Reprinted from ARCHAEOLOGY, *Volume 9, No. 3 (Autumn 1956), pages 159-165*

BUILDING AN EGYPTIAN PYRAMID

By Dows Dunham

CURATOR EMERITUS OF EGYPTIAN ART, MUSEUM OF FINE ARTS, BOSTON

THE QUESTION of how the ancient Egyptians went about the building of a pyramid has been the subject of speculation and wonder as far back as the days of Herodotus, whose account in his History (II, 124-125) seems to have been based on tales told him by Egyptian dragomans of the fifth century B.C. In recent times such scholars as Petrie and Borchardt have written on the subject, and as late as 1947 it was treated by I. E. S. Edwards in his *Pyramids of Egypt* in the Pelican Series. (Reference should also be made to *Ancient Egyptian Masonry,* by Somers Clark and R. Engelbach [London 1930] Chapter X.) The fundamental difficulty in arriving at a definitive solution of the problem, however, remains that the Egyptians themselves left no clear account of how it was done, and we therefore have to rely on our very imperfect knowledge of what they actually knew of engineering, and of the methods which we know they used in handling heavy and bulky materials.

In the spring of 1950 the Museum of Science in Boston undertook the construction of a model of one of the Egyptian pyramids as the first in a series of representations of great engineering achievements of the past. Mr. Theodore B. Pitman, an experienced model-maker of Cambridge, Massachusetts, was chosen to undertake the work, and Mr. Bradford Washburn, Director of the Museum, asked the writer to act as archaeological consultant.

1. General view of a diorama in the Museum of Science, Boston. In the foreground the Third Pyramid at Giza is shown in course of construction. To the right the emplacement for the funerary temple (not yet built) is being used as an assembly and sorting area, while farther to the right may be seen the upper end of the causeway leading to the valley and the site on which the Valley Temple was later constructed. In the background rises the Second Pyramid of Chephren and behind it the Great Pyramid of Cheops, both recently completed. The observer is looking north-northeast.

2. View looking down into a quarry from which blocks of limestone for the core of the Pyramid of Mycerinus are being cut. In the upper center a block, freed from the quarry face, is being levered onto a sledge. This quarry lies in a depression southeast of the Third Pyramid.

Professor Walter Vose of the Massachusetts Institute of Technology gave us the benefit of his practical engineering knowledge in order that the model might represent work which would have been mechanically feasible with the means at the disposal of the ancient builders.

The pyramid selected for representation was the third of the Giza group, that of King Mycerinus of the Fourth Dynasty, who died about 2570 B.C. Several reasons determined this choice. The Harvard University-Museum of Fine Arts Egyptian Expedition under the late G. A. Reisner had excavated the temples of this pyramid as well as the quarry adjacent to it, and there was a large collection of photographs and plans of the site available in the Museum of Fine Arts. This was the smallest of the three great pyramids at Giza and a scale model could therefore be of reasonable size. Furthermore, being the last of the group, the model could have as background the first and second pyramids as they must have looked when newly completed (Figure 1).

The work was finished in March, 1951, was installed in the Museum of Science in time for the opening of its new galleries shortly thereafter, and has been favorably noticed by a number of scholars who have seen it. Photographs of the model will, therefore, be of interest to a wider public.

THE PROBLEM WE HAD TO FACE in constructing the Science Museum model was to build on a tiny scale (actually 1:120) a pyramid of known size and proportions, using only the means with which we know the Egyptians were familiar. In this way we could visualize the many practical problems with which they must have been faced, and

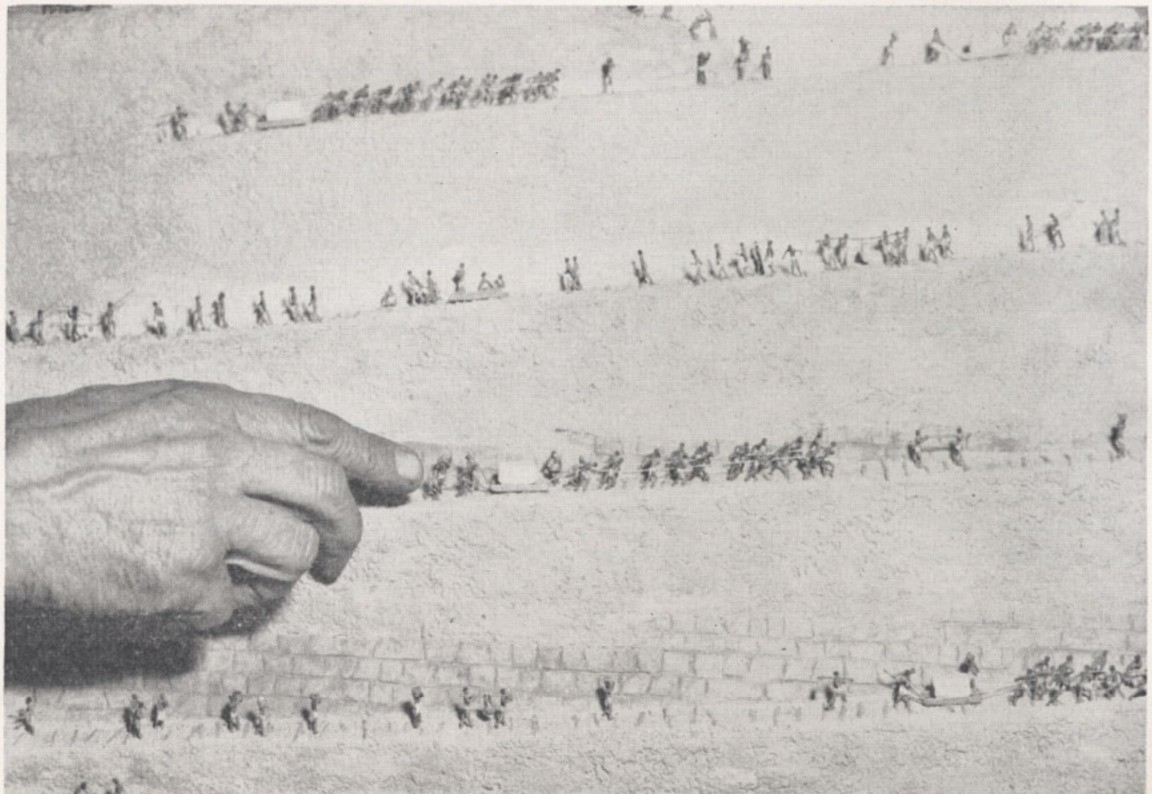
3. Building materials for the pyramid arriving from the causeway at the sorting and distribution area—site of the pyramid temple of Mycerinus. Here joints of facing blocks are being dressed and fitted. In the foreground a fresh group of men is hauling a block to the base of one of the long ramps for the journey up the sides of the pyramid to the working face.

could attempt to solve them by the methods which they would have used.

We know by actual measurement the size and weight of the blocks of stone commonly employed at this time, as well as the methods of quarrying them and the location of at least some of the quarries. We know that such blocks were moved on wooden sledges, of which remains have been found, and that there is no evidence as early as the Fourth Dynasty for any knowledge of the wheel, the pulley or the derrick. We know that inclined planes or ramps were employed in raising stones, for at Giza itself there are the remains of at least two, one in an unfinished part of the Funerary Temple of Mycerinus, and another against the side of one of the large *mastabas* (rectangular tombs with sloping sides and flat tops) in the western cemetery. These ramps show a slope or incline of not more than one in eight. We can reasonably infer, from remains found at one of the Middle Kingdom pyramids at Lisht, that wooden timbers were laid like railway cross-ties on the ramps so that the heavy sledges could slide over them with reduced friction, especially when the timbers were wetted or greased. These timbers would also have the effect of preventing deterioration of the roadway from the passage of the sledge runners, since the ramps were made of rubble bound with Nile mud. We also know that the Egyptians of the Pyramid Age did not have draught animals and that the power used must needs be that of men hauling on ropes. Finally, we had observed in many instances at Giza and elsewhere that it was the practice to lay masonry with its exposed faces unfinished and to dress the final surface beginning at the top and working down.

4. General view of the half-finished pyramid, showing the system of rubble construction ramps on the south and east faces. Blocks are being dragged up three of them, while the fourth is reserved for workmen descending with empty sledges. In the background may be seen the northwest corner of the Second Pyramid with its enclosing walls, and beyond some of the *mastaba* tombs of the great West Cemetery at Giza. In the far distance the Nile valley is shown during the inundation which extends to the edge of the western desert plateau.

5. Close-up view of the south face of the model of King Mycerinus' pyramid under construction. The scale is 1:120, as shown by the man's hand. Gangs of men are hauling blocks up the ramps which have been built against the stepped faces of the still undressed casing blocks of the pyramid. Behind, men with levers assist, while others pour water on the timbers over which the sledges slide up the gradient. The second ramp from the top is reserved for descending traffic.



All these points were fairly clear and undisputed. What was not known was just how construction ramps were disposed in order to deliver materials to the working faces in sufficient quantities and at sufficient speed to make possible the completion of the monument within the reign of the king—in the case of Mycerinus, not more than twenty-eight years. (Cheops, who built the Great Pyramid, which is much larger, reigned only twenty-three years.) The reconstructions hitherto generally favored have proposed ramps running perpendicularly to the face of the pyramid, but these have serious drawbacks and I believe them to be out of the question as means of bringing the great mass of blocks for the main bulk of the structure, for every time the building rose by only a few courses the entire length of such a ramp would have to be extended and raised in order that the slope might remain reasonably easy. During such extension the ramp would be out of use and the waste of time represented, not to mention the labor and materials required, would render such ramps quite impracticable. It is true that traces of such vertically placed ramps have been preserved in a few places, notably at Medum, but I venture to suggest that they are most likely to have been constructions erected for the removal of casing blocks from these ancient buildings which were so extensively used as convenient quarries in later centuries.

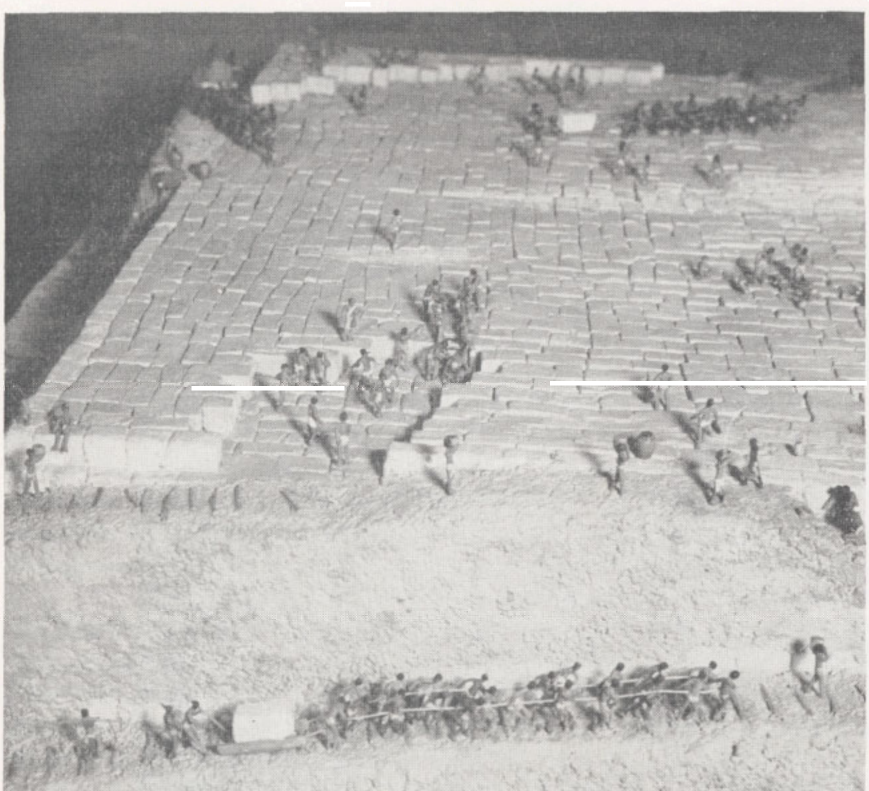
The main bulk of the pyramid was constructed of blocks of limestone taken from various quarries in the immediate vicinity. One of these lay close at hand to the south of the pyramid and was excavated by the Harvard-Boston Expedition. It is represented in Figure 2, where the terracing of the rock face and the roadways for removal of the blocks may be seen, the latter laid with timbers on which the transport sledges could slide without cutting into the surface of the roadway. Since this particular quarry lay at a level considerably below that of the base of the pyramid, the blocks from it had to be dragged by a circuitous route to the east and north in order to reach the main construction causeway which rose in a gentle slope from the Nile valley westward to the site of the monument. Figure 3 shows the upper end of this causeway and the area immediately east of the pyramid itself: an area artificially leveled and destined to be the site of the pyramid's funerary temple. This temple site served as an assembly and distribution area for the blocks, and probably for dressing of the joint faces of those destined for the casing. The casing blocks were of two kinds: the fifteen, or possibly sixteen, lowest courses were cased with blocks of red Assuan granite, quarried at the First Cataract and brought down the Nile on barges; the upper courses were made of fine white limestone from the great quarries at Tura, and were brought across the valley during the annual inundation when barges could deliver them by water to the base of the main causeway.

Figure 4 is a general view of the model and shows the arrangement of the ramps for reaching the working area, in this case when the pyramid was about half finished. There are four ramps, one starting at each corner and rising at a slope of one in eight (see drawing, Figure 8). Since the casing-blocks were left rough they formed a step-like surface which gave adequate footing for the rubble and mud ramps, which had a considerable batter on the outer face for greater stability. Given the known angle of the pyramid slope, this allowed of a roadway on each ramp about ten feet wide, sufficient for the accommodation of the sledges and a double file of men hauling them up the incline. This arrangement of ramps seems both practical and economical of labor and materials. Each of the four remained in use throughout the construction and only had to be extended at the upper end as the building rose. We envisage the use of three for the delivery of blocks to the working area, while the fourth would be reserved for the men descending with empty sledges to get more blocks from the assembly area. This organization of a circulation system agrees with present practice in large-scale excavations where the workers returning from the dump with empty baskets follow a different route from those going out with their loads.

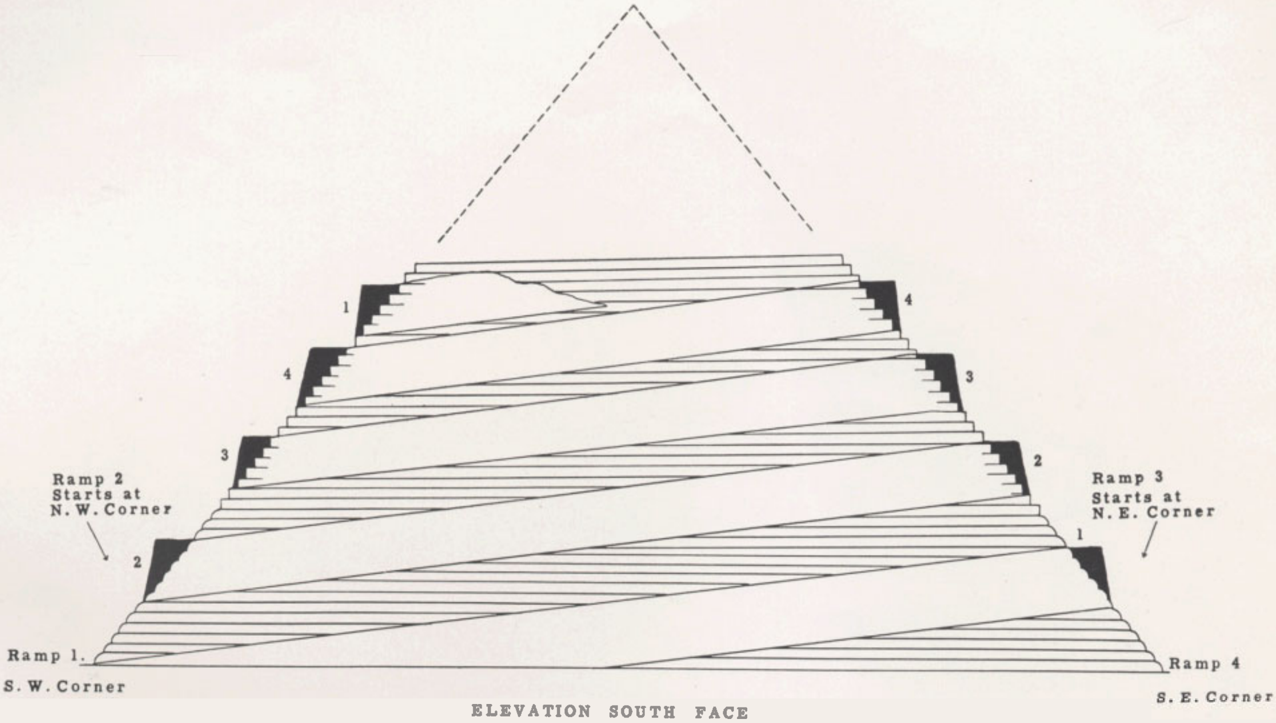
In Figure 5 a detail of the south face of the pyramid shows the scale of the model compared with a man's hand. It also shows blocks being hauled up the ramps with eighteen to twenty men pulling on the ropes and others with long levers giving added power when needed, and holding the sledge from sliding back when the men on the ropes had to stop for a rest, which they must have done several times during the long haul to the top. Other men may be seen carrying jars of water for the men to drink or for wetting down timbers to reduce friction, some carrying spare timbers for the roadway, and others with baskets of materials for the extension of the ramps. On one ramp we may also see workmen descending with empty sledges after delivering their loads.

One of the problems involved in negotiating such relatively narrow ramps with lines of men hauling on ropes was how to get them around the corners. As the loaded sledge approached a corner it would become impossible for the men at the front to continue pulling in a straight line. We attempted to solve this problem by placing

6. Detail of the southeast corner of the model. In the center a block is being maneuvered around the corner with levers. A heavy post at the corner acts as a pivot around which the sledge is turned. Below, extra men await the arrival of a loaded sledge to assist it around the corner. The timbers on the roadway, wetted or greased, reduce friction of the sledges, which carry blocks weighing over two tons.



7. Looking diagonally down at the top of the half-finished pyramid. In the foreground a block is approaching the top. Above, men are extending one of the ramps. Other workmen are levering a core block into position under the watchful eye of a foreman, while in the background a new course has just been started. The rising joints of the casing have been carefully fitted but their faces are left rough, to be dressed back to the pyramid angle when the building is completed. Jars of water are placed at intervals for the thirsty workmen.



8. Elevation of the south face of the Science Museum model showing the distribution of construction ramps. Starting at each of the four corners, they are numbered. At the stage represented ramps 1 and 4 have each made a complete circuit of the pyramid.

BUILDING AN EGYPTIAN PYRAMID *continued*

heavy posts upright at each corner, braced against the wall behind with additional timbers. As the line of men came to this post they would turn the corner, allowing the ropes to bear against this post, and so transmit its pull at right angles. As the loaded sledge reached the same point, men with levers at the front and rear of the sledge could then work it around, using the post as a bearing point. We envisaged extra men stationed at each corner to facilitate this maneuver. We also widened the ramps slightly at each corner to allow more room for manipulation at these points. Figure 6 will give an idea of how this was done.

Figure 7 shows the working face on top of the rising structure. In the foreground a block is coming up one of the ramps. Immediately above, some men are extending the end of another ramp and to the left still others are completing the laying of core blocks on a nearly finished course, a gap to be filled in later having been left in the casing for the purpose. In the distance a new course has been started, the blocks for its construction coming off another ramp. In actual fact it is probable that the core of the pyramid was composed of rather more irregular blocks than those represented, and there may well have been a number of internal or "accretion" faces, for while there is no definite evidence of such in any of the three major pyramids at Giza, they do exist in other and more ruined pyramids both earlier and later. The casing blocks, of fine Tura limestone, are represented in our model as being whiter than the core blocks. Upon completion of the structure they would have been dressed back progressively from the top down as the construction ramps were removed, and when finished the pyramid would have presented a smooth even slope from top to bottom.

The Science Museum model gives a graphic picture of one way in which the Third Pyramid may have been built, and one which the writer believes would have been feasible with the knowledge and equipment possessed by the Egyptians of the Fourth Dynasty. There is not, of course, any way of proving that it is correct and it is presented, therefore, simply as a plausible suggestion. One further comment may be of interest. Herodotus says that 100,000 men were employed in building the Great Pyramid. Our model shows approximately 2500 figures, and one doubts if very many more could have worked efficiently within the area represented. There must, of course, have been many more men employed in the various quarries and in transport work, but even so the writer is inclined to wonder whether the figure of 100,000 for the Great Pyramid was not a piece of gross exaggeration.