of at least 100 Mg and perhaps as much as 1,000 Mg. For larger loads, it is likely that rafts made of logs were assembled. Imported lumber was rafted to Egypt from Lebanon, so this concept would have been known. No wheels were known to exist during the Fourth Dynasty. The builders did not have the use of wheels or pulleys for moving or lifting loads. Instead, blocks of stone were levered onto wooden sledges and then dragged to the construction site by teams of laborers. Wooden levers were used to move loads over short distances, but for longer hauls it was necessary to construct ramps to bring blocks of stone up to the higher levels of the structure. Alternatively, stones could be "tumbled," or rolled, for short distances by pulling on them with a rope harness while another laborer used a lever to raise the rear of the stone. For stone placement, a block could be set on a round diorite stone (much like a ball bearing) and maneuvered into place. For placing very large backing stones, raised bosses were left on the base for levering, and notches for levers were cut in the foundation platform or adjacent stones. These were later filled in or covered.

Like the Egyptians, the Mesoamerica Maya were highly adept at planning, designing, and executing large public works projects. The siting of their cities and structures, however, was dictated by different considerations. The main concern was the availability of water. As to design, little has been discovered through the ages that can help us understand how the Maya planned their structures.

The Maya did, however, have an advanced numbering system with a base of 20 (a vigesimal system, as opposed to a decimal system). They are credited with discovering the concept of zero as well. The Maya had various ways of representing numbers; in the simplest, 0 was denoted by a tortoise shell, 1 by a dot, and 5 by a bar (—). Other numbers were written as combinations of these three symbols. They also used different hieroglyphics to represent numbers. They could perform all of the basic arithmetic operations (multiplication, division, addition, subtraction, squaring, and finding the square root).

The Maya also developed an accurate calendar and knew that the year had 365.24 days. Their systems for keeping track of dates evolved, and they employed several different calendars, including one that was based on the day rather than the year.

The Maya made paper from the bark of trees, and archaeologists have found various codices—articles written in hieroglyphics with drawings—that escaped burning by the Spanish. The codices deal with astronomy, history, food, agriculture, and war.

To build the structures that we see today, the Maya had to have developed an accurate system of measurement as well as the ability to survey. However, little has been discovered on how they calculated measurements or what their units of measurement were. In their article "An Ancient Maya Measurement System," which appeared in the January 1986 issue of *American Antiquity,* Patricia J. O'Brien and Hanne Christiansen provide an overview of what is known about the Maya measurement system. They also report that they collected measurements of principal dimensions from 10 buildings at three ancient Maya sites, including Chichén Itzá. By looking at common as-built dimensions, it is possible to speculate what a standard unit of measurement might have been. This research yielded 1.47 m ± 5 cm, which the authors called a *zapal*. They postulated that that unit was divided into 16 smaller units, called *kab,* and that each of those in turn comprised 9 even smaller units, the *xóot*. Thus 144 *xóot* make up a *zapal,* the *xóot* being equivalent to 1.02 cm. The authors explain that *zapal* is the Yucatán Maya term for the distance between extended arms. Even today, Guatemalan Indians from Maya areas use a measure called a *haah,* which is the distance between outstretched hands. This is approximately 1.5 m for a person of moderate stature.

To test this hypothesis, we took a number of the principal dimensions of Kukulcán's pyramid and converted them into *zapal* equivalents. The results are seen in the following table:

Width	Meters	*Zapal* equivalent	Conversion factor
Top	19.52	13	1.50
Base	55.3	37	1.49
Temple	13.42	9	1.49
Stairs	8.85	6	1.48

Given that our field measurements were rough (probably with an uncertainty of ± 2 cm) and that Kukulcán has been restored and the original dimensions may not be faithfully represented, these results are intriguing, particularly as it is known that the numbers 9 and 13 held significance for the Maya, 13 being associated with the levels of paradise and 9 referring to the levels of the underworld.

Our literature search found one other piece of circumstantial evidence. Excavations of Maya ruins in Guatemala uncovered a plaster floor inscribed with perpendicular lines that run roughly east-west and north-south. As described in the work edited by Ray T. Matheny in 1980 ("El Mirador, Peten, Guatemala—An Interim Report," *New World Archaeological Foundation Paper No. 45* [Provo, Utah: Brigham Young University]), there are three lines that are approximately 0.7 m apart (1.4 m overall) and then two more that are approximately 1.4 m apart. The purpose of these lines is unknown, but the fact that the spacing is close to the *zapal* is curious. The entire question of the Maya system of measurements is a subject that requires further research.

From the roads built by the Maya and the level terraces on the pyramids, as well as from the right angles and level floors in their structures, it is apparent that they must have had a means of leveling and controlling angles and slopes. Surveying was probably done with a system of cords, canes, or rods, as some of the ancient writings make reference to land surveyors carrying what translates as "walk sticks."

Clearly, the Maya were skilled at orientation and had the ability to combine astronomical observations and predictions with siting decisions for major structures. It is also possible that this was done on a trial-and-error basis by establishing reference benchmarks and observing them for an appropriate period of time.

The tools used by Maya builders were similar to those used by the ancient Egyptians. Neither had iron tools and instead used such hard stones as flint, jade, diorite, basalt, and serpentine to make axes, knives, and chisels. Examples can be seen in several museums. Numerous stone tools have been recovered and studied. They include a mason's kit with various shapes for cutting limestone and finishing masonry work and mortar; a plumb bob fastened from limestone; and tools for cutting, scraping, chiseling, planing, and sawing wood. At first it was thought that the Maya did not have copper tools. However, in 1926 Edward H. Thompson described a number of copper chisels that were recovered from the sacrificial cenote at Chichén Itzá, so the Maya clearly had this technology, although it is not known whether copper tools were available at the time Kukulcán's pyramid was built.

The chief building material of the Maya was limestone. As in Egypt, limestone was readily available almost everywhere in Yucatán, so it was not necessary to transport stone any great distance. The Chichén Itzá site is dotted with excavations, presumably locations where limestone was quarried for the various structures. One difference between the Maya and the Egyptians was that the Maya had ample wood, including some very durable hardwoods that they used as structural members in temples and other buildings. One of those woods, chicozapote (sapodilla), was frequently used for lintels over doorways. An example can be seen in the temple at the top of Kukulcán's pyramid.

Like the Egyptians of the Fourth Dynasty, the Maya did not have the wheel and did not make use of draft animals; they relied on human labor for transport. However, at the Chichén Itzá site, one can see large stone rollers that may have been used as rollers or graders in road building and site preparation.

The Maya developed a lime-based mortar that appears to be superior to anything the ancient Egyptians had. This was made by burning limestone in wood-fired kilns to produce lime. The mortar was made by combining one part lime with three parts of a white soil called *sahcab* (which was mined in certain locations) and then mixing the combination with water until the desired consistency was obtained.

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The faces of the individual steps of Kukulcán are sloped at an angle of approximately 73 degrees. Note the serpent's head at the base of the stairs.

When one considers the fact that the ancient Egyptians had no pulleys, wheels, or iron tools, the logistic challenges they overcame in building the immense structures that command the Giza site are nothing short of staggering. Large blocks of limestone and granite—some weighing as much as 50 Mg—had to be cut at the quarry established at the site or, in some instances, at distant quarries. The local limestone was then transported from the quarry to the Giza plateau. After the masons cut and trimmed the stone, it was levered onto a wooden sledge and dragged up a sloping earthen ramp to the work site. Examples of such sledges can be seen today in Cairo's Egyptian Museum. The stones from distant quarries had to be brought to the shore of the Nile and transported across or down the river by boat to the site. The rock used to construct the pyramid core was carved from a quarry at the site (located in the area that today is situated between the Great Sphinx and the pyramid) but the white limestone used as the exterior casing of the pyramid came from a site called Turah, across the Nile River. Even today, limestone is produced in the Turah area.

The builders of Khufu's pyramid waited until the flooding of the Nile—the annual inundation that took place from July through October—taking advantage of floodplains that brought water to within about a quarter of a mile of the site to transport materials. Blocks of limestone weighing anywhere from 1 to 5 Mg made up the bulk of the construction of the pyramid. A little more than 2 million such blocks were used in the construction. These were cut from the quarry at Giza, near the pyramid site. In addition, approximately 100,000 blocks of the white Turah limestone facing blocks—the blocks used to impart a dazzling white finish to the pyramid's faces—were added to complete the construction.

Egyptian workmen perfected the technique of using stone axes and hand-driven copper chisels or drills to cut slots or holes in the stone faces. After a slot (just wide enough to accommodate a man standing sideways) had been chiseled out along each side of a block, holes were cut at the bottom edge. Wedges were then inserted into these holes and the block of stone was broken loose by pounding on the wedges with mallets. These rough blocks were subsequently dressed down to finished dimensions. On the exterior faces of the pyramid the final dimensions of these stones were extremely accurate, so joints could be made that were less than 1 mm—in some cases less than 0.50 mm. Less care was taken with the interior blocks; gaps in the masonry there were filled with chips, rubble, small stones, or mortar.

The pyramid was oriented with its major sides either north-south or east-west. This in itself was a remarkable undertaking given the accuracy to which it was executed, as the ancient Egyptians had to perform the work using astronomical observations.

There is considerable evidence supporting the use of an inclined ramp or series of ramps as the means of elevating the blocks. We know that sloping ramps were used in the construction of other pyramids, and the remains of construction ramps can be seen at several sites in Egypt. But it is unlikely the Egyptians built a single ramp because constructing a ramp that would reach to the top of the pyramid would have involved constructing a structure nearly 1 km long and containing more material than the pyramid itself. It is likely that they built a series of ramps, some supported off of the pyramid structure itself.

After the site had been leveled, an initial course of blocks was placed to outline the base of the pyramid. This placement was executed with extreme care because it formed a reference point for the other dimensions as construction proceeded. At this point construction of the Descending Corridor began, and openings were left for the Ascending *(continued on page 79)* *(continued from page 49)* Corridor, which would provide access to the chambers within the pyramid itself.

As construction reached the level of the horizontal corridor that leads to the Queen's Chamber, those spaces were undoubtedly built in place, slightly ahead of the rising terraces of the pyramid. Thus it was possible for the workmen to install the finely dressed walls, lintels, and ceiling blocks of the corridors and chambers from a level surface and then build the rest of the pyramid up around them as construction proceeded. As to the construction of the chambers, a logical approach would have been to erect the pyramid to the elevation level with the floor of the Queen's Chamber (approximately course number 23). The walls would have been erected, the chamber backfilled with sand, the ceiling beams put in place, and the sand then removed. This approach would have provided a flat working surface for maneuvering and placing the large granite roof beams and other heavy stones. A similar approach was used to construct the King's Chamber and the Relieving Chambers above it. From this level on to the apex of the pyramid, it was then simply a matter of piling up more blocks.

A striking feature of Khufu's pyramid is that the height of the courses of masonry in the pyramid is not uniform. As the builders proceeded upward, the height of the exterior casing stones decreased. Course 0 is the 1 cubit thick base platform, which was carefully measured and prepared to provide a level base for construction. Course 1 consists of very large stones that served to delineate and fix the base of the structure. A stone in course 1 would have a height of 149 cm, a width of 212 cm, and a length of 230 cm, giving a volume of 7.27 m^3 and a weight of 16,000 kg. Each succeeding course becomes progressively smaller. For example, the stone in course 9 would have a height of 90 cm, a width of 80 cm, and a length of 100 cm, giving a volume 0.72 m^3 and a weight of 1,584 kg. This general trend continued up to approximately course 19, where once again there is a layer of blocks about 1 m high, the height decreasing again until course 35, where there is a layer 1.26 m thick. This progression is repeated a number of times, until finally, at the higher courses, the blocks become uniform at about 50 cm (1 cubit) in height. There are more than 200 courses of masonry from the platform level to the top of the pyramid. The exact number is not known with certainty but is probably somewhere between 210 and 220.

The outer courses of the pyramid were constructed of limestone backing stones, which were cut and fitted more accurately than the rough core stones. Once the last course of backing stones was in place and the pyramidion (capping stone) had been installed, the ramp and scaffolding were removed to expose several courses of the backing stones. Then the finishing layer of white limestone casing stones from Turah was placed over the backing stones to give the pyramid its smooth exterior surface. It is possible that the topmost casing stones were precut and finished on the ground and then placed at the apex of the pyramid. The others were installed by working downward as the ramp and scaffolding were removed. The edges of these stones would have been trimmed to the precise angle of the pyramid (51.9 degrees), but the stones would have been left with excess material to be trimmed in place, ensuring very fine joints and a seamless surface. Examples of casing stones prepared in this manner can be seen on Menkaure's pyramid and a few remain on the north side of Khufu's pyramid.

Unfortunately, we must resort to our mind's eye to see what Khufu's pyramid looked like when it was fully sheathed in dazzling white Turah limestone. The exterior finish has been removed, except for a few pieces near the base of the pyramid. Modern historians speculate that it was stolen over the millennia and used in constructing bridges, houses, and terraces in Cairo and the surrounding area. Today, all the visitor can see is the weathered stairstep appearance of the backing stones, although segments of the white limestone terrace that surrounded the pyramid have survived.

Like the ancient Egyptians, the Maya had no wheels or iron tools. The site they selected for Chichén Itzá was ideal in one respect—it is situated between two large, permanent water supplies. Still, at the beginning, the difficulties of constructing a city in the jungle must have been comparable to the challenges the Egyptians faced in building in the desert. First, the site had to be cleared of trees and undergrowth. Stone was abundant, and it appears that limestone was brought to the site from many small rock quarries nearby.

It is not certain if the Maya understood the need for good foundations, but they appear to have planned carefully at Chichén Itzá. The northern portion of the site is constructed on a raised and leveled plain. The entire area is surrounded by a retaining wall. This is where Kukulcán's pyramid, the Ball Court, and the Temple of the Warriors, whose associated structures are distinguished by the hundreds of columns that remain—are located. The structures in this area all appear to be founded on bedrock and there is no evidence of subsidence or settlement.

After laying out the site, the Maya erected a base course of carefully cut casing stones. These are finely trimmed and dressed and feature closely fitting joints. The courses are horizontal, but the stones are not all of uniform height or width, and in some cases two stones are placed one on top of the other to maintain the height. The size of the stones is such that they could be maneuvered into place by two masons. The vertical joints are staggered. As the outer casing stones rose, the interior void space was filled with closely packed stones set in mortar. The interior stones are of random shapes and sizes and appear to have been broken out of the quarry with no attempt at trimming or dressing.

The Maya were skilled stoneworkers. Not only could they cut and polish stone; they also had the ability to drill holes. The ornate relief carvings that distinguish virtually every structure provide further evidence of both skill and artistic ability. Panels, friezes, and columns all bear extraordinarily beautiful scenes of jungle animals, Maya gods, warriors in full dress, and so on.

As has been noted, the orientation of Maya structures was important and also was skillfully done. We have no evidence of precisely how it was done but presume that it was carried out by observations of the sun, planets, or stars.

Stones were transported from nearby quarries by laborers. It does not appear that the Maya used any form of sledge. They were skilled road builders, and the remnants of carefully graded roads can be found throughout Yucatán and the neighboring states. These were paved with stones. Thus, although the Maya had the ability to construct *(continued on page 80)* (continued from page 79) ramps, it appears that the four staircases (one on each side of the pyramid) provided an adequate means of bringing up the stones, rubble, and mortar required by the builders.

As each of the nine steps was completed, there would have been an opportunity to check all of the measurements, do fine leveling, and set new benchmarks for the next lift in the construction. At the top, the challenge to the Maya was easier than that faced by the ancient Egyptians, as the Maya had a large flat working surface for the construction of the temple that surmounted every pyramid.

At first, the temples were of wood and thatch construction. The temples of some of the earliest pyramids have been lost to time, but holes in the rock that once supported wooden poles can be seen. Later, more durable structures were built of stone. Like the Egyptians, the Maya had difficulty constructing roofs—the result of the limitations of the materials they used. For this reason, the rooms tended to be small, limited by the span that could be supported with limestone (approximately 2 to 4 m). However, wood was more available to the Maya than to the Egyptians—in particular some very durable hardwoods that resisted insects and rot. For example, in the temple on top of Kukulcán's pyramid, some of the ceiling beams and lintels over doors are made from massive chicozapote beams that still appear to be in very good shape. And in some of the buildings the Maya, like the Egyptians, made use of corbeled ceilings. These can be seen over some of the large arched entryways, as well as in certain small rooms and chambers.

While there can be no question that the pyramid construction of the ancient Egyptians reached its apex at Giza and that these pyramids represent extraordinary accomplishments in terms of design, engineering, and construction, the pyramids of the Maya are intriguing in their own right. Much remains to be discovered about the Maya and their remarkable structures. Certainly only a fraction of the edifices they built have been located; hundreds must still remain hidden within the jungles of southern Mexico, Belize, Honduras, and Guatemala. Little is known about the engineering, surveying, and construction techniques of the Maya. While some of the ruins have been carefully reconstructed, measurement details are lacking, as are survey data on many of the major structures—data that would permit future investigations and possibly reconstructions of monuments that otherwise will continue their slow disintegration under the relentless attack of the forces of nature that seek to return the jungle to its native state. ■

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