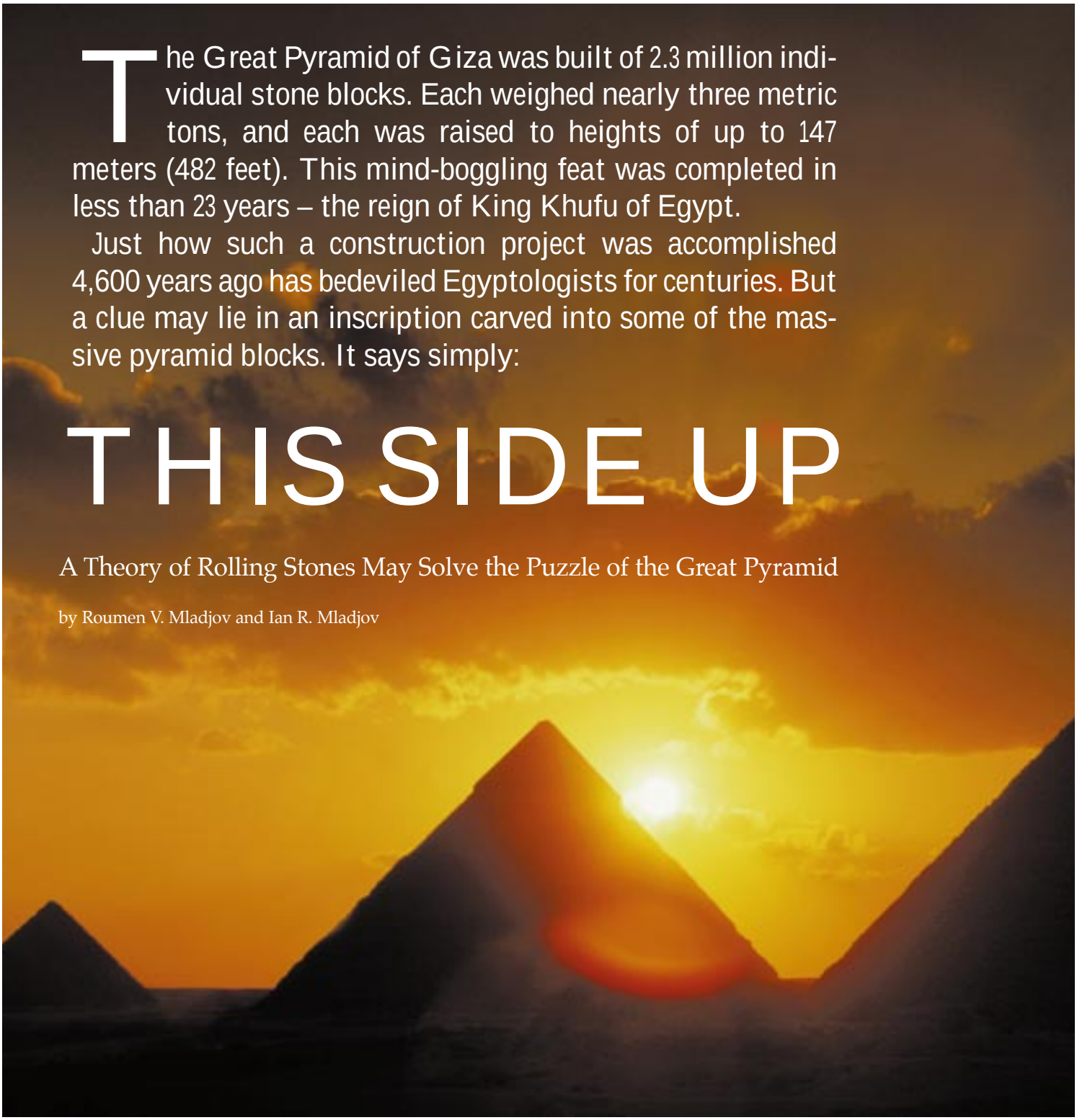


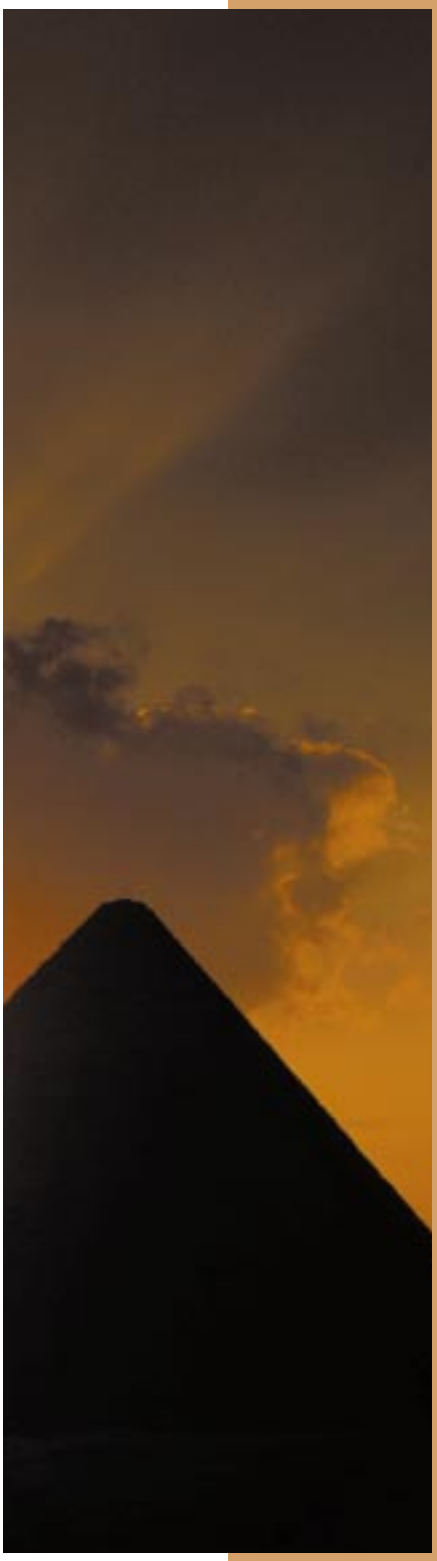
The Great Pyramid of Giza was built of 2.3 million individual stone blocks. Each weighed nearly three metric tons, and each was raised to heights of up to 147 meters (482 feet). This mind-boggling feat was completed in less than 23 years – the reign of King Khufu of Egypt.

Just how such a construction project was accomplished 4,600 years ago has bedeviled Egyptologists for centuries. But a clue may lie in an inscription carved into some of the massive pyramid blocks. It says simply:

THIS SIDE UP

A Theory of Rolling Stones May Solve the Puzzle of the Great Pyramid

by Roumen V. Mladjov and Ian R. Mladjov



Why would ancient builders inscribe such a note on a rock that would simply be dragged up a ramp? Orientation should not have been a problem: Such heavy, squared blocks were unlikely ever to be tipped upside down.

This curious inscription makes sense only if we reject the popular hypothesis – that huge gangs of men dragged the blocks up temporary ramps. We propose instead that the rectangular blocks were literally rolled up the ramps and onto the growing pyramid.

A few other authors, recognizing problems with dragging hypotheses, have suggested various rolling devices, although few if any directly address pyramid construction. Our hypothesis is unlikely to be the final word, but we believe it is viable in terms both of engineering and of the technological capabilities of the time. We hope it will ignite more discussion of an issue long considered one of the unsolved mysteries of the ancient world. Certainly, an alternative theory for construction of the Great Pyramid is clearly needed.

The most popular modern hypothesis suggests the stone blocks were hauled by ropes up huge ramps. This dragging theory is based on the general conclusion that, at the time of the pyramids, Egypt did not use the wheel. In addition, images on a number of artifacts from this and later Egyptian periods show scenes of dozens to hundreds of men dragging enormous stone sculptures.

A second theory grows from a description by Greek historian Herodotus, writing 1,400 years after the last stone pyramids were built. He wrote vaguely of machines used to raise the stones, but no one has proposed a viable solution for machine-based construction.

An insurmountable weakness of the dragging theory is the great number of blocks that had to be moved into place. By our calculations, placing 2.3 million blocks in 20 years, would require placing an astounding 426 blocks per day. That rate of construction would be impossible, even if all 23 years of Khufu's reign were devoted to it.

We assume crews worked 10 hours a day, seven days a week for 270 days a year (subtracting three months a year for harvests, religious holidays and time to extend the ramps to each new height). We also assume dragging teams of 25 to 35 men, with two teams working each of two ramps. Given the very low efficiency of labor under such heavy conditions, we concluded an actual hauling time of four hours a day, excluding time for breaks, lunch, returning to the starting position, and so on.

Too Many Stones

To move so much stone, the teams would have had to drag the 2.85-metric ton (6283-pound) blocks upward at an average speed of 1.6 kilometers (almost one mile) per hour. It's unlikely that could be accomplished for a single stone; to maintain this speed block after block, day after day, is clearly impossible. There must be another solution.

Hemiunu, the official charged with building King Khufu's pyramid from about 2550 to 2530 B.C., must have realized the vastness of the task he faced. Other pyramids had been built, but the scale of this one was unprecedented. He had to reduce the workload.

First, Hemiunu picked his site wisely. He chose an outcrop, with an average thickness of perhaps five meters (16 feet), and incorporated it into the foundation of the pyramid. That existing

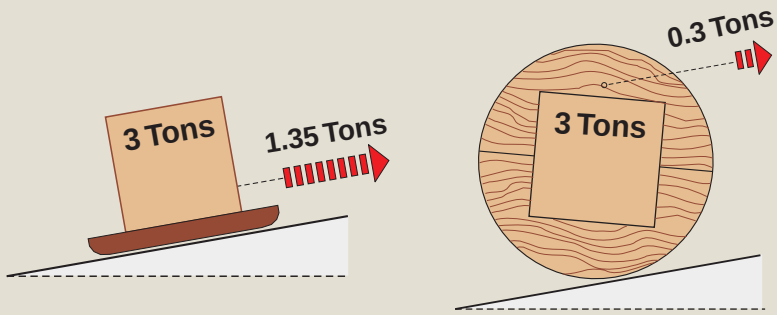
rock may well have amounted to about 8 percent of the total volume.

Then, through excavations, the ground level surrounding the pyramid could have been lowered by six to eight meters (20 to 26 feet). B y digging down instead of piling up, the builders would have effectively added that much to the pyramid's height and another 12 percent of its volume. Such clever strategies could account for fully one fifth of the pyramid's total volume.

But even so, the builders still faced the daunting task of placing 1.85 million blocks. Based on our previous assumptions, that works out to an average speed of 1.4 kilometers per hour – still impossible to achieve by dragging.

But rolling a three-metric ton stone would require just one-fourth the force needed to drag it, so that speed could be maintained. And work crews could be reduced to 12 to 15 people, so more teams could work simultaneously atop the ramps.

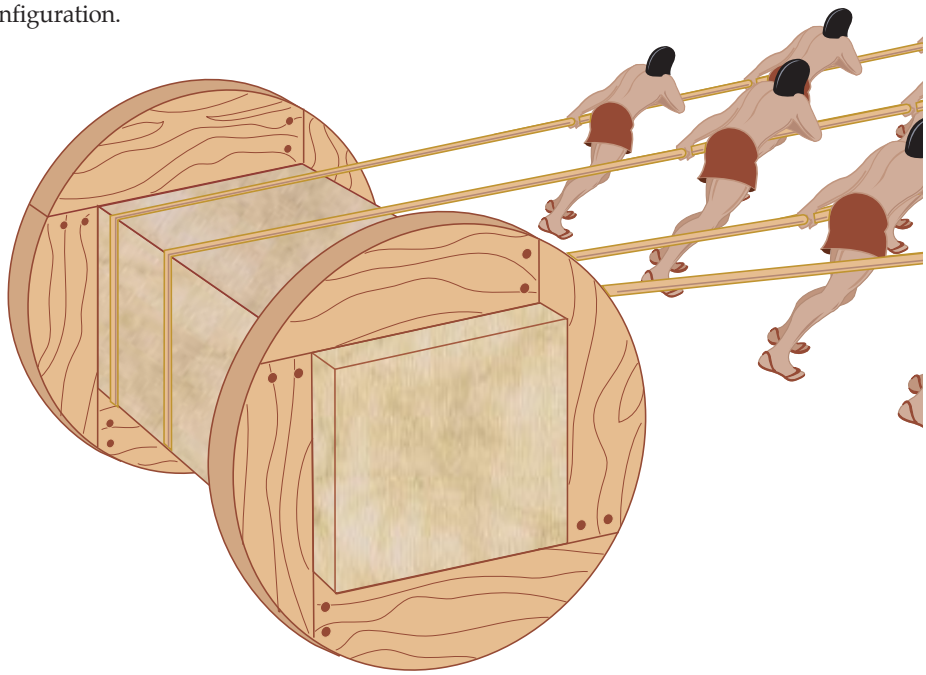
But what could the Egyptians have used to roll rectangular stones? The biggest stumbling block to this hypothesis is that Egyptians of this time were not believed to have possessed the wheel.



Engineering computations show that the force necessary to drag a typical three-ton stone block mounted on a sled is 1.35 tons. Build a wheel around the same block and roll it up the same slope and the required force falls to just 0.3 tons.

Where's the Wheel?

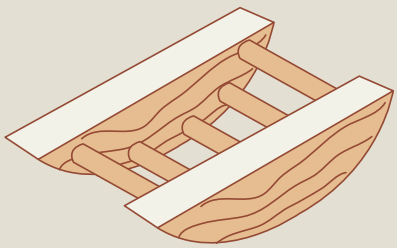
We are not suggesting the Egyptians used carts to move the blocks; just getting the stones on and off a cart would have been extremely difficult. What the Egyptians needed was not the cart and the wheel, but the principle of rolling. A simple assembly of curved wooden parts can create a solid wheel-like device around the block. Mounting such a device near either end of the block would give it an easy-to-roll configuration.



Such removable, wooden devices may, in fact, explain the mysterious "rockers" known from the New Kingdom (1550-1070 B.C.), which some scholars believe were parts of presumed levering machines used to raise the stones. The rockers comprise a pair of thick wooden boards with curved bottom edges shaped like the supports used today for rocking chairs; they were connected with round wooden bars.

We think such rockers or similar components were parts of the rolling device. Four interconnected rockers (or two semicircular ones) near each end of the block would form, in effect, two solid wheels.

This theory would be the only sensible explanation for the "This Side Up"

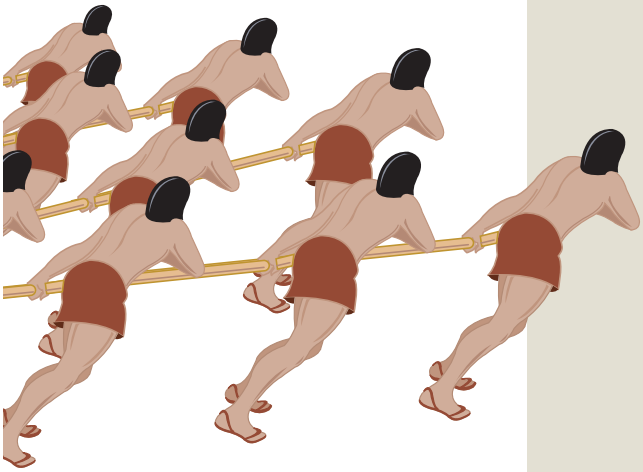


Timbers shaped into rockers have been identified in ancient Egypt. The authors believe such rockers may have been parts or prototypes of rolling devices for pyramid blocks.

inscriptions. A stone shaped to fill a specific gap would need to be oriented correctly before placement. That should be automatic if it was simply dragged. If, however, it was rolled end over end, its orientation would change constantly on the trip upward.

The most compelling argument for dragging comes from depictions of colossal statues being dragged on sleds. Our hypothesis, however, applies only to regularly shaped blocks of consistent weight. Very large blocks, such as those used to top the King's and Queen's chambers, the capstone of the pyramid and irregularly shaped statues, would require another method of transport.

The assumption that the Egyptians were already acquainted with the principle of the wheel is often questioned. However, a royal tomb excavated at Ur, a city of Sumer in present-day Iraq, yielded the remains of heavy carts and battle chariots with solid wooden wheels, each built of two semicircular pieces. The tomb is dated to about 2600 B.C. Another Ur tomb from the same period revealed a mosaic-decorated box, now known as the "Standard of Ur," which portrays a procession of war chariots with four solid wheels.



This solid wheel was used in Sumer, and the Egyptians had ample opportunity to borrow, if not the wheel itself, at least the principle of rolling, since cultural exchange between the two regions was extensive.

In Egypt itself, a bas-relief on a tomb at Saqqara, depicts a siege ladder on wheels. The tomb is only a century later than the Great Pyramid. And our hypothesis is based on a significantly simpler device than the wheel itself.

Cutting the Rocks

One last line of evidence involves the size of the stones used to build the pyramids: To accomplish this enormous amount of work, the Egyptians must have chosen the optimal average block size to minimize the total work of quarrying, transporting, and arranging the stones.

The larger the block, the less work required to quarry it. For example, quarrying one block of 27 cubic meters (954 cubic feet) requires three times less work than cutting 27 blocks of one cubic meter (35 cubic feet) each.

Once the Egyptians were able to haul heavy blocks, they must have used the largest possible size to reduce total effort. Hauling heavier loads requires more people on each team, but the same number of people per ton. Thus, a smaller number of heavier blocks would not only reduce time at the quarry, it would get more stone moved into place more quickly.

Yet rather than choosing, say, 10 cubic meters for their typical block, the ancient builders used stones that averaged just over one cubic meter. Why? They must have possessed a technology that allowed them to transport the smaller blocks more efficiently.

The most likely explanation is the rolling technology. The blocks must have been the largest that could be rolled, possibly because of strength limitations of the rolling device or pressure limits of the ramp material.

This hypothesis explains for the first time three major issues in building the Great Pyramid: the required transportation speed, the "This Side Up" inscriptions, and the average block size.

We envision small teams of men mounting consistently shaped blocks of two to three tons each on wheel-like devices, rolling them up ramps and sliding them correctly into place. The device itself would have been disassembled and brought back down from the growing artificial mountain to be reused on the next stone destined for a place in the Great Pyramid. This went on, day after day, for 20 years. □

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