



Seeing Beneath the Surface *by Glen Dash*



Archaeological excavation is slow, painstaking work. Remote sensing can be a helpful adjunct with its indirect look below the surface based on geophysics. This past fall we put some remote sensing techniques to the test in a pilot season of the Giza geophysical survey, sponsored by the National Geographical Society with AERA (Ancient Egypt Research Associates), the University of Birmingham's Institute of Archaeology, and the California firm of Tremaine and Associates. Here AERA board member Glen Dash describes the work carried out by Tremaine and Associates.

The basic technology to see beneath the soil has been around for decades. "Remote sensing" tools such as magnetometers, surface penetrating radars and electromagnetic induction machines are routinely used in geological, environmental, and criminal investigations. But their use in archaeology has been relatively limited. Part of the reason is their complexity. In order to do remote sensing well, the operator needs to know something about electromagnetism, geology, and archaeology all at the same time.

One goal of our 2003 geophysical pilot season was to bring together people from all these disciplines to explore unexcavated areas of the Giza (Continued on page 6)

Staring up the mouth of the Central Wadi. This wide gully washes down from the desert across the Giza Plateau. Fourth Dynasty pyramid builders may have hauled stone through the wadi from the harbor up to the construction site. Using remote sensing we hoped to find traces of hauling tracks. The fresh tracks visible in the photo were made by Tremaine and Associates' ATV towing a boom with remote sensing equipment over the ground. The minute figures on the right at the edge of the wadi include the ATV, its driver, and another Tremaine staffer. A clearer shot of the equipment is shown on the next page. The results of the remote scanning in the wadi can be seen in the illustration on page 9. The pyramid on the horizon is Menkaure's accompanied by one of his queen's pyramids. The structures at the bottom of the photo are tombs in the Islamic cemetery.

Tools for Probing the Past: Tremaine's Technology

During our fall 2003 geophysical pilot season Tremaine and Associates "looked" below the surface using their remote sensing technology system. This is how eScan™ works:

Tremaine's system uses a venerable remote sensing technology known as "electromagnetic induction," or simply EM, as its geophysical sensor. EM works as follows: A coil of wire in the shape of a solenoid is suspended over the surface to be sensed. A time varying (sinusoidal) electrical current is passed through the coil, creating a time varying magnetic field in its vicinity. If a second "receiving" coil is placed adjacent to the first, some of the magnetic field produced by the first (or "transmitting") coil will pass through the coils of the second, inducing a current in it through a process known as electromagnetic induction. The electrical current induced is a function of, among other things, the distance between the coils, their alignment, and the proximity of nearby objects.

It is this last variable that makes EM useful for geophysical surveys. Since most soils are at least partially conductive, the magnetic field produced by the transmitting coil will cause electrical currents to flow in the soil. These currents will affect the amount of signal picked up by the receiving coil. If the two coils are fixed relative to each other and moved over a surface, the change in current in the receiving coil can be used as a measure of the soil's apparent conductivity. Abrupt changes in apparent conductivity are known as "anomalies" and can be a marker of past cultural activity.

The conductivity of soil is a function of many factors including its porosity, clay content, and the degree of water saturation. At the molecular level, the conductivity of soil is largely due to the number and mobility of dissolved ions and is measured in units of millisiemens per meter (mS/m). Sands tend to have low conductivity, around 1 to 10 mS/m. On the other hand, clays tend to be more

conductive, on the order of 10 to 50 mS/m.

EM sensors can be used to measure soil conductivity as a function of depth. The technique works as follows: The farther apart the transmit and receive coils are, the larger the volume of soil being sensed. Therefore, the spacing between the transmit and receive coils can be adjusted to measure progressively larger volumes of soil. The Tremaine system uses three receiving coils spaced at three different distances from the transmitting coil. This allows three measurements to be made simultaneously over three different soil volumes. Post measurement processing can then be used to derive a profile of soil conductivity with depth. The system deployed at Giza used three receiving coils spaced so as to allow measurement at depths of 1.5 to 2

meters, 3.5 to 4 meters, and 8 to 10 meters below the surface. To do that a 24 foot boom was required (see photo below).

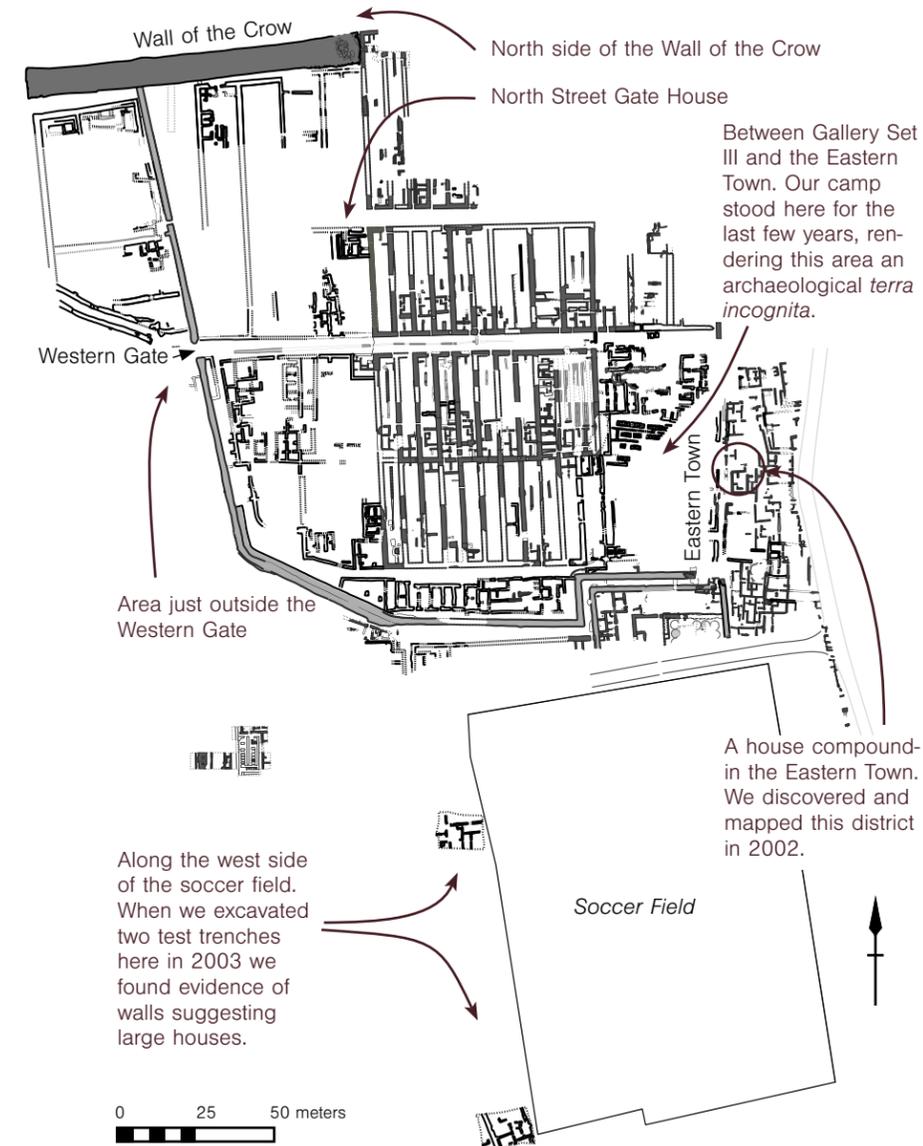
Tremaine's system also combines EM sensing with real time kinematic Global Positioning Sensor (GPS) technology. As the system is moved, its location is continuously logged to a precision of 50 centimeters vertically and 1.5 centimeters horizontally. Therefore, through post processing, maps of both soil conductivity and topology can be produced. The system used here logged data at a rate of four readings per meter. Under optimal conditions, the entire system was capable of traveling at speeds greater than 6 miles per hour. To learn about the results of the survey work see the article starting on page 1. *Glen Dash*

Tremaine's eScan™ system maps soil conductivities as a function of depth using Electromagnetic Induction (EM) sensors which are mounted in the boom trailing behind the ATV driven by Maggie Trumbly. Khufu's pyramid stands in the background.



Season 2004: Honing the Details

By the time you receive this newsletter we will have completed another season of excavation and will be immersed in analysis. As during our Millennium Project, we did a broad sweep across a large area and intensive excavation in selected places, shown on the map below. We look forward to reporting these findings in our next newsletter.



Thanks to All who Made the 2003 Geophysical Pilot Season Possible

The geophysical pilot season was possible because of financial support from the National Geographical Society and David Koch.

We are grateful to **Dr. Zahi Hawass**, Undersecretary of State and Secretary General of the Supreme Council of Antiquities. We thank **Mr. Adel Hussein**, Director of Giza and Saqqara, and **Mr. Mansour Bureik**, Chief Inspector of Giza, for their kind assistance. We thank **Essam Shehab**, **Fedahi Helmi**, **Reda Abdel Haleem**, and **Shazli Ahmed** who represented the Supreme Council of Antiquities.

AERA's crew included archaeologists Dr. Mary Anne Murray, Ana Tavares, Tobias Tonner, and Glen Dash. Tremaine and Associate's team included archaeologist John Lopez, geophysicists Dr. Mark Armstrong and Dr. Yi Liao; geologist Dr. Ken Lajoie; engineer Rod Sorenson; GIS specialist Shannon DeArmond; EM technicians Maggie Trumbly and Randy Yonemura. The University of Birmingham group included Meg Waters, Steve Wilkes, Emma Hancox, Kate Bain, Tim Evans, Mark Kinsey, and Glynn Barrett.

AERAGRAM

Volume 7 Number 1, Spring 2004

Editor

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Harvard University

AERAGRAM is published by AERA, Ancient Egypt Research Associates. It reports on ongoing research and other developments on the Giza Plateau for friends and supporters of AERA and others interested in ancient Egypt.

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AERA Board Member Profile

Glen Dash used to write regularly for *Conformity*. An engineering professional's journal, it deals with certification of electrical products and the regulations to which they must conform. Glen's own professional life, though, has had little to do with conformity. Over two decades, spent mostly as an electrical engineer, Glen went through odd career twists and turns along with tumultuous highs and resounding crashes. In 1995 with one more career turn, life settled into the relatively even keel where it has been coasting along ever since. Glen established his own archaeological foundation and became an expert in remote sensing. Since then he has provided funding and resources for excavations and carried out remote sensing surveys which combine his engineering expertise with a long-standing interest in archaeology. He has joined us in the field at Giza three times, most recently this past fall for survey work which he describes in an article starting on page 1.

From Archaeology to Engineering

While Glen has spent most of his adult life as an electrical engineer, he first considered a career in archaeology. Actually it was palaeontology that really captured his interest but MIT, where he was enrolled as an undergrad, offered no courses in the field. After Glen took several anthropology classes as his second choice, he was hooked and set out to go on a "dig." But his first excavation convinced him that he was not cut out to be a field archaeologist.

In the summer of 1973 he joined the excavations at remote Tepe Yahya in Iran, directed by Prof. Carl Lamberg-Karlovsky of Harvard University. Early into the three-month-long season it was clear that Glen with his dyslexia could not recognize flat surfaces; in his efforts to follow an ancient floor surface, he was cutting through hundreds of years of deposits. Prof. Lamberg-Karlovsky wisely pulled Glen out of the field and transferred him to a "desk job" where he worked as registrar for the rest of the season. By the end of the summer Glen had dropped all notions of making a living as an archaeologist but never lost his interest in ancient civilizations.

Upon returning to MIT in the fall he decided to major in electrical engineering, the other field that held his interest. In fact, one of the main reasons he chose MIT was for its strength in this discipline. As a child growing up outside of Chicago, he was deeply impressed by the Time Life book *Engineering*, in its series on science. He decided that when he grew up he would be an engineer like the men featured in the book and MIT, which figured prominently in *Engineering*, was the place to do it.

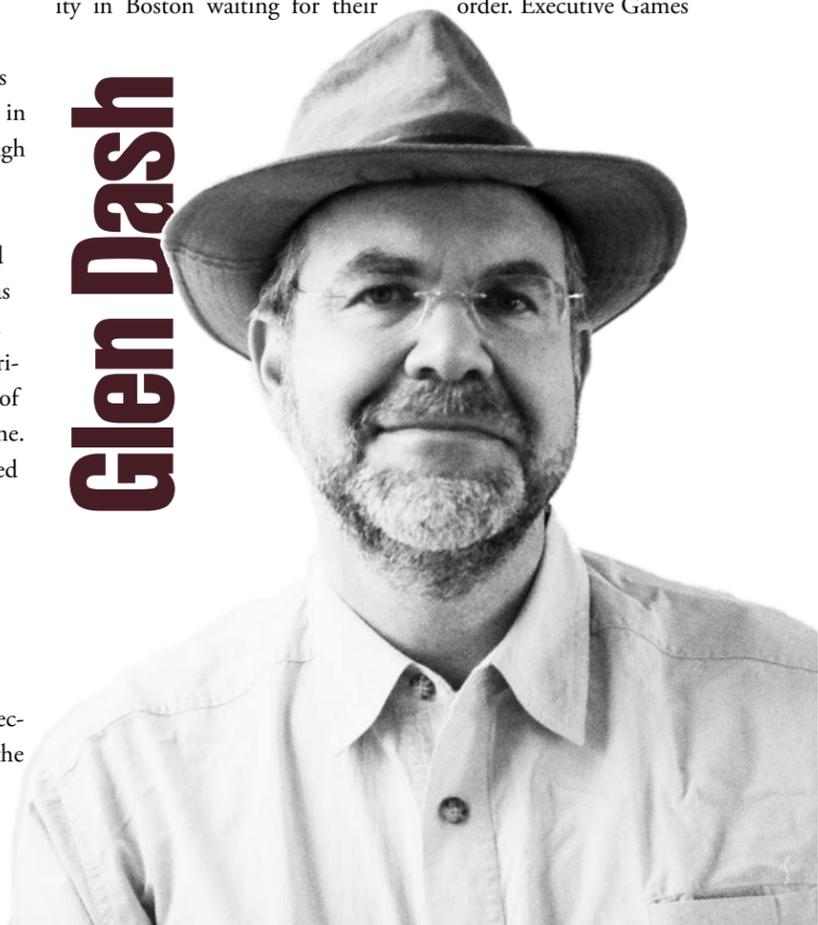
In electrical engineering Glen found his metier; he loved the field. But after graduation in 1975 he was "bored to tears" in his first real engineering job, endlessly measuring end resistance in electrical parts. He lasted only a few months. That might have been the end of his electrical engineering career, had it not been for video games—not playing them, but developing them. During his last

semester at MIT Glen had worked at the Innovation Center, a laboratory for aspiring inventors, and helped develop a low cost version of a video game. At that time nearly all video games were played on coin-operated machines. The few available for home use were relatively primitive. Peter Stepanek, president of Executive Games who contracted the work, specified that "Television Tennis" be played on a conventional TV and cost no more than \$25 in parts. By the end of the semester Glen, with the help of four of his fraternity brothers, had developed a working prototype of the game. After many redesigns they got the cost of parts down to the target \$25.

The work continued through the summer on into the fall after Glen had gone off to his ill-fated first real job. When he quit in September, he had no trouble returning to the television tennis project, this time as Chief Engineer at Executive Games. Thus began a remarkable roller coaster ride that would crest and then tumble within less than a year and a half.

As Glen and his team prepared the product for its launch, Peter Stepanek was aggressively marketing it. When the game was finally ready late in the fall, well over 400,000 units were already committed. The game was a runaway success and soon the only problem facing Executive Games was keeping up with demand. The small company could not manufacture units fast enough. Department stores were so eager to get the games on their shelves that their truck drivers would park in Executive Game's manufacturing facility in Boston waiting for their order. Executive Games

Glen Dash



became the third largest producer of video games and Glen became a minor celebrity. He appeared in the *People Magazine* column "Up and Coming" (photo below right) and even received fan mail.

Celebrity was short lived though. In early 1977 Executive Games collapsed after having been quickly eclipsed by aggressive competitors, Atari and Coleco, who could produce games faster for less money.

From Laws to Gadgets to Emissions

Now an unemployed video game developer, Glen heeded his parents' pleas to get a "real education" and become a lawyer. He enrolled in a joint law and business program at the Harvard Law School and MIT's Sloan School of Management. But this turned out to be another short-lived career. By the time Glen graduated he knew he would never be a lawyer. His summer work clerking with a Boston law firm had convinced him that the law was not for him. He passed the bar exam but never walked into a courtroom as another's lawyer.

Having tried a "real career," and found it not to his liking, Glen decided to do something he loved, tinkering. He would be a "poor inventor rather than a rich lawyer." He started his own firm in 1981 and over the next two years he and his partner worked on a series of marvelous inventions that almost made it. They developed one of the earliest cordless phones and even a rudimentary camcorder, but these gadgets never made it to the marketplace. One of their inventions, the first true three-dimensional display, worked very well—images floated exquisitely in space—but there was no market for it.

Glen's fledgling business might have foundered after two years of near successes had it not been for the FCC. In 1981 the Federal Communications Commission set forth new regulations for consumer electronics. Personal computers, peripherals, and other electronic devices could no longer interfere with television and radio reception, which meant that their electromagnetic emissions had to be suppressed. And Glen was the man to do it. While working

in the frivolous business of video games he had learned a great deal about the serious business of emissions. At that time video game devices were one of the few consumer electronics that *were* regulated so that their emissions did not interfere with TV reception. Glen soon co-founded Dash, Straus and Goodhue, Compliance Design and Compliance Engineering, in order to sell this expertise.

The company flourished for ten years, eventually with 70 employees in a wood farmhouse—a nonconductive structure, necessary when testing electromagnetic emissions—in Boxboro, 20 miles northwest of Boston. Facing a recession in the early 1990s, Glen and his partners sold out to Inchcape, PLC, one of world's largest



Glen Dash, featured in *People Magazine* in 1975 with "Television Tennis."

companies. For the next few years Glen worked as an employee of his own firm.

Casting about for other opportunities after he sold his company, Glen began investing in start-ups, one of which is the publishing company that puts out *Conformity*. The journal was a perfect vehicle for Glen since by that point he knew much about the regulations for electronic devices everywhere in the world. Indeed he has published extensively on the subject and some of his works have been enduring references for electrical engineers working on electronic devices around the world.

Back to Archaeology

In 1995 his career took yet another unexpected turn. Glen and his wife Joan were on a "grand tour" of archaeological sites at the invitation of Prof. Larry Stager, director of the Harvard Semitic Museum, and his wife Susan. Dr. Stager, Harvard Dorot Professor of the Archaeology of Israel, has run an excavation for many years at the site of Ashkelon. He mentioned to Glen that people had tried unsuccessfully to carry out remote sensing at the site. As Glen listened, he began mulling over this problem. Within the next few days he decided that with his technical expertise and understanding of archaeology he could probably develop remote sensing techniques that would work here. He would train himself in geophysical surveying methods and possibly be able to develop better equipment.

Thus was born a new mission and the Glen Dash Archaeological Foundation.

Since then Glen has worked with teams in Israel, Greece, and Cyprus, in addition to the Giza Plateau Mapping Project. On the Gulf of Corinth, he helped in the search for the lost Classical Greek city of Helike, destroyed and submerged by an earthquake and tsunami in 373 BCE. Using magnetometry, he mapped nearly the entire island of Yeronisos off of Cyprus, now thought to be the location of a palace for Cleopatra VII.

Back in the U.S. Glen is working at historic St. Ignatius Church in Port Tobacco, Maryland. With remote sensing, he hopes to locate a tunnel believed to have been used as part of the Underground Railroad.

Glen's foundation has helped support a number of projects including ours at Giza. He joined our board of directors in 1999 and has been a great resource on all things technical.

If the past is any indication of the future, we can expect that Glen's career will take yet another turn. We just hope that it does not draw him away from archaeology.

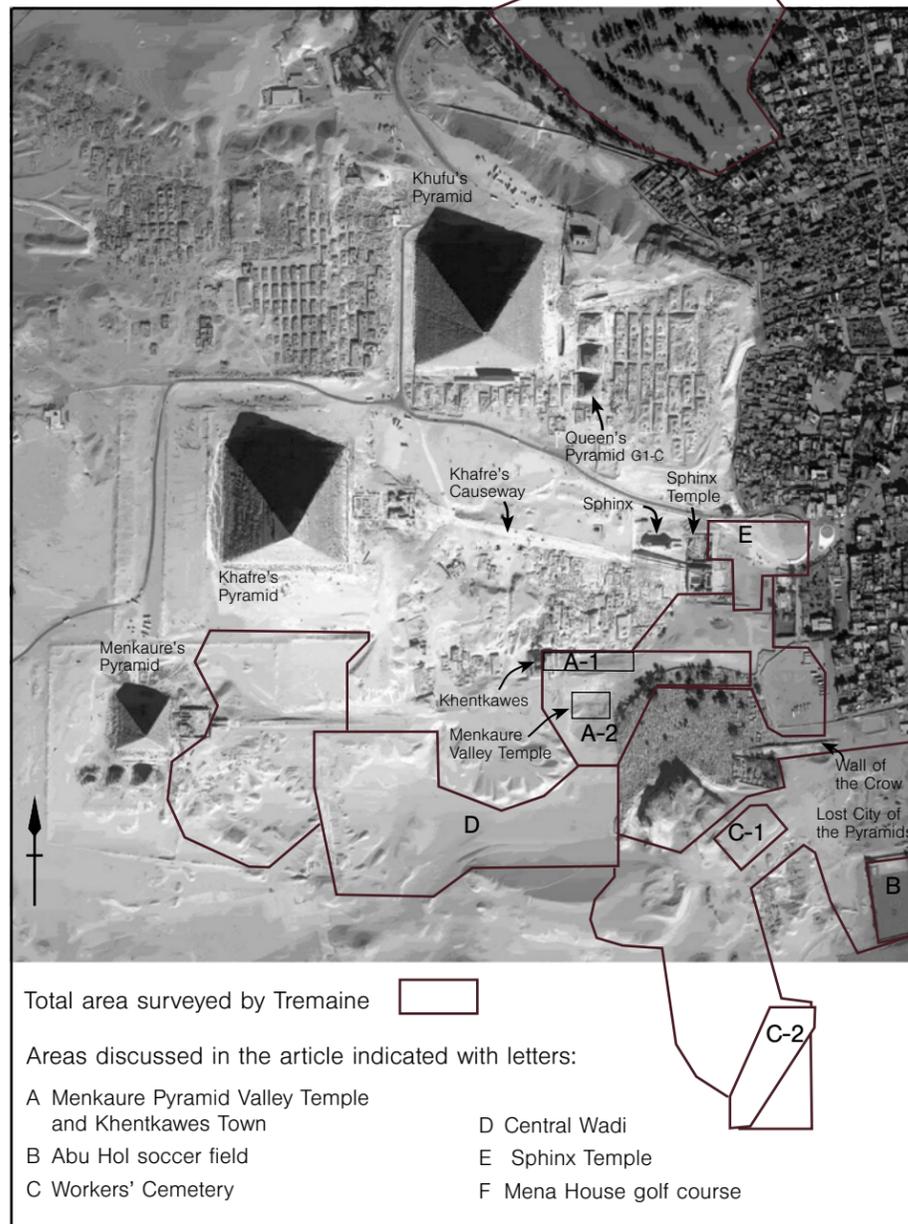
— Wilma Wetterstrom

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Plateau with remote sensing tools. With National Geographic sponsorship and in collaboration with Dr. Zahi Hawass, and the Supreme Council of Antiquities, AERA assembled a multi-disciplinary team (listed on page 3) that included AERA crew members and staff from Tremaine and the University of Birmingham. The Birmingham group carried out radar and magnetometry surveys of part of the areas covered by Tremaine plus a survey of the

Satellite photo, taken November 11, 1999, courtesy of www.spaceimaging.com.



area north of the Khafre Causeway. Glynn Barrett did a survey of the Menkaure Pyramid and Queen's Pyramid G1-C using LiDar, a laser scanning technique. In this installment I report only on the Tremaine survey using electromagnetic conductivity.

Tremaine's Survey

Tremaine uses equipment that "sees" under the surface with "electromagnetic induction" (EM). In the simplest terms, a transmitting device suspended over the ground, generates an electrical current that flows

into the soil. A receiving device, located nearby, "reads" the current in the ground which varies depending on the substances that it passes through. Some materials conduct electrical currents readily, such as clay; others impede it. An abrupt change in the current, called an "anomaly," may signal cultural material such as walls. (See page 2 for a detailed explanation of Tremaine's technique.)

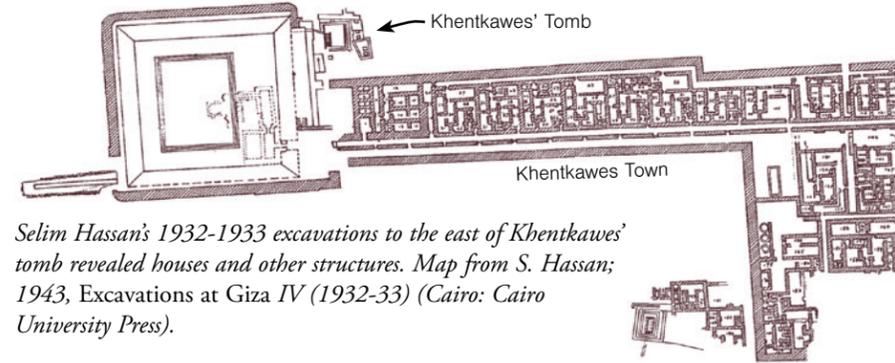
Mark Lehner, as archaeological director of the geophysical survey, selected a number of areas across the Giza Plateau for remote sensing (see map on the left). Some of these were of special interest to our project, or of interest for understanding cultural features on the plateau. The team chose some locations as test sites. Only a portion of the surveyed area is discussed here since the data are still being analyzed.

The Khentkawes and Menkaure Pyramid Valley Temple Towns

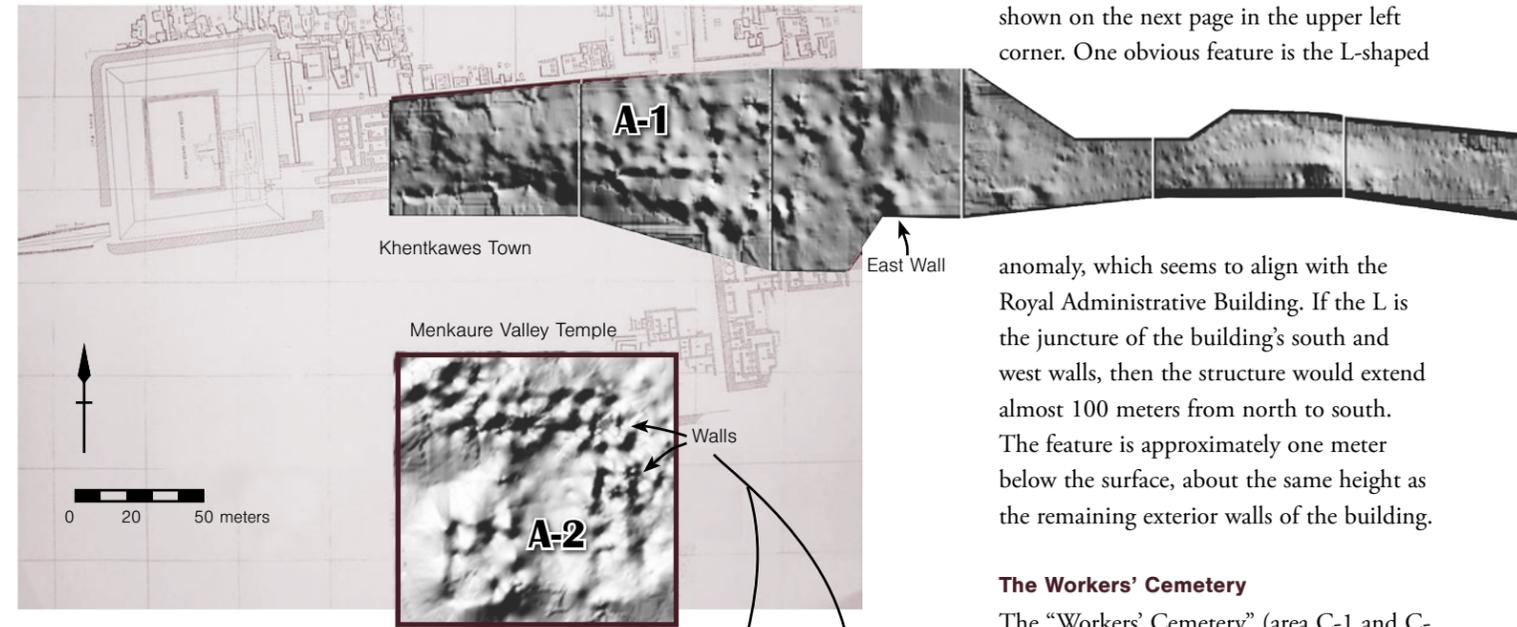
In 1932 and 1933, Selim Hassan found an orderly collection of houses that lined the causeway running east from the tomb of Khentkawes, a queen who lived at the end of the 4th Dynasty (shown on facing page and marked A-1 on map on the left). (See *AERAGRAM* 5/2, Spring 2002.) When Hassan uncovered the walls, they stood chest high and still bore traces of red, white, and black paint. These features were not backfilled and over the intervening 70 years they deflated, leaving little remaining today except for dark patches on the ground.

Nearby is the Menkaure Pyramid Valley Temple (see facing page). George Reisner began excavations here in the summer of 1908 and found a temple that had been in service from the 4th to 6th Dynasty. During that time it had been destroyed by flooding, was rebuilt, and then invaded from the east by small irregular houses and granaries. Sand layers intervene between the 4th and 6th Dynasty levels testifying to a period of neglect or abandonment.

Because these two sites had been previously excavated, they served as ready test beds for the Tremaine technology. Though Tremaine's system has been widely used in



Selim Hassan's 1932-1933 excavations to the east of Khentkawes' tomb revealed houses and other structures. Map from S. Hassan; 1943, *Excavations at Giza IV (1932-33)* (Cairo: Cairo University Press).



Above: Tremaine's results superimposed over Hassan's map of the Khentkawes and Menkaure Valley Temples. The "shaded relief" format creates an artificial texture. Right: George Reisner's map of the Menkaure Pyramid Valley Temple. Tremaine's eSan™ readily detected the north and east walls and some internal features. Map from Reisner (see reference 3, page 13).

the U.S. and elsewhere, each site has its own unique characteristics and tests of this sort are usually advisable.

On this page Tremaine's data are superimposed over Hassan's 1932-'33 map. The features found by remote sensing correspond well to the structures Hassan mapped in the Khentkawes town. The northern and eastern walls of the Menkaure Pyramid Valley Temple also show clearly. Within the rectangle lie possible Valley Temple structures or perhaps artifacts resulting from Reisner's backfilling. He did not excavate

the temple in complete horizontal levels, but rather, excavated the western part first, then the southern, backfilling the western area as he worked. Lastly, he cleared the court in the east and the northeast sections, which he may have left exposed. Sand seems to have gradually filled and covered this area, resulting in a shallower, less dense overburden than the layer covering the rest of the temple. This could account for the fact that the north and east walls show readily in the image above, whereas the east and south walls are less visible.

The Soccer Field

It is certain that the large Royal Administrative Building found in 2002 extends under the Abu Hol sports club (area B in the map on the facing page). Excavations to date have mapped the northern end of this building, exposing an area 25 meters in length and close to 50 meters wide. The structure could be a royal palace dating to the reigns of Khafre and Menkaure.

Tremaine's remote sensing results are shown on the next page in the upper left corner. One obvious feature is the L-shaped

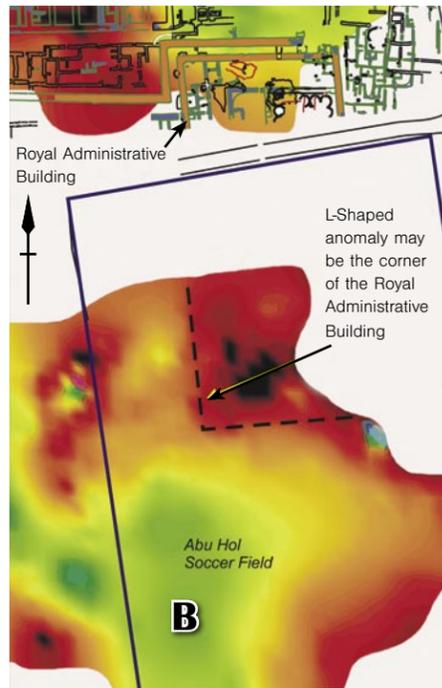
anomaly, which seems to align with the Royal Administrative Building. If the L is the juncture of the building's south and west walls, then the structure would extend almost 100 meters from north to south. The feature is approximately one meter below the surface, about the same height as the remaining exterior walls of the building.

The Workers' Cemetery

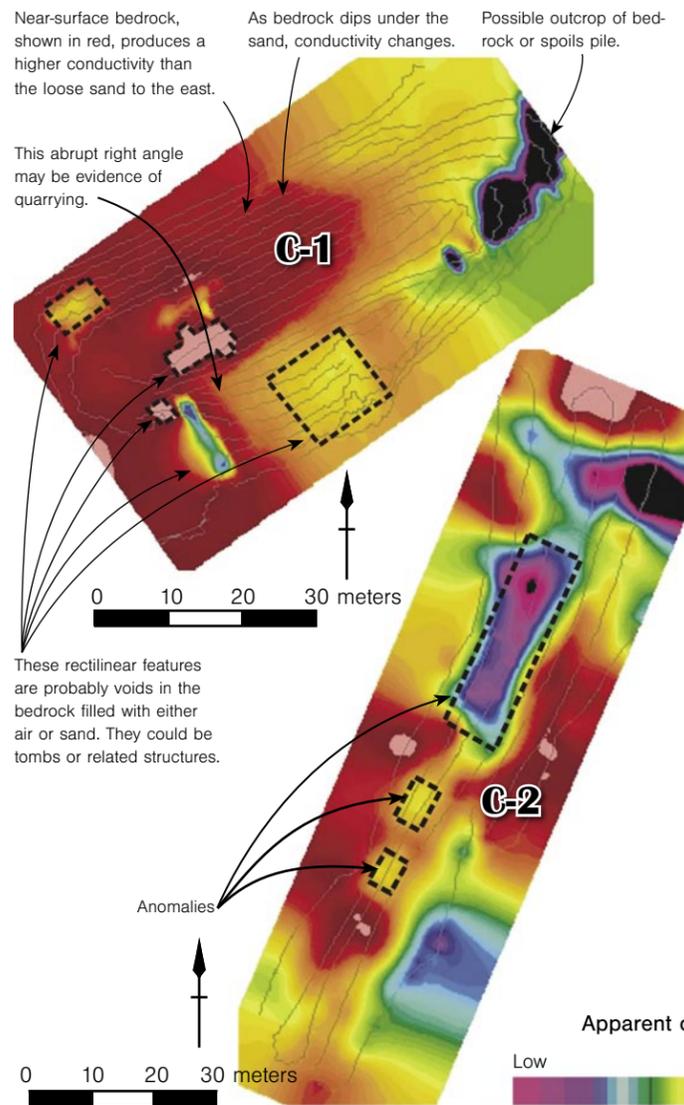
The "Workers' Cemetery" (area C-1 and C-2 on map on facing page and next page) sits on the eastern slope of the Maadi formation. Currently being excavated by Dr. Zahi Hawass, the cemetery is thought to be the final resting place for some of the workers who built or serviced the Giza necropolis in the 4th and 5th Dynasties.

The remote sensing results are shown in the maps of C-1 and C-2 on the next page. Rectilinear anomalies dot the areas surveyed. The darkened anomaly to the northeast in the diagram on the left could be an outcrop of bedrock or a spoils pile. As one moves to the south and west, the conductivity rises from a lower (yellow) to a higher level (red). This could be a result of bedrock (higher conductivity) dipping under a layer of sand (lower conductivity). The several rectilinear features in the diagram may reflect tomb shafts or voids. In addition, there is an abrupt transition from yellow to

(Continued on next page)



Left: Results from the soccer field
Below left: Tremaine's map of an unexcavated area of the Workers' Cemetery. This figure maps conductivity changes by color. Contrast this presentation of the data with the shaded relief method in the figure on the facing page.
Bottom: This unexcavated portion of the Workers' Cemetery exhibits several rectilinear anomalies including a truly enormous one about 50 x 15 meters.



Near-surface bedrock, shown in red, produces a higher conductivity than the loose sand to the east.
As bedrock dips under the sand, conductivity changes.
Possible outcrop of bedrock or spoils pile.
This abrupt right angle may be evidence of quarrying.
C-1
C-2
Anomalies
Apparent conductivity
Low High
0 10 20 30 meters

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red forming a distinctive 90° angle, possible evidence of quarrying.

At the southern end of the Workers' Cemetery (Area C-2 below) Tremaine's surveys detected a number of features along with one truly huge anomaly, approximately 50 x 15 meters, oriented to the northeast-southwest. Areas of high conductivity probably reflect bedrock closer to the surface. Lower conductivity rectilinear anomalies may indicate air- or sand-filled voids in the bedrock.

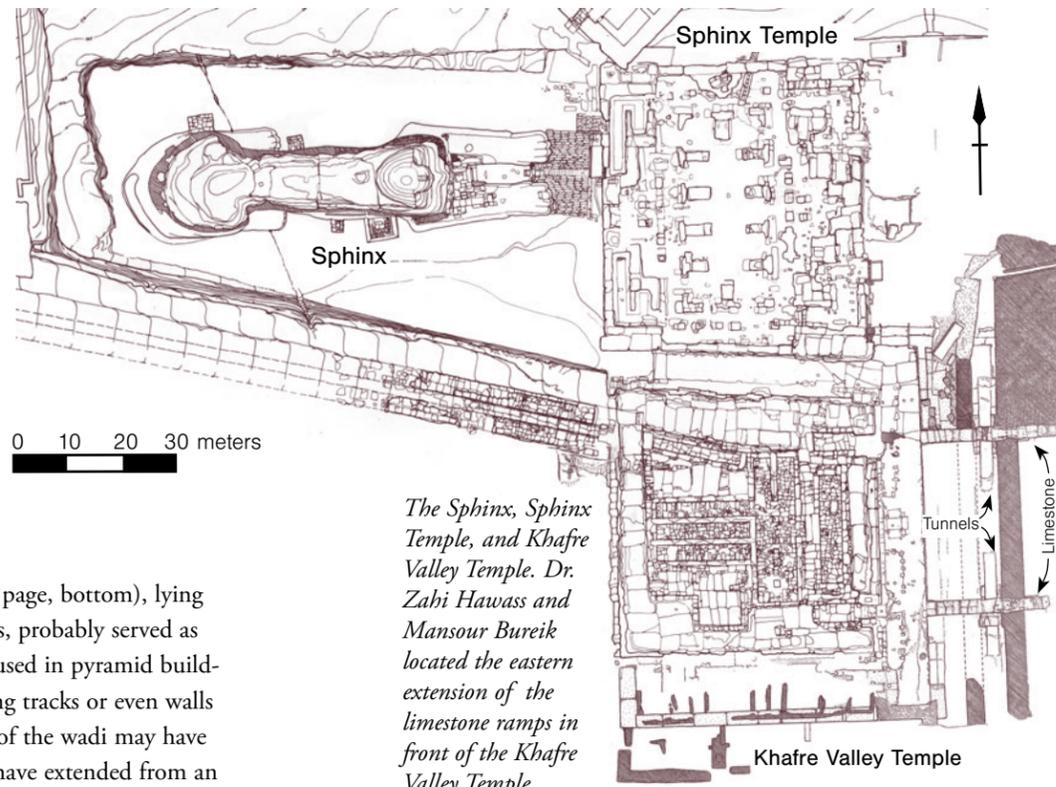
The Wadi, the Sphinx, and the Harbor

The Central Wadi (D on map, page 6; facing page, bottom), lying between the Mokattam and Maadi formations, probably served as the principle conduit for non-local materials used in pyramid building. The sandy wadi surface could hide hauling tracks or even walls built to control flash floods. The eastern end of the wadi may have emptied into an ancient harbor which could have extended from an area to the east of the Khafre Pyramid Valley Temple, up along the eastern edge of the Menkaure Pyramid Valley Temple, and down along the north side of the Wall of the Crow—a distance of more than 250 meters.

Tremaine surveyed the eastern and western sections of the Central Wadi. The results are shown in the figure on the bottom of the facing page. The eastern section was largely devoid of changes in conductivity which could indicate a relatively uniform layer of sand overlying the wadi floor. To the west, more variation in conductivity was recorded. The L-shaped anomaly could be due to quarrying.

The Sphinx, Sphinx Temple, and adjacent Khafre Valley Temple (E on map, page 6; above) have buried features that Dr. Zahi Hawass is still discovering. Remote sensing could be useful in detecting these. During excavations in 1980, Dr. Hawass found that a relatively smooth bedrock terrace extends some 35 meters east of the Sphinx Temple. This terrace probably runs no more than 10 or 15 meters beyond the excavated area, based on core sampling done in 1980 by the Egyptian Institute of Underground Water and the Ministry of Irrigation. One coring taken 50 meters east of the Sphinx Temple revealed deposits 16 meters deep: a thick blanket of sand, then dense, dark clay, and finally a hard surface from which the core drill pulled up red granite.

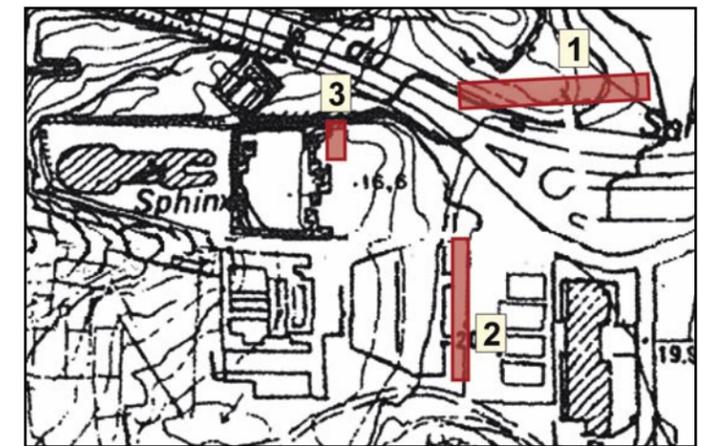
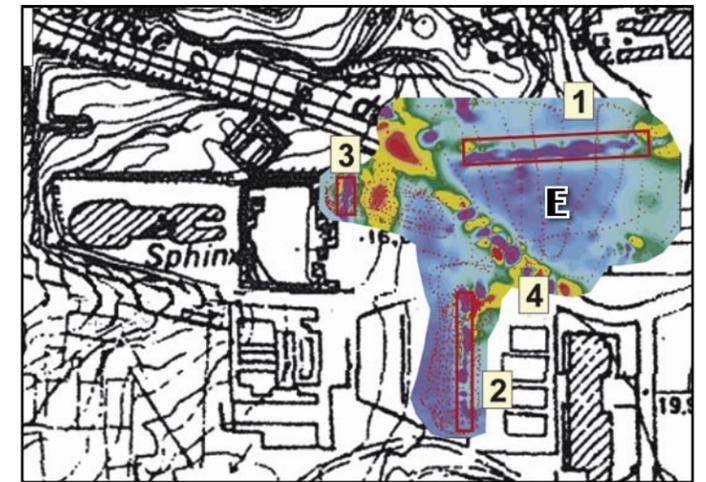
What is visible in the area today on the surface is shown in the map above. Further excavations by Dr. Hawass and Mansour Bureik revealed more of the eastern extension of two limestone ramps at least 26 meters in length leading from a terrace in front of the Khafre Pyramid Valley Temple



The Sphinx, Sphinx Temple, and Khafre Valley Temple. Dr. Zahi Hawass and Mansour Bureik located the eastern extension of the limestone ramps in front of the Khafre Valley Temple.

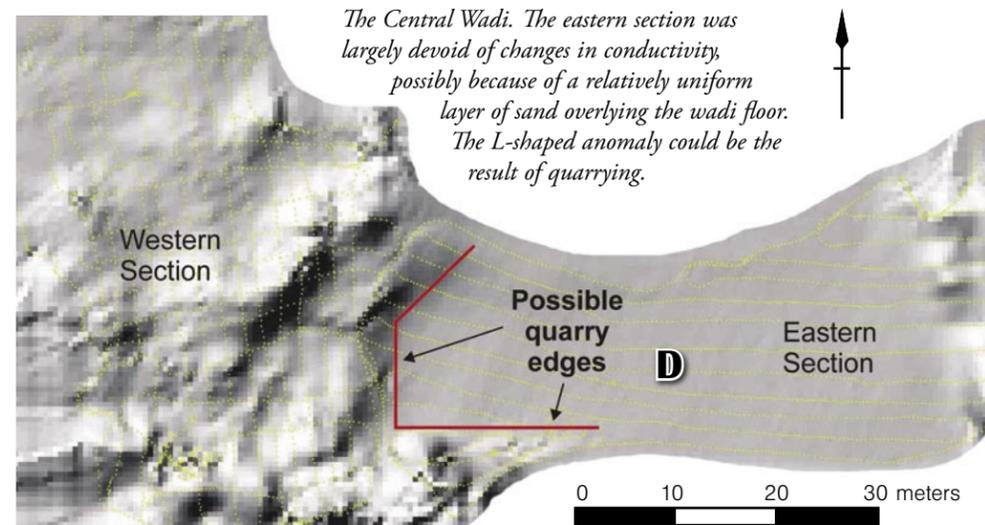
eastward. Part of a group of enigmatic structures here, the ramps slope downward, with one disappearing under more than 3 meters of overburden at an elevation less than 14 meters above sea level. Tunnels pass under the ramps.

In surveying the area directly to the east of the Sphinx, Tremaine found several distinct anomalies. Number 1 in the image above on the right does not correlate with any features visible on the surface and seems to align with the northern end of the Sphinx ditch. This could be an ancient wall. Anomaly 2 is likely to be the remnant of a low wall which once bordered the eastern edge of a stage built in 1969 and removed in 1996. Number 3 is a short, linear anomaly



Four anomalies were located in the area in front of the Sphinx and Khafre Valley Temples. The upper diagram shows the results of Tremaine's survey. The lower one highlights the anomalies.

of an unknown nature, probably a void. Drilling and bore scope inspection may be appropriate here. The anomalies labeled 4 are likely evidence of modern road building, perhaps pipes or cables laid parallel to the road edge.



The Central Wadi. The eastern section was largely devoid of changes in conductivity, possibly because of a relatively uniform layer of sand overlying the wadi floor. The L-shaped anomaly could be the result of quarrying.

The Golf Course

The golf course (F on map, page 6; top, next page) is twenty green, grassy hectares of archeological *terra incognita*. The 9th and 18th holes lie at the very foot of the Great Pyramid of Khufu. Thus, there is every reason to expect that features associated with pyramid building will be found here.

Before urban Cairo encroached on this area, the golf course was part of a sandy plain that spread out along the base of the Giza Plateau. Today it sits approximately 18 meters above sea level. Early in the last century this area was inundated by Nile floods. However, in (Continued on next page)

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ancient times flood levels were lower. Thus it is possible that Old Kingdom occupation could be found beneath these 20th century flood deposits. Indeed, basalt paving stones associated with the Khufu Pyramid Valley Temple were found reportedly more than 2 meters below the alluvial layer in sewage trenches dug by the British American consortium AMBRIC in the late 1980s.

Geophysically the golf course is a difficult target. In addition to the flood layers, the golf course has been continuously loamed, seeded, irrigated, and landscaped. All these factors create layers of high conductivity which can mask features below.

Tremaine's golf course survey data are shown in the diagrams the right. Most of what was detected was modern, such as the dark, linear features which are irrigation pipes. But the nature of the vertical feature is yet to be determined.

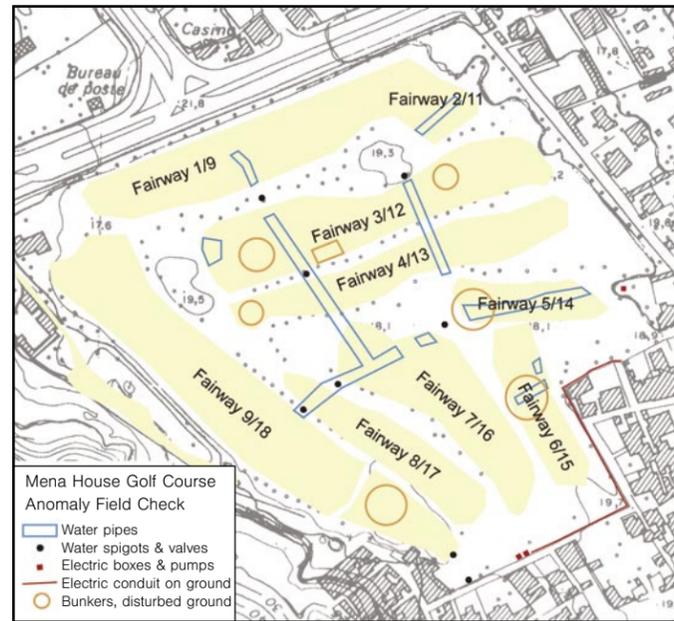
The areas bordered in red are places where the Tremaine device could not go. What shows up within these rectangles are mostly artifacts of computer processing.

However, a computer derived 3-D section shown at the bottom of the page reveals a distinct layer 2 to 3 meters below the surface. According to Mark Lehner, this is the elevation at which the archaeological horizon from the 4th Dynasty would be expected—about 15 or 16 meters above sea level. (Fifteen meters above sea level is one of the “bench marks” for the 4th Dynasty in this area.) By way of comparison, the base of the Wall of the Crow is approximately 15.4 meters above sea level and the base of the basalt pavement of the Khufu Pyramid Valley Temple, about 14.5 meters.

Remote sensing will not take the place of intensive excavation but it is a very useful tool. Tremaine's work demonstrates that it can provide a head start by locating buried features and offering clues to their nature. We look forward to more insights when Tremaine completes its analysis.

Glen Dash directs the Dash Foundation for Archaeological Research. Learn more about him in an article starting on page 4.

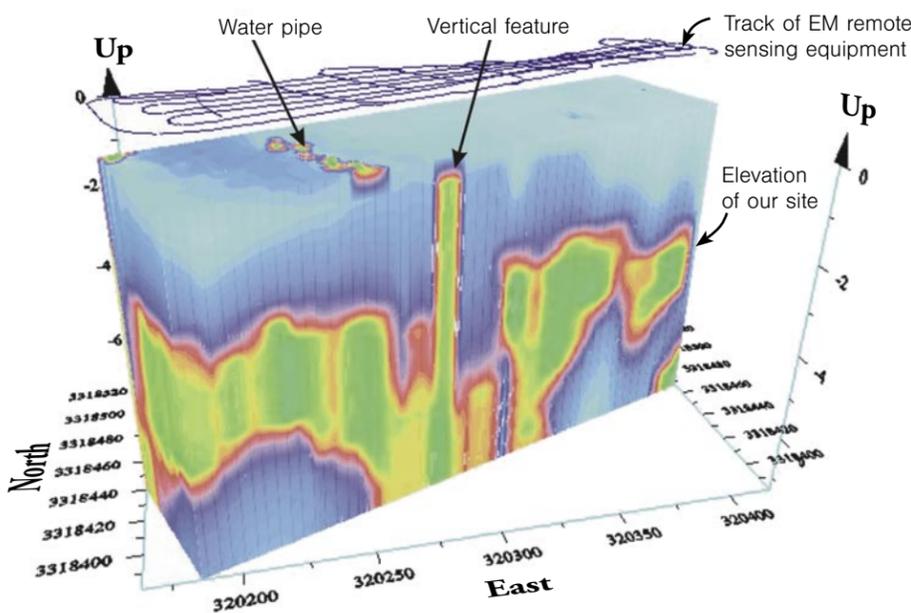
The golf course lies at the very foot of the Great Pyramid of Khufu. The map shows its present surface features, many of which were detected by Tremaine, as shown in the diagram immediately below.



Right: At first blush, most of features that Tremaine detected, the dark areas, appear to be modern, as can be seen in the map above. But look at the diagram below.



Below: Subsurface profiles, such as this 3-D cube, can be created by exploiting Tremaine's ability to map soil conductivity as a function of depth.



Of Gangs and Graffiti: How Ancient Egyptians Organized their Labor Force

How did the ancient Egyptians organize their society and mobilize labor for building the Sphinx and pyramids? This is one of the questions that has driven our research at Giza, even before we turned a trowel of dirt. Working in Egypt we are fortunate to have texts that shed light on this question. Some of the most compelling were left by the laborers themselves: graffiti hidden within the monuments on the stone walls. From their writings and other texts, Egyptologists have pieced together a picture of a labor force organized into a hierarchy of work gangs that built monuments, serviced the mortuary temples, and possibly worked in the palace.

Gangs and Graffiti

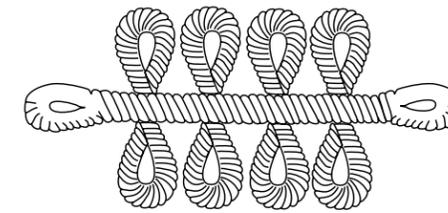
Some of the first clues to the organization of labor came from Khufu's pyramid. Above the granite-lined King's Chamber five small rooms are stacked one over the other, never meant to be seen, although the ancient builders left a small tunnel leading up to the lowest chamber.

In 1832 Howard Vyse blasted a vertical passage that breached the whole stack. Above the top chamber, huge gabled limestone beams span the width, so that the weight of the pyramid above presses down on the lower ends of the beams, rather than directly onto a flat ceiling. This may have been the 4th Dynasty builders' attempt to relieve the stress on the King's Chamber. Hence, the name relieving chambers.

When Vyse went into the upper chambers he saw bright red marks left by the ancient builders: leveling lines, axis markers, cubit notations, and the names of work gangs (*aper* in Egyptian, determined with the hieroglyph , compounded with the name of the king).

Competing Gangs

Looking at the record of the masons' graffiti that Vyse and his collaborator, J. S. Perring¹ made, Egyptologist Ann Roth² noticed a curious pattern. The name of one gang occurs on the north side of the relieving chambers' stack, and the name of another, on the south side. The end walls are divided in half, each bearing the name of the gang from the nearest side wall. The division suggests that two gangs competed, and cooperated, in transporting the stones. In addition to these names, there is a single graffiti of “The Friends of Khufu Gang.”



A cattle hobble, the hieroglyph for *za*, a subdivision of a work gang.

Between 1906 and 1907 George Reisner³ found similar marks on the huge limestone core blocks of the Menkaure Pyramid Temple. Menkaure's builders had begun to apply a casing of hard granite over the blocks but stopped, presumably upon the king's death. Under the successor, Shepseskaf, workmen hastily finished the temple wall in plastered mud brick. When Reisner peeled off this thick casing he saw the brightly painted leveling lines, cubit notations, and graffiti in glyphs 30 centimeters high, naming work gangs, including “The Friends of Menkaure Gang.”

Again Ann Roth⁴ found evidence that the gangs competed with each other. From Reisner's records she found that the two graffiti naming the Friends of Menkaure occurred on the south side of the temple,

while thirteen names of another gang, “The Drunkards of Menkaure,” were on the north side of the temple. (Our Czech colleague Vassil Dobrev⁵ would read “drunkards,” *thw*, as “laborers.”)

The *Zau*: From “Great” to “Last”

Another hieroglyph appeared with the gang names painted on Menkaure's temple. It was the word *za* (plural *zau*), a subdivision of the gang. The hieroglyph is a cattle hobble, a rope tied in a series of loops used to keep the animals moving together (shown on the left).

The *za* was known throughout nearly three millennia of Egyptian history. During the Old Kingdom there were five which are often listed in a particular order, with names that roughly translate as “Great;” “Asiatic;” “Green” or “Fresh;” “Little” or “Small;” and “Perfect,” “Lowest,” or “Last.”

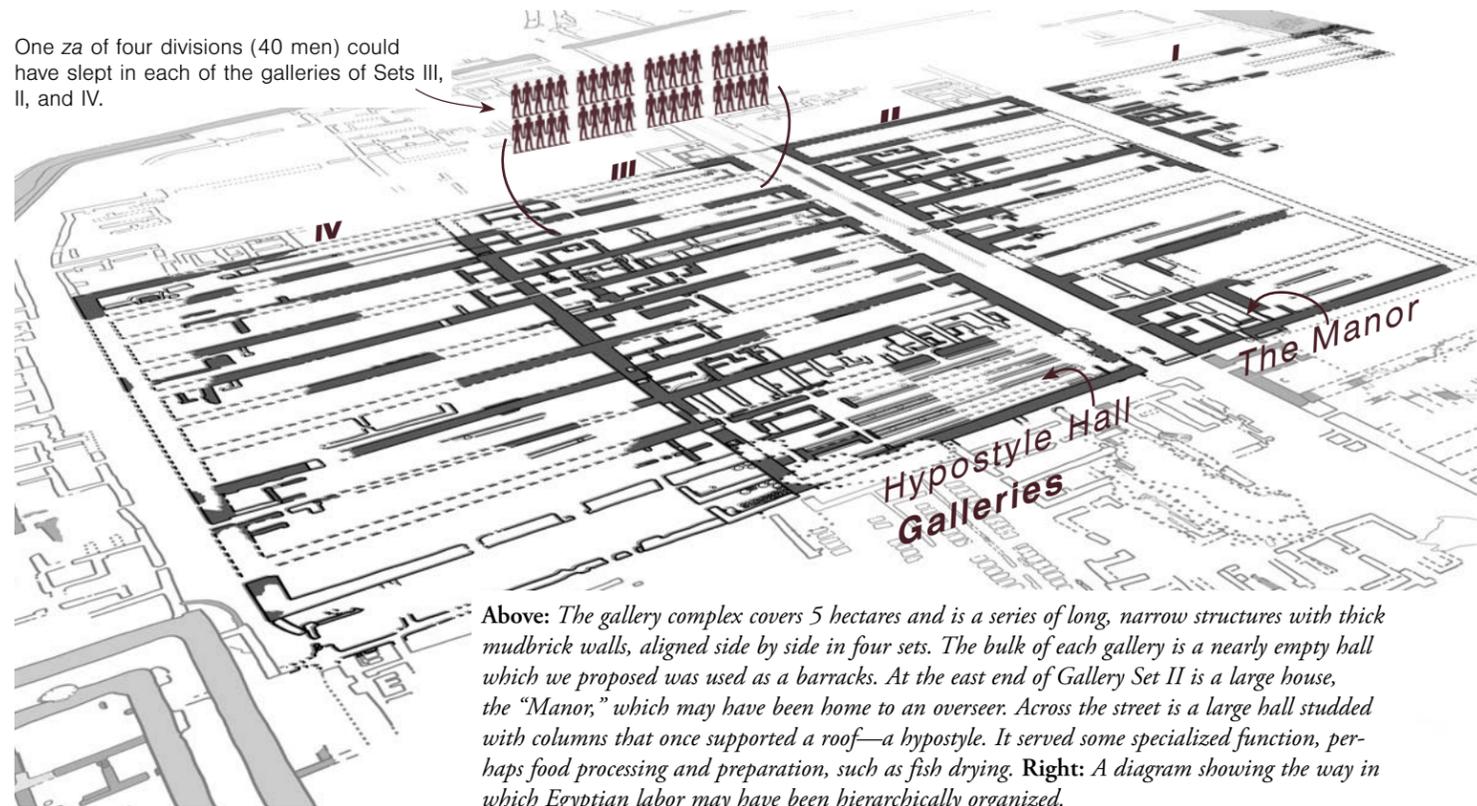
Bilingual texts of the Graeco-Roman period translated *za* with the Greek word, *phyle*, “tribe.” This would suggest some natural tribal or community system, were it not for the fact that the rulers of Greek city states created artificial tribes in the late 6th Century BC.

The Labor Hierarchy

The builders' graffiti seem to reflect a system in which the royal house assigned a crew of two competing gangs to one area of the pyramid complex. The same *za* names were repeated in each gang. But only the first four are known from the masons' marks of the 4th Dynasty, suggesting that the “Last” *za* was not used until later.

In Menkaure's upper pyramid temple additional hieroglyphs following the *za* glyph were thought to represent smaller divisions. In texts dating after Dynasty 4 each *za* has (Continued on next page)

One za of four divisions (40 men) could have slept in each of the galleries of Sets III, II, and IV.



Above: The gallery complex covers 5 hectares and is a series of long, narrow structures with thick mudbrick walls, aligned side by side in four sets. The bulk of each gallery is a nearly empty hall which we proposed was used as a barracks. At the east end of Gallery Set II is a large house, the "Manor," which may have been home to an overseer. Across the street is a large hall studded with columns that once supported a roof—a hypostyle. It served some specialized function, perhaps food processing and preparation, such as fish drying. Right: A diagram showing the way in which Egyptian labor may have been hierarchically organized.

How Ancient Egyptians Organized ...

(Continued from page 11)

two divisions, designated with hieroglyphs that mean "strong," "first," "noble," and "rising." Ann Roth⁶ believes that there were at least four divisions in each *za* of the Menkaure Temple. For other projects there may have been more or less depending on the labor required. Many representations of the *za* cattle hobble glyph have ten loops, suggesting ten divisions.

The smallest unit of labor, the division, may have consisted of ten individuals, as reflected in the Old Kingdom title, "Overseer of Ten," referring to the head of a division. This title might also mean "Overseer of One-Tenth" of a gang, with two divisions per *za*, times five *zā*.

The general picture, then is a hierarchy of crews, gangs, *zau*, and divisions (see diagram on the facing page). For Dynasty 4 Ann Roth sees a royal work crew composed of two gangs, each consisting of four or five *zau*, with four or more divisions. Obviously, large pyramids like those of Khufu and Khafre might have required many crews. (See "An Alternative Interpretation..." on the next page for another view of the *za*.)

Rotating Service, Sacred Ritual

The graffiti appear to indicate that *zau* rotated in and out of service. Another indication of rotating service comes from the Abu Sir Papyri, 5th Dynasty accounts from the pyramid temple of Neferirkare, located in Abu Sir near Sakkara. The documents show that Egyptians used the same *zau* system for the pyramid temples and that these *zau* served periodically. In effect, the identities of social groups attached to the pyramid were similar, whether constructing the monument or serving in its temple long after it was completed. Perhaps building the pyramid was as much a sacred ritual as the daily service in the temples.

Documents from later periods indicate that many or most people owed service to the royal house on a temporary basis. Such obligatory labor gets confused in the question as to whether the Egyptians used slave labor to build pyramids, but all the evidence points to people rotating in and out of the unskilled labor force.

Order of Magnitude

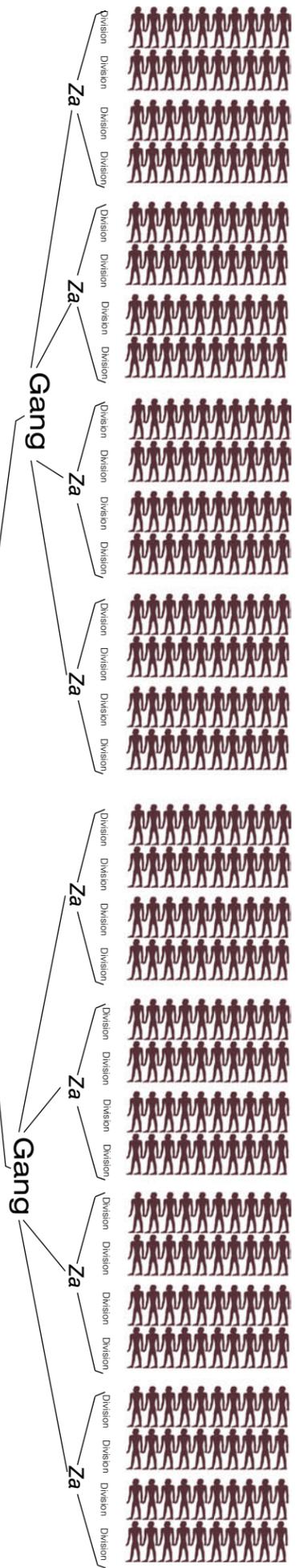
We do not know how many men belonged to these units of labor organization, or

even the order of magnitude. Some clues, though, come from inscriptions in the later Old Kingdom, when pyramids were much smaller and involved far fewer blocks. They inform us that the royal house mounted quarry expeditions ranging from 300 to 1,600 to 2,400 men.⁸

For Giza we can offer high and low estimates for the number of men needed to erect the pyramids (not including infrastructural support such as provisioning and preparing food). For an upper figure of 4,000 laborers we could start at the top of the hierarchy and assume two crews of 2,000 men.⁹ There would be 1,000 men in a gang (half of a crew), and 200 in each of five *za*, or 250 in each of four *za*. This leaves 20 or 25 divisions of ten men each.

For a low figure of 2,000 men, we start at the bottom and accept that "Overseer of Ten" indicates a division of ten men, which is, by the way, the most that can efficiently work on an average-sized pyramid block. If we assume at least four divisions per *za*, that is 40 men per *za*. With four or five *zau*, a gang would be 160 men and a crew, 320. At least six or seven such crews would be needed to build the pyramid.

Crew



This was a flexible system; the modular labor units could be added, subtracted, and overlapped to adjust the numbers.

Gangs and Galleries

Turning now to our site, do the great galleries (on facing page) in some way reflect the organization of *zau* and divisions?

The modularity of the galleries, which we believe were barracks, brings to mind a hierarchical organization.

Consider the number of people who could have slept in the galleries (see table on the right). The total for the whole complex is around 1,630, just about the size of the larger expeditionary forces sent to distant quarries in the late Old Kingdom.¹⁰ If more men were squeezed in, say 50 per gallery, the whole might accommodate closer to 2,000, the size of a crew in the larger of the two estimates above. This would be too few men, however, to build a pyramid, since probably twice that many were needed.

How Many Workers Could Have Slept in the Gallery Complex?

Gallery Set	Gallery Length (meters)	No. of Men*	No. of Galleries	Total No. of Men
I	55	50	11 est.†	550
II	35	40	8	320
III	35	40	8	320
IV	35	40	11	440
TOTAL				1,630

*Our crew demonstrated that about 40 people could comfortably stretch out in Gallery III-4 during our 2002 season.

†Gallery Set I was partially destroyed by floods in antiquity; hence the number of galleries is an estimate.

Who then lived in the galleries? They do not seem to be residences except for a possible foreman's house at the back end of each gallery. Instead they are rigid, barracks-like. It seems reasonable that they were housing for *zau*, but not the average laborer. In the article on the next page we consider the possibility that they were a military barracks. — Mark Lehner

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- 3 Reisner, G.; 1931, *Mycerinus, The Temples of the Third Pyramid at Giza*. (Cambridge: Harvard University Press), pls. XI-XII.
- 4 Roth, Ann; *Egyptian Phyles...*, pp. 127-30, fig. 7.3.
- 5 Dobrev, Vassil; 2003, "Administration of the Pyramid." In, Zahi Hawass (ed.), *The Treasures of the Pyramids*. (Vercelli: White Star).
- 6 Roth, Ann; *Egyptian Phyles...* pp. 142.
- 7 Roth, Ann; 1991, *Egyptian Phyles...*, pp. 120-21.
- 8 Eyre, Chris; 1987, "Work and the Organization of Work in the Old Kingdom." In. M.A. Powell (ed.), *Labor in the Ancient Near East*. (New Haven: American Oriental Society), pp, 5-47.
- 9 Lehner, Mark; 1997, *The Complete Pyramids*. (London: Thames and Hudson), p. 225.
- 10 Eyre, Chris; "Work" p. 14.

An Alternative Interpretation

Vassil Dobrev¹ recently suggested that the *zau* were not subdivisions of larger crews and *aper* gangs but rather, the reverse. The crews and gangs were assembled as needed, whereas the four or five *zau* appear to have been broader and more permanent affiliations of both high and low status folk. We might think of the *zau* along the lines of college sororities and fraternities (so more like the Greek phratry or brotherhood), to which we might belong no matter what school or dormitory we were in, or year we attended college.

Dobrev attributes the confusion to ancient Egyptian grammar. In the workmen's graffiti, *aper* gangs are listed first because they were compounded with the name of a pharaoh. In Egyptian any glyph combined with the pharaoh's name moves forward according to "honorific transposition." The gang name therefore appears first, whereas it was actually the *za* that had first place as the broader category.

1 Dobrev, Vassil; 2003, "Administration of the Pyramid." In, Zahi Hawass (ed.), *The Treasures of the Pyramids*. (Vercelli: White Star), p. 30.

Zau of What? The Royal Guard?

Pyramid building required far more workers than the 1,600 to 2,000 that we estimate the Gallery Complex might have accommodated (see page 13). Most likely the laborers slept elsewhere, perhaps in tents or makeshift shelters out on the plateau. If so, who stayed in the galleries? Who ate all the fish and meat, including prime beef, documented by abundant faunal remains found here? One hypothesis worth considering is that the galleries housed elite troops who accompanied the king on his visits to the pyramid project.

Fragments of relief decoration from demolished Old Kingdom pyramid temples offer a glimpse of the troops attached to the royal escort. In the early 20th century excavators from the Metropolitan Museum of Art in New York pulled a series of fragments of Old Kingdom troop scenes from the stuffing of Amenemhet I's Middle Kingdom pyramid at Lisht.¹ They were among other fragments of Old Kingdom pyramid temples and mastaba tomb chapels inexplicably dumped into the core of the later pyramid. We see guards in procession, naked except for streamers around the waist or attached to a girdle, or short kilts with the open end at the back and tied at the waist, or just a belt with two hanging loops. They carry weapons, mostly long staffs but also bows in their cases. Two men each carry what might be a battle axe and sling.

The artists bunched them in groups of ten—reminding us of the title “Overseer of Ten”—followed by a lone man who might be the commanding official. A larger fragment shows two groups of ten in two registers.² A hieroglyphic label at the front of the upper group reads “Following of gangs (*aperu*) of recruits (or “youths;” the word is *neferu*, the same word as in the name of the “Last” *za*).

This is very similar to the label and the grouping in another fragment from the Valley Temple of the 5th Dynasty pyramid of King Sahure at Abusir³ (see facing page).

The text in the front reads “Escort (*na-shemsu*) of Gangs of Young Recruits.” The inscription above the Sahure group gives the name of the gang, compounded with the cartouche name of the king, something like “The Gang, Sahure is Noble.” The house sign at the front is part of a damaged group of glyphs that probably read, *Per-A'a*, literally, “the Great House,” the origin of our word, “pharaoh,” which is to say, the palace. Similarly, hieroglyphs at the back of the lower group in the scene from the Amenemhet pyramid read, “Escort of the August Places of the Palace.”

Is it possible that the our Giza galleries were military barracks for troops of the royal guard or escort such as we see in these scenes? The bakeries and food processing facilities flanking the Gallery Complex make sense as part of the provisioning—the caterers for these special troops. The deterioration and abandonment of the Gallery Complex, even while the site was still occupied, also squares with this hypothesis. The galleries could have fallen into neglect when the troops’ rotations in and out of the galleries declined as the royal entourage’s visits became fewer and fewer.

Barracks in the Archaeological Record

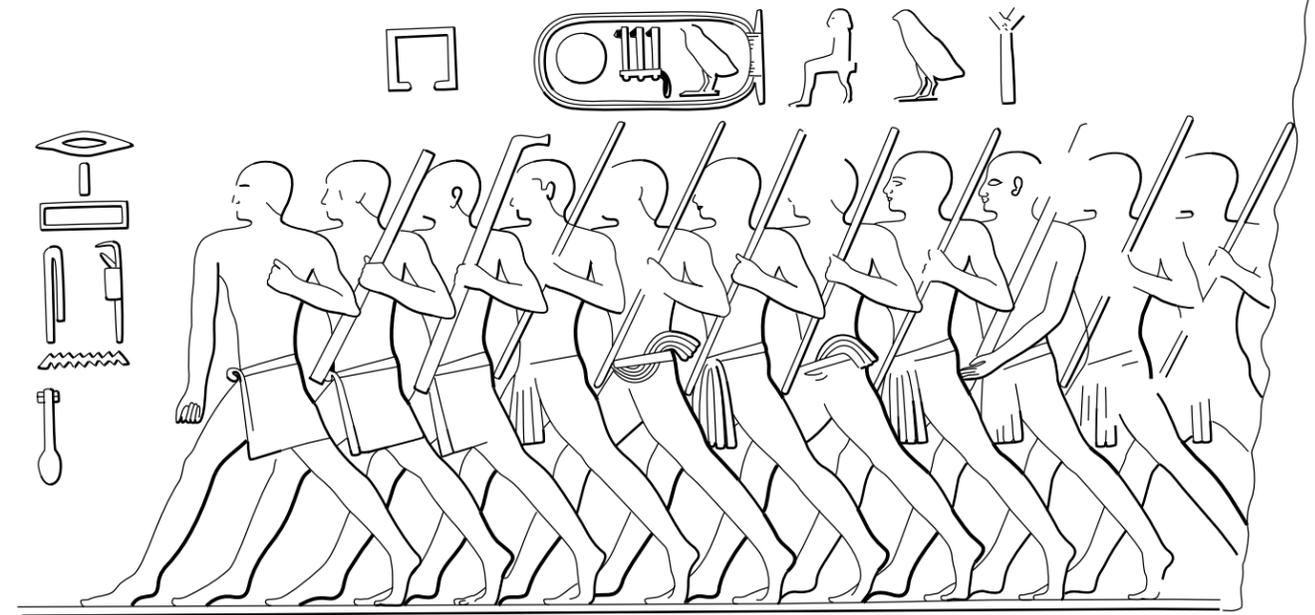
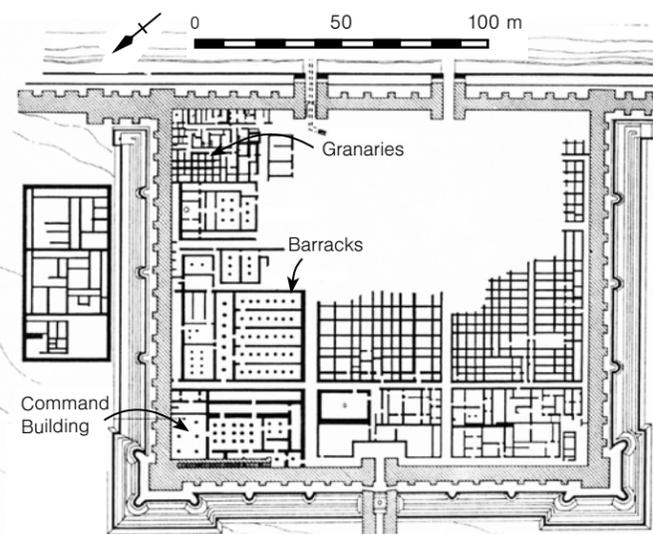
Finally we must ask if this hypothesis bears comparison with what archaeologists have identified as barracks elsewhere in the archaeological record, particularly in Egypt. This is a task of scholarship in progress. For

Buhen, a Middle Kingdom fort near the Second Cataract in Nubia. Drawing from Emery, Smith, and Millard, p. 70 (see references).

now I will briefly cite a New Kingdom and Middle Kingdom example.

At Amarna, the 18th Dynasty capital of Pharaoh Akhenaten, a long rectangular complex on the southeastern edge of the central city has long been identified as military and police quarters⁴ (see maps on facing page). The northeastern corner of this complex features six galleries nearly sixty meters long. These are securely identified as horse stables on the basis of cobbled floors, tethering stones, and thick manure layers in the streets outside. Since there were no horses in Old Kingdom Egypt there is little to inform our Gallery Complex. However, separated from the stables by broad courts and a deep well pit are what the excavators identified as the “dormitories” of the guard personnel. These take the form of long gallery-like rooms, with a width to length ratio of 1:5, paved with brick and entered by stone thresholds. The dormitories lie northeast of a house with three pillared halls that the excavators identified as the “Commandant’s House.” Magazines and large circular granaries occupy a court to the south.

The pattern of barracks, command house, and granaries is also found in Middle Kingdom forts near the Second Cataract in Nubia. One of the largest, the Buhen fort,



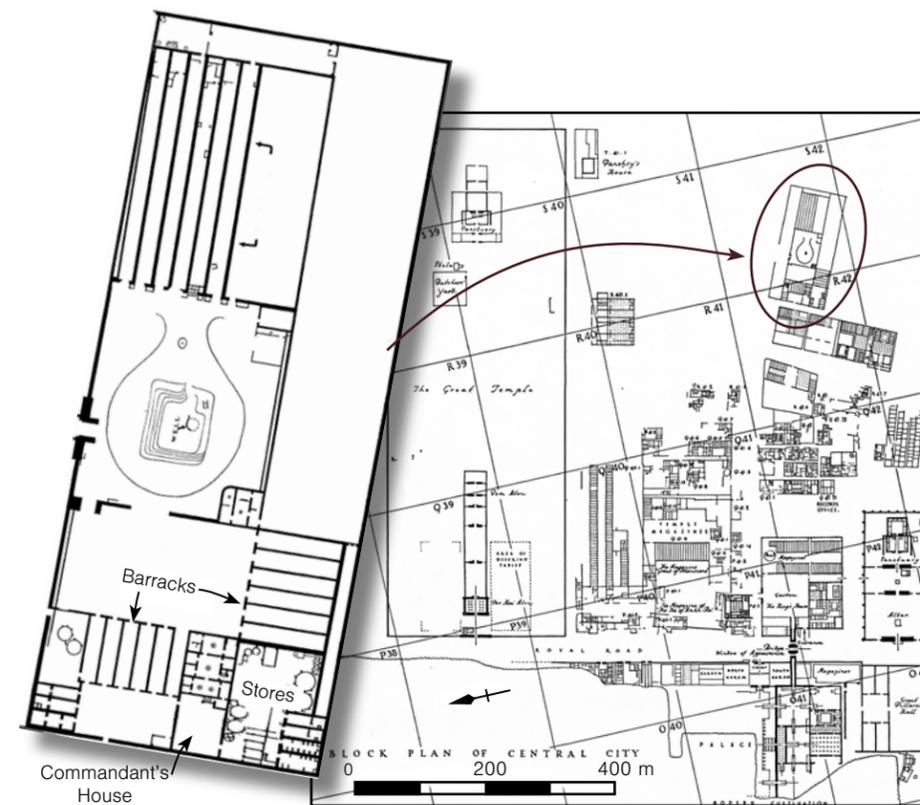
contains a series of long columned halls that W. B. Emery identified as barrack blocks.⁵ Barry Kemp objected: “This would... imply official provisioning for communal living, whereas on comparable sites small modular houses seem to have been the norm.”⁶ We should consider this at Giza, but note that our site is immense, more like Amarna than the Nubian forts.

Elsewhere in the Buhen fort Kemp identified a large columned structure as the “command building,” and a dense group of rectangular chambers as grain storage cellars entered from above (see illustration on the facing page). The same three features—command

building, granary, and possible barracks with elongated rooms—occur in a smaller fort along the Second cataract.

Our site shares some of the same features as these examples of military barracks. The Gallery Complex has the long gallery-like rooms. The large house on the east side of the complex, the Manor, could have served as a “commandant’s” house. Just south of the galleries is a complex of magazines and in the nearby royal building, a court of sunken grain silos. The barracks hypothesis is promising and in future seasons we will put it to the test with intensive excavations in the Gallery Complex.

—Mark Lehner



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Above: Scene of troops attached to the royal escort. On a block fragment from the valley temple of King Sahure's 5th Dynasty pyramid at Abusir. After Borchardt (see references).

Far left: This long rectangular complex, on the far left, has long been identified as military and police quarters at Amarna, the 18th Dynasty capital of Pharaoh Akhenaten.

Left: The central city of Amarna. Drawings from Pendelbury (see references).

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Mark Lehner (left) shows Ed Fries the Lost City of the Pyramids, orienting him with field drawings. Ed, just retired from directing X-Box, the Microsoft game division, is assisting with AERA development. In late February he came with his family to see our project in full operation.



Photo by Brian Hunt