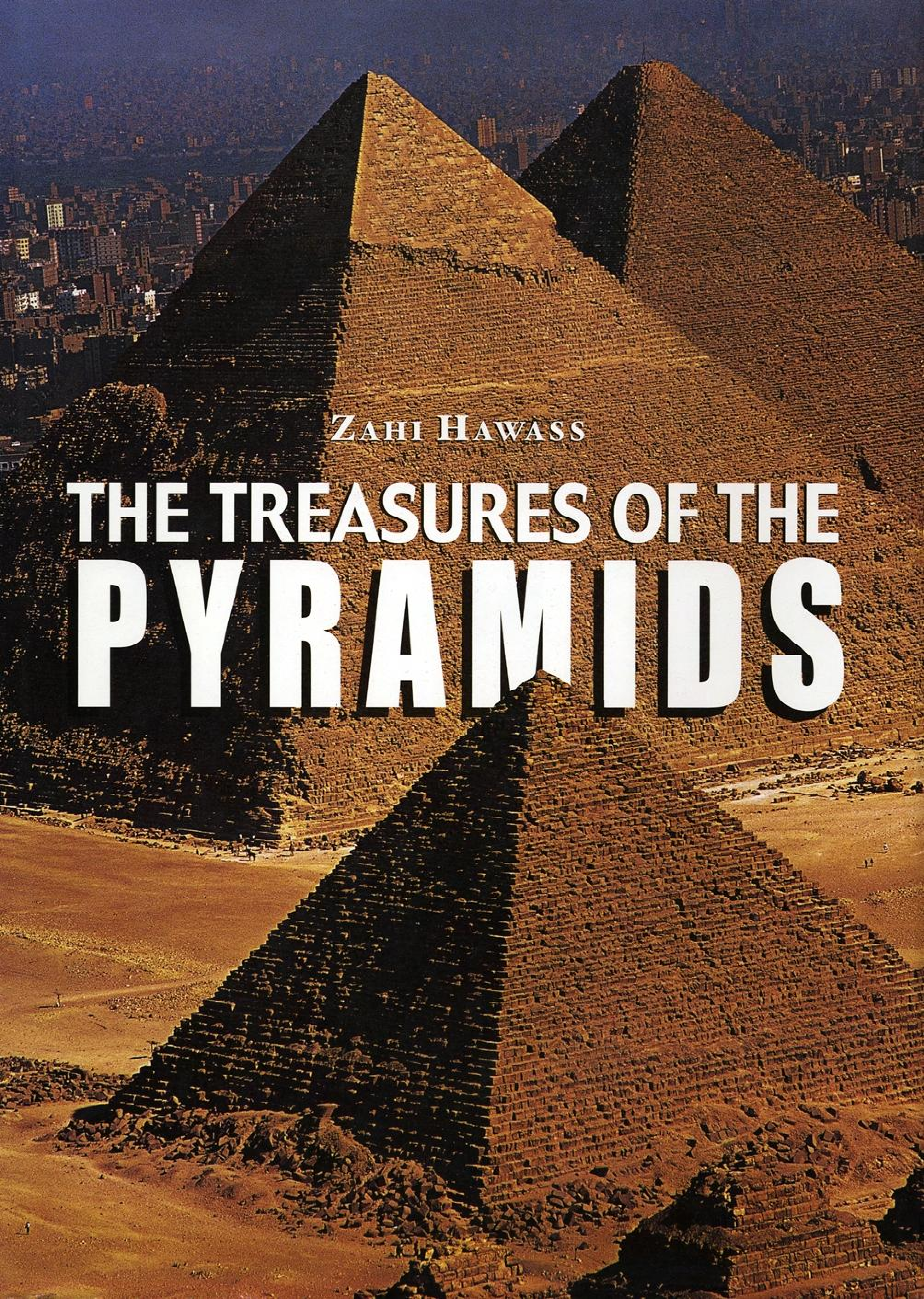
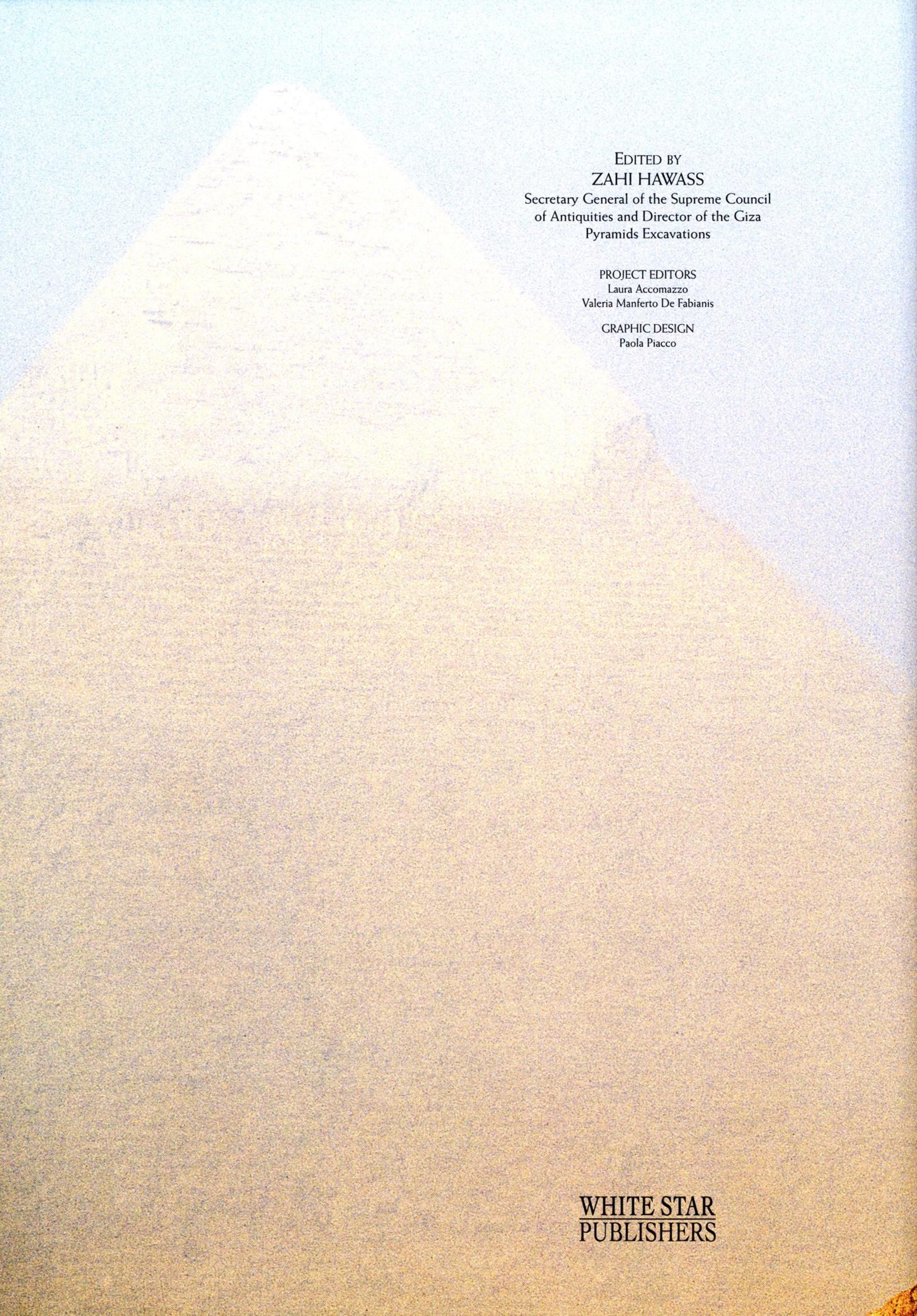
Zahi Hawass

THE TREASURES OF THE PYRAMIDS





EDITED BY

ZAHI HAWASS

Secretary General of the Supreme Council of Antiquities and Director of the Giza Pyramids Excavations

PROJECT EDITORS

Laura Accomazzo

Valeria Manferto De Fabianis

GRAPHIC DESIGN

Paola Piacco

WHITE STAR PUBLISHERS

THE TREASURES OF THE PYRAMIDS

Contents

The Publisher would like to thank:
H.E. Farouk Hosny - The Egyptian Minister of Culture;
Nabil Osman - President of the Egyptian Information Center;
Attiya Shakran - General Director of the Cairo Press Center;
M. El-Damaty - Director of the Egyptian Museum, Cairo;
Mena House Oberoi Hotel, Cairo;
Gamal Shafik of the Cairo Press Center;
The curators and assistants of the Egyptian Museum, Cairo;
Rajiv Kaul;
Guido Paradisi and Fabio Calamante - photographers' assistants.

The Editor would like to thank Mark Linz and Neil Hewison of the American University in Cairo Press. He also wants to thank Essam Shehab of the Giza Inspectorate, and Mohamed Ismail, Mohamed Megahed, Brook Myers, and Sahar Mabrouk from the Technical Office of the Supreme Council of Antiquities.

10-11
Scene showing the 'Meidum geese,' Egyptian Museum Cairo, Old Kingdom.

© 2003 White Star S.r.l.

Via C. Sassone, 22/24
13100 Vercelli, Italy
www.whitestar.it

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without written permission from the publisher.

ISBN 88-8095-233-1

Reprints:
1 2 3 4 5 6 07 06 05 04 03

Printed in Italy by Officine Grafiche De Agostini
Color separation by Fotomec, Turin

Building an Old Kingdom Pyramid

by Mark Lehner

The question, "How did the Egyptians build the Pyramids?" is commonly asked with the gigantic pyramids in mind and it seeks some kind of standard answer. There are only five or six gigantic stone pyramids, built within only three or four generations. The irony is that just these pyramids, belonging to the experimental phase of pyramid building, show the greatest variation in construction materials, sizes, and methods.

It is also the case that in such colossal pyramids there are a variety of 'how-to' questions. Not only how do you survey such a perfect square across many acres of surface, level the base, maintain control of slope and square as you build upward surrounded by debris and ramps, but how do you choose a site, and select a quarry? How do you quarry the blocks, haul the blocks, lift the blocks, and place the blocks? What do you use as mortar, how much hard granite do you use, how do you dress the hard granite, how do you dress the many acres of the pyramid face into smooth even sides?

Mundane operations, not to be taken for granted, include loading and off-loading multi-ton blocks on a transport sled or boat, turning corners with heavy blocks as laborers ran out of space near the top of the pyramid. Acres of casing stones had to be smoothed with small chisels. All these facets had to operate in harmony to ensure that the crew completed the pyramid within the lifetime of the king. The sum total of all these tools, techniques, and operations was the *technical system* of pyramid building.

With most of the questions, we have the Great Pyramid of Khufu in mind—the apogee of pyramid construction. Many of the answers might have little to do with the construction of a Sixth Dynasty pyramid, or a mud-brick pyramid of the Middle Kingdom, but some of the answers will be the same (dressing the outer face, for example). On the other hand, much of what has been written assumes a generic pyramid on a level surface.

Stone Transport

Tomb scenes rarely show transport or other operations of pyramid building (and why that is the case is an intriguing question that would take us too far afield here). However, the tomb artists did render coffins, possibly of stone, transported on small boats. The coffin is raised off the deck by a series of supports. The relief scenes in the causeway of the Unas Pyramid show the transport, end to end on a single barge, of two granite columns with capitals in the form of palms such as were actually set up in the pyramid temple. They ranged from 5.5 to 6.5 meters in height. The columns in the scene rest on hauling sledges which, like the coffins, are raised off the deck by a support framework of beams or girders. These could have been used to relieve the weight of the load on the deck. The supports could also have had played a role in the loading and unloading, critical operations considering that a 50-ton block of granite, like those in the Khufu Pyramid, would readily capsize any boat if rolled too far to one side.

We must look ahead a millennium, to the New Kingdom, for further pictorial information (with the question in mind of how much that operation could have changed in the interim). Reginald Engelbach thought that in the Eighteenth Dynasty, Hatshepsut's builders loaded and off-loaded her great granite obelisks from the large barges shown on the walls of her Deir al-Bahri temple by building an earthen embankment all around the barge and right up to the deck. Once the obelisk was removed, the barge could be excavated from the embankment. Another possibility is that the barge was brought into a narrow canal so that a series of great cedar beams were thrust underneath the load between the supports. The ends of the beams rested on supports set up on the banks of the canal. The transport barge could have been weighted with ballast and slipped out from under the load.

Whether or not this is feasible (obelisks weigh up to hundreds of tons which might stress any number of cross beams), no transport crews wanted to 'flat bed' their load, whether on ground or on barge. Contact between one face of a multi-ton block and deck or ground gives it inertia of rest, hard to maneuver, and get on the move again. Modern stone workers always keep their load on pivots, supports, or levers until they are ready to set it into place.

The inscription above the scene of transporting Unas's granite columns reads ". . . the coming of these barges from Elephantine, laden with [granite] columns of twenty cubits" or 10.46 m, probably the total length of both columns. A fragment of inscription belonging to the unnamed official responsible for the delivery claims to have made the journey (back?) in seven days, indicating a round-the-clock speed of 5.5 kilometers per hour. The inscription actually reads "four days in transit"!

A Sixth Dynasty official named Weni fetched an offering table from the alabaster quarry at Hatnub, and granite from Aswan for a false door and other parts of King Merenre's pyramid. He says he:

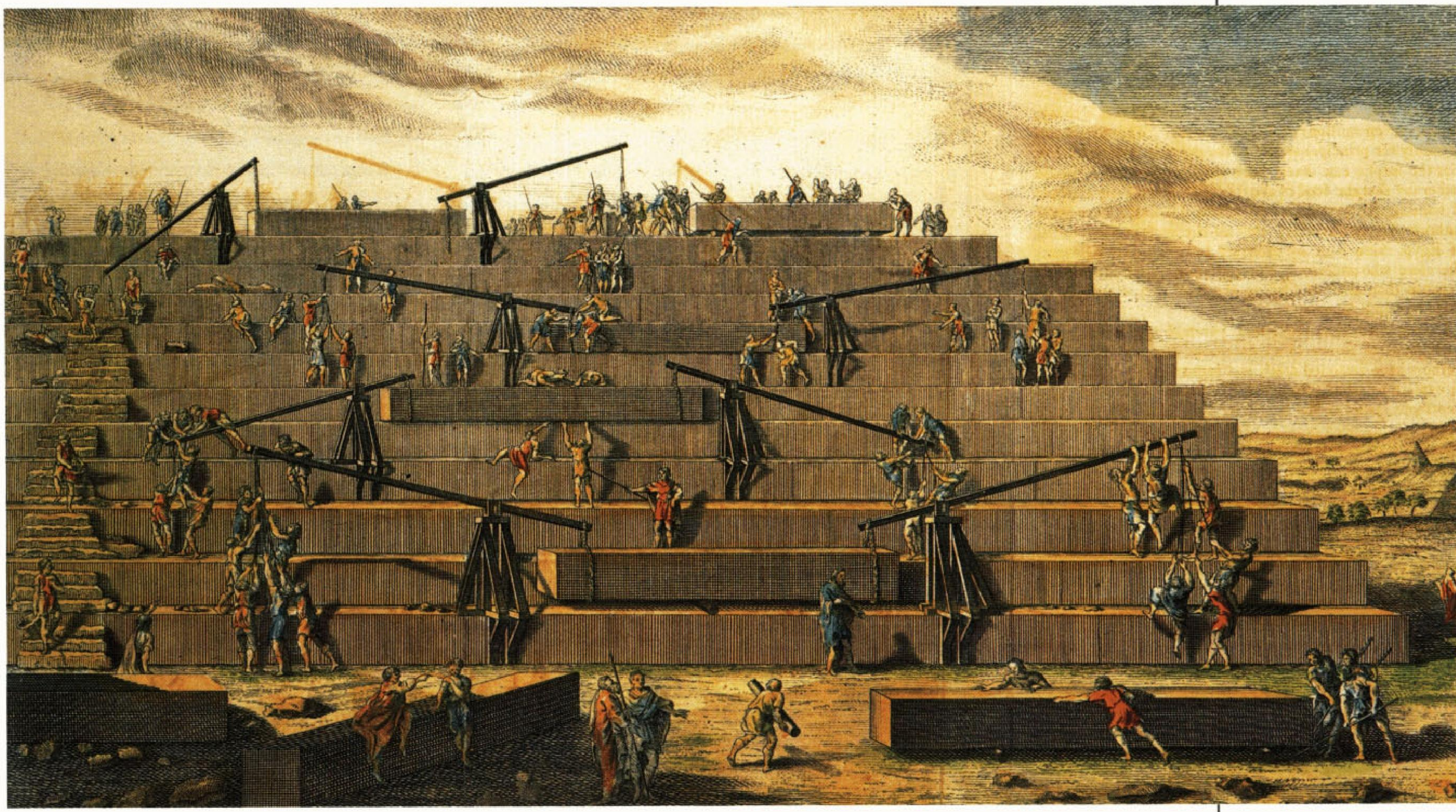
". . . traveled north with them to the pyramid 'Merenre-appears-in-splendor' in six barges and three tow boats of eight ribs in a single expedition.

"His majesty sent me to Hatnub to bring a great altar of alabaster of Hatnub. I brought this altar down for him in seventeen days. After it was quarried from Hatnub, I had it go downstream in this barge I had built for it, a barge of acacia wood of sixty cubits (31.5 m) in length and thirty cubits (15.75 m) in width. Assembled in seventeen days, in the third month of summer, when there was no water on the sandbanks, it landed at the pyramid 'Merenre-appears-in-splendor' in safety...

"His majesty sent me to dig canals in Upper Egypt, and to build three barges and four tow-boats of acacia wood of Wawat (Lower Nubia). Then the foreign chiefs of Irtjet, Wawat, Yam, and Medja cut the timber for them. I did it all in one year. Floated, they were loaded with very large granite blocks for the pyramid, 'Merenre-appears-in-splendor.'"

Weni's boasts about these achievements in the Sixth Dynasty contrast with the silence of the officials responsible for far greater and more numerous loads of granite and alabaster for the gigantic pyramids of the Fourth Dynasty. We have only names, like Hemiunu and Ankh-khaf, who bore the title 'Overseer of All the King's Works.'

Ships were built of pieces stitched together with rope, so that they could be taken apart and reassembled. When the pieces wore out, the pyramid builders might use them like railroad ties in tracks for dragging heavy stones overland to the actual building site. Excavators from the Metropolitan Museum in



New York have found such hauling tracks around the Twelfth Dynasty pyramids of Lisht.

Transport teams used hauling tracks to get the load from the quarry to the river or canal, and from the waterway to the building site. These tracks needed to be hard and solid; nothing stops a two-ton stone block quicker than when it comes to rest on soft sand. At Lisht, the transport roads were five meters wide and composed of limestone chips and mortar. The wood beams were inserted so that their upper faces were buried in the fill. The beams provided a solid bedding. Thin layers of wet mud or gypsum served as lubricant for the runners of the sledge. Construction embankments and ramps that remain intact from the Pyramid Age to this day at Giza are composed of limestone chips, gypsum, and *tafla*, which is a fine, calcareous, tan desert clay as opposed to the gray alluvial clay of the Nile Valley. This mixture occurs in millions of cubic meters at Giza, filling the vast quarried areas along the southeast of the plateau. There is *tafla* between and underneath large building blocks in the Giza Temples; so it was ısed as packing material *and* as lubricant.

Tomb scenes show teams pulling statues of wood or stone on sledges. One worker usually pours liquid, probably water, under the front of the runner of the sledge. The most cited of these scenes is in the Middle Kingdom tomb of Djehutihotep. One hundred seventy-two men pull what is estimated to have been (if it existed in reality) a 58 ton statue of this local ruler. This amounts to one-third of a ton per man. This might have been possible on a nearly friction-free surface. In his work at the Karnak Temple, the French engineer, Chevrier used a sledge and a water-lubricated track to move a five or six ton block with only six workers. In 1991, during the experimental building of a small pyramid for the American scientific documentary television program NOVA, 10 to 12 men could easily pull two-ton blocks mounted on sledges up an inclined roadway.

We have an ancient scene where the Egyptians employ cattle to drag stone or assist humans in pulling. At the Eleventh Dynasty complex of Mentuhotep in Luxor, excavators found the carcasses of draft cattle in the builders' debris. Dieter Arnold pointed out that cattle allow "greater force to be distributed over a smaller area," with one ox being equivalent to five men.

33 top

Schemes about how the pyramid builders raised stones by levering imagine all blocks are well-squared and very regular steps wide enough for working platforms. The reality of the largest pyramids is quite different. Lithograph from the 19th century.

33 bottom

The pyramid builders must have brought much of their support materials (gypsum, wood, grain, copper, and cattle) on small transport boats with truncated prows and hooded sterns. Detail from Egyptian Museum relief, Sixth Dynasty tomb of Ibi.

Quarries: Mass and Material

The size of the base set the goal for the mass of material that the builders had to compose into a pyramid before the king died. Base areas like those of Khafre or Khufu (around 53,000 square meters), demanded, therefore, completion of a pyramid as high as 146.5 meters and 2,600,000 cubic meters of material in the case of Khufu. Surely this reflects the supreme confidence of the royal house in marshalling human and natural resources. Most of the stone for the three Giza Pyramids was probably quarried directly from the plateau, down slope from the great northeast-southwest diagonal on which the pyramids are aligned.

Massive amounts of fine white homogenous limestone, a quality that is not found at Giza, did come into Giza from the eastern quarries of Muqqatam, Maasara, and principally, Tura, for the outer pyramid casings. Supply teams brought granite, the other major type of non-local stone in the pyramid complexes, from Aswan, 933 kilometers south of the pyramid capital zone. Giza builders used red granite extensively for the burial chambers of Khufu and Menkaure, the lower seventeen courses of Menkaure's casing, and for the lowest pyramid casing course and the lining of the temples of Khafre. As much as 45,000 cubic meters of granite was quarried from the Aswan quarries during the course of the Old Kingdom. Pyramid builders imported alabaster and basalt from a variety of places for temple pavements. They used alabaster, granite, and gneiss for statuary, and diorite and quartzite for pounding and polishing tools.

It would have been most advantageous for the builders to quarry the bulk of the core material near the site of the pyramid. We should expect, perhaps, a hole in the ground of an order of magnitude equal to the sizes of the respective pyramids. Some of the large Middle Kingdom pyramids were built of mud brick, and we should expect that a tremendous amount of mud was scooped from the nearby valley floor.

The location of the quarry must have been a major consideration for the pyramid builders. The quality of local bedrock may have been one of the primary reasons for the various kinds of masonry that make up the cores of pyramids. The large 'moat' or depression that is suspected of surrounding the Djoser complex may in fact be the source for much of the filler stone and clay in the pyramid and the massive 'dummy' architecture that surrounds it. At Giza, the geological bedding along the low southeast part of the plateau is comprised of thick layers interspersed with softer thin layers perfect for the extraction of large blocks. Here the quarries for the Khufu and Menkaure pyramids are rather clearly delimited, in the form of great horseshoe-shaped basins.

About 300 meters due south of Khufu's pyramid is the quarry that must have furnished the bulk of its core stone. The deepest part of the quarry is 30 meters below the original surface, so the Fourth Dynasty quarrymen removed close to 2,760,000 cubic meters of stone. Although this is slightly more than the volume of the Khufu pyramid, it is still not sufficient since as much as thirty percent of the stone would have been wasted in the quarry channels. The quarry extends an unknown distance to the south beyond the line of the Menkaure causeway, where Abd al-Aziz Saleh cleared part of the western quarry face for Cairo University in 1980. Much stone was taken from the Central Wadi itself, which represents a volume of 4,400,000 cubic meters. With a combined volume of 5,220,000 cubic meters for the Giza Pyramid complexes, there is enough stone in the quarries at Giza for the cores of the three pyramids, without even considering the quarries specific to the Khafre and Menkaure projects.

Until the excavations in this century, millions of cubic meters of limestone chips, gypsum, sand, and *tafla* filled the quarry south of the Khafre causeway.

34
Blocks at the base of Khufu's pyramid, while not of modular sizes, are enormous, weighing up to 15 tons. The stones get progressively smaller toward the top. This pyramid is founded on a platform of fine limestone.

35 top
Granite casing on Khafre's valley temple. Rather than modular sizes laid in level ashlar courses, the blocks are custom cut and fitted to one another in trapezoidal patterns.

Much of this material could be the remains of the ramp that the workers pushed back into the quarry as they completed the Khufu pyramid. The western edge always showed above surface, but the fact that most of the quarry was buried led pyramid explorers, like Sir Flinders Petrie, to believe that the stone for the pyramids was mostly brought from across the river. When Egyptian archaeologist Selim Hassan carted away much of this debris in the 1920s and 1930s, he exposed rock shelves, about 1.5 m high, that the quarrymen left when they separated blocks the size of those in the core of the pyramid. On the surface behind the shelves are long narrow channels that they cut to define the width of the blocks they would cut away.

Between the basin quarry directly south of Khufu's pyramid and the Sphinx, there is a triangular area that is honey-combed with tombs cut out of the bedrock. Some tombs are burrowed in and are under rectangles of bedrock the size of several railroad boxcars or small houses, separated by yawning corridors. These rectangles are mapped as *mastaba* tombs in Egyptology reference books, but the Fourth Dynasty workmen originally created them in the earlier stages of organizing the surface for quarrying building blocks. In the older Khufu quarry, the rectangles were exhausted, and the quarrymen continued to take out blocks along open banks or terraces. But here, southwest of the Sphinx, they did not exploit the rock as deeply, so one can wander through silent corridors that once resonated with the clink-chink of stone hammers, chisels, and the chanting of workers who pulled away the blocks. The large bedrock blocks are subdivided with narrower channels, just wide enough for one man to fit inside swinging a pick to cut the channel clear through a rock massif that is about one story tall and a few score meters across. There are a few places where the quarrymen separated and then abandoned a block about the size of the great multi-ton blocks in the core walls of Khafre's temples.

The Menkaure quarry, also horseshoe shaped, with the deep end toward the pyramid, lies just southeast of the third pyramid. One can still see here large sockets for wooden levers the size of railroad ties cut in rows along a softer limestone layer. Having separated the block around three sides, the quarrymen had only to pry it up and crack it free.

Quarries at Tura for the fine casing became galleries that followed the best layers of stone deep into the escarpment. To follow the beds of highest quality, the ancient quarrymen would tunnel in and under the overburden of poorer stone, thereby

creating cavernous, rectilinear, covered quarries. They began with a 'lead' shelf cut along what would become the ceiling of the gallery. Then they extracted the stone in terraces or banks, as they did in the bottom of the Giza quarry.

The quarries at Aswan, some 933 kilometers south of Giza, yielded the granite blocks for lining Khufu's burial chamber, for encasing Khafre's pyramid temples, Menkaure's pyramid, for the columns of the Fifth and Sixth Dynasty pyramids, false doors, offering tables, and some pyramid capstones. It has been said the Old Kingdom builders simply took away and then shaped the numerous natural granite boulders found along the First Cataract of the Nile. Given that granite is so much harder to work than limestone, this may be largely true. But the longer granite pieces that the Egyptians worked into the ceiling beams of Khufu's burial vault, and of four of the five stress-relieving compartments above it, and the temple columns throughout the Old Kingdom, were up to 5.5 m long and weighed as much as 60 tons. It is likely that these were separated, like the limestone blocks, by channeling out the mother rock, except that with granite, the channels had to be formed by excruciating pounding with dolerite hammer stones, a technique of quarrying granite that lasted for most of the Pharaonic period. 'Being sent to the granite' must have been the most painful task of all in pyramid building.

Puzzles of Pyramid Building

Pyramid construction was far less regular and standardized than our mental templates have led us to believe or allowed us to see. If the blocks are not of modular sizes, the tools for hauling, such as wooden sledges or cradles, could not be standardized. It is hard to imagine the builders using levers, fulcrums, and cribbage supports to raise 'blocks' that are not square, but trapezoidal or oval or irregular. Given that much of the fill is little more than rubble, it is far more likely that ramps and embankments, rather than fulcrums and levers, were used for lifting material. We even have to wonder if the builders sometimes used the same stony stuff for both ramps and pyramid fill. Also, there was probably no manual for building the early pyramids. Rather, using some basic masonry techniques, the builders varied layout methods, blocks, courses, and other features in an *ad hoc* approach to building one pyramid after another.

Surveying the Base Square

Many assume that finding true north to orient the pyramid, laying out the square of the base, and leveling, were one-time discrete operations. Once the ancient surveyors had drawn the gigantic square on the ground, the builders could receive trains of stone-laden sledges and start setting the blocks. This may have been true for some pyramids—those that were built on the natural desert surface. But for the giant pyramids at Giza, the builders started with a natural stone surface that they carved away, down to the level they chose for the base. They left an irregular patch of natural rock protruding in the middle of the square, up to a height of seven meters in Khufu's pyramid and five meters in the northwest corner of Khafre's pyramid. They built this rock protrusion into the core of the pyramid.

The builders leveled an area approximately about the width of a city street around the base of this core. In fact, their best leveling in bedrock was only about as wide as a modern sidewalk. Their finest leveling of Khufu's pyramid, off by only 2.5 cm in the entire circumference, was on a platform built of fine Tura-limestone slabs. The baseline of Khafre's pyramid was simply a vertical cut in the foot of the bottom course of casing stone, where the slope of the pyramid would meet the top surface of the pavement of the pyramid court. The natural rock was cut into sockets of various depths to receive the granite casing blocks and to bring flush at the top (it was easier to cut away the natural limestone base than the much harder granite). And so, the layout and leveling of these pyramids presents a 'chicken and the egg' situation. In order to know approximately where to level, the builders had to lay out the square. But the accuracy of the square—with the mass of natural rock protruding in the center, needed a surface that was as level as possible.

Therefore, the builders had to proceed in steps of *successive approximation*. They took aim on true north and laid out their reference lines at several stages as they worked the rock down to the broad terrace on which they would build the pyramid, its surrounding court and enclosure wall, and the mortuary temple. At various stages they refined their orientation to the cardinal directions, and the perpendicularity of the corners which became hidden from one another behind the core massive as they quarried away the rock for the final baseline.

Finding True North

Ancient texts call the circumpolar stars 'the Imperishable Ones' because they neither rise nor set as they circle around the celestial pole about 26 degrees up in the northern sky. In a fragment of a scene from the Fifth Dynasty sun temple of Niuserre, the king and the goddess Seshat pound long stakes connected by a looping cord. A wall in the temple of Edfu dating two millennia after the Old Kingdom pyramids shows the king performing foundation ceremonies with Seshat and Thoth, the divine couple associated with writing and science. An inscription from the Temple of Dendara has the king "looking at the sky, observing the stars, and turning his gaze toward the Great Bear."

In his book, *The Pyramids*, I.E.S. Edwards suggested that the ancient surveyors could have constructed a circular wall, "with a diameter of a few feet on the already leveled rock-bed of the pyramid." Standing in the center of the circle and facing north, the observer could mark the point at which a star rose above the wall on his right (east) and where it set below the wall on his left (west). The bisection of the angle between rising and setting points (plumbed down to the base of the wall) and the center of the circle would give true north.

Kochab, Mizar, and 2467 BC

Kate Spence suggested the pyramid surveyors could have found north by observing the circumpolar stars Kochab, in the bowl of the Little Dipper, and Mizar, in the handle of the Big Dipper. Since the celestial North Pole was only aligned exactly with these stars in 2467 BC, she takes that as the date of the founding of the Great Pyramid. Again the theory may work out mentally, but there are practical concerns. Her method requires that the Egyptians find the alignment of the two stars above and below the celestial pole and project it onto the ground with a plumb line. Anyone who has used a plumb line extensively in mapping or building knows how much harder it is to keep the line from swinging, the higher above the head it is held. The celestial pole is some 26 degrees above the horizon, and so we must envision some kind of large wooden frame to hold the plumb line. It is also hard to imagine how any stellar method could have been carried out in the darkness of night without the aid of modern illumination. Spence envisions a ring of "torches everywhere." If so, the trick must have been to illuminate the desired line on the ground, and the plumb line hanging from the frame, without obscuring the light of the distant stars. Finally, all this would have to be done in the very brief time that Kochab and Mizar align with the pole.

Sun and Shadow

The same scenes and texts of building foundations also speak of 'the shadow' and the 'stride of Ra' in connection with cord-stretching ceremonies. Martin Isler maintains that the Egyptians could have accomplished the astonishing precision of north alignment with a simple pole, or *gnomen*, "a stick in the ground, a bit of cord, and a shadow." The shadow method is based on the awareness that the sun rises and sets in equal and opposite angles to the meridian (true north). A pole is plumbed to vertical. The length of its shadow on a level surface is measured about two to three hours before noon. This becomes the diameter of a circle that is scribed with a cord and stick with the pole as its center. As the sun rises in the sky toward noon, the shadow withdraws from the circle. In the afternoon the shadow lengthens again at an angle with the morning shadow. When its end reaches the circle, the bisection of the angle between morning and afternoon corresponds to the meridian. The method is most accurate if carried out during the solstices.

Extending and Measuring Line

However they found true north, the ancient surveyors had next to extend the resulting north line. Their north line was only a few feet if they used the circle and star method. Had they extended it the more than 230 meters (755 feet) from Khufu's pyramid base, the slightest inaccuracy would have vastly increased what surveyors call 'the angle of error.'

Along the extended line, they had to measure the distance of one side of the pyramid base. Then they had to turn good right angles to make the corners. Finally, they had to measure the perpendicular sides to the opposite corners and turn another set of right angles.

The different suggestions for finding north all assume an initial starting point—the center of the circle in both Edwards' north star and in Isler's sun/shadow method. Using the shadow method, they might have used a series of gnomens, arrayed roughly north to south, but staggered slightly east to west. By performing the bisection of the morning and afternoon shadow on each gnomen circle, they would end up with a series of short north lines that paralleled and partially overlapped down the north-south direction. They could use each line as a check for extending the north orientation by measuring the appropriate amount to the master reference line for the pyramid base.

Isler suggested another method, inspired by the scenes of the king with the goddess Seshat, holding stakes with a cord looped double around each stake. A double cord is pulled tangent to either side of round stakes. The line is off when one cord bends on the last stake while the other cord passes without touching the stake. The line is pulled accurately when both cords are exactly tangent to the stake. The exact line is the split between the parallel cords.

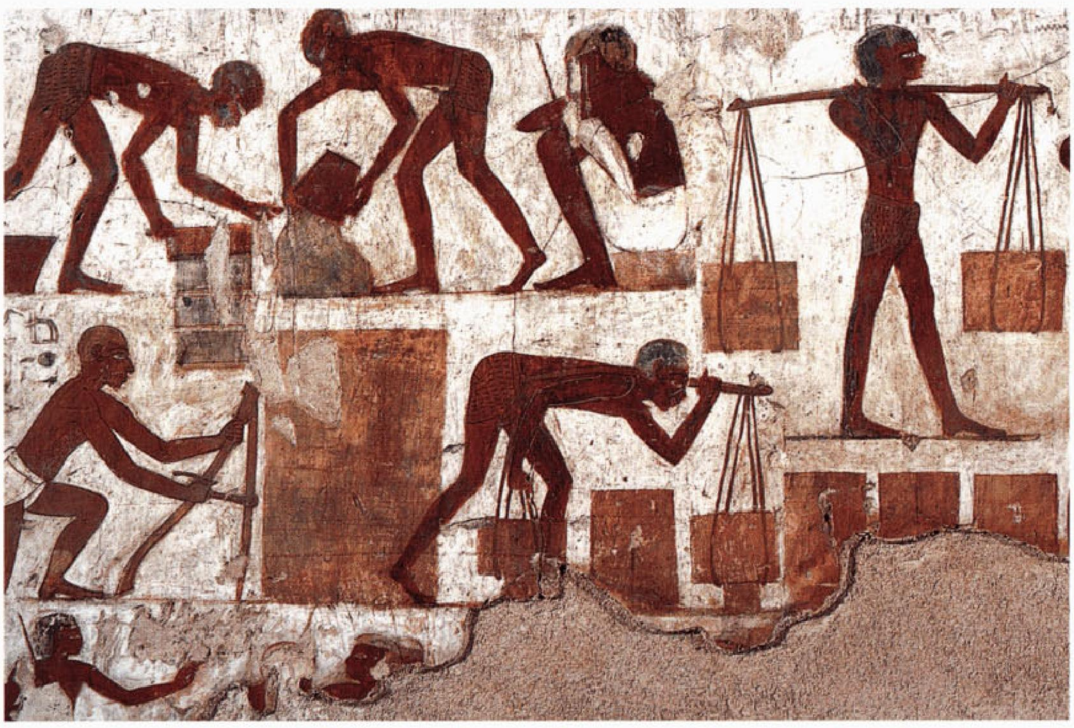
This last method may have required poles of exactly the same diameter. While ancient carpenters could have achieved this, we cannot take this kind of standardization for granted in a technology that did not know the lathe. The parallel line-pole method also requires that the stakes be embedded in the ground. The builders could have simply pounded them in when staking out a temple down on the valley floor or pyramids that were built on the desert clays and gravel. But the *final* layout (after a series of ever-closer approximations) of the pyramids of Khufu and Khafre was on prepared limestone bedrock. Here the builders either had to etch or paint lines on the rock floor, or they had to quarry out small holes in which to set the stakes.

Marks of the Ancient Surveyors

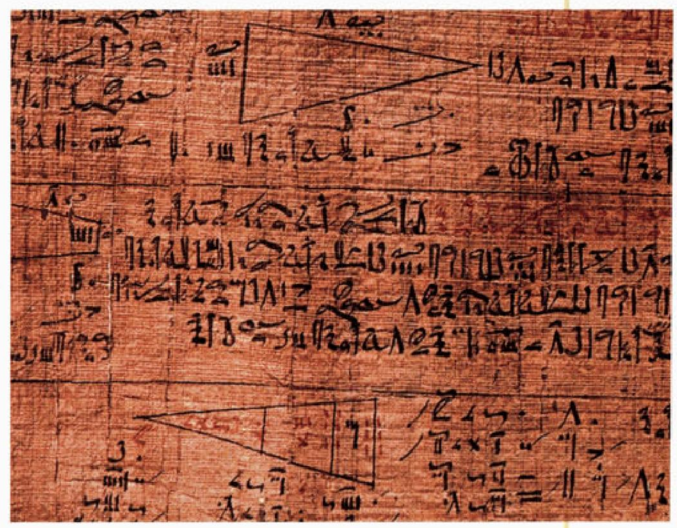
The bottom casing blocks of both these pyramids weighed up to several tons. Moving them into position must have obscured the temporarily drawn baseline. It is likely that the ancient surveyors would have set a reference line *outside* the actual baseline of the pyramid, which would have been scrapped, scratched, pounded, and covered with debris as they began to build the bottom of the pyramid.

In fact, around the bases of the pyramids of Khufu and Khafre we *do* find lines of holes at regular spaces. A series of holes runs along the eastern side of Khufu's pyramid, and partly along the other three sides. The holes are rectangular, with sides varying from 35 to 68 centimeters, from 45 to 85 centimeters deep, spaced from 3.5 to 3.8 m apart (center to center) on line about three meters from the base of the pyramid. The builders fitted many of these holes with slabs of limestone, and obliterated others when they laid

36 top
Tools of the pyramid builders. Left to right: Wooden mallet and copper chisel; mold for mud brick, mattock for digging dirt and debris; triangle with extended sides, and plumb line for leveling.



37 left
Making mud brick, from the tomb of the Eighteenth Dynasty vizier of Thutmose III, Rekmire, at Thebes. The pyramid builders used mud brick in some later Old Kingdom pyramids and ancillary structures.



37 right
Figuring triangles from the New Kingdom Rhind Mathematical Papyrus. The Egyptians figured slopes by a ratio called seked *of so many units rise to run.*

the limestone pavement of the pyramid court at the end of the building project. At Khafre's pyramid there are three separate lines of holes, possibly from the final stages of layout. The holes here are round, from 30 to 50 centimeters in diameter and spaced from 5.1 to 5.9 meters apart. There is a double line of staggered holes along the outside line of the pyramid enclosure wall 13.5 meters from the pyramid base, and another two lines of staggered holes along the inside line of the enclosure wall, from 9.1 to 9.9 meters from the pyramid base. At both pyramids, the holes are wide enough to allow a finer adjusted line of posts which might have carried the final line in cord running over the tops of the posts.

The spacing of the holes, varying within a certain range, is certainly not for measuring distance, but just for carrying line. Egyptian tomb scenes show measuring cords with knots to mark increments. This might have been fine for measuring fields, but probably not for an accurate line and distance as long as 230 meters. Cords stretch and sag, so Khufu's surveyors might have achieved their amazing results with rods.

Ancient Egyptian cubit rods have been found from later times. The royal cubit used in building was 0.525 meters. Joseph Dorner, a modern surveyor and Egyptologist, has shown that the Egyptians could have achieved the length and accuracy of Khufu's baseline with rods of 4 or 8 cubits (2.1 to 4.2 meters).

Constructing a Right Angle

By the time Khufu and Khafre's builders cut the bedrock down to the level of the pyramid base and were ready to scribe the actual baseline, they had already repeatedly performed the extension of the line and turning the right angles for the corners. They began these operations at the original surface of the plateau, some five to ten meters higher. They refined the base square in *successive stages* as they worked the surface down.

For the final layout of the pyramid base, the protrusion of natural rock would have prevented the builders from measuring the diagonals to check the accuracy of their square. At the northeast corner of Khufu's pyramid, enough core stones are missing to expose the natural rock rising in four steps to a height of four meters. Here, the bottom of the bedrock massif is six to seven meters back from the series of holes that may mark the external reference lines for setting and cutting the casing stones to make the base.

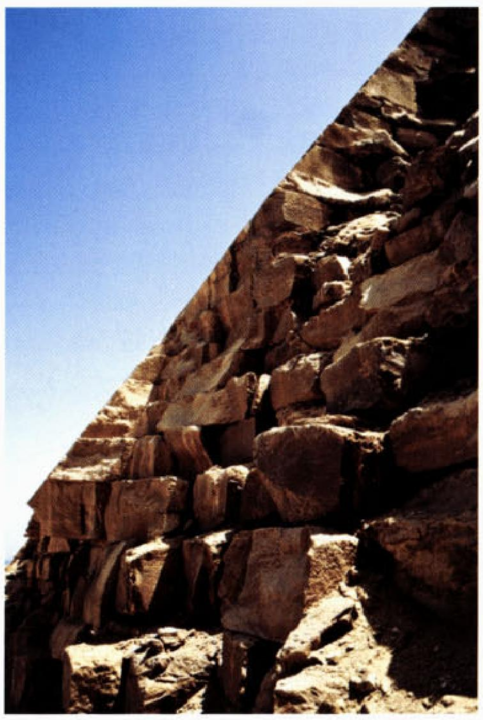
For the corners, the ancient surveyors could have achieved a right angle in three ways. They could have used the 'Sacred' or Pythagorean triangle—three of any unit on one side, four on the other and five on the hypotenuse. Such triangles seem to be present in the design and layout of the Old Kingdom mortuary temples attached to pyramids. But the evidence is not conclusive. Or, they could have used the Egyptian set square—an A-shaped tool with perpendicular legs set at right angles and a cross brace. One leg is placed on the already established line and the perpendicular is taken from the other leg. The square is then flipped and the operation repeated. The exact perpendicular is taken from the small angle of error between the two positions. Thirdly, they could have used a measuring cord to pull two intersecting arcs of the same radius from two points on the same line. A line connecting the points of intersection will be at a right angle to the original line.

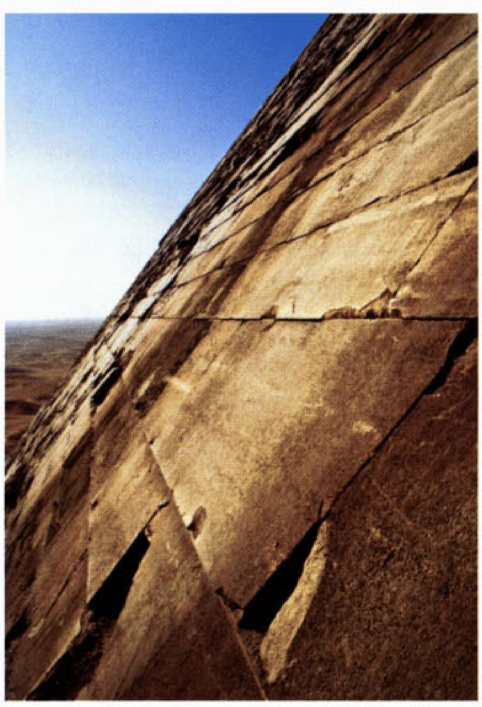
Laying the Foundation Platform

The extraordinarily accurate leveling of Khufu's pyramid, so admired by all, is actually on the surface of the foundation platform, not the bedrock floor. The masons formed the corners of the platform from extraordinarily large slabs, still marked on all but the southwest corner by seats, or sockets, cut several centimeters into the bedrock floor. The setting line of the foundation platform would have been scuffed and scratched as the large slabs were laid in. The line would also have been covered by the extra stock of stone left on the front face of the platform slabs, a practice in evidence on unfinished masonry throughout ancient Egypt. Therefore, an outside reference line would have been required, which may have now been marked by stakes, cord, and pins set into the holes forming a line three meters from the platform. The lines of the front face and upper edge of the platform were marked on each slab as it was laid in by measuring inward from the reference line.

When it was required to cross the reference line to drag in more slabs on a hauling sled, parts of the staked line could have been removed, and later re-established by sighting along the line from either side.

38 top
Casing and backing stones near the top of Khafre's pyramid. The fine outer casing hid tremendous irregularity in the core, packing, and backing masonry.





38 bottom
Looking out across the casing on upper east side of Khafre's pyramid. The slabs are slightly out of flush, indicating they may have been trimmed before setting.

Raising the Pyramid Body

Most pyramids are composed of core stones, making up the bulk of the pyramid. The cores of some, if not all, pyramids have tiers or steps, in other words, an internal step pyramid. The masonry that filled in the steps we could call 'packing stone.' The pyramid was finished off with a smooth outer casing of limestone or granite. The softer stone that the builders set between the core and casing, we might call 'backing stone.'

The Fabric of the Pyramids: Core Stone

Many times it has been written that Khufu's pyramid contains an estimated 2,300,000 blocks of stone, weighing on average about 2.5 tons. Theorists, both professional and amateur, assume that the pyramids are composed of generic two-and-a-half-ton blocks. They then set about solving the puzzles of how the builders raised and set the blocks. If we take the giant Giza Pyramids as the starting point, we should look carefully at their composition, rather than assuming regular courses of modular stone blocks.

At first glance, the Giza Pyramids, stripped of most of the smooth outer casing in the Middle Ages, look like regular steps. These are the courses of 'backing stones,' so called because they once filled the space between the pyramid core and outer casing. At close look the steps are not at all regular. Here is a step more than a meter wide, over there almost nothing! The idea of regular steps is a mental template, one assumed by most theorists. However, instead of regular, modular, squared blocks of stone neatly stacked, there is a considerable 'slop factor' even in the Great Pyramid of Khufu.

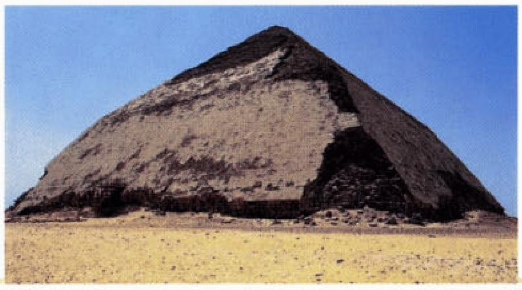
The outer backing stones are not only irregular, but are also progressively smaller toward the top. Behind them, the core stones are even more irregular. During the 1830s, Howard Vyse blasted a hole in the center of the south side of Khufu's pyramid while looking for another entrance. In this wound we can see how the builders dumped great globs of mortar and stone rubble in wide spaces between the stones. There are big blocks, small chunks of rock, wedge-shaped pieces, oval and trapezoidal pieces, as well as smaller stone fragments jammed into spaces as wide as 22 centimeters between larger blocks.

At the base of Khafre's pyramid, the coursing of the core stones are not uniformly horizontal. The builders tailored blocks to fit the sloping bedrock that they left protruding in the core as they leveled the surrounding court and terrace. In the northeast and southeast corners, where the downward slope of the plateau left no bedrock in the core, the builders used enormous limestone blocks, two courses thick, to level the perimeter.

Higher above the base, the pyramid core is made up of very rough, irregular stones. Covering more than the lower third of the pyramid, this rubble layer could be backing between core and casing, left after the casing stones were ripped away. The upper third of the pyramid core appears to be stone blocks in regular stepped courses. But on closer inspection the heights of these steps range from ninety centimeters to 1.20 meters and the widths of the steps varied from 23 centimeters to a meter.

Like Khufu's pyramid, Khafre's core is composed of loose, irregular fill. Through seams and gaps in the stepped core blocks, limestone chips and rubble are visible. In 1818, when Giovanni Belzoni cleared out a tunnel that robbers had forced through the center of the north side of the pyramid, the core fabric of the pyramid kept collapsing. Vito Maragioglio and Celeste Rinaldi, who surveyed the pyramids between 1963 and 1975, wrote, ". . . this was due without doubt to the incompactness of the internal masonry and the lack of mortar, so that the blocks are not always in contact at the sides, and cannot mutually support each other."

In spite of the irregularity of their cores, the Giza Pyramids have the most massive, large-block masonry of all pyramids. The first pyramid, Djoser's Step Pyramid, began as a *mastaba*, built with small, gray limestone blocks of a size that one man could carry, set along roughly horizontal courses in gravel and desert clay (*tafla*), and encased with fine white limestone. The builders twice expanded the *mastaba* before they conceived the idea of a pyramid, built in six steps from roughly shaped, larger core stones, directly over the fine Tura limestone casing of the earlier *mastaba*. They built the core as a series of accretions that lean inward about 74°, an effect achieved by tilting each course toward the core of the



39
Sneferu's Bent Pyramid at Dahshur, with much of the smooth outer casing covering the cruder core masonry. We know little about the structure of the inner core of the gigantic pyramids of the early Fourth Dynasty.

pyramid. This kind of core masonry is found in all later step pyramids: Sekhemkhet; the Zawiyet al-Aryan Layer Pyramid; seven small 'provincial pyramids' located at or near Elephantine, Edfu, Hierakonpolis, Ombos, Abydos, Zawiyet al-Meitin, and Seila; and the two step-pyramid building stages (E1 and E2) inside the Meidum Pyramid.

During the reign of Sneferu, in the pyramid of Meidum and the lower part of the Bent Pyramid at Dahshur, builders still set core blocks at a tilt toward the center of the pyramid rather than on horizontal beds. They built upon the desert gravel and clay, but at Dahshur, the softer surface, and the steep slope of some 60 degrees that they attempted, soon threatened the pyramid with settling and collapse. They added a girdle around the base of the pyramid, reducing its slope to 54° 31′ 13″, and then, at about half its height, built up at the reduced slope of 43° 21′, creating the Bent Pyramid. At this point they began to lay core blocks along horizontal, rather than tilted, beds.

Sneferu's builders raised the North Pyramid at Dahshur with a uniform 43° slope. They filled out the steps of his Meidum pyramid with packing stones and Tura casing, laid on horizontal beds, to create a true pyramid (E3) of 51° 50′ 35″, practically the same slope as Khufu's pyramid and within the 52–53° range of the classic Old Kingdom pyramid.

The gigantic stone pyramids, the classic pyramids of popular imagination, were built in only three generations. All other king's pyramids combined, including those of the Middle Kingdom (but excluding queens' and other satellite pyramids), contain only 54 percent of the total mass of the pyramids of Sneferu, his son Khufu, and grandson, Khafre.

Until the Giza Pyramids, builders set blocks more in natural desert clay, *tafla*, than gypsum. *Tafla* can be simply mixed with water, while to use it as mortar, gypsum needs to be heated from 100° to 200°C (212° to 392°F), so the Giza builders needed much fuel for many fires to prepare their pyramid mortar. The size of stone blocks and the quantity of gypsum mortar, as opposed to *tafla*, increased from the Dahshur to Giza pyramids. Khufu's was the largest and most accurately built and aligned of all Egyptian pyramids, rising more than 146 m from a base 230 meters square and containing about 2.3 million blocks. Menkaure still used multi-toned stone blocks for the Third Pyramid of Giza, but the total mass was less than that of Djoser's Step Pyramid.

Fifth and Sixth Dynasty builders composed pyramid cores of small stones, rubble, and sometimes clay binding in the retaining wall—the kind of material their predecessors had used for the construction ramps on the large stone pyramids of the Fourth Dynasty. In effect, it became more convenient to put the ramp inside and cover it with fine limestone casing! Middle Kingdom builders used stone retaining walls, debris fill, and, eventually, mud brick for the core.

The Inner Step Pyramid

Although considerable irregularity shows in the inner core of even the largest and finest pyramids at Giza, the builders did not simply pile up rubble as, in all probability, they built the core slightly ahead of the casing. The evidence is that they built up in large chunks of structure, like the *mastaba* (Arabic for 'bench') tombs that surround the pyramids.

Pyramid theorists have suggested that a stepped core makes up the bulk of every pyramid. Some believe that the rise and run of the steps have a specific relationship to the slope of the outer casing. These ideas are inspired by the Pyramid of Meidum, where the steps of the inner seven-step pyramid, superseded by the eight-step pyramid, have fine sharp corners and faces that might have served as references for measuring set amounts out to the slope of the enlarged true pyramid.

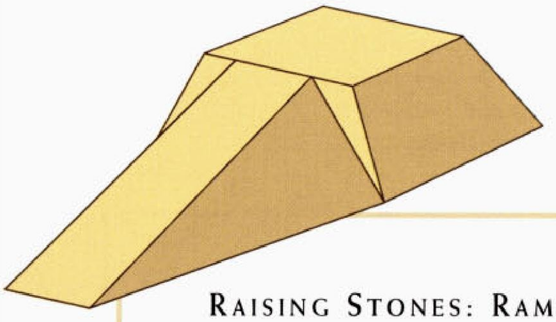
We do not know if the largest pyramids of the Fourth Dynasty, from Sneferu to Khafre, are built with an inner step pyramid.

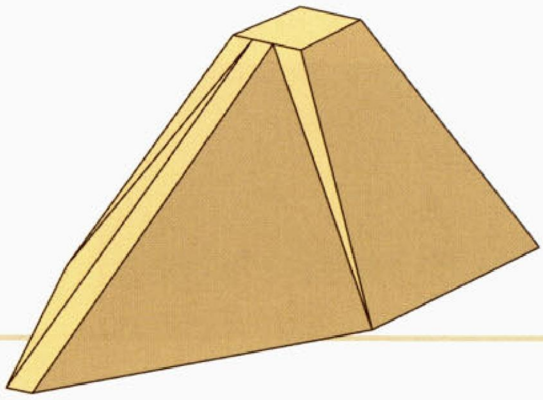
Howard-Vyse blasted a gash more than nine meters deep into the south side of Khufu's pyramid, about eighteen courses above the base and rising up to the thirty-first course. In this wound we see nothing close to the regular stairs that Martin Isler envisions in the core structure (see below). Not a single vertical joint corresponds with another. None of the blocks are the same size, and there are no clear impressions of regular rising joints. There are only horizontal joints, and these are not very clear; in places, two stones make up a single 'course.' In the eastern face of the cut, the courses are not regular, but there could be two crude steps, 1 and 1.2 m, of a large inner structure, perhaps the tier of a crude stepped core.

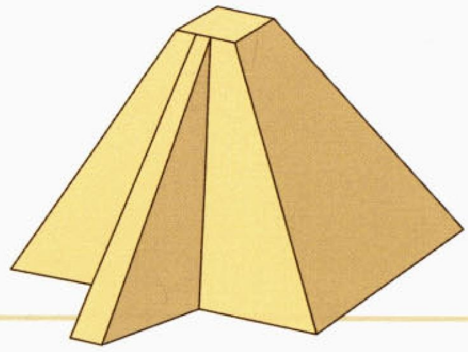
Similar crude structure is to be seen in the cores of the partially destroyed or unfinished queen's pyramids of Khufu and Menkaure, and in the gash in the north face of Menkaure's pyramid. It seems likely that the cores of these pyramids are composed of great rectangular blocks of crude masonry similar in form to *mastabas*—a kind of 'chunk approach' to assembling an inner step pyramid that lacks the beautifully finished faces and corners of Meidum. On queen's pyramid G 1c, the *mastaba* pattern is obscured by packing stones, of almost equal size to those forming the *mastaba*-like chunks, that filled in the broad steps, and by smaller backing stones, that filled the space between the core and the casing.

At this height, the reference lines on the ground would have been inaccessible, covered with ramps and building debris. But the builders could have transferred measurement and control up onto the top of the truncated pyramid. Above the mass of natural rock that the builders left in the base of Khufu's and Khafre's pyramids, the masons could have measured across the truncated pyramid to insure that its diagonals and sides were of equal length. If the core masonry rose ahead of the fine outer casing, the masons could have measured from reference points and lines on the core out to the facial lines of the pyramid as they brought up the casing.

Built in crude rectangular parts with irregular fill, the core masonry must have risen a good height above the casing. The three-tiered step pyramid in the queens' pyramids was certainly not in itself a reference for the rise and run of the outer casing. However, the core could have carried reference lines and points with paint, pegs, and cord. On the southernmost pyramid of Khufu's queens, there are small holes, about five centimeters diameter, near the corners of the tiers of the inner step pyramid. Some of these align with the sharp corners yet preserved in the fine casing down near the base of the pyramid. The holes might be the sockets for small pegs that carried temporary cord reference lines from which the masons measured out the appropriate amount to mark the line of the outer pyramid face when the setting crews built up the casing.







Raising Stones: Ramps or Levering?

There are only three basic techniques that the ancient Egyptians could have used for lifting blocks: the inclined plane (ramp), levering, and some assembly using rope, wood, and stone. To raise most of the stone, the builders probably used ramps that, however they were shaped, must have been enormous structures in their own right.

Ramp Material

It has often been suggested that the ramps would have been made of mud brick. Indeed, ramps found at the Middle Kingdom pyramids at Lisht have mud-brick retaining walls with fill of Nile alluvial mud and bricks. However, at Giza, there are no signs of the great deposits and stains of mud rubble that a gigantic construction ramp of mud would have left behind, even if the builders removed most of the ramps. Millions of cubic meters of limestone chips plus gypsum and *tafla*, fill the quarries south of the Giza pyramids. This must be the material that the builders used to make the pyramid ramp. But would a ramp composed of this material have been able to make an ascent more than a hundred meters skyward, leaning against the ever narrowing faces of the pyramid?

In Khufu's time, as today, there must have been specialists for construction in broken stone and clay. Today, they build very quickly in this material. An advantage of this mixture is that when the walls, ramps, or embankments need to be dismantled, it easily picks apart into its constituent chips, gypsum, and clay.

Archaeological Ramp Remnants

At Giza, there still remain small ramps attached to certain *mastaba* tombs. East of Khufu's pyramid and south of the queens' pyramids and *mastabas* in the Eastern Field, archaeologists from Cairo University excavated two parallel walls formed of broken stone and *tafla*. One of the walls is thicker and composed of segments 10 cubits long (5.25 m). These must be retaining walls, which, when filled with debris, formed a ramp or embankment that leads in the direction of the *mastabas* and queens' pyramids east of the Great Pyramid.

North of Khafre's pyramid, the modern paved road runs up onto an ancient construction embankment where, now, tour buses park. The embankment runs along a colossal unfinished wall of large limestone blocks. The sides of the embankment have collapsed into a sandy slope, but in 1881, Petrie saw a series of cross-walls that formed compartments for retaining debris fill. The pyramid ramps must have been similarly composed, at least at Giza. In 1993, Zahi Hawass excavated trial pits in thick deposits of debris similar to that comprising the above-mentioned walls and embankments. At the bottom of a point off the southwest corner of Khufu's pyramid, and south of the modern road, he found the foundations of broken stone walls that are oriented in the direction of the southwest corner of the pyramid. These may be vestiges of the kind of ramp leading from the southern quarry to the pyramid's southwest corner.

The form of the construction ramps, or whether they were used at all, is one of the thorniest problems of pyramid building. The numerous theories can be reduced to two major proposals—a ramp that ascends one face of the pyramid by sloping up in a straight line from some distance away, and one or more ramps that begin near the base and wrap around the pyramid as it rises during construction.

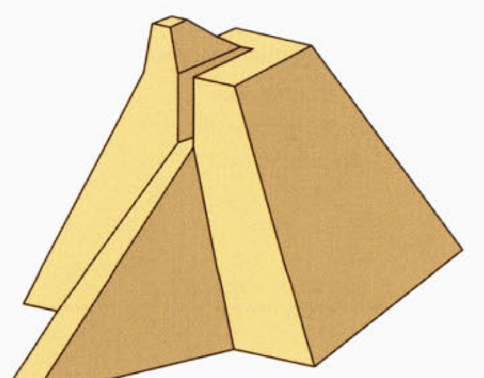
Straight-On Ramps

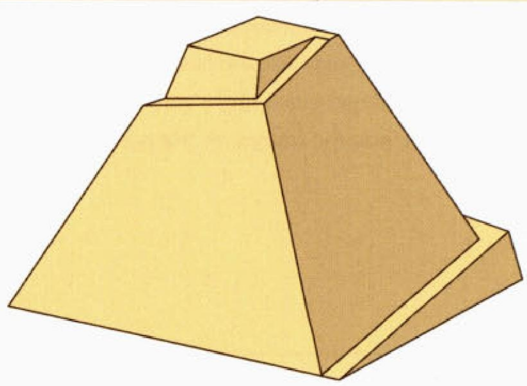
The straight-on ramp must be lengthened each time its height against the pyramid is increased in order to maintain a low functional slope of about one unit of rise per ten units of length. Either work stops during these enlargements, or the ramp is built in halves and one side serves for builder traffic while the ramp crew raises and lengthens the other half. But the biggest problem is that the ramp would need to be extremely long in order to maintain a functional slope up to the highest part of the pyramid. At Giza, this slope would take the ramp for the Great Pyramid far beyond the quarry to the south, where Khufu's builders took most of the stone for the core of his pyramid.

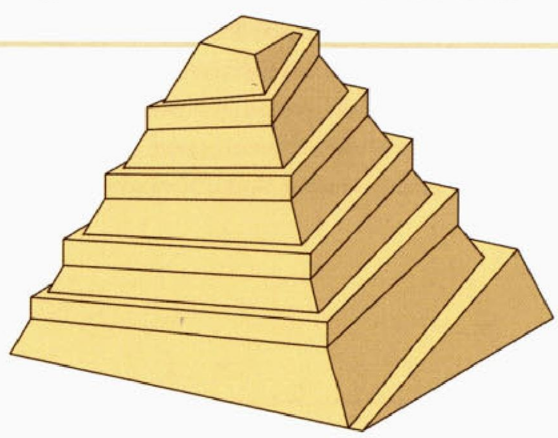
Wrap-Around Ramps

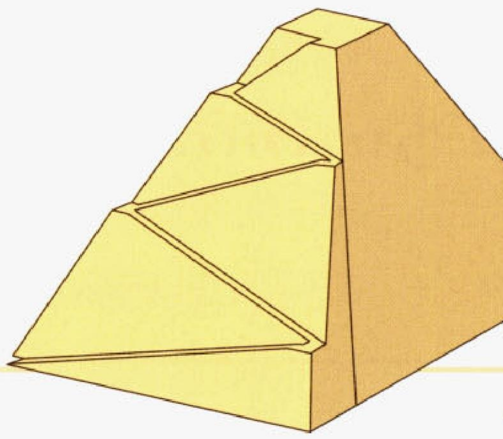
The wrap-around ramp either had to be footed on the slope of the pyramid or on the ground, in which case it would have leaned against the faces of the pyramid like a giant envelope with a rising roadbed. If it cloaked the entire pyramid, it might have presented a problem for controlling square and slope as the pyramid rose. If it was footed on the 52 degree slope of the pyramid, the extra stock of stone on the casing blocks would have to protrude step-like enough to support the weight of the ramp. The unfinished granite casing blocks on Menkaure's pyramid do not fill this requirement. But recently, Zahi Hawass has excavated at the bases of Khufu's queens' pyramids to reveal that the builders here left a great deal of extra stock in rough steps protruding beyond the plane of the pyramid. These may be unusual because they are part of the foundation, but if this much extra stock was left on higher casing stones, it might well have supported a spiral ramp.

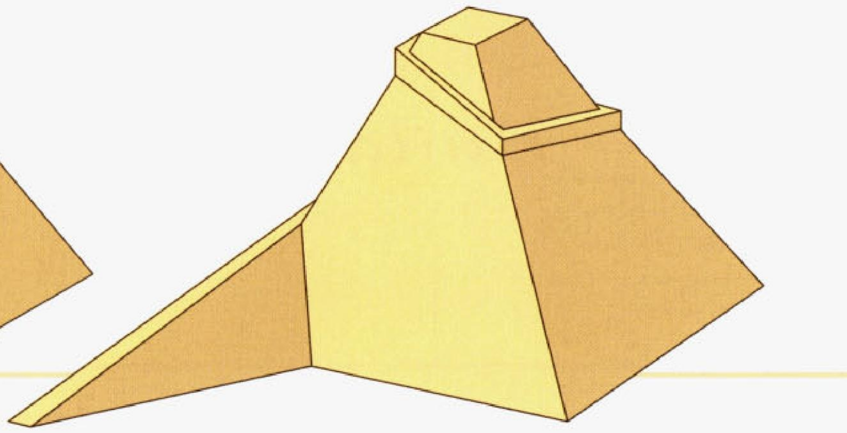
If the ancient builders had opted for this solution, it would have been necessary to leave the protruding casing stones staggered diagonally up across the pyramid face in order to allow the roadbed to rise.











Or, they could have left horizontal courses protruding at certain intervals so that the foundation wall of the ramp would be level but step up at intervals, while the roadbed rose at a gradient.

All ramp suggestions run into trouble near the top of the pyramid, where the slope becomes increasingly steep, and where the faces of the pyramid become too narrow to support a ramp from one corner to the next.

Quarry Delivery Ramp

When the pyramid was at its lower levels of construction, the builders could have delivered stone over many short ramps. As the pyramid rose, the ramp builders would want to gain some height in the course of the approach from the quarry. If the Khufu delivery ramp began at the north mouth of the southern basin quarry, where the quarrymen left a bedrock incline down to the quarry floor, it would have extended 320 m to the southwest base of the pyramid. If it connected to the pyramid 37 meters above the base, it would have sloped 6° 36′. A roadbed 30 meters wide would have easily accommodated two-way traffic. A ramp of similar dimensions was posited by a scribe Papyrus Anastasi I: 383 m (730 cubits) long, 29 meters (55 cubits) wide, 31 meters (60 cubits) high, and a side slope of eight meters (15 cubits).

Levering

While pyramid theorists have proposed that the ancient builders raised most of the stones by levering, all indications are that levering was used for sideways movements and for final adjustments. Loads can be see-sawed up by levering up one side, putting supports underneath, and then levering up the other side. But as it becomes clear to any reasonable person who climbs the Khufu or the Khafre pyramids—it is inconceivable that this lever lifting took place on the stepped courses of the core stone or the undressed casing stone. Those who think so have in mind very regular wide courses, like a stairway rather than the actual fabric and structure of the pyramid core. Many of the 'blocks' are odd shapes and sizes that would be unwieldy to lever. The sheer slope itself precludes levering many tons of stone for the higher courses.

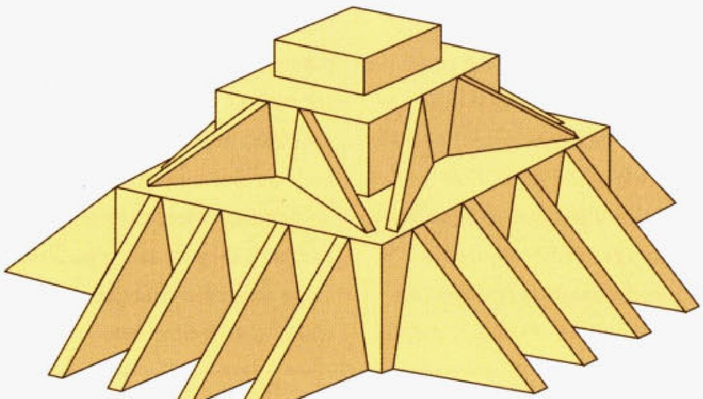
Martin Isler proposed that the builders used massive stone stairways ascending the center of each face of the pyramid core, later covered by the casing and packing stone. Isler imagines small stones and rubble, "passed up the steps by hand; larger stones moved on two-, four-, or six-man litters . . . sledges with runners can be used for the smaller blocks; made to span two or more steps, sledges can be dragged up a few courses at a time or boards made to span several steps can be used as slides over which blocks are pulled . . . ." (*Sticks, Stones, and Shadows*, p. 250) And, he imagines the builders levering even larger blocks up these steps. The builders rocked the stones up and tumbled them over each step of the supply stairway.

Isler's only evidence of these steps embedded into the pyramid core is the stepped courses showing on the upper third of Khafre's pyramid. Isler quotes Maragioglio and Rinaldi in saying that these courses, "formed an actual flight of steps." But when one measures the widths of these very steps, they range from 58 to 86 centimeters! A meter is just too narrow to lever the ends of heavy stone blocks up a 53 degree slope. Yet Isler has the huge granite beams of Khufu's burial chamber being levered up similar steps. In his drawings, only two men stand on steps and lever up the ends of these beams, which weigh several tens of tons, but he admits it would have taken ten levers at each end. There is simply no room for ten men on a step a meter wide, to say nothing of a step with a width of only 58 centimeters. And there are many, many other very particular problems with raising pyramid stones by levering.

When he tested his method with a 1,500 lb stone on the experimental NOVA tv show pyramid, Isler asked the masons to carve two lever sockets on the lower edge of the sides of his block. Right here is a bit of a hitch in his theory, since the core stones of the pyramids do not show side sockets, although casing stones sometimes do, presumably for side adjustments. The men used two levers on each side of the block, with two men per lever. Two additional men worked in front of the block (they actually stood on the ground), inserting supports. Each pull of the levers raised the side of the block just enough to slip in a well-planed flat board. Again, there is a problem.

How much flat-planed lumber would be required to construct Khufu's pyramid? The amount of wood for levers and sledges alone must have been enormous; raising all the blocks on lumber supports vastly increases the amount of wood. In our age, we take machine-planed boards for granted. But in the third millennium BC, the fact that the supports must be planed smooth vastly increases the amount of labor. If the supports were not planed smooth, the stack that supports the block is not at all stable. Even with our machine-planed boards, the support stack, 12 layers of board per 72 centimeter rise, was becoming a little unwieldy. In order to get purchase (good leverage), the fulcrum—a stack of stone—had to be raised as the block went up. However, the fulcrums were also becoming unwieldy. Isler answers for this by conveniently drawing solid masonry platforms under the ends of the blocks, raising the fulcrum. But in practice, such sturdy platforms cannot be built under a heavy load that rises by small increments. If not well-planed lumber, all that can be inserted are small stones that result in another unwieldy pile.

It is doubtful that most of the stones of the pyramid were raised this way. However, it is very possible that levering was the only means to raise the blocks of the highest courses, near the apex, once the builders had brought them as high as they could on ramps. In general, these are much smaller blocks than those of the lower courses.



40 and 41
The many different theories about building ramps can be grouped into two major variations: a straight sloping ramp up one face of the pyramid (drawings top left); or one or more ramps starting close to the base of the pyramid and wrapping around the building (drawings top right and bottom left). Alternatives include a zigzag ramp up one face or an internal ramp.

Building Khufu's First Course

Khufu's masons built the first course of his pyramid of casing, backing, and core blocks about 1.5 m thick. They set the foot of the sloping casing back 38 centimeters from the line marking the upper edge of the foundation platform. Leaving extra stock of stone on the front faces of the platform, and on the faces of the casing stones would have ensured that the final smooth surfaces would not have been damaged as the stones were moved into their positions. We see extra stock and handling bosses on the casing stones in the undressed lower part of the pyramid, G 1c, built for one of Khufu's queens. There could not have been much extra stock on the lower front of Khufu's casing stones because the platform did not extend out very far.

After they had set all the casing stones, the masons could have trimmed the front face and top edge of the foundation platform. Then the ancient builders could have measured the setting line, or baseline, of the casing from the line of the platform's upper edge, or from the reference line marked by stakes in the holes. Once again, segments of the staked reference line could have been taken up when large casing block needed to be brought in, and then later replaced. The casing blocks were probably brought in rough on sledges, then, while parked on rollers or wedges, each join-side was custom-dressed to fit into position with its mates in the pyramid casing. Once the join faces have been finished, the masons drew the lines of the sloping pyramid face at the front of each block. The marked pyramid slope defined the extra stock on their fronts.

Incorporating Slope and Alignment: Casing Stone

The core stone in pyramids was irregular because it was only fill for the gleaming shell. It was in this outer casing, formed of blocks of homogeneous fine white limestone from eastern quarries at Tura, that the builders achieved the great precision in the pyramids. Khufu's builders required about 67,390 cubic meters of Tura-quality limestone to cover the Great Pyramid. From the very few of these casing stones that remain at the base, we can see with what skill and care the builders placed them to form the foot of the pyramid. Joints between large blocks, some weighing as much as 15 tons, are often so fine that one cannot even insert a razor blade, and these fine seams sometimes run back from the outer face for more than a meter.

The evidence of unfinished pyramids indicates that the masons shaved off the extra stock of rough stone after the entire pyramid had been built, starting from the top and working down to the baseline as they removed the construction ramps and embankments. How did they make certain that under all the extra rough stone they had four straight corners and four good, flat faces that would sweep up evenly to a point? How could they dress the acres of fine limestone without chiseling away too much stone and so creating waves and undulations across the acres of the pyramid faces?

Masons incorporated guidelines for the final pyramid trim into each and every casing block as they joined one block to another. We know this from the unfinished limestone casing on the bottom of the pyramids of Khufu's queens, and from the unfinished granite casing at the bottom of Menkaure's pyramid. They probably began, like modern masons, by setting 'leader' casing blocks at the corners and in the middle of each side of the pyramid. The rough extra stock on the front of each block stuck out beyond the intended plane of the pyramid face. The masons parked the blocks to be joined beside one another, hoisted on wooden wedges or rollers just above their intended positions on the pyramid. They then custom dressed the join-faces to be parallel. The join-faces were not necessarily at right angles to the horizontal bedding planes, they could be angled laterally and vertically. Before they concealed the joint side on each block by setting the next block against it, they had to draw the line of slope of the pyramid face—the lines along which that gigantic cut would shave away the extra stock at the end of the building project. For the first course, the masons measured a set amount from an outside reference line, then they marked the point where the baseline of the pyramid would intersect with the smoothly dressed join-sides of the block. Then they etched the slope line of the pyramid face on the join-sides.

The ancient Egyptians determined the slopes of walls with a measurement called *seqed*, the amount that the face of the wall is set back for a rise of one cubit (.525 of a meter). A set back of one cubit for a rise of one cubit results in a 45° slope. The nearly 52° angle of Khufu's pyramid could be obtained from a set back, or run, of 11 to a rise of 14.

We are not certain how they laid out the *seqed* angle. Khufu's builders could have measured in 11 and up 14 units from the already determined baseline with a plumb line to mark the top of the slope. Perhaps they drew the slope by placing wooden set squares made to the desired angle against the join-face of each block. However, in order to use a triangle, one should ideally have a surface that is absolutely parallel to the ground. In modern drafting, angles are extremely sensitive to a T-square that is not perfectly perpendicular to the side of the drafting board. Using a plumb line against the vertical side of the triangle may have helped, but plumb lines move. At best, the error in each block would have been compensating, not cumulative, over hundreds and thousands of blocks. Also, the pyramid builders probably had long distance markers to sight to as checks on the cumulative slope.

Next, the masons beveled or chamfered away the extra stock of stone on the outer face of each block from the lines where all four join-faces (top, bottom, and two sides) intersected with the plane of the pyramid face. This beveling was a lead, created block by block, for the final dressing of the pyramid casing. When the masons bought up the next block in sequence and set it down, creating the side join with its neighbor, the new stone had extra stock on the non-joining front face, and extra dressed join face, extending out beyond the beveled sloping side joint of its older partner. The masons beveled away the extra stock on the newest block along the slope of its neighbor. On the opposite free join face, they repeated the procedure, marking the slope and beveling away the extra stock along this line and along the top and bottom where these sides intersected the sloping plane of the pyramid face.

Block by block, the ancient masons created the sloping planes of the pyramid faces, leaving it hidden behind the extra stock of stone. If the slope as marked on one block was a little off in one direction, the others might deviate in another direction so that the errors averaged out.

Reaching for Perfection: The Apex

As the four sides of the pyramid narrowed toward closure at the top of the pyramid, the builders ran out of room for ramps and for men to pull on ropes. They could have used levering to raise some of the last few blocks. It is clear that they were using smaller blocks, and that they could no longer use the loose core masonry as the finished edges came together. They needed a finer grade of stone for edges and the final point. Careful observation of the backing stone now showing on Khufu's pyramid shows that all along the arris lines, and toward the now truncated top, the builders used a finer grade of limestone, even if not Tura-quality. The masonry that remains of the tops of pyramids shows that the builders dispensed with core stone altogether, and came to the point with fine casing-quality limestone.

43
The Giza Pyramids from the south. Menkaure's horseshoe-shaped quarry (lower right) lies southeast of his pyramid (left). Fieldstone walls form great rectangular precincts around each of the main pyramids.

The Apex of Sneferu's North and Khufu's Satellite Pyramid

Rainer Stadelmann found the pieces of the oldest pyramid capstone, also called a pyramidion, on the east side of Sneferu's North Dahshur pyramids. This was a simple culmination of the casing, a plain capstone of good quality limestone.

Zahi Hawass found the second oldest pyramid capstone, a large piece of fine Tura-quality limestone that once crowned Khufu's satellite pyramid off the southeastern corner of the Great Pyramid. He also found a large piece with three exterior sloping faces of the pyramid that once formed a little more than half of block(s) forming the second course down from the top. Obviously, here the pyramid superstructure is all casing, with no fill or core material, as it narrows to the apex.

The second course down from the top is missing, but Zahi Hawass found the actual apex stone of the satellite pyramid, a single piece of fine, Tura-quality limestone. The underside of the pyramidion is convex, with four triangular faces sloping slightly to the raised center point of the base. This convex, protruding base was meant to fit into the concavity of the top of the second course from the top, just as the convex underside of the second course had evidently fit into the concave top surface of the third course down. The mean slope of the faces is 51° 45′, almost exactly that of Khufu's main pyramid (51° 51′).

below it on the pyramid. Such slabs once formed the final upper courses that the builders composed entirely of fine casing stone, since the pyramid was now too narrow for any loose and irregular core masonry. The raised and rebated undersides and tops of these pieces of the pyramid corners and top once fitted into one another like Lego blocks.

Peter Jánosi described the remains of a capstone that might have been the crowning stone of G 3a on the south side of the queen's pyramid. He reported that the broken capstone retained parts of three smoothly finished sides, and that its original width was 1.125 m (15 'palms').

the south side of the third course below the apex. The underside of the block is flat, but the top surface was shaped as a concavity. When it completed the square of the top of the third course down from the top, there were four triangular planes sloping 2.6 meters (five cubits) to the center and forming the lines of the diagonals. The diagonal lines must have helped the builders square the top of the pyramid so that the sides met at a point. This concavity of the top surface was also intended to receive the convex underside of the

The Apex of Menkaure's Queen's Pyramid G 3a

Excavations in recent years turned up numerous fragments of Tura-quality casing stones around the northeastern corner and eastern side of G 3a. Certain pieces show how the masons gave the corner special treatment to ensure firm joins. The undersides of large corner slabs are rebated, or recessed, to fit a raise edge of the casing course

A square rebated or sunken panel, about 7.5 centimeters (one palm) deep, on the underside measured 1 x 1 cubit (about .525 meter). The sunken panel would have fitted over a raised panel of nearly equal size on the course below as a way to fix the capstone. With an angle of 52 degrees, the pyramidion was originally about ten palms (75 centimeters) high.

KHAFRE'S POINT

The capstone of Khafre's pyramid is missing, but 40 to 45 meters down from the top of the pyramid, fine limestone casing remains intact. The truncated top shows the socle, or anchoring, of the last blocks that would receive the pyramidion, which could have been granite to match the base.

I measured the thickness of the casing courses where I could reach them on the overhang of the northeast corner. From lower to upper they are: 82, 67, 35, 45, 66, 44, and 45 cm thick. These courses are from one-third to two-thirds the thickness of the lowest course of casing stone, which was granite, 1.05 m thick.

Looking out across the expanse of casing, one sees that the slabs are not flush, but stagger by a few millimeters. We would expect the faces to be flush if the masons had trimmed them in place on the pyramid, a practice well in evidence in the lower parts of unfinished pyramids. Perhaps they were unable to do so in the tight working space of the upper reaches, and this is one indication that working methods had to change as the pyramid grew toward the top. Perhaps the slope was cut into the casing blocks of the highest courses before they were laid. (It is also possible that the stones shifted after the casing farther down was removed.)

When the builders completed the body of the pyramid, masons began to free, from the top down, the smooth, sloping faces hidden in the rough extra stock of stone on the lower part of the pyramid.

FIRST AND LAST: THE PYRAMID BASELINE

There is a certain irony in the Giza Pyramids that the baseline was the both the first and last thing the builders did. This is certainly indicated at Menkaure's pyramid, where the builders never completed the base.

Petrie dug down to the foot of the casing at some points on the Menkaure pyramid. There is no clean baseline. The builders left the pyramid base without trimming the granite casing on the lower part of the pyramid. The lowest course rests on the rough limestone foundation. The builders had smoothed the sides of the individual granite blocks to join them together. As they set each block, they beveled the rough extra stock of stone on the outer face away from the smooth side where the block would eventually join the next block. This beveling, or chamfering, followed the intended slope line of the pyramid face (about 51 degrees) which ended about six to 18 inches above the foundation. Menkaure's builders probably intended to dress the bottom of the lowest casing course into a vertical foot that would have met the pavement of the court—had it ever been finished—to finally form the true baseline. This is the configuration at Khafre's pyramid where the only baseline is the top of that cut at the bottom of the lowest course of casing. The masons truly completed the baseline when they laid the pavement of the court up to that cut. Paving the court was one of the last operations, which is also indicated at Menkaure's pyramid. It may seem odd to form the clean baseline as the last, rather than the first task of creating the pyramid, but such was their procedure.

Since Menkaure's builders did not get to that end, what should we consider as the true baseline of this pyramid? The answer is that there isn't any—the bottom of the slope chamfered or beveled into the side joins of the granite blocks stops at different levels. If there is no true base line, how did the ancient builders control its square? Petrie took the average height of all the granite courses, which are all nearly the same—"a rather short two cubits each"—except for the bottom course being four to eight inches thicker. He reckoned the base as the height of one course below the top of the first course.

For their purposes, the builders could certainly not have used the actual bottom of the lowest course as their base reference because the thickness of the blocks of this course vary from 1.11 to 1.40 m. For this lowest course of casing, they shaved the tops of blocks even and flush, while leaving the bottoms at different levels upon the rough foundation. As we saw at Khafre's pyramid, the ancient builders must have used the top of the first course as a level reference, similar to the way Petrie used it to obtain a theoretical baseline. For laying in the bottom course, they must have used a temporary outside reference line that may or may not have left traces, such as the lines of post holes around the bases of the Khufu and Khafre pyramids.

Khufu's builders proceeded differently. They had already prepared a good level baseline—the contact of the lowest course of large limestone casing blocks with the foundation platform. But it is still likely that they left the baseline obscured under extra stock of stone until they shaved down the casing at the end of building the pyramid.

THE HUMAN HAND: IMPERFECTIONS

As good as they were, the Giza Pyramid builders were not perfect. The pyramids are very human, not supernatural, monuments. The square of Khafre's pyramid, completed by the casing, is not perfect. In 1881, Petrie determined the square of the pyramid base by extrapolating the corners from the casing socle, the bedding of the lowest course. He then checked the angles of the casing at the top of the pyramid in relation to the square of the base and discovered a slight twist to the pyramid of 3° 50′. The builders had to bend the corner angles slightly to make them meet at the apex. Even with such discrepancies, pyramid builders never again attained the accuracy of the Giza Pyramids. As Petrie did with the Fourth Dynasty Giza Pyramids, Borchardt used modern instruments to survey Sahure's Fifth Dynasty pyramid at Abusir. He found the southeastern corner shifted 1.58 m farther east than the northeastern corner, making a rhombus or trapezoid base instead of a perfect square. Sahure's builders compensated in the upward slope of the pyramid and hid the imperfection of the base under the back end of the pyramid temple. Seeing the imperfections of the human hand only increases our admiration for the astonishing achievements of the people who built the pyramids. And it helps us relate to the sense of accomplishment and community that they must have felt when the pyramid was completed. Recently, Zahi Hawass discovered a scene carved in fine limestone relief from the causeway of Sahure's pyramid. It shows the dancing, singing, and celebration that broke out with the setting of the capstone.

45
The fine limestone top of Khafre's pyramid. The masonry below the casing appears regular and stepped, but widths of steps and block sizes vary greatly. Lower rubbly backing masonry adheres after the casing was ripped away.

THE PYRAMIDS
Text by Zahi Hawass

Zahi Hawass is a world-renowned Egyptian archaeologists. Now he is the General Secretary of the Supreme Council of Antiquities and the Director of the Excavations at the Giza Pyramids, Saqqara, and Bahariya Oasis. He has been excavating around the pyramids for the last twenty years and has made several major discoveries, including the Tombs of the Pyramid Builders and the Valley of the Golden Mummies in Bahariya Oasis. He is the author of many books and articles on the Pyramids, such as *The Pyramids of Ancient Egypt* and other books related to Egyptology. He has lectured all over the world. Hawass has brought Egypt into the homes and hearts of people worldwide through numerous television appearances. Zahi Hawass received the First Class Award for Arts and Sciences from President Mubarak in 1988 for the Sphinx conservation. In October 2000, he was one of thirty international figures to receive the Golden Plate Award from the American Academy of Achievement in honor of his accomplishments in archaeology. In 2001, National Geographic announced him as an Explorer in Residence and in 2003 his name was written on a CD for the Mars exploration and Rover Mission.

Photo credits:
1 Marcello Bertinetti/Archivio White Star
2-3 Giulio Veggi/Archivio White Star
4 Marcello Bertinetti/Archivio White Star
5 Araldo De Luca/Archivio White Star
6-7 Araldo De Luca/Archivio White Star
8 Araldo De Luca/Archivio White Star
9 Araldo De Luca/Archivio White Star
10-11 Araldo De Luca/Archivio White Star
13 Kenneth Garrett
16-17 Kenneth Garrett
19 Araldo De Luca/Archivio White Star
20-21 Araldo De Luca/Archivio White Star

WHY A PYRAMID? PYRAMID RELIGION
Text by James Allen

James Allen received his degree in Egyptology from the University of Chicago, with a dissertation on the grammar of the Pyramid Texts. He has served as epigrapher with the University's expedition in Luxor, Egypt, and as Cairo Director of the American Research Center in Egypt. Since 1986 he has held a research appointment at Yale University, and has taught there as well as at the University of Pennsylvania. He is currently Curator of Egyptian Art at the Metropolitan Museum of Art and Vice-President of the International Association of Egyptologists. Dr. Allen's specialties include ancient Egyptian language, texts, and religion, and he has written extensively on these subjects as well as the history of the Middle Kingdom and Amarna Period. He is the author of *Genesis in Egypt: the Philosophy of Ancient Egyptian Creation Accounts* and, most recently, *Middle Egyptian: an Introduction to the Language and Culture of Hieroglyphs*.

Bibliography:

Allen, J. "Reading a Pyramid," in *Hommages à Jean Leclant* (Bibliotheque d'Étude 106; Cairo: Institut Français d'Archéologie Orientale, 1994), vol. 1, pp. 5-28.
Barta, W. "Die Beudeutung der Pyramidentexte für den verstorbenen König," *Münchner Ägyptologische Studien* 39 (Munich, 1981).
d'Auria, S. H., et al., *Mummies & Magic: the Funerary Arts of Ancient Egypt*. Boston, 1988, pp. 27-59.
Quirke, S. *Ancient Egyptian Religion*, London, 1992.
Ritner, R. K. "The Cult of the Dead," in D. P. Silverman (ed.), *Ancient Egypt*, London, 1997, pp. 132-147.

Photo credits:
22 Araldo De Luca/Archivio White Star
22-23 Giulio Veggi/Archivio White Star
24, 25, 26, 27 Araldo De Luca/Archivio White Star

THE ADMINISTRATION OF THE PYRAMID
Text by Vassil Dobrev

Vassil Dobrev, a French archaeologist, was born in 1961 in Varna (Bulgaria). In 1992, he received is PhD in Egyptology from the University of Paris-Sorbonne for his dissertation "Researches on the Kings of the Fourth Egyptian Dynasty." From 1995 until 1998, he was Scientific Member of the French Archaeological Institute in Cairo (IFAO). Since 1987, he has worked on the excavations of the pyramids and temples of Pepy I and his Queens at South Saqqara. Since 2000, he has been responsible for the IFAO Mapping Project of South Saqqara and Director of the IFAO Mission at Tabbet al-Guesh (South Saqqara). The author of several scientific studies, and he is specialized in the inscriptions of the pyramid builders and pyramid history.

Bibliography:

Dobrev, V. "Les marques de la pyramide de Pépy Ier. Notes complémentaires," *BIFAO* 98 (1998), pp. 151-170.
Eyre, C. J. "Work and the Organisation of Work in the Old Kingdom," in M. A. Powell (ed.), *Labor in the Ancient Near East*, New Haven, 1987, pp. 5-47 (American Oriental Series, vol. 68).
Posener-Kriéger, P., *Les Archives du temple funéraire de Néferirkarê-Kakaï (Les papyrus d'Abousir). Traduction et Commentaire, 2 vol.* IFAO, Le Caire, 1976 (*BdÉ* 65).
Reisner, G. A. *Mycerinus: The Temples of the Third Pyramid*, Cambridge, Massachusetts, 1931, pp. 273-275, appendix E, pl. XI-XII.
Roth, A. M., "Egyptian Phyles in the Old Kingdom. The Evolution of a System of Social Organization," *SAOC* 48 (Chicago, 1991).

Photo credits:
28 Giulio Veggi/Archivio White Star
29 Vasko Dobrev
30 Marcello Bertinetti/Archivio White Star

BUILDING AN OLD KINGDOM PYRAMID
Text by Mark Lehner

Mark Lehner is one of the leading experts on Giza's Great Sphinx and Pyramids. He is president of the nonprofit research organization AERA, Inc., that sponsors the Giza Plateau Mapping Project. The project conducts excavations of Old Kingdom settlements near the Sphinx and Pyramids with a team of archaeologists, geochronologists, paleobotanists, and faunal specialists. Lehner has appeared on television in National Geographic's *Explorer* program, and on NOVA's *Secrets of Lost Empires* series on ancient technology including *This Old Pyramid and Obelisk*. He is author of *The Complete Pyramids* published in 1997. In addition to books and articles in print, Lehner's book on the Great Sphinx is in preparation with the University of Chicago Press. From 1990 until 1995 Lehner was Assistant Professor of Egyptian Archaeology at the University of Chicago. He is now a Research Associate at the Oriental Institute of the University of Chicago and at the Harvard Semitic Museum. Lehner was born, raised, and began his college education in North Dakota. He went to Cairo in 1973 as a Year Abroad Student at the American University in Cairo where he received his B.A. in Anthropology. He lived in Egypt in for thirteen years, working for American, Egyptian, British, French, and German archaeological projects. From 1979 until 1983 he was the Field Director and then Director of the Sphinx Project sponsored by the American Research Center in Egypt. In 1984 he began the Giza Plateau Mapping Project (GPMP), sponsored by ARCE and Yale University where Lehner received his Ph.D in Egyptology in 1990. In 1988 the GPMP began to excavate in search of the settlement and infrastructure that supported the pyramid work force. The team has discovered a workers' city that includes work shops, storage buildings, bakeries and a large royal administrative center from the time of the pyramids (ca 2,500 B.C.).

Bibliography:

GENERAL
Arnold, D., *Building in Egypt. Pharaonic Stone Masonry*, New York and Oxford, 1991.
Badawy, A., "The periodic system of building a pyramid," *JEA* 63 (1977), pp. 52-8
Dunham, D., "Building an Egyptian Pyramid," *Archaeology* 9, no. 3 (1956), pp. 159-65
Garde-Hansen, P., *On the Building of the Cheops Pyramid*, Cascais, 1974.
Hodges, P. and E. B. J. Keable, *How the Pyramids Were Built*, Shaftesbury, Dorset, England, 1989.
Isler, Martin, *Sticks, Stones, and Shadows: Building the Egyptian Pyramids*, Norman 2001.
Lauer, J.-P., "Comment furent construites les pyramides," *Historia* 86 (1954), pp. 57-66.
Mencken, A., *Designing and Building the Great Pyramid*, Baltimore, 1963.
Petrie, W. M. F., "The Building of a Pyramid," in *Ancient Egypt* (1930), pp. 33-9.
Smith, Craig, "Program Management B.C.," *Civil Engineering* (June 1999), pp. 34-41.

SUPPLY AND TRANSPORT
Bietak, M., "Zur Marine des Alten Reiches," in *Pyramid Studies and Other Essays Presented to I.E.S. Edwards* (London, 1988), pp. 35-40.
Bradbury, L., "Kpn-boats, Punt trade, and a lost emporium," *JARCE* 33 (1996), pp. 37-60.
Fischer, H. G., "Two tantalizing biographical fragments of historical interest, 1. a speedy return from Elephatine," *JEA* 61 (1975), pp. 33-5.
Goyon, G., "Les navires de transport de la chausée monumentale d'Ounas," *BIFAO* 69 (1971), pp. 11-41.
Goyon, G., "Les portes des pyramides et le grande canal de Memphis," *RdÉ* 23 (1971), pp. 137-53.
Haldane, C., "A new method of ancient Egyptian hull construction, preliminary report," *Mariner's Mirror* 74 (1988), pp. 141-52.
Haldane, C., "The Lisht timbers: a report on their significance," in D. Arnold (ed.), *The Pyyramid Complex of Senwosret I*, New York, 1992, pp. 102-12.
Landström, B., *Ships of the Pharaohs*, Garden City, 1970.
Schenkel, W., "Kanal," *LÄ* III, (1980), pp. 310-12.
Sølver, C. V., "Egyptian obelisk ships," *Mariner's Mirror* 33 (1947), pp. 39-43.

ORGANIZING THE LANDSCAPE
Aigner, T., "Facies and origin of nummulitic buildups: an example from the Giza Pyramids Plateau (Middle Eocene, Egypt)," *N. Jb. Geol. Paläont. Abh.* 166 (1983), pp. 347-68.
Aigner, T., "Zur Geologie und Geoarchäologie des Pyramidenplateaus von Giza, Ägypten," *Natur und Museum* 112 (1983), pp. 377-88.
Lehner, M., "The Development of the Giza Necropolis: The Khufu Project," *MDAIK* 41 (1985).

QUARRIES
Engelbach, R., *The Aswan Obelisk*, Cairo, 1922.
Engelbach, R., *The Problem of the Obelisks: From a Study of the Unfinished Obelisk at Aswan*, London, 1923.
Harrell, J. A., "An inventory ofancient Egyptian quarries," *NARCE* 146, (spring 1989), pp. 1-7.
Harrell, J. A. and T. M. Bown, "An Old Kingdom basalt quarry at Widan el-Faras and the quarry road to Lake Moeris," *JARCE* 32 (1995), pp. 71-92.
Harrell, J. A. and V. M. Brown, *Topographical and Petrological Survey of Ancient Egyptian Quarries*, Toledo, 1995.
Klemm, D. and R. Klemm, "Herkunftsbestimmung altägptischen Steinmaterials," *SAK* 7 (1979), pp. 103-40.
Klemm, D. and R. Klemm, *Steine der Pharaonen*, Munich, 1981.
Röder, J., "Steinbruchgeschichte des Rosengranits von Assuan," *Archäologischer Anzeiger* 3 (1965), pp. 461-551.

THE NOVA PYRAMID
Lehner, M., "The Pyramid," in *Secrets of Lost Empires*, New York, 1996, pp. 46-93.

TOOLS, TECHNIQUES, AND OPERATIONS
Hinkel, F. W., "Hölzernes Fördergerüst an der Cheopspyramide?" *Das Altertum* 2, no. 28 (1982), pp. 113-18.
Lane, M., "The pull-saw in Egypt," *Ancient Egypt and the East*, (June 1935) pp. 55-8.
Lucas, A. and J. R. Harris, *Ancient Egyptian Materials and Industries*, London, 1962
Moores, R. G., "Evidence for the use of a stone-cutting drag saw by the Fourth Dynasty Egyptians," *JARCE* 28 (1991), pp. 139-48.
Petrie, W. M. F., *Tools and Weapons, Egyptian Research Account* 22, London, 1917.
Ryan, D. P., "Old rope," *KMT* 4, no. 2 (1993), pp. 72-9
Teeter, E., "Techniques and terminology of rope-making in ancient Egypt," *JEA* 73 (1987), pp. 71-7
Zuber, A., "Techniques du travail des pierres dures dans l'Ancienne Egypte," *Techniques et Civilizations* 29.5, no. 5 (1956), pp. 161-78.
Zuber, A., "Techniques du travail des pierres dures dans l'Ancienne Egypte," *Techniques et Civilizations* 30. 5, no. 6 (1956), pp. 196-215.

SURVEY AND ALIGNMENT
Borchardt, L., 'Ein altägyptisches astronomisches Instrument,' ZÄS 37 (1899) pp. 10-7
Borchardt, L., *Längen und Richtungen der vier Grundkanten der grossen Pyramide bie Gise* (Berlin, 1926)
Cole, J. H., *The Determination of the Exact Size and Orientation of the Great Pyramid of Giza* (Survey of Eygypt Paper No. 39) (Cairo, 1925)
Dorner, J., 'Die Absteckung und astronomische Orientierung ägyptischer Pyramiden' (Innsbruck, 1981).
Dorner, J., 'Studien über die Bauvermessung und astronomische Orientierung,' AfO 32 (1985) pp. 165-66
Goyon, G., 'Quelques observations effectuée autour de la pyramide de Khéops,' BIFAO 47 (1969) pp. 71-86
Isler, M., 'An ancient method of finding and extending direction,' JARCE 26 (1989) pp. 191-206
Isler, M., 'The merkhet,' VA 7 (1991) pp. 53-67
Isler, M., 'The gnomen in Egyptian antiquity,' JARCE 28 (1991) pp. 155-86
Lauer, J.-P., 'À propos de l'orientation des grandes pyramides,' Bulletin de l'Institut d'Égypte (1960) pp. 7-15
Lehner, M., 'Some observations on the layout of thepyramids of Khufu and Khafre,' JARCE 20 (1983) pp. 7-25
Lehner, M., 'The Giza Plateau Mapping Project season 1984-85,' NARCE 131, no. (Fall 1985) pp. 23-56
Lehner, M., 'The Giza Plateau Mapping Project,' NARCE 135 (Fall 1986) pp. 29-54
Lepsius, R., *Die alt-ägyptische Elle* (Berlin, 1865)
Neugebauer, O., 'On the orientation of pyramids,' Centaurus 24 (1980) pp. 1-3
Petrie, W. M. F., *Ancient Weights and Measures* (London, 1926)
Pochan, A., 'Observations relatives au revetement des deux grandes pyramides de Giza,' Bulletin de l'Institut d'Égypte 16 (1934) pp. 214-20
Zába, Z., *L'orientation Astronomique dans l'ancienne Égypte, et la précession de l'axe du monde* (Prague, 1933)

RAMPS, LEVERS, LIFTING THEORIES
Arnold, D., "Überlegungenzum Problem des Pyramidenbaues," *MDAIK* 37 (1981), pp. 15-28.
Cunningham, J., "Techniques of pyramid building in Egypt," Nature 332, no. 3 (1988).
Dunham, D., "Building an Egyptian pyramid," Archaeology 9, no. 3 (1956), pp. 159-65.
Fitchen, J., "Building Cheops' pyramid," *Journal of the Society of Architectural Historians* 37 (1978), pp. 3-12.
Isler, M., "Ancient Egyptian methods of raising weights," *JARCE* 13 (1976), pp. 31-41.
Isler, M., "On pyramid building," *JARCE* 22 (1985), pp. 129-42.
Isler, M., "On pyramid building II," *JARCE* 24 (1987), pp. 95-112.
Lowdermilk, R., "Re-inventing the machine Herodotus said built the Great Pyramid," *KMT* 2, no. 4 (1991), pp. 45-53.

Rise and Run - Casing

Arnold, D., "Maneuvering casing blocks of pyramids," in John Baines, et al. (eds.), *Pyramid Studies and Other Essays presented to I. E. S. Edwards*, London, 1988, pp. 12-24.
Isler, M., "Concerning the concave faces on the Great Pyramid," *JARCE* 20, no. 27-32 (1983).
Lally, M., "Engineering a pyramid," *JARCE* 26, no. 207-218 (1989).
Lauer, J.-P., "Sur le choix de l'angle de pente dans les pyramides d'Égypte," *Bulletin de l'Institut d'Égypte* 37 (1956), pp. 57-66.
Lauer, J.P., "Observations sur les pyramides," *BdÉ* 30 (Cairo, 1960).
Robins, G. and C. C. D. Shute, "Determining the slope of pyramids," *GM* 57 (1982), pp. 49-54.

Photo credits:

33 top Archivio White Star
33 bottom Araldo De Luca/Archivio White Star
34, 35 Giulio Veggi/Archivio White Star
36, 37 Alberto Siliotti/Archivio Geodia
38 Mark Lehner
39 Alfio Garozzo/Archivio White Star
43, 45 Marcello Bertinetti/Archivio White Star

THE ARCHITECTURAL DEVELOPMENT OF THE EGYPTIAN ROYAL TOMB

Text by Zahi Hawass

Bibliography:

Edwards, I.E.S., *The Pyramids of Egypt. rev. ed.*, New York, 1985.
Hassan, S., *The Sphinx: Its History in the Light of Recent Excavations*, Cairo: Cairo University, 1949.
Hawass, Z., "The Khufu Statuette: Is It an Old Kingdom Sculpture?" *Melanges Gamal Eddin Mokhtar. Bibliotheque d'Etude, Institut Francais d'Archeologie Orientale* no. 971, (1985).
---, *The Funerary Establishments of Khufu, Khafra, and Menkaura During the Old Kingdom*, Ph. D. Dissertation University of Pennsylvanaia microfilm, Ann Arbor, MI, 1987.
---, "Histories, Mysteries of Man" in W.M.F. Petrie, *The Pyramid and Temples of Gizah*, London, 1990.
--- "Pyramid Construction: New Evidence Discovered in Giza," in H. Guksch and D. Polz (eds), *Stationen Beiträge zur Kultur-geschichte Ägyptens Gewidmet R. Stadelmann*, Mainz, 1998.
---,*The Pyramid of Ancient Egypt*, Carnegie Institute, Pittsburgh, 1990.
Lehner, M., "The Development of the Giza Necropolis: The Khufu Project." *MDAIK* 41, 1985.
Maragioglio, V., and C. Rinaldi., *L'Architettura della piramidi menfite*. Vols. 2-8. Turin and Rapello, 1963-77.
Reisner, G. A., *The Development of The Egyptian Tomb Down to the Accession of Chéops*, Cambridge, Mass., 1935.
Smith, W. S., *The Art and Architecture Of Ancient Egypt*. 2nd ed., revised by W. K. Simpson, Harmondsworth, 1981.

Photo credits:

46 Giulio Veggi/Archivio White Star
47 Marcello Bertinetti/Archivio White Star
48 Alfio Garozzo/Archivio White Star

THE ARCHITECTURAL COMPONENTS OF THE PYRAMID COMPLEX

Text by Zahi Hawass

Bibliography:

Badawy A., *A History of Architecture I*, Berkeley, University of California, 1966.
Brinks, J., *Die Entwicklung der Königlichen Grabanlagen des Alten Reiches*, Hildesheim, 1979.
Edwards, I.E.S., *The Pyramids of Egypt*, rev. ed., New York, 1985.
Fakhry, A., *The Pyramids, 2nd ed.*, Chicago: University of Chicago Press, 1974.
Hawass, Z., "The Pyramid," in D. P. Silverman and D. Baird (eds), *Ancient Egypt*, London and New York: Oxford University Press, 1998.
---, *The Funerary Establishments of Khufu, Khafra, and Menkaura During the Old Kingdom*, Ph. D. Dissertation University of Pennsylvanaia microfilm, Ann Arbor, MI, 1987.
---, "Pyramid Construction: New Evidence Discovered in Giza," in H. Guksch and D. Polz (eds.) *Stationen Beiträge zur Kultur-geschichte Ägyptens Gewidmet R. Stadelmann*, Mainz, 1998.
Maragioglio, V., and C. Rinaldi, *L'Architettura della piramidi menfite*, vols. 2-8. Turin and Rapello, 1963-77.
Petrie, W. M. F., *The Pyramids and Temples of Gizeh*, London, 1883.
Smith, W. S. *The Art and Architecture Of Ancient Egypt*, 2nd ed, revised by W. K. Simpson, Harmondsworth, 1981.
Stadelmann, R., *Die ägyptischen Pyramiden*, Mainz, 1985.

Photo credits:

52, 53 Araldo De Luca/Archivio White Star

THE PREDYNASTIC PERIOD

Text by Renee Friedman

Renee Friedman is the Heagy Research Curator in the Egyptian Department of the British Museum and Director of the Hierakonpolis Expedition, specializing in Egypt's Predynastic Period. Educated at the University of California, Berkeley, she has excavated at a number of sites in Egypt, including Giza, Mendes, Tell el-Muqdam, and Hierakonpolis, where she has worked since 1983. She has co-authored and edited several books including *Egypt Uncovered* (1998), *The Followers of Horus* (1992), and *Egypt and Nubia: Gifts of the Desert* (2002).

Bibliography:

Adams, B., *Predynastic Egypt* (Shire Egyptology 7), Aylesbury, 1988.
--- , *Ancient Nekhen: Garstang in the City of Nekhen* (ESA no.3), SIA Publishing, 1995.
Adams, B and K. Cialowicz, *Protodynastic Egypt* (Shire Egyptology 25), Great Britain, 1997.
Darnell, J.C., *Theban Desert Road Survey in the Egyptian Western Desert, Volume 1: Gebel Tjauti Rock Inscriptions 1-45 and Wadi el-Hôl Rock Inscriptions 1-45*, Oriental Institute Publications 119, Chicago, 2002.
Friedman, R. et al., "Preliminary Report on Field Work at Hierakonpolis 1996-1998," *JARCE* 36 (1999), pp. 1–35.
Friedman, R. and B. Adams (eds.), *The Followers of Horus: Studies dedicated to Michael Allen Hoffman*, Oxford, 1992.
Friedman R., *Egypt and Nubia: Gifts of the Desert*, London, 2002.
Hoffman, M. A., *Egypt Before the Pharaohs*, New York, Texas, 1979/1991.
Midant-Reynes, B., *The Prehistory of Egypt: From the First Egyptians to the First Pharaohs*, Oxford, 2000.
Spencer, A. J., *Early Egypt: The Rise of Civilization in the Nile Valley*, London, 1993.
--- (ed.), *Aspects of Early Egypt*, London: British Museum Press, 1996.
Shaw, I. (ed.), *The Oxford History of Ancient Egypt*, Oxford, 2000.
Wendorf, F. and R Schild, *Holocene Settlement of the Egyptian Sahara, vol. 1: The Archaeology of Nabta Playa*, New York, 2002.

Photo credits:

54, 55 Araldo De Luca/Archivio White Star
56, 57 left Renee Friedman
57 right Araldo De Luca/Archivio White Star
58, 59 Renee Friedman
60 The British Museum
61 Kenneth Garrett

THE TOMBS OF THE FIRST AND SECOND DYNASTIES AT ABYDOS AND SAQQARA

Text by Günter Dreyer

Günter Dreyer studied Egyptology, Assyriology and Ancient Near Eastern archaeology in Hamburg and Berlin, where he completed his Ph.D. in 1978 about temple donations in the early periods of Egypt. He excavated with the German Institute of Archaeology at Luxor, Elephantine, Wadi Garawi, Abydos and Giza. He became assistant director of the German Institute in 1989, and director in 1998. He completed his Habilitation at Berlin University in 1997 on Early Writing from Egypt and is now mainly conducting the excavations of the earliest Royal Tombs at Abydos.

Bibliography:

Spencer A. J., *Early Egypt*, London: British Museum Press, 1993.

Abydos

Amélineau, E., *Les Nouvelles Fouilles d'Abydos I-III*, Paris, 1895-1904.
---, *Le Tombeau d'Osiris*, Paris, 1899.
Petrie, W. M. F., *The Royal Tombs of the First Dynasty I-II* (Mem. Egypt Expl. Fund 18, 21), London, 1900-1901.
Dreyer, G., *Umm el-Qaab I, Das prädynastische Königsgrab U-j in Abydos und seine frühen Schriftzeugnisse* (Archäologische Veröffentlichungen 86), Mainz, 1998.
Dreyer G., et al., "Umm el-Qaab, Nachuntersuchungen im frühzeitlichen Königsfriedhof. Vorberichte (preliminary reports)," *Mitteilungen DAI Kairo (MDAIK)* 38, 46, 49, 52, 54, 56 (Mainz, 1982-2000).

Saqqara

Emery, W. B., *Great Tombs of the 1st Dynasty I-III, Excavations at Saqqara*, Cairo, 1949; London, 1955-58.
--- *The Tomb of Hemaka, Excavations at Saqqara*, Cairo, 1938.
---, *Hor Aha, Excavations at Saqqara*, Cairo, 1939.
Lauer, J. Ph., "Histoire monumentale des pyramides d'Égypte," *Bibliothèque d'Étude* 39, Cairo, 1962.

Photo credits:

62 Araldo De Luca/Archivio White Star
63 Günter Dreyer
64 top RMN
64 center and bottom Günter Dreyer
66 Araldo De Luca/Archivio White Star
67 top Günter Dreyer
67 center Araldo De Luca/Archivio White Star
68-69 and 68 bottom Günter Dreyer
69 bottom left Araldo De Luca/Archivio White Star
70 and 71 private collection
72-73 private collection
73 top, center and bottom Araldo De Luca/Archivio White Star
74 Günter Dreyer
75 Araldo De Luca/Archivio White Star
76 top and bottom Araldo De Luca/Archivio White Star
76-77 Günter Dreyer

THE ROYAL MORTUARY ENCLOSURES OF ABYDOS AND HIERAKONPOLIS

Text by David O'Connor and Matthew Adams

David O'Connor is Lila Acheson Wallace Professor of Egyptian Art and Archaeology at the Institute of Fine Arts, New York University. He is also a Professor Emeritus of the University of Pennsylvania and Curator Emeritus of the Egyptian Section, University of Pennsylvania Museum of Anthropology and Archaeology. David O'Connor has excavated extensively in Egypt and the Sudan, and his publications include *Ancient Nubia: Egypt's Rival in Africa; Ancient Egypt: a Social History* (co-author); and several others. He is currently completing a book entitled *Abydos: The Evolution of a Sacred Landscape*.

Matthew Douglas Adams holds a dual Ph.D. in Anthropology and Egyptology from the University of Pennsylvania. He is Research Scholar at the Institute of Fine Arts, New York University, and a Research Associate of the University of Pennsylvania Museum. He has worked at Abydos since 1981 and has been a project director there since 1991. He is Director of the Abydos Settlement Site Project, and has undertaken excavations in the ancient town of Abydos. He is Associate Director of the Abydos Early Dynastic Project and has excavated many of north Abydos' Early Dynastic royal monuments. In addition to Egypt, Dr. Adams has also done archaeological fieldwork in Turkey, Syria, and North America. The author of several articles and reviews, his research interests include Egypt as a complex society, kingship and the nature of the early state in Egypt, Egyptian socio-economic organization, and the archaeology of settlement in Egypt.

Bibliography:

Kemp, B., "Abydos: The Royal Tombs of the First Dynasty," JEA 52 (1966), pp. 14-22.
O'Connor, D., "New Funerary Enclosures (Talbezirke) of the Early Dynastic Period," *Journal of the American Research Center in Egypt* 26 (1989), pp. 51-86.
---, "Boat Graves and Pyramid Origins: New Discoveries at Abydos, Egypt," *Expedition* 33/3 (1991), pp. 5-17.
O'Connor, D. and M. Adams, "Moored in the Desert: Digging an Ancient Armada," *Archaeology* (May/June 2001), pp. 44-45.

Photo credits:

78, 79, 80 top, 80-81 Giulio Veggi/Archivio White Star
81 top, 82-83, 83 David O'Connor
84, 85 Giulio Veggi/Archivio White Star

THE STEP PYRAMIDS

Text by Ali Radwan

Ali Radwan is a Professor at Cairo University where he teaches Egyptian Art and Archaeology. He was the former dean of Cairo Uninersity and excavated at Abusir.

Bibliography:

Allen, J. P., "Funerary Texts and Their Meaning," in S. D'Auria, P. Lacovara and C. H. Roehrig (eds.), *Mummies and Magic: The Funerary Arts of Ancient Egypt*, Boston, 1988, pp. 38-49.
Altenmüller. H., "Bemerkungen zur frühen and späten Bauphase des Djoserbezirkes in Saqqara," *MDAIK* 28 (1972), pp. 8-12.
Barsanti, A., "Ouverture de la pyramide de Zaouiét el-Aryan," *ASAE* II (1901), pp. 92-4.
Cwiek, A., "Date and Function of the So-called Minor Step Pyramids," *GM* 162 (1998), pp. 39-52.
Dreyer G. and W. Kaiser, "Zu den kleinen Stufenpyramiden Ober-und Mittelägyptens," *MDAIK* 36 (1980), pp. 43-59, Taf. 68-77.
Dreyer G. and N. Swelim, "Die kleine Stufenpyramide von Abydos-Süd (Sinki)," in *MDAIK* 38 (1982), pp. 83-93, Taf. 11-14.
Dreyer, G., "Der erste König der 3. Dynastie," in H. Guksch and D. Polz (eds.), *Stationen, Fs. R Stadelmann*, Mainz, 1998, pp. 31-34.
Dodson, A., "On the Date of the Unfinished Pyramid of Zawyet el-Aryan," *Discussions in Egyptology* 3 (1985), p. 21.
Edwards, I. E. S., *The Pyramids of Egypt*, Harmondsworth, 1961.
Fakhry, A., *The Pyramids*, Chicago, 1969.
Faulkner, R. O., *The Ancient Egyptian Pyramid Texts*, Oxford, 1969.
Firth, C. M., J. E. Quibell and J-Ph. Lauer, *The Step Pyramid, I, II*, Cairo, 1935, 1936.
Fischer, H. G., "Some Emblematic Uses of Hieroglyphs with Particular Reference to an Archaic Ritual Vessel," in *Ancient Egypt* in *The Metropolitan Museum Journal* (1977), pp. 31ff, 181 (palette from Helwan).
Friedman, F. D., "The Underground Relief Panels of King Djoser at the Step Pyramid Complex," *JARCE* 32 (1995), pp. 1-42.
Goneim, M. Z., *The Buried Pyramid*, London, 1956.
---, *Horus Sekhem-Khetm the Unfinished Step Pyramid at Saqqara, I* Cairo, 1957.
Greven, L., "Der Ka in Theologie und Königkult der Ägypten des Alten Reiches," *ÄF* 17 (Glückstadt, 1952).
Hawass, Z., "A Fragmentary Monument of Djoser from Saqqara," *JEA* 80 (1994), pp. 45-56.
Helck, W., "Der Name des letzten Königs der 3. Dynastie un die Stadt Ehnas," *SAK* 4 (1976), pp. 123-130.
---, "Gane," *LÄ* II (1977), pp. 391, n. 95.
---, "Die Datierung der Gefäßaufschriften aus der Djoserpyramide," *ZÄS* 106 (1979), pp. 120-132.
---, "Sanacht" *LÄ* V (1984), pp. 375f.
---, "Zum Statuensockel des Djoser," in I. Gamer-Wallert and W.Helck (eds.), *Gegengabe, Fs Emma Brunner-Traut*, Tübingen, 1992, 143-150.
Hornung, E., "Exploring the Beyond," in E. Hornung and B. M. Bryan (eds.), *The Quest for Immortality: Treasures of Ancient Egypt*, Munich, London and New York, 2002, pp. 33.
Kaiser, W., "Zu den Königlichen Talbezirken in Abydos und zur Baugeschichte des Djoser-Grabmals der 1. und 2. Dynastie," *MDAIK* 25 (1969), pp. 1-21.
---, "Ein Kultbezirk des Königs Den in Sakkara," *MDAIK* 41 (1984), pp. 47-60.
---, "Zur unterirdischen Anlage der Djoserpyramide und ihrer entwicklungsgeschichtlichten Einordnung," in I. Gamer-Wallert and W. Helck (eds.), *Gegengabe, Fs Emma Brunner-Traut*, Tübingen (1992), pp. 167-190.
Kees, H., *Der Götterglaube im Alten Agypten*, Leipzig, 1941, pp. 214ff.