CONTENTS

Ardito Desio
Which is the Highest Mountain in the World? 90

Gilbert M. Grosvenor
The National Geographic Society
Looks to the Future 96

Russell H. Gurnee
Lowell Thomas and the Youth Activities Fund 104

Niklaus Salański
What is Adventure? 105

Farouk El-Baz
In Search of Pharaoh’s Ship 108

Barry M. Goldwater
Long Vistas and Stone Arches 114

John Loret
Our Arctic Heritage 120

Henry S. Evans
Matthew Henson, Polar Explorer 124

Judith Schrafft
Quest for the Coelacanth 126

Serge A. Korff, Ph.D., FR. 1938, Medalist
Book Reviews 130

The Long Table 134

The Explorers Club 135

John C. D. Bruno, FR. 1974, Medalist
The Ethics of Exploration 136

The Polar Explorers Stamp Series Inside Back Cover

About the covers
The National Geographic Society and members of The Explorers Club have shared goals through history, as told by National Geographic Society President Gilbert M. Grosvenor in this issue. Front cover: Dr. Eugenie Clark, FN 1985, examines an active bull shark snagged on the bait hook of a commercial fisherman during her 1975 study of “sleeping” sharks off the coast of the Yucatán Peninsula. Photograph by David Doubilet © National Geographic Society. Back cover: A 14-foot sixgill shark batters a cage of bait during a 1986 study. Photograph by Emory Kristof, Alvin M. Chandler and Tim Marzolf © National Geographic Society.
IN SEARCH OF

PHARAOH'S SHIP

by Farouk El-Baz
"The air inside the chamber might be as valuable as the boat," I said to Omar El-Arini, a longtime friend and classmate. He had come to ask for my assistance in finding "non-intrusive ways" to study the environment inside a sealed chamber at the foot of the Great Pyramid of Giza. As an archaeological chemist, he was concerned about the state of the royal barque of Pharaoh Khufu (named Cheops by the Greeks). The chamber he referred to was located in 1574 and found to be aligned with another one, 18 meters south of the base of the Great Pyramid. The two cavities were revealed by the removal of a heap of sand, rubble and blown sand and were found to be separated by the axis of the pyramid.

The eastern of the two pits was excavated in 1954 after the removal of an overlying wall that rested on a layer of mud bricks that covered the pit. The cavity that was revealed was covered by a cap of 41 limestone blocks (each measuring about 4.5 meters wide and weighing 15 tons) was 28.5 meters long and 2.5 meters wide. Gypsum mortar sealed the crevices between the cap blocks, which suggested that the cavity was hermetically sealed. Another suggestion of the tight seal was that when this excavation was opened, it emitted a cedar wood odor. The pit contained 651 parts of a wooden boat grouped in 12 layers under reed mats. Individual pieces, 1,224 in number, varied from 10 centimeters to 23 meters long. The rebuilt boat measured 43.4 meters long and 5.9 meters wide at the beam, and is now housed in a Boat Museum that was especially designed and built on the site of the discovery.

Archaeologists maintain that boat pits form an integral part of the pyramid complex of the Old Kingdom, but the original function of the boats remains unclear. Theories include: funerary boats to carry the body of pharaoh west of the Nile to the burial place; solar boats in which pharaoh might have visited the sun god; or symbolic boats to accompany the sun god on the voyage across the sky.

The wood of the vessel on exhibit at the Boat Museum had shrunk about 0.5 meters since it was put on display in 1982. It was feared that such deterioration may have been caused by the changing environmental conditions inside the museum. Because the second (western) pit was thought to also contain a boat much like the first, it was hoped that the investigation of its environmental surroundings would lead to a better understanding of how best to preserve the ancient wood. This idea was the driving force behind the project. Furthermore, El-Arini agreed with me that sampling the air inside the potentially hermetically sealed pit may reveal important data about the atmosphere of the Earth as it was 4,600 years ago.

In August 1985, El-Arini and I met several times with officials of the National Geographic Society to discuss a plan for the "Nondestructive Investigation of the Second Boat Pit of Pharaoh Khufu." Shortly thereafter, a proposal was submitted to the Egyptian Antiquities Organization (EAO) by National Geographic. In the meantime a Science Council was established composed of interested scientists who agreed to serve in an advisory role. The Science Council was supported by research team members, who participated in planning the research and conducting the investigation.

Members of these teams met regularly to discuss various aspects of the proposed investigation. Results of the deliberations were periodically communicated to the Permanent Committee of the Egyptian Antiquities Organization and its scientific advisory panel in Cairo.

After two years of deliberations, designs and testing of ideas and equipment, a research plan was developed. The suggested procedures were made known to the scientific community at large through a report published in Science. Several recommendations were received from scientists and were taken into consideration in the formulation of the final plan.

The research plan called for the following: (1) surveying the shape of the chamber and its contents by remote sensing techniques for the selection of a proper drilling site; (2) drilling a vertical hole in a block of chalky limestone up to two meters thick without using any lubricants or cooling fluids that might contaminate the pit's environment — and with assurances that no air or other gases would be transferred into the pit; (3) sampling the air inside the cavity at different levels, making sure that no chlorofluorocarbons (freons) are introduced into the sample, and passing the air through filters to separate any pollen grains or

Near the complex of the Pyramids at Giza and the Sphinx, two pits were found containing royal barques of ancient Egypt. The first boat was discovered in 1954 and is now housed in a special museum at the base of the Pyramid of Khufu. Last year, a second pit was the object of "non-intrusive" exploration — a challenge to Explorers Club member Farouk El-Baz carrying Flag No. 101. The expedition was a joint project of the National Geographic Society and the Egyptian Antiquities Organization.

PHOTOGRAPH (opposite page) BY WINFIELD PARKS
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PHOTOGRAPH (below) BY JEANNE GURNEE

PYRAMIDS OF GIZA

To Cairo

Great Pyramid of Khufu (Cheops)

Sealed Boat Museum

Pyramid of Khafre (Chephren)

Sphinx

Pyramid of Menkaure (Mecerina)

(not to scale)
other micro-organisms for analysis; (4) measuring the pressure, temperature and relative humidity inside the chamber; (5) photographing the interior with a video system and a 35-millimeter still camera without raising the temperature inside; and (6) sealing the hole, leaving behind sensors to measure periodically the temperature and the humidity inside the cavity.

The first step to be taken was to determine the shape of the chamber and obtain a profile of its contents by remote sensing techniques. This was attempted by using ground-penetrating radars. Radar instruments sent short pulses through the ground, and reflected waves were recorded and treated as an image. The images were then computer-enhanced for improved interpretation. Unfortunately, because of the water content in the cap rock, the data were not very useful. Similar investigations using an electromagnetic sounding were equally unsuccessful.

We knew that it was necessary to drill through up to two meters of limestone vertically by using a specially designed platform. The limestone properties were first established from tests at the laboratories of the Massachusetts Institute of Technology. The limestone was found to be easily drivable with 25 percent porosity. The drill had to use no water, oil or air pressure in order to avoid contamination of the environment of the pit. Another requirement was that the rotary motion of the drill had to be extremely slow (975 rpm) to avoid heating the rock and increasing the temperature inside the cave.

Also, the drilling and other operations had to be conducted under air-tight conditions. A special arilock was manufactured of aluminum and steel at the National Geographic machine shop based on a design by R. Moores of Black & Decker.

The drill operated well, cutting through a 2.5-centimeter segment at a time. Upon completion of the drilling of each segment, it was necessary to break the core and remove it. This was accomplished by the use of a specially designed core breaker and the removal of the crushed rock fragments by an industrial-strength vacuum cleaner. This process continued until the base of the drilled block was almost reached. The last piece of cap rock (about 1.5 centimeters thick) was dropped into the chamber.

During site investigations the rock surface was first flattened and polished and then covered with epoxy and left to dry. A 47-centimeter steel plate was placed on it with a nitro-rubber ring to seal the contact between the metal and the layer of epoxy. A 15-centimeter o-ring was placed inside the steel plate surrounding the area of the drill. The latter o-ring was made of lead to keep the drill system freon-free. All other o-rings were made of freon-protected nitro-rubber. Two rings always separated a zone of vacuum in between, similar to methods of helium leak-detection in mass-spectrometry. Such precautions assured keeping the air inside the chamber freon-free and totally separated from the outside atmosphere.

Peiter Tans, who represented the National Oceanic and Atmospheric Administration (NOAA), retrieved the air samples by inserting a stainless steel tube into the pit soon after drilling. Because of potential stratification that might have resulted from air stagnation for 4,600 years, samples were sucked into vacuum bottles at three different levels at (18 centimeters, 94 centimeters, and 145 centimeters below the ceiling). The samples were shipped to the laboratories of NOAA in Boulder, Colorado. The sample taken from the lowest level beneath the ceiling of the pit was passed through a membrane filter to determine if there might be any pollen grains and other microorganic particles.

To measure the relative humidity inside the chamber, microsensors were inserted into the pit. Also, sensors to measure air temperature and pressure were used to better understand the environment that preserved the wood inside the chamber. The temperature measured 27°C (81°F). The relative humidity was 85 percent. It is interesting that the humidity measured in the first cavity a few days after opening it was also high — 88 percent.

The pit’s contents were photographed with both video and still cameras — the video camera with its own fiber-optic light source. It was the product of the Rees Company Ltd. of England, and was designed for investigating interior walls of nuclear power plants. The fiber-optic light was used to avoid increasing the temperature of the interior during the process of photography. The camera head was designed to rotate 360 degrees on a manipulator arm, and a television monitor outside allowed the review of data quality.

Upon the completion of video photography, a single-lens camera designed by National Geographic specialists was used to obtain 35-millimeter color photographs. In addition to full-field views, stereo pairs were taken of small areas.

Photography of the interior revealed a disassembled boat. Much like the one that was opened in 1954, the second pit contained stacks of wood with pieces of the cabin arranged on top. The second boat appeared to be smaller than the first, with four small pointed oars on top. Bronze hooks were revealed, which appeared similar to those that hinged the cabin doors in the first boat.

After five days of documentary photography, the drilled hole was sealed to secure the pit. This was done at only four inches from the ground surface to allow for the option of reopening the hole for the improvement of its environment or for additional studies. Keeping this option open would also allow the manipulation of a video camera much like the one used in the investigation to peer into the chamber and view the contents in the future.

As soon as air samples reached NOAA’s laboratories, atmospheric scientists and physicists began to monitor the contents of the canisters and analyze their components. In addition, samples of outside air were taken in three small canisters. Their freon content varied from day to day, but these variations were in the range of what was shown in the air sample from inside the pit, confirming communication between the inside and outside environments.

There was an unusually high value of CO₂ inside the chamber in dry air. (CO₂ measured 720 parts per million — double the amount in the ambient atmosphere.) It was expected that CO₂ may have been produced by degassing from the organics inside the pit or even driven off the limestone walls of the chamber. However, because of communication between the air inside and outside, this value should not have remained high.

A further test was to date CO₂. Such a test required the Tandem Accelerator at the University of Arizona. Douglas Donahue studied a sample and gave the age of 2,000 years. This indicated
a mixture between ancient air and a modern counterpart.

Donahue also dated a sample of mud-brick retrieved from the base of the wall above the pit. Some archaeologists believed that the wall was ancient, built to surround the pyramid complex. Others believed that it was much younger, perhaps Roman in age, judging by the mix of rubble it contained, its width and probable original height. The C14 date of about 2,500 B.C. resolved the issue.

During pumping from the pit, air was allowed to pass through membrane filters that would capture any pollen grains or bacteria in suspension. These samples were studied using powerful microscopes at Boston University. Both filters had mineral particles but no evidence of pollen or bacteria.

Also, three attempts were made to capture organic particles from the air for Egyptian specialists to identify any micro-organisms. Antiseptic bottles containing a water-and-alcohol mixture were brought to the site, and air from the cavity was allowed to flow through them. Three groups of scientists took samples for analysis at the Al-Azhar University, the Suez Canal University and the Egyptian Atomic Energy Establishment.

"The samples were completely free of microbial contaminants," wrote biologist Ahmed Dowidar of the Suez
Pharaoh Khufu's 4,600-year-old boat (top) is now reconstructed in a Boat Museum at the foot of the Great Pyramid. A second boat chamber was not disturbed, exploration being carried out with a specially developed camera. A mosaic of ten photo images of the new pit (bottom) shows the second wooden boat in place. Scattered on it are bits of white mortar that fell from between the stone blocks that cap the underground chamber.

PHOTOGRAPHS BY VICTOR R. BOSWELL, JR., (top) AND CLAUDE E. PETRONE (bottom)

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Canal University. “Not a single cell grew in the numerous cultures that we prepared.” This may have been because the air was pumped from nearly one meter above the contents of the chamber, whereas bacteria or other organisms may have settled to the bottom of the pit or the upper surface of the wood.

The success of this project signals a new beginning in nondestructive archaeology. The investigative techniques can be used not only at archaeological sites worldwide, but also for exploratory investigations in mine or submarine rescue, nuclear reactor probing and earth resources surveys.

To me, the project had special significance. It applied space-age technology, which I became familiar with through 20 years of working with the American space program, to an important site in my Egyptian cultural heritage. Also, as a Fellow of The Explorers Club, it was thrilling to fly its Flag No. 101 at the Great Pyramid of Giza.

(Below) Dr. Farouk El-Baz was geology instructor to the astronauts for the moon program. When Al Worden declared from the moon, “Marhaba ahle el-ard min Endeavor elaykum salam,” it was a phrase El-Baz had taught him. The translation: “Hello, people of earth; greetings from Endeavor.”

DR. FAROUK EL-BAZ, LF 1978, is Professor of Remote Sensing and founding Director of the Boston University Center for Remote Sensing. He previously founded the Center for Earth and Planetary Studies at the National Air and Space Museum of the Smithsonian Institution, and also served as science advisor to the late President Anwar Sadat of Egypt.