

# **THE EGYPTIAN PYRAMIDS: THEORIES OF CONSTRUCTION**

Research Paper Prepared

by

Scott Guirlinger

Undeclared Engineering Major



For the Course

ARCH 316 - ANALYSIS OF HUMAN SETTLEMENTS (Cities)

Fall Semester 1999

Instructed by

Dr. Gideon Golany  
Distinguished Professor of Urban Design  
Department of Architecture  
The Pennsylvania State University

# **LIST OF CONTENTS**

Preface

Introduction

I. The People Behind the Construction

II. Locating and Preparing the Construction Site

III. Quarrying and Transporting the Stones

IV. Constructing the Core

V. Sealing the Pyramid

Conclusion

Endnotes

Bibliography

## **PREFACE**

Researchers and experts have developed numerous theories as to how the great Egyptian pyramids were built. Unfortunately, these theories are all very different. My goal with this research paper is to provide a look at several of the different ideas presented by modern Egyptologists and to compare them and their relative support and value to each other. I found many sources for this project, more than I could ever fit into the small space of this paper in fact, mostly from books written by pyramid experts and encyclopedia articles.

## **INTRODUCTION**

The construction of the ancient Egyptian pyramids is not a matter that can be explained by facts, but must be explained by numerous extensive theories. Of the many theories that are explained in this paper, some provide more factual support than others and are therefore more credible. The many beliefs presented by modern Egyptologists sometimes overlap, but many times do not. Because of the lack of concrete evidence concerning the pyramids' construction, it is impossible to prove any one theory to be correct. It is much more possible and plausible to present some of the more popular and understandable theories on the subject. By generalizing in this way, the process becomes more vague, but it also becomes more realistic. Because it is highly unlikely that any one pyramid was constructed in an identical way to another, all of the theories presented here could have been put to use at some time or another.

## I. THE PEOPLE BEHIND THE CONSTRUCTION

### Laborers

In order to build the Great Pyramid at Giza about one hundred thousand workers labored for twenty years to construct what is one of the largest man-made monuments on the planet. Where these men came from is a question that is often debated by experts. Because of the significant number of barracks discovered near the pyramids, many believe that the Egyptians captured slaves and put them to work. Others think that these barracks were merely temporary housing for those men working on the project at the time it was being built. And if these were free men, whether or not they were forced by the government to do the labor is also unclear.

Experts disagree as to when work was done on the pyramids as well. Some believe that work only took place between July and November when the Nile flooded the nearby fields and farming was impossible. Others think that work continued all year long with just an increase in the labor force from the farmers each flood season. Still others believe that while the actual construction stopped for people to return to their farms from December to June, the skilled men who planned the construction worked year round on their designs.

Nevertheless, ancient pictures show that the laborers were organized into work gangs of twenty-five men each, with one of them acting as the soldier foreman.<sup>1</sup> The question is often asked why the Egyptians used men to do the labor instead of animals. The simple answer is that men, not animals, can work in unison. By organizing themselves in this way, the laborers were able to maximize their efforts by all pulling or pushing at exactly the same time. It was the job of one of the men in the work gang to keep the cadence, usually done by clapping the hands.<sup>2</sup>

Overseers watched over the entire building process, keeping workers in line and checking the finished work constantly to make sure that everything was carried out correctly. They checked to make sure each level was truly level and that the angles on each side were correct. Even the slightest imperfection could weaken the entire pyramid structure.<sup>3</sup> These overseers took a great interest in the safety and welfare of their gang, and boasted to the other gangs if no men were injured under their supervision.<sup>4</sup> However,

accidents on the job were somewhat common and all Egyptians villages lived with the understanding that not all of their members might return by the end of construction.

## Skilled Workers

While the laborers definitely comprised the largest group that worked on the great pyramids, they were far from the only group. The pharaohs handpicked their own personal architect for the project whose sole responsibility it was to build the pyramid.<sup>5</sup> This one man would determine and design the angle, the size, and the interior and exterior rooms. While this job provided a lot of authority to the architect, it also came with a lot of responsibility. If the pharaoh was not pleased with the work being done on his pyramid, the blame fell on the architect and could possibly end his life.

Several priests were also required for the many ceremonies that were involved with the construction process. Every time that a major stone was laid or major building was completed a ceremony was held to honor the occasion and bless the workers and their accomplishments. Because of the enormous amount of stone blocks and separate buildings associated with a pyramid, many ceremonies had to be held. It required several priests working in a constant rotation in order for each stone and building to be blessed on schedule.<sup>6</sup> The granite capstone's journey to its place on top of the pyramid usually involved a grand ceremony, which had many prayers and lasted several days.

## Tools

The Egyptians used only the simplest of tools in the construction of the pyramids. Their tools were made of copper, iron, quartz, flint, or wood, all very simple materials found in Egypt. These materials were shaped to make the chisels, hammers, mauls, and wedges used to carve out the great stones. To transport the stones up from the ground to their final resting-place in the pyramid, the laborers used wooden sledges and possibly wooden rollers.<sup>7</sup> Other tools such as the square, level, plumb rule, and plumb line were developed and were used to align the blocks correctly on the pyramid.<sup>8</sup>

## II. LOCATING AND PREPARING THE CONSTRUCTION SITE

### Location

The first step in building a pyramid was to select the location. All of the pyramids were located in the northern portion of Egypt within twenty miles of the ancient capital city of Memphis on the west bank of the Nile. This side of the river was chosen for several reasons. The solid, flat, elevated plateau that makes up the west bank offers a sufficient sturdy base for the pyramid to rest on<sup>9</sup> and because of its increased elevation, the Nile's annual floods would not submerge this site in water. The plateau was also primarily made of a yellowish limestone, the rock used for the great blocks that make up the main infrastructure of the pyramid. If this site was indeed used to quarry the stones (as is discussed later), then the distance that the workers had to drag the heavy blocks would be effectively shortened.

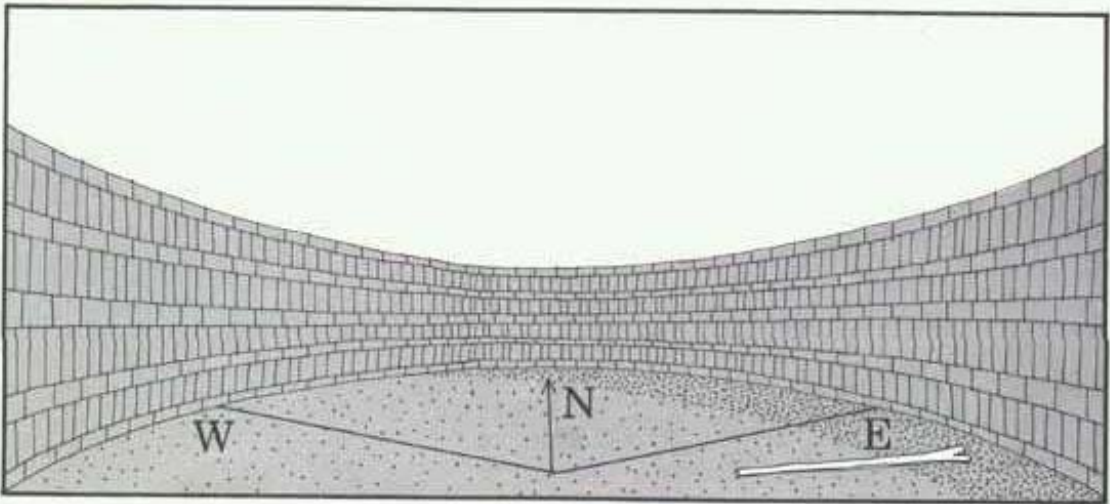
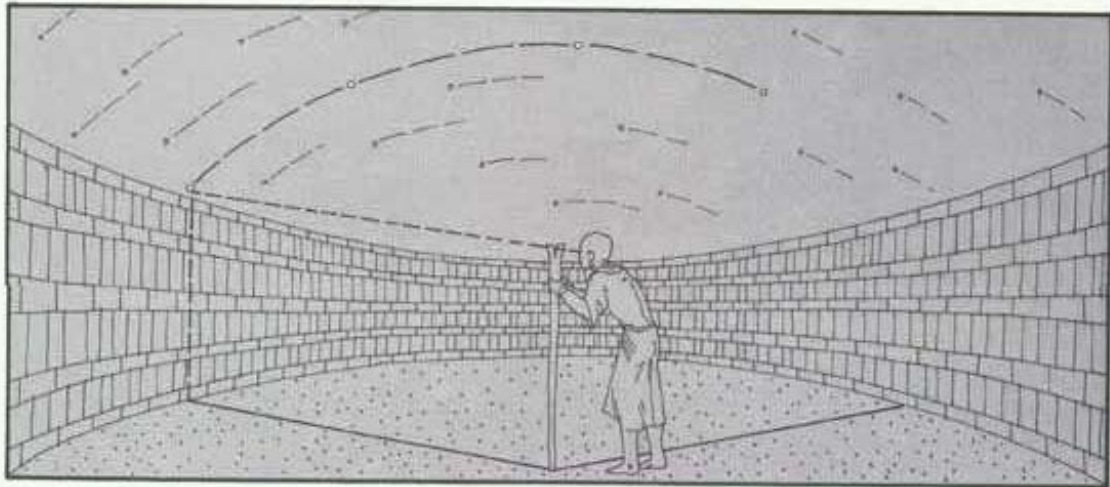
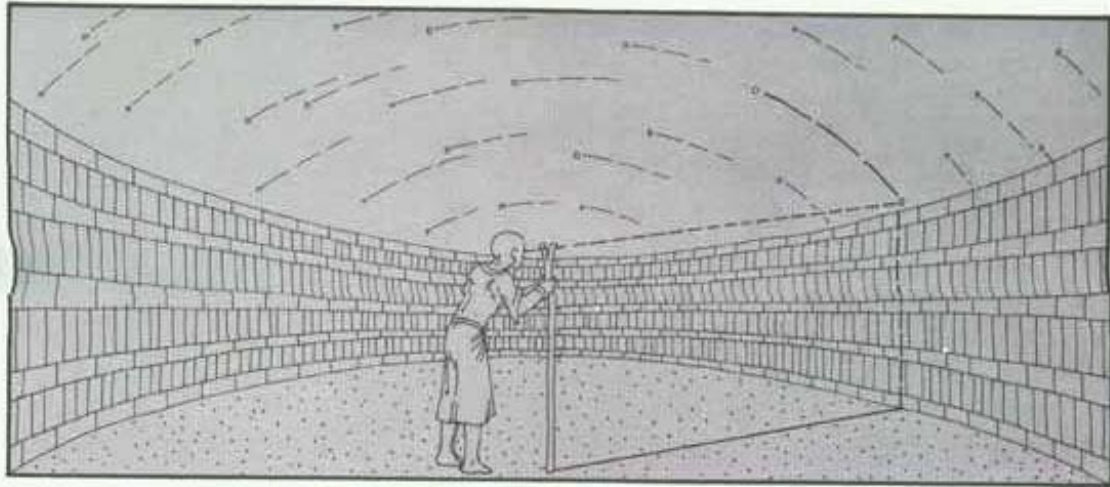
Location was not completely based on physical criteria however. The Egyptians, having a basic knowledge of astronomy, observed the sun setting in the west and likened this phenomenon to death. The pyramids were built on the west bank for this reason, so that the pharaoh's soul, or *ka*, could follow the sun god Re as he made his nightly journey into the other world.<sup>10</sup>

### Orientation

Once the site for the pyramid had been selected, the orientation of the base had to be mapped out. Each side of the pyramid faced a different cardinal direction with the main entrance always located on the northern face. This selection of orientation probably has to do with the Egyptians' heavenly view of the North Star, which the Egyptian priests would use to determine which direction was true north.

Dr. Ahmed Fakhry points out that using the North Star to accomplish this task would not have been impossible for the Egyptians to do. Even in the early stages of their civilization, they already had enough knowledge of astronomy to develop a workable calendar.<sup>11</sup> Pyramid expert J. P. Lepre adds that some combination of the astrolabe, V-shaped bay, and the merkheth or plumb bob was probably used by the Egyptians to find true north.<sup>12</sup> Researcher and author David Macaulay argues a slightly different method:

FIGURE 1



A circular wall was built in the center of the site. It was built high enough to block a view of the surrounding hills and the top was made level. This created a perfect horizon line.

In the evening a priest stood in the center of the circle and watched for the appearance of a star in the east. Its position was marked as it rose above the wall and a line was drawn from that point on the wall to the center of the circle. He watched the star as it moved in an arc through the sky and finally set in the west. As it dropped behind the wall its position was marked again and another line was drawn to the center of the circle. Because stars appear to rotate around the north pole, the priests knew that a third line drawn from the center of the circle through the center of the space between the first two lines would point directly north (Figure 1).<sup>13</sup>

Because there is no written record of exactly how this task was carried out, almost any method can easily be accepted or rejected. The North Star may not have even been used; it is possible that a perpendicular line drawn against the east-west passage of the sun would have produced the same result.

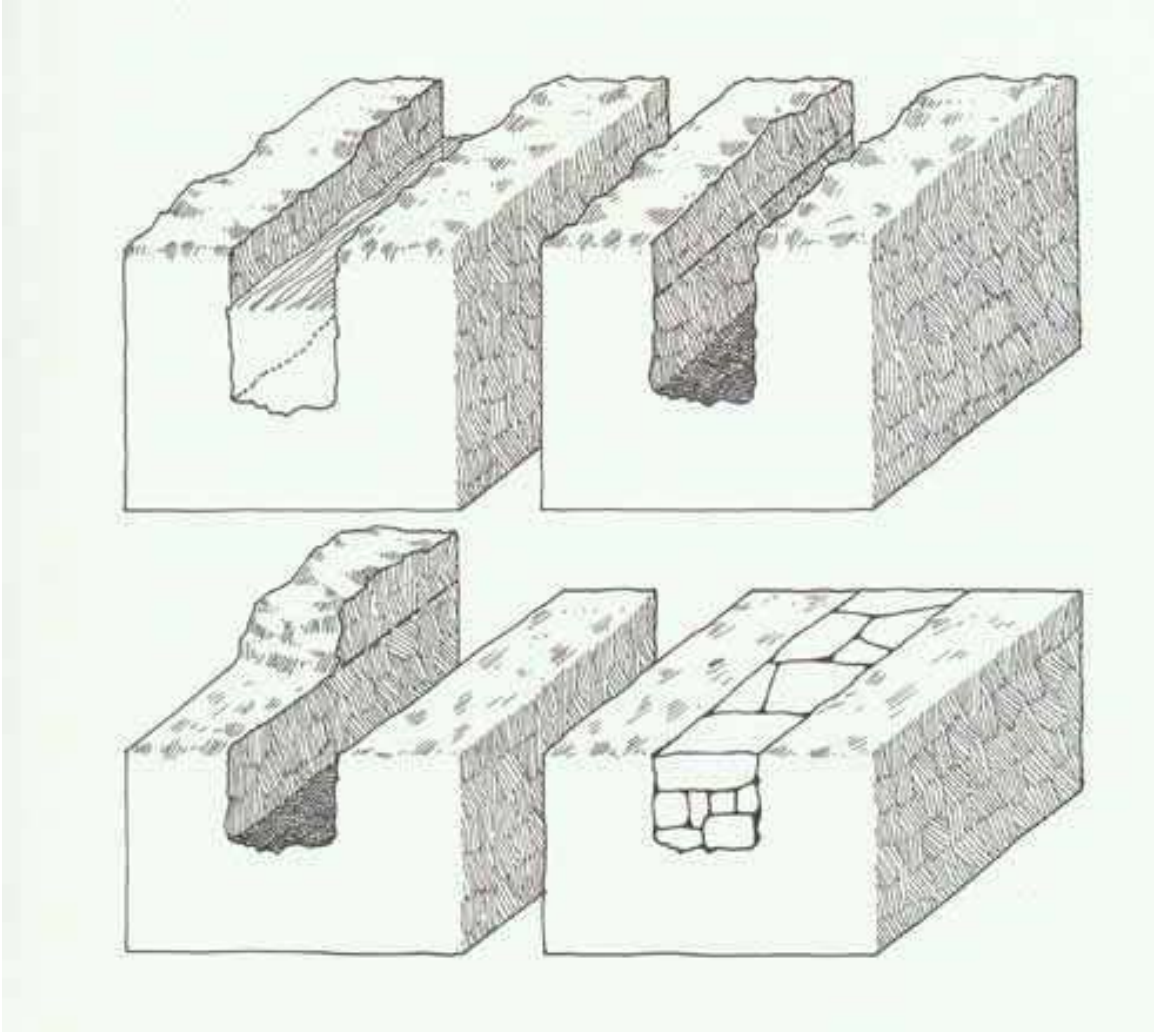
## Leveling the Ground

After selecting the site and determining true north, the architects then sketched into the sand where the pyramid would be laid. The sand and rubble covering the sturdy rock of the plateau was removed from the site so that construction could begin.

Pyramid experts are once again not in agreement, this time about how the leveling of the ground actually took place. Some feel that dikes were erected around the edges of the site and the entire area was flooded with water to remove the excess rock and material and smooth out the land. It is generally believed that not all of the excess rock was removed from the site to make the pyramid perfectly level; some was left behind to help support the base.<sup>14</sup>

In addition to the flooding method, another idea for leveling the site involves trenches (Figure 2). Several parallel ditches could be dug out and then filled about halfway with water. The excess material above the water line on either side of the trench would be removed and then used to fill in the rest of the ditch. In this way, the entire foundation of the pyramid could be made on exactly the same level<sup>15</sup>.

**FIGURE 2**



Macaulay, David. *Pyramid*. Boston: Houghton Mifflin Company, 1975. 25.

### III. QUARRYING AND TRANSPORTING THE STONES

According to J. P. Lepre, there are three processes involved in the actual construction of a pyramid: quarrying, manipulation, and sealing. The remainder of this text will focus on these three processes and how they were carried out.

#### Quarrying the Stones

##### *Location*

Pyramid experts do not agree on where the stones for constructing a pyramid came from. Some believe that the rocky plateau surrounding the base of the pyramid provided the necessary amount of yellowish limestone to build. Many others disagree, saying that the stones were brought across the Nile from a large quarry on the east bank. It seems likely that a combination of the two is probably what really occurred. The Egyptians probably used what stone they could from around the construction site and then quarried the additional stone on the other side of the river. In either case, experts agree that the better quality white casing stones used on the pyramids outer shell must have come from a quarry down the Nile, not the surrounding area.<sup>16</sup>

Another debate surfaces concerning what type of quarries the stone came from. Were open face rock quarries or cave rock quarries used? If caves were used, then the work gangs would have to have cut the stones out from the inside of a cliff, keeping some stone pillars in the cave to support the ceiling. This would have provided some shade for the laborers from the scorching sun of the Egyptian summer, but would add the possible danger of a collapsing cave ceiling. Open face quarries would eliminate this danger and would make the transportation of the stones much easier, but would not be able to offer any shade to the laborers.

##### *Cutting the Rock*

But how were these great stones cut out into blocks? The experts also argue the answer to this question. Some think that the simple means of using either single or multiple wedges was employed to split the rocks along the desired cut lines. But others feel that this was not precise enough. Pyramid expert Peter Tompkins writes that sometimes fire followed by cool water was used in grooved lines to obtain a clear

fracture.<sup>17</sup> But many others discredit this idea for safety reasons and because it still would not provide a truly clean break along the rock's surface.

Instead, the most popular method for splitting the rocks has been using "wet wood." This method begins with hammering out vertical lines into the side of the rock with a wooden mallet and copper chisel. Extremely dry wooden wedges were then inserted into the space on the line. Pouring water onto these wedges made the wood expand, splitting the rock precisely along the given line.<sup>18</sup>

## Transportation

### *Over the Land*

If the theory that the stones used to build the pyramids were brought from across the river is true, as it most likely is, then how did the ancient Egyptians transport them? The most common idea is that large wooden sledges were used to drag the blocks over land. These sledges would have two wooden runners along their underside and a wide platform to hold the stone. Ropes would be attached to the front of the sled to make it easier for the laborers to pull the heavy load.<sup>19</sup>

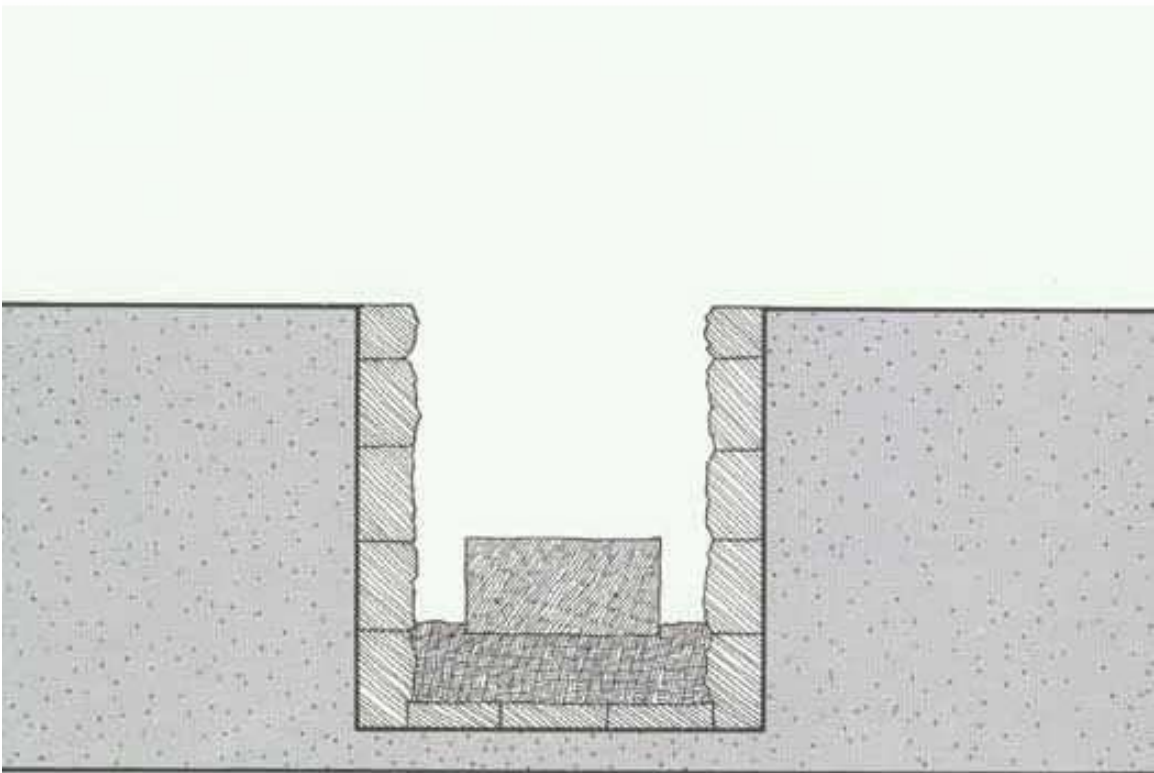
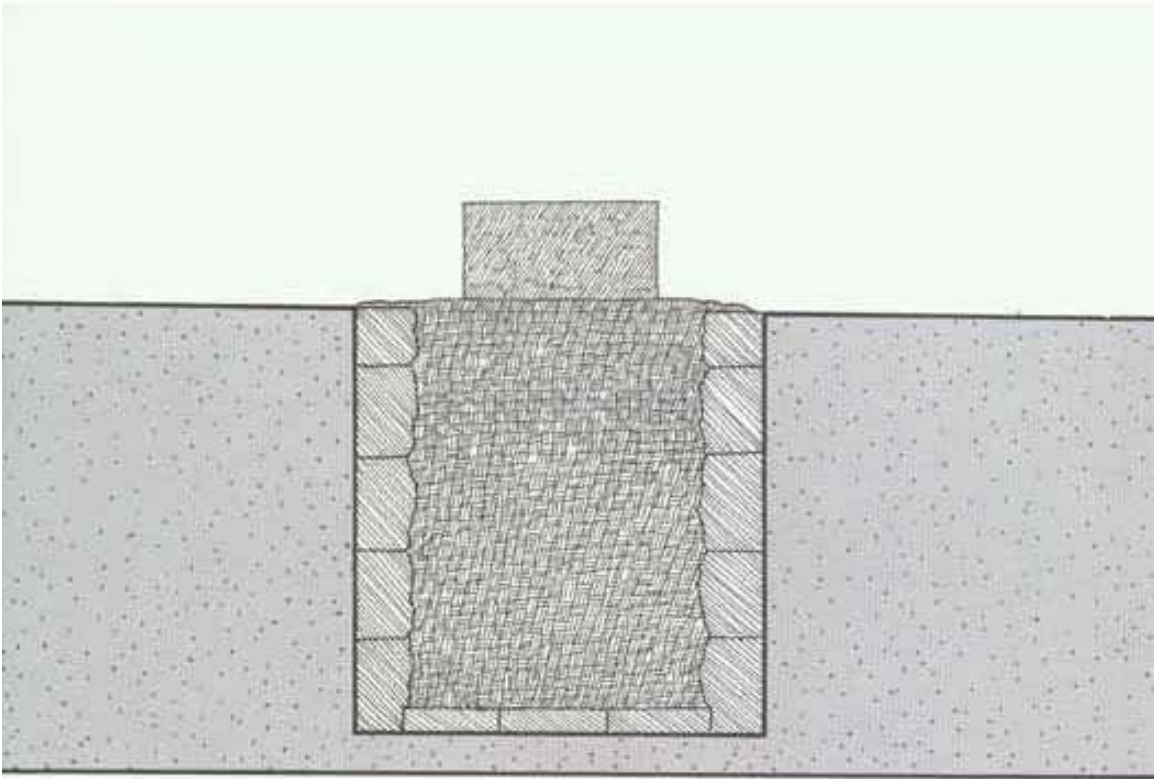
An alternative method has been suggested, however, that requires lashing four circular wood pieces onto each side of the stone (Figure 3).<sup>20</sup> By doing this, a large circle would be made that could be easily rolled over the land. This design may have brought up certain safety issues and so it is not entirely likely that it was put to practice.

### *Across the River*

To move the giant stones from the quarries down the Nile to the construction site where they would be laid required a means of transportation across the river. A popular theory suggests that boats fashioned out of wood and/or reeds were used to float the blocks across to the other bank. In this case, the Egyptians would have been able to use the flooding of the Nile to their advantage. Loading the stones onto the boats when the water level was low and then waiting until the floods came to leave would help to avoid the troublesome process of beaching and unbeaching the boats.<sup>21</sup>

But because of the amount of time required by the flooding to carry out this method, it may not have been used. In all likelihood the architects needed stones to be transported to the building site much faster than the seasons would allow. Lepre has suggested in his

**FIGURE 3**



writing that perhaps a sort of bridge was used to move the stones across the Nile. "Surely," he writes, "if the ancients were capable of building such enormous pyramids, they were capable of building at least one bridge."<sup>22</sup>

Either way, before the stones were taken across the river each one was marked with the number of the work gang who was transporting it. Upon reaching the construction site on the opposite bank, the block's number was checked off a list.<sup>23</sup> This policy helped to keep the laborers working hard and actually may have started some inter-group competition among them.

#### **IV. CONSTRUCTING THE CORE**

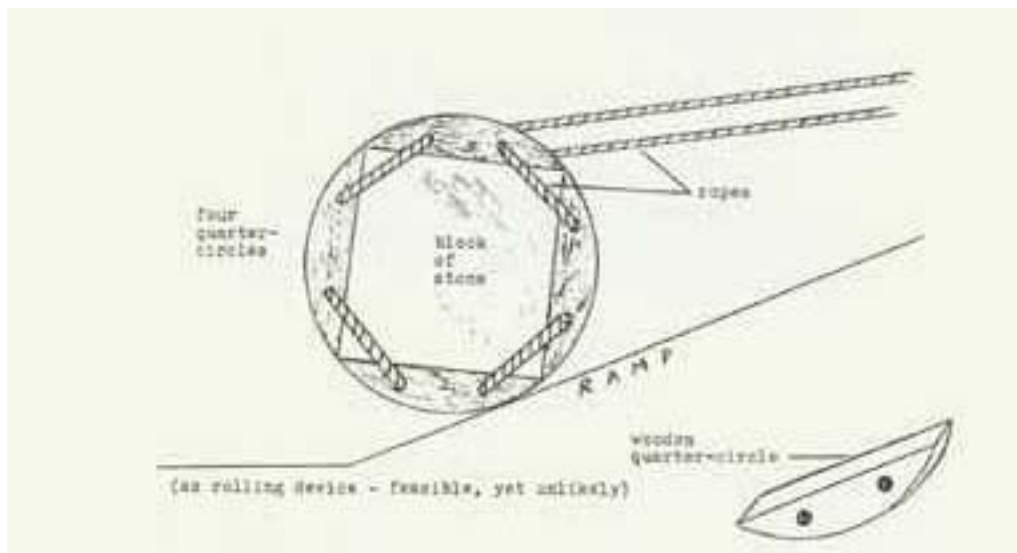
##### **The Pyramid Substructure**

A pyramid's substructure usually consisted of just two rooms: the storage room and the tomb, where the sarcophagus was laid. Blocking the passageway into the storage room, which led into the tomb, usually were three large stone portcullises, built to keep intruders out. The entire substructure was lined with massive granite slabs quarried farther south and brought via the Nile to the construction site.

Once the construction site had been cleared of all rubble and debris a tunnel was started near the outer edge of the base sloping downwards towards the center. Upon reaching fifteen feet below the surface, the tunnel leveled out into the passageway that led to the underground rooms. The granite slabs were then put into place along the passageway to support the structure.<sup>24</sup>

The two underground rooms had ceilings higher than fifteen feet for a reason. The sarcophagus was much too heavy and much too large to be brought down the narrow, cramped passageway. Instead it was lowered into the tomb from the surface before the roof of the room was put on. This process could have been accomplished by either using ropes and beams or by filling the entire tomb with dirt. The sarcophagus could then be placed on top of the rubble and as the workers removed the sand and debris surrounding it, it would slowly be lowered down to the floor (Figure 4). A similar method could also have been used to put the roof stones into place. By once again filling the tomb with

**FIGURE 4**



Lepre, J. P. *The Egyptian Pyramids*. Jefferson, North Carolina: McFarland & Company, Inc., 1990. 248.

excess material and placing the stones on top, the rubble could be removed from underneath using the underground passageway and the ceiling would be left completed.<sup>25</sup>

## Raising the Stones

The most debated area concerning the construction of the pyramids is how the stones were transported from the ground up to their current level. A wide range of possibilities has been presented over the years, most of which involve some sort of ramp for the wooden sledges to slide on. Indeed, waste banks have been found near the great pyramids, some of which comprise almost half the volume of the Great Pyramid at Giza. Expert August Mencken believes that these waste deposits must be the remains of the dismantled ramps used during construction.<sup>26</sup>

The ramps might have been made out of mud, straw, brick, stone, or any combination of these materials.<sup>27</sup> As sliding a wooden sledge up a ramp of this sort would create an enormous amount of friction and heat, one worker from each gang was assigned to pour a lubricating liquid on the track to make the process easier.<sup>28</sup> The Egyptians may have used water as this liquid or something completely different.

### *Single Ramp Theory*

The single ramp theory presented by experts shows one ramp leading up the side of one face of the pyramid. This along with banks of rubble on the other three side of the pyramid should have given the Egyptians plenty of room to work.<sup>29</sup> The trouble many people have with this theory is that in order for the ramp to be sloped at such an angle that the workers could effectively pull the sledges up, the ramp would need to be close to a mile long. A ramp of this size would require an enormous amount of time and material to build, and so is likely to have not been used.

A slight variation of the single ramp method presented by Mencken still uses only one ramp but employs switchbacks on the pyramid's face once a certain height is reached, usually about the fifth level.<sup>30</sup> Constructing a ramp in this fashion would save space and material, but would require the workers negotiate extremely difficult 180 degree turns on their journey up.

### *Multiple Ramps Theory*

The most popular theory presented so far concerning pyramid construction involves four spiraling ramps starting at each of the four different corners of the pyramid's base. Closer to the top space would limit the workers to only two ramps. Using this method, space and material could be conserved in constructing the ramps, meaning also that less work would be required to dismantle the ramps once construction was completed.

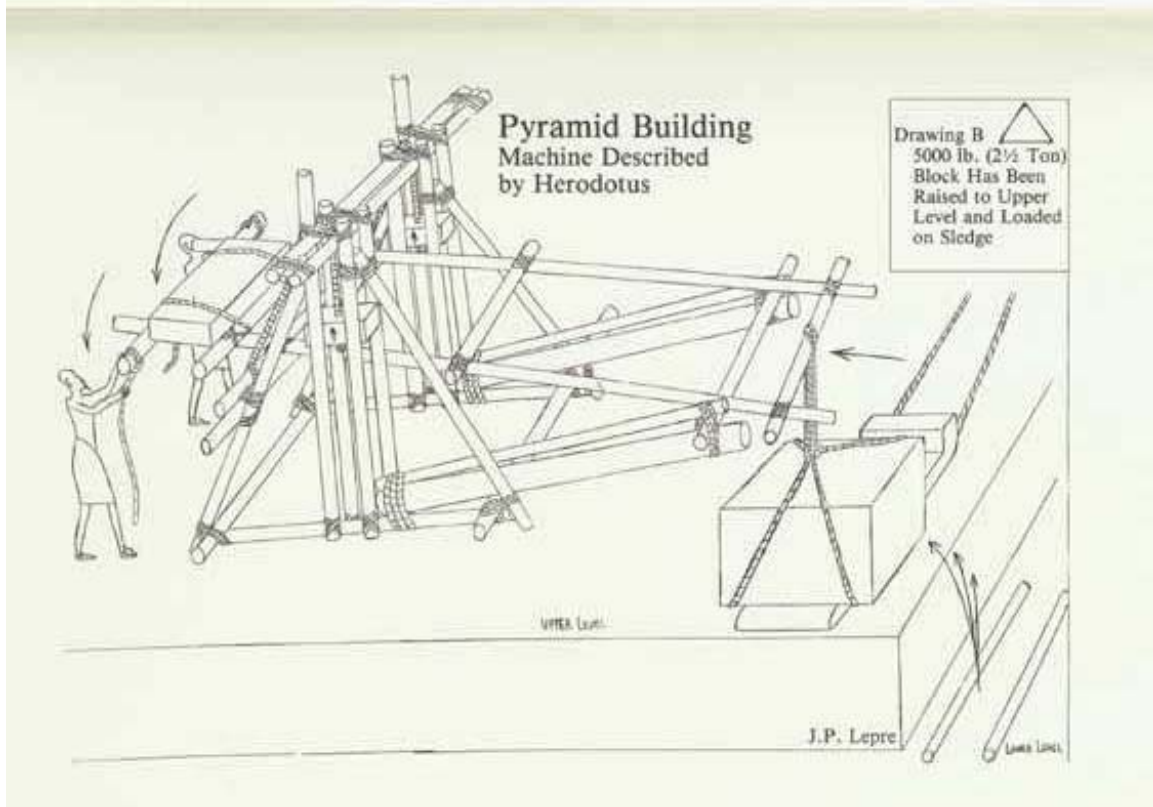
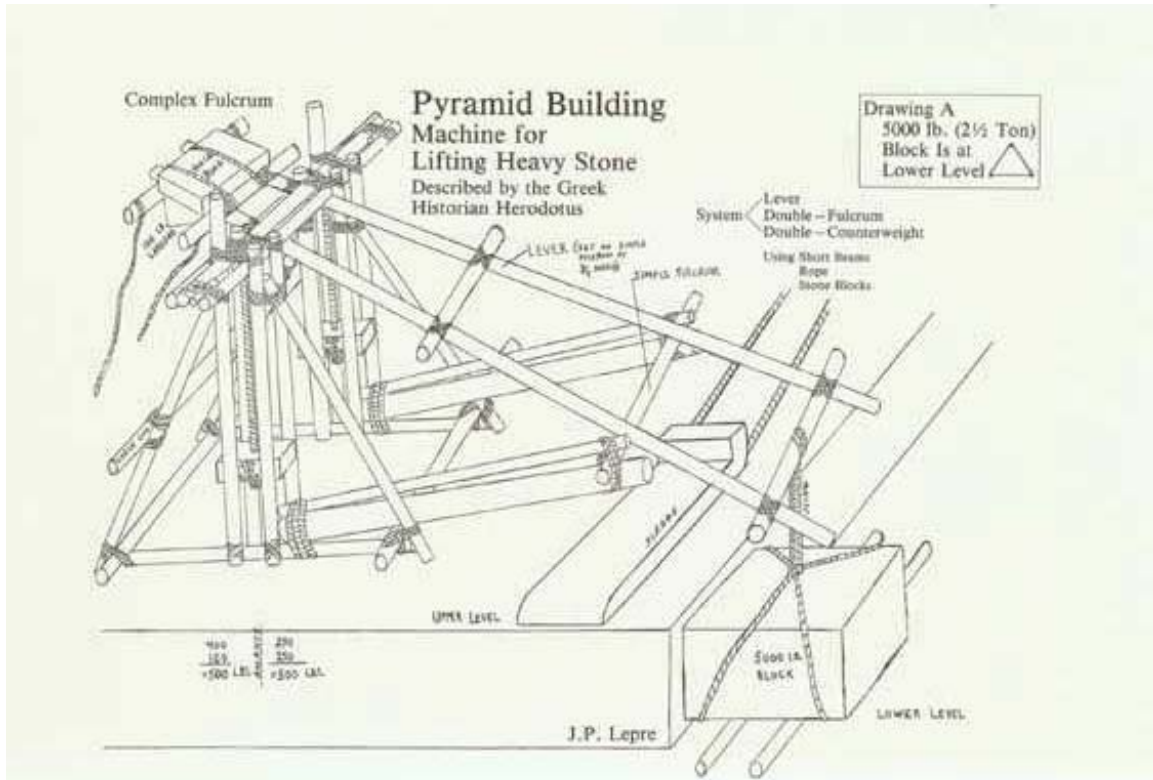
By using four ramps, experts believe that work could be conducted much more efficiently than using a single ramp. Two ramps could be used for hauling stones to the top while the remaining two could be used to slide the sledges back down to be reloaded. Also if the sealing of the pyramid was conducted at the same time as the core was constructed (this topic is discussed more later), then one ramp could be used for the casing stones, one for the larger stones comprising the nucleus, and the other two for empty sledges coming down.

### *Machine Theory*

The ramp theories, while they are popular, are not completely feasible. Constructing such large ramp structures would require an enormous amount of time and energy. Commander F. M. Barber, a naval officer stationed in Egypt at the beginning of the century, wrote that the work required to build the inclined plane would be almost four times that required to build the pyramid.<sup>31</sup> Using anything besides the single ramp method would also require having to make numerous turns with an awkward wooden sledge that was anything but adapted to turning.

So as an alternative to the ramp theories, some experts have come up with a completely different hypothesis. Because of the high intellectual ability of the Egyptians many believe that a simple machine used to raise the stones would not have been an impossible thing for them to build. J. P. Lepre has proposed a design for such a machine that requires only short timbers, a double fulcrum, a lever, ropes, double counterweights, and stones (Figure 5).<sup>32</sup> The design allows the Egyptian to raise a large, heavy stone while minimizing the workload. The machine is not overly complex and certainly gets the job done within the constraints of the Egyptian supplies, but whether or not it was ever actually employed may never be known.

FIGURE 5



## Settling the Stones

Once the stones were on their desired level, a thin mortar line used underneath them made it easier to slide them into place.<sup>33</sup> In order to level the large stones accurately, small water troughs were chipped into a few blocks on each level. Once again, even the slightest imperfection could weaken the entire pyramid.

Iron bars and protruding edges were also used to align the stones properly. By leaving certain pieces of stone sticking out and carving matching indentations into others, the blocks of the pyramid could be fit together almost like a puzzle. Evidence of blocks shaped as such has been found at Khufu's Pyramid, although it cannot be proved as to exactly how these blocks were used.<sup>34</sup>

The average weight of a stone block was around two and a half tons, with the blocks' size decreasing as the height of the pyramid rose.<sup>35</sup> The capstone was made of solid granite and was placed on top as mentioned earlier only after a grand ceremony had taken place. Prayers and offerings were made all during its arrival, its ride to the top, and its placement there. A small piece of stone protruded from its base and slipped snugly into a matching hole carved into the center of the top layer. Because of the capstone's size and weight, several work gangs were required to move it up the pyramid and to walk behind it making sure it could not slide back down.<sup>36</sup>

## V. SEALING THE PYRAMID

After the capstone was laid the sealing process could begin. Generally experts agree that the core of the pyramid was constructed first, bottom to top, and then the better quality white casing stones were laid, top to bottom, as the ramps were deconstructed.<sup>37</sup> The ancient Greek Herodotus, who journeyed to Egypt several centuries after its fall, indicates in his report that this was the method employed by the Egyptians. This means that indeed four ramps would have been required in construction.

To seal the pyramid, about thirty vertical feet of the ramps would be removed at a time and wooden scaffolding erected to allow the workers to polish the stones. When the polishing was completed, the scaffolding would be disassembled, thirty more feet of ramps would be dismantled, and then the scaffolding would be reassembled farther down

the pyramid.<sup>38</sup> This process would repeat itself until the base of the pyramid was reached and the pyramid was finished.

However, this theory does not convince all the pyramid experts. William Petrie, a mechanical engineer by trade, believes that the casing stones were laid first on each level, creating an outline for the placing of the core stones.<sup>39</sup> Maragioglio and Rinaldi, two Italian scholars researching the pyramids, believe that the casing and the nucleus were laid simultaneously.<sup>40</sup> By laying the blocks in either of these two ways, the casing blocks could be levered into position from the back and any damage to the stones could be avoided. The perfection with which the pyramids were built certainly supports this case.

While some work gangs laid the casing stones in place, others came behind them polishing the outside surface. This task may have been accomplished using an abrasive such as powdered pumice stone<sup>41</sup> or perhaps a softer substance such as red ochre. Petrie claims to have found the latter on the outside of some of the remaining casing stones that had not been perfectly dressed.<sup>42</sup>

A single small entranceway to the underground tunnel was left open on the north side to allow workers to transport the pharaoh's gifts and possessions to the interior. Upon the death of the pharaoh, the mummy was laid in the sarcophagus and the granite walls securing the passageways were lowered. The final casing stone was pushed into place and the pyramid was officially completed.

## CONCLUSION

The entire construction process that I have described usually took the Egyptians many years to complete, and the pharaoh often died before his pyramid was complete. The Great Pyramid at Giza took over twenty years, about one hundred thousand workers, and over two million stone blocks to complete.<sup>43</sup>

The Egyptians' belief in an eternal afterlife led them to construct these giant monuments. They believed that life on earth was short and so they built houses of mud, but life after death was eternal so they constructed tombs of stone.<sup>44</sup> The pyramid was the house for the pharaoh's *ka*, or soul, and was intended to last forever. So far this task has been accomplished; the great pyramids still stand today even after numerous centuries of abuse from the harsh climate of Egypt.

The study of the pyramids is quite obviously a very complex task, part of the reason that there are so many theories regarding the construction of them. These theories may be proved correct or incorrect with the passage of time, but more than likely their truth will remain unclear forever. The ancient Egyptians have left us today with more than just some of the greatest monuments of all time; they have left us with what might be the greatest mystery of all time.

## ENDNOTES

- <sup>1</sup> Macaulay, David. *Pyramid*. Boston: Houghton Mifflin Company, 1975. 13.
- <sup>2</sup> Tompkins, Peter. *Secrets of the Great Pyramid*. New York: Harper & Row, 1971. 223.
- <sup>3</sup> Macaulay 36.
- <sup>4</sup> "work, history of the organization of" *Encyclopædia Britannica Online*.  
<<http://www.eb.com:180/bol/topic?eu=115710&sctn=14>> [Accessed 10 November 1999].
- <sup>5</sup> Macaulay 7.
- <sup>6</sup> Fakhry, Ahmed. *The Pyramids*. Chicago: The University of Chicago Press, 1961. 18.
- <sup>7</sup> Fakhry 9.
- <sup>8</sup> Lepre, J. P. *The Egyptian Pyramids*. Jefferson, North Carolina: McFarland & Company, Inc., 1990. 236.
- <sup>9</sup> Fakhry 10.
- <sup>10</sup> Macaulay 6.
- <sup>11</sup> Fakhry 11.
- <sup>12</sup> Lepre 235.
- <sup>13</sup> Macaulay 22.
- <sup>14</sup> Fakhry 11.
- <sup>15</sup> Macaulay 25.
- <sup>16</sup> Macaulay 18.
- <sup>17</sup> Tompkins 222.
- <sup>18</sup> "Learning Family learns about Pyramids" *Learning Family Home*.  
<<http://www.learningfamily.net/reiser/9901-act/012pyramid.htm>> [Accessed 10 November 1999].
- <sup>19</sup> Jeunesse, Gallimard, Claude Delafosse, and Philippe Biard. *Pyramids*. New York: Scholastic Inc., 1994. 5.
- <sup>20</sup> Lepre 247.
- <sup>21</sup> Mencken, August. *Designing and Building the Great Pyramid*. Baltimore: Schneidereith & Sons, 1963. 54.
- <sup>22</sup> Lepre 242.
- <sup>23</sup> Macaulay 21.
- <sup>24</sup> Macaulay 28.
- <sup>25</sup> Macaulay 32.
- <sup>26</sup> Mencken 51.
- <sup>27</sup> Jeunesse 8.
- <sup>28</sup> Macaulay 39.
- <sup>29</sup> Macaulay 45.
- <sup>30</sup> Mencken 53.
- <sup>31</sup> Tompkins 231.
- <sup>32</sup> Lepre 260.
- <sup>33</sup> Mencken 53.
- <sup>34</sup> Lepre 250.
- <sup>35</sup> Lepre 254.
- <sup>36</sup> Macaulay 52-55.
- <sup>37</sup> Fakhry 13.

- 
- <sup>38</sup> Macaulay 58.  
<sup>39</sup> Tompkins 228.  
<sup>40</sup> Tompkins 229.  
<sup>41</sup> Lepre 239.  
<sup>42</sup> Tompkins 229.  
<sup>43</sup> Jeunesse 10-11.  
<sup>44</sup> Macaulay 5.