

# The Rolling Stones

by JOHN D. BUSH, '55

I once had to move a 16-ton block of granite by tumbling it end over end, and it occurred to me that, if I tied segment-shaped pieces of wood on four of the block's faces, it would roll like a drum. Since the idea seemed simple enough, I wondered if someone else might not have thought of it first. I looked up a few books on the pyramids, and sure enough, the Egyptians had the perfect device for the job—something known as a "cradle."

According to S. Clarke and R. Englebach in *Ancient Egyptian Masonry*, numerous models of cradles have been found. But, as far as I can determine, no one in recent times has suggested using four of them for moving stones with a parbuckle. A parbuckle is a sling for rolling cylindrical objects up or down an inclined plane. It consists of a rope looped over a post or the like, with its two ends passing around the object being moved.

I tried making a model cylinder using a 20-pound granite cobblestone. The stone is not a perfect rectangle so my cylinder is more oval than round. Nevertheless, it has so little friction that it will roll by itself down a 1°-slope.

That corresponds to a coefficient of friction of less than 2 percent.

There are three reasons why it is vastly easier to hoist a drum by parbuckling than by hauling it on a sledge with rollers. First, rolling friction is inversely proportional to the diameter of the roller. As far as we know, the Egyptians' rollers were small—about three inches in diameter according to Clarke and Englebach. But a pyramid-block cylinder would be about 16 times that diameter. Therefore, the rolling friction would be cut to one-sixteenth.

Second, the friction of a sledge is two times worse because it has double friction: The sledge rolls on the rollers at the same time as the rollers roll on the ground.

Finally, with sledges, the haulers must not only raise the load but also their own body weights as they march ahead of the vehicle. This could easily cut their usable output in half. With parbuckles, however, the men can haul on the level as the stone rolls up the ramp. If we multiply these three factors together, we find that the parbuckle-cradle hoist could be as much as 64 times more efficient than a sledge.

We can also calculate the *theoretical* minimum number of haulers needed to build the Great Pyramid. A man's output for an eight-hour day is about one-tenth horsepower, or 55 foot-pounds per second. If he puts in a six-day

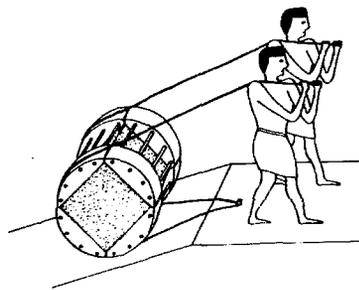
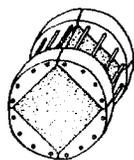
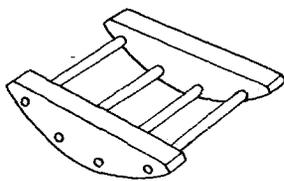
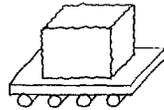
week, the man's output totals 0.5 billion foot-pounds per year.

Next, multiply the weight of each course of stones by its height above the base, add up these products, and you get a grand total of 1.8 trillion foot-pounds. That's the total potential energy, due to gravity, of all the blocks in the pyramid. Dividing 1.8 trillion by 0.5 billion, you find you need 3600 man-years of hauling.

Historians are generally agreed that the Great Pyramid was built in about 20 years. Therefore, it seems the Pharaoh would need  $3600 \div 20$ , or 180 haulers. But that figure would apply only if the men worked continuously at 100 percent efficiency. The mechanical efficiency of the parbuckle-cradle hoist could easily be 50 percent; and if the men spent half their time walking back for the next block, the overall efficiency would be 25 percent. Therefore, the Pharaoh needed four times as many haulers as the theoretical minimum, or 720.

The conventional method of building a pyramid with sledges would require hordes of slaves—perhaps as many as 100,000. There's considerable doubt whether that much manpower was available in ancient Egypt. But a fraction of 100,000 could have done the job with parbuckles and cradles.

Surprisingly, the archeological evidence supporting the sledge theory is meager, and even proponents of the theory like Clarke and Englebach have acknowledged that the evidence is comparatively slight. Only a few sledges have been found, and they were all much too big to haul pyramid blocks. It is generally agreed that the Egyptians were efficient organizers of manpower, and since they built up columns of drums of stone, they must have discovered how easily drums rolled. Therefore, using cradles to roll blocks would have been a simple, logical extension of rolling drums. We may never know for sure just what they used, but I'd bet on the "rolling stones." □



... cradles around a block . . . make a cylinder . . . which can be parbuckled.