

Building the Great Pyramid

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The recent robotic explorations of the 'air-shafts' in the Great Pyramid have demonstrated that there are still many mysteries surrounding the ancient monument. Ian Shaw discusses the debate around the building of the great structure and investigates the methods used in its construction.

Great debate

Since at least the time of the ancient Greeks, there has been considerable debate about exactly how the Egyptians constructed King Khufu's Great Pyramid at Giza.



A reconstruction of a pyramid-worker chiselling stone in a quarry ©

Few texts concerning Egyptian engineering methods have survived the centuries, and in recent years

experimental archaeology has been the main means for discovering the methods used for building the structure. Despite this, there are still many questions concerning the quarrying, dressing and transportation of the stone building blocks, let alone the methods by which they were placed meticulously in position. And there are further questions still about how the gigantic edifice was erected on a totally horizontal base, and aligned precisely with the stars.

Levelling

Between 1880 and 1882, Flinders Petrie, the first truly scientific archaeologist to work in Egypt,



Flinders Petrie standing outside a tomb at Giza in which he lived for two years ©

undertook some careful survey work on the Giza plateau. This was the site of the pyramid complexes of the rulers Khufu, Khafra and ě - all of whom lived in the Fourth Dynasty.

The results of Petrie's work suggested to him that the Egyptians had levelled the area intended for the Great Pyramid

by cutting a grid of shallow trenches into the bedrock, flooding them with water, and reducing the intervening 'islands' of stone to the necessary height.

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After this was suggested, for most of the next century, there was surprisingly little archaeological work on the pyramids at Giza, but in the 1980s the American Egyptologist Mark Lehner began to produce a meticulous new map of the plateau, incorporating the various holes and trenches cut into the rock around the pyramids. On the basis of this project, Lehner argued that the Egyptians had in fact not levelled the whole area intended for the pyramids, but had simply ensured that the narrow perimeter strips around the edges of the pyramid were as perfectly horizontal as possible.

Aligning

Egyptian architects, surveyors and builders are known to have used two specialised surveying tools, the *merkhet* (the 'instrument of



Bronze statue of Imhotep, chief architect to the Third Dynasty King Djoser ©

knowing', similar to an astrolabe) and the bay (a sighting tool probably made from the central rib of a palm leaf). These allowed construction workers to lay out straight lines and right-angles, and also to orient the sides and corners of structures, in accordance with astronomical alignments.

It is clear that the Egyptians were using their knowledge of the stars to assist them in their architectural projects from the beginning of the pharaonic period (c.3100-332 BC), since the ceremony of *pedj shes* ('stretching the cord'), reliant on astronomical knowledge, is first attested on a granite block of the reign of the Second-Dynasty king Khasekhemwy (c.2650 BC).



Reconstruction of an official ceremony in which the pyramid is aligned to the stars ©

This *pedj shes* ceremony relied on sightings of the Great Bear and Orion constellations, aligning the foundations of the pyramids and sun temples very precisely with the north, south, east and west. They usually achieved this with an error of less than half a degree. In later periods, the process of stretching the cord continued to be depicted in texts and in the reliefs of temples such as that of Horus, at Edfu, but it appears to have gradually become just a ritual, since these temples were aligned less precisely than the earlier ones, often simply with reference to the direction of the river.

How did this astronomically based surveying work in practice? The British Egyptologist IES Edwards argued that true

north was probably found by measuring the place where a particular star rose and fell in the west and east, then bisecting the angle between these two points. More recently, however, Kate Spence, an Egyptologist at the University of Cambridge, has put forward a convincing theory that the architects of the Great Pyramid sighted on two stars (*b-Ursae Minoris* and *z-Ursae Majoris*), rotating around the position of the north pole, which would have been in perfect alignment in around 2467 BC, the precise date when Khufu's pyramid is thought to have been constructed. This hypothesis is bolstered by the fact that inaccuracies in the orientations of earlier and later pyramids can be closely correlated with the degree to which the alignment of the two aforementioned stars deviates from true north.

Ramps

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Most archaeologists agree that a system of ramps must have been used to drag the millions of blocks into their positions in the various pyramids. No such ramps have actually survived at the Great Pyramid itself, but enough traces can be seen around some of the other Old Kingdom pyramids to suggest that at least five different systems of ramp might have been used.



The Meidum Pyramid ©

The most straightforward method would have been the so-called linear ramp, probably used in the Third-Dynasty pyramid of Sekhemkhet, at Saqqara. Such ramps, however, were probably rarely used, because they would have had to be very wide. An alternative would have been the 'staircase ramp', a steep and narrow set of steps leading up one face of the pyramid, traces of which have been found at the Sinki, Meidum, Giza, Abu Ghurob

and Lisht pyramids.

In the case of the 'spiral ramp' (perhaps described in the Nineteenth-Dynasty Papyrus Anastasi I), the question arises of what it would have rested on, and how corrective calculations and checks could have been made from the corners if most of the pyramid was continually covered up. The 'reversing ramp', a zigzag course up one face of a pyramid, would probably have been most effective for the construction of step pyramids, although, frustratingly, there are no signs of its use on the step pyramids at Saqqara, Sinki and Meidum.

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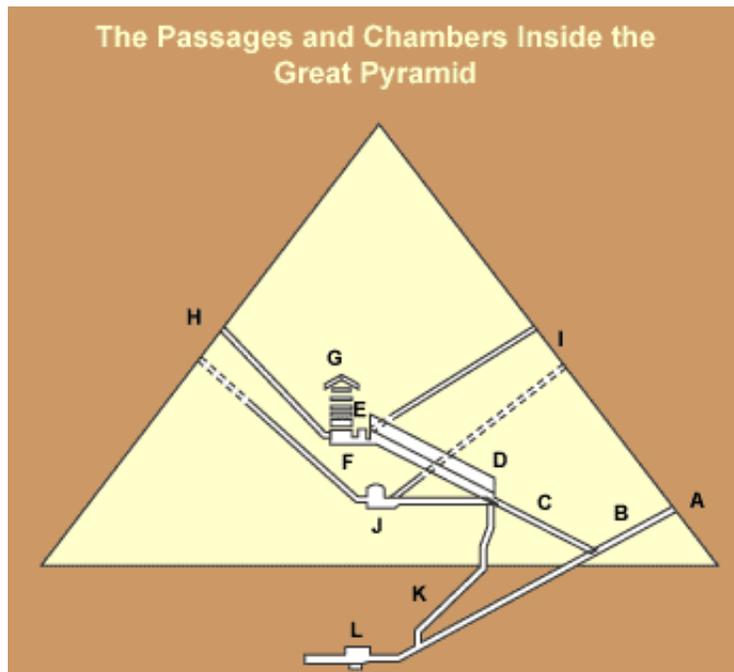
Traces of 'interior ramps' have survived inside the remains of the pyramids of Sahura, Nyuserra and Neferirkara, at Abusir, and of Pepi II, at Saqqara, but some kind of exterior ramp would still have been needed after the interior was filled in. The terraced nature of the pyramid core would often have made it more convenient to use a series of much smaller ramps built along the sides of the pyramid from step to step. The remains of these would no doubt have been lost when the outer casing was applied. It is also possible that the causeways stretching from pyramid to valley temple might originally have served as builders' ramps from quay to construction site (the quay being connected with the Nile by canal).

Raising blocks

Experts have also talked a lot about the methods by which individual stone blocks were raised into position. Since the Egyptians made no use of block and tackle methods, or cranes, it is usually assumed that wooden and bronze levers were used to manoeuvre the blocks into position.

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The level of structural engineering was incredibly high in the internal chambers of the Great Pyramid. Indeed, the roof of the so-called Grand Gallery was the Egyptians' earliest attempt at corbel-vaulting on a colossal scale. The architects surmounted particularly difficult logistics in the creation of the corridor leading up to the main burial chamber of the Great Pyramid (the so-called King's Chamber). The corridors in other pyramids are all either level or sloping downwards, whereas this one slopes steeply upwards, which would have presented problems when it came to blocking the passage with granite plugs, after the king's body had been placed in the chamber.



A Entrance, **B** Descending passage, **C** Ascending passage
D Grand Gallery, **E** Antechamber, **F** King's Burial Chamber
G Stress-relieving chambers, **H** Diagonal shafts orientated towards the stars of Orion, **I** Diagonal shafts orientated towards the north pole stars
J 'Queen's Chamber', **K** 'Well Shaft',
L Subterranean Chamber

©

It is clear from the fact that the plugs in this 'ascending corridor' are an inch wider than the entrance that the plugs must have been lowered into position not from the outside, as was usually the case, but from a storage position within the pyramid itself (perhaps in the Grand Gallery). It is also clear that the design had to allow the workmen who pushed the plugs into position to be able to escape down a shaft leading from the Grand Gallery to the 'descending corridor', through which they could exit.

Quarrying



Pink granite from the pyramid of Khafra at Giza ©

The King's Chamber was made entirely from blocks of Aswan granite. Since the Second Dynasty, granite had frequently been used in the construction of royal tombs. The burial chambers and corridors of many pyramids from the Third to the

Twelfth Dynasty were lined with pink granite, and some pyramids were also given granite external casing (eg those of

Khafra and Menkaura, at Giza) or granite pyramidia (cap-stones).

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The Aswan quarries are the only Egyptian hard-stone workings that have been studied in detail. It has been estimated, on the basis of surviving monuments, that around 45,000 cubic metres of stone were removed from the Aswan quarries during the Old Kingdom (Third to Sixth Dynasties). It seems likely that loose surface boulders would have been exploited first.

It is unclear what kinds of tools were used for quarrying during the time of the pharaohs. The tool marks preserved on many soft-stone quarry walls (eg the sandstone quarries at Gebel el-Silsila) suggest that some form of pointed copper alloy pick, axe or maul was used during the Old and Middle Kingdoms, followed by the use of a mallet-driven pointed chisel from the Eighteenth Dynasty onwards. This technique would, however, have been unsuitable for the extraction of harder stones such as granite. As mentioned above, Old Kingdom quarries were probably simply prising large boulders of granite out of the sand.

Cutting blocks

There has been much debate concerning the techniques used by



A quarry floor showing quarrying marks made by the ancient Egyptians ©

ancient Egyptians to cut and dress rough-quarried granite boulders or blocks for use in masonry. No remnants of the actual drilling equipment or saws have survived, leaving Egyptologists to make guesses about drilling and sawing techniques on the basis of tomb-scenes, or the many marks left on surviving granite items such as statues.

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In recent years, however, a long series of archaeological experiments has been undertaken by the British Egyptologist Denys Stocks. Like many previous researchers, Stocks recognised that the copper alloy drills or saws would have worn away rapidly if used to cut through granite without assistance. He therefore experimented with the addition of quartz sand, poured in between the cutting edge of a drill and the granite, so the sharp crystals could give the drill the necessary 'bite' into the rock, and found that this method could work. It seems a practical solution, as no special teeth would have been needed for the masons' tools, only a good supply of desert sand - and this theory is gaining acceptance in academic circles.

...there is still a great deal that remains mysterious about the basic structure of pyramids...

As the recent robotic explorations of the so-called air-shafts in the Great Pyramid have demonstrated, there is still a great deal that remains mysterious about the basic structure of pyramids, and the technology that created them. If we are to gain a better understanding of pyramid-building, the best way seems to be a blend of detailed study of the archaeological remains and various kinds of innovative experimental work. Above all, this is the kind of research that relies on collaboration between Egyptologists and specialists in other disciplines, such as engineering, geology and astronomy.

Find out more

Read on: a bibliographical essay

As far as stone masonry is concerned, many volumes have been published describing the surviving remains of pharaonic temples and tombs, whether in the form of traveller's accounts, archaeological reports or architectural histories (Badawy 1954-68, Smith 1958, being the first attempts to provide comprehensive historical surveys).

Although there have been many meticulous studies of specific sites or buildings, only a few - notably Petrie's surveys of the pyramids at Giza and Meydum in 1883 and 1892 - have focused on the technological aspects of the structures. On the other hand, it is remarkable that, despite Petrie's concern with the minutiae of many aspects of craftwork and tools, his general works include no study of the structural engineering of the Pharaonic period.

This gap in the literature began to be filled in the 1920s with Reginald Engelbach's studies of obelisks (Engelbach 1922, 1923), Ludwig Borchardt's many detailed studies of pyramid complexes and sun temples (eg Borchardt 1926, 1928), and the first edition of Alfred Lucas' *Ancient Egyptian Materials and Industries* (Lucas 1926), which included a substantial section devoted to the scientific study of stone working.

However, the first real turning point arrived in 1930 with the publication of *Ancient Egyptian Masonry*, in which Engelbach collaborated with Somers Clarke to produce a detailed technological study of Egyptian construction methods from quarry to building site (Clarke and Engelbach 1930).

The meticulous excavations of George Reisner at Giza and elsewhere soon afterwards bore fruit in the form of the publication of *The Development of the Egyptian Tomb down to the Accession of Cheops* (Reisner 1936), and Reisner's work at Giza was later supplemented by the architectural reconstruction of the Step Pyramid of Djoser at Saqqara by Jean-Philippe Lauer, whose *Observations sur les pyramides* (Lauer 1960) was also informed by a sense of the fundamental practicalities of ancient stone masonry.

Both I.E.S. Edwards (1947, 5th ed. 1993) and Rainer Stadelmann (1985) produced general books on Egyptian pyramids which built on the observations of Borchardt, Reisner, Lauer and others, including substantial discussion of the technological problems encountered by Pharaonic builders.

Christopher Eyre (1987) has provided a detailed study of the textual and visual evidence for the organization of labour in the Old and New Kingdoms, which includes a great deal of data relating to quarrying and building (particularly covering such questions as the composition, management and remuneration of the workforce involved in procuring, transporting and working stone, as well as the timing of quarrying and construction projects).

Most recently, Dieter Arnold's *Building in Egypt: Pharaonic Stone Masonry*, published in 1991, is a wide-ranging study of the data, including meticulous discussion of the surviving evidence for quarrying and stone-working tools, and sophisticated, well-illustrated studies of the grooves and marks on stone blocks which can indicate many of the ways in which they were transported, manoeuvred into position and interlocked with the rest of the masonry. Like Clarke and Engelbach's *Ancient Egyptian Masonry*, it serves as an essential and welcome basis for all future study of Pharaonic stone masonry. Arnold's primary concern is with the technology rather than the materials; for a detailed discussion of the different types of stone utilised by the Egyptians in art and architecture, see De Putter and Karlshausen (1992).

Links

The Giza Mapping Project. Under the direction of Mark Lehner, the project is dedicated to research on the geology and topography of the Giza plateau, the construction and function of the Sphinx, the Great Pyramids and the associated tombs and temples.

PBS - Pyramids: The Inside Story. The site allows you to tour the insides of the pyramids at Giza and includes interviews with Egyptologists such as Mark Lehner and Zawi Hawass.

Fathom: The World of the Pyramids. Fathom offers online learning experiences, developed with leading scholars and experts, including in-depth courses and free seminars, shorter features, interviews and articles.

The Egypt Exploration Society The Society was founded in 1882 to fund and mount archaeological expeditions to Egypt, and to publish the results. This work continues today at sites such as Amarna, Memphis and Qasr Ibrim in Egyptian Nubia, and is published in full in a series of monographs, the annual *Journal of Egyptian Archaeology* and bi-annual magazine, *Egyptian Archaeology*. Membership of the Society is open to all those interested in ancient Egypt, indeed without its members' subscriptions the Society could not continue to operate.

About the author

Ian Shaw is Lecturer in Egyptian Archaeology at the University of Liverpool. He excavates regularly in Egypt, and his research interests include Egyptian urbanisation, ancient technology and the provenancing of ancient materials. From 1986 to 1990 he edited the ancient Egyptian section of the *Macmillan Dictionary of Art*. From 1990 to 1994, he undertook research into Egyptian quarrying and mining sites as a British Academy Research Fellow at New Hall, Cambridge. From 1994 to 1999 he was Lecturer in Egyptian Archaeology at the Institute of Archaeology, University College London. He is the author of *Egyptian Warfare and Weapons* (Shire Publications, 1992) and *Exploring Ancient Egypt* (Oxford University Press, 2003), co-author of the *British Museum Dictionary of Ancient Egypt* (British Museum Press, 1995), editor of *The Oxford History of Ancient Egypt* (Oxford University Press, 2000), and co-editor of *Ancient Egyptian Materials and Technology* (Cambridge University Press, 2000) and *Blackwell's Dictionary of Archaeology* (Basil Blackwell, 1999).