Plotting the pyramids

Owen Gingerich

There is no evidence in ancient texts that Egyptians used astronomical knowledge in building the pyramids. But analysis of the night sky in 2500 BC could help explain how the pyramid builders knew the direction of true north.

The Egyptian pyramids at Giza — one of the seven wonders of the ancient world — are roughly 4,500 years old. Their construction can be dated, at best, to within 100 years by existing methods. In this issue (*Nature* **408,** 320–324; 2000), Egyptologist Kate Spence proposes a more accurate way to date these monuments using subtle deviations in the alignment of their bases from true north. At first glance, this idea seems as likely as sharpening razor blades by placing them under small pyramids (one of the claims made for 'pyramid power' in the 1970s). But on closer inspection, Spence has come up with an ingenious solution to a long-standing mystery: how were the great pyramids so accurately aligned in relation to north?

Since the nineteenth century it has been known that the western and eastern sides of the Khufu (Cheops) pyramid deviate from true north by an average of three arcminutes. This corresponds to one-tenth the diameter of the full moon and is not far from the 1–2 arcminute precision achieved several millennia later by Tycho Brahe, the greatest of the pre-telescopic observers.

Such an accurate alignment is possible only by some astronomical procedure, but the surviving Egyptian texts seem silent on the method used. One way to define north would be to compare the rising and setting positions of the Sun in the east and the west and bisect the angle between them. Such a procedure would have to be carried out near the time of a solstice, when the Sun seems temporarily to stand still in its seasonal march higher or lower in the sky. But problems with observing objects near the horizon (because of interference from the Earth's atmosphere), and with having a perfectly level view both east and west, make this technique unreliable.

An alternative method would involve building some sort of scaffolding to provide a sight line for alignment with the north pole star — except there was no suitable pole star when the pyramids were built. Directly above their terrestrial counterparts, the celestial poles are points in the night sky around which the stars appear to rotate. Today, the north celestial pole points close to the star Polaris — currently designated the pole star. Because the Earth's axis of rotation is not fixed, but swings in a stately conical motion known as precession, the positions of the celestial poles drift slowly among the stars in a 26,000-year cycle.

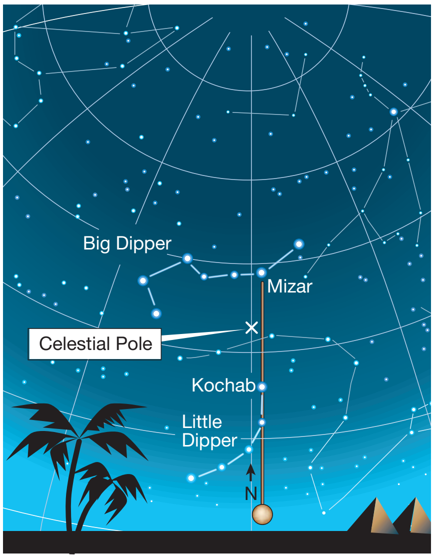

Figure 1 **The night sky in ancient Egypt. Kate Spence argues on page 320 of this issue that Egyptian pyramid builders used the vertical alignment of two bright stars in the constellations of the Big and Little Dipper to align their pyramids north–south. In around 2500 BC, the star Mizar in the Big Dipper and Kochab in the Little Dipper were located on opposite sides of the north celestial pole — the fixed point in the sky around which all the stars rotate. In 2467 BC an invisible line linking these two stars, when they are vertically aligned, would pass precisely through the north pole. A plumb line intersecting these stars would then point straight to north on the horizon. A similar observation made before or after this date would include a systematic error caused by the alignment being offset slightly from true north (as is the case here). Such astronomical errors show up in the orientations of the ancient pyramids of Giza.**

This is where Spence's idea comes in. Although there was no pole star available for accurately pinpointing north in ancient Egypt, there was a pair of fairly bright stars, one either side of the ancient celestial pole, which in 2467 BC lay precisely along a straight line including the pole. One is Kochab in the bowl of the Little Dipper, the other Mizar in the middle of the handle of the Big Dipper (to use the popular American names for Ursa Minor and the main stars of Ursa Major). Kochab and Mizar are technically known as β-Ursae Minoris and ζ-Ursae Majoris. In 2467 BC, an Egyptian astronomer could wait while the heavens slowly pivoted around the unmarked pole until a plumb line exactly intersected both stars, one above the invisible pole and the other below it (Fig. 1). The sight line to the horizon point directly below the plumb line would then point straight to north.

So far Spence's suggestion is as speculative as it is ingenious. But she then introduces a second, hitherto unrecognized, mystery. The great pyramid of Khufu is the most accurately aligned to north, deviating just slightly to the west. The pyramid of Menkaure, the second pharaoh after Khufu, errs by about 13 arcminutes in the other direction, whereas the three earlier pyramids of Snofru, Khufu's predecessor, are oriented more westward as they get older. Other pyramids, built between 2600 and 2300 BC, confirm this trend, and their orientations form a straight line when plotted against time.

How can this puzzle be explained? Because of the Earth's precession, the celestial north pole was exactly aligned between Kochab and Mizar only in the year 2467 BC, and the errors in the orientations of earlier and later pyramids faithfully track the slow drift of Kochab and Mizar with respect to true north. Because the error in the Kochab–Mizar alignment can readily be calculated for any date, the error in each pyramid's orientation corresponds to a specific year. Although each alignment is subject to individual measurement errors, the collection of several data points makes the method more robust. So it is not preposterous to believe that Spence can calculate dates for pyramid construction to within five years or so, considerably better than the 100-year error currently accepted for their chronologies.

A modern astronomer noticing the drift of the two stars could easily come up with a simple observational solution to the problem. After 2467 BC, with Kochab directly above Mizar, the alignment missed the pole to the left. But 12 hours later, with Mizar directly above Kochab, the offset would move equally to the right. These two positions could be bisected to give true north. (If the 12-hour wait moved the observation into daylight, it would mean waiting several months to observe the opposite configuration at night.)

Spence's interpretation requires that the determinations of north take place at just one of the two vertical alignments of Kochab and Mizar, generally with Mizar above. Two pyramids that do not conform to this pattern — the second great pyramid at Giza (Khafre) and the later pyramid of Sahure — can easily be explained if the north alignment was done with Kochab above Mizar, producing an error to the west instead of the east.

Spence argues that there was an elaborate 'fixing the north' ceremony that took place early in a new pharaoh's reign, rather than a systematic sequence of observations over months or years. It is an interesting idea, but one that needs to be tested. Can Egyptologists find references to such a ceremony in the ancient texts? This evidence would seem to be crucial for the ultimate acceptance of Spence's ingenious hypothesis, but sadly there is no documentation relating to the construction of the ancient pyramids.

In general, little is known about early Egyptian astronomy, and even the constellations recorded on the ceilings of tombs remain for the most part unknown and unmatched with the actual starry sky. One of the few identified constellations is the Egyptian adze, the sculptor's mythically powerful tool for making magical images; the adze matches the modern Big Dipper. A pair of such images are depicted in the wall mural of Tutankhamon's tomb — probably the Big and Little Dippers — and elsewhere there is a text about two sharp claws chasing each other around the pole. Could this be an echo of Kochab and Mizar making their alignment rounds? Be on the lookout, Egyptologists, for any such obscure hints. ■

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Speciation

Fish found *in flagrante delicto*

Mark Kirkpatrick

Genetic analysis of cichlid fish in Nicaraguan lakes reveals a possible case of repeated sympatric speciation: the creation of two species from one in the same environment.

A species of vertebrate gives rise to another species on average once every few million years. That is somewhat longer than the time span of a typical research grant, which is one reason why speciation is a tough subject to study. But sometimes the process can be caught in the act, giving us a window onto the origin of biodiversity.

A paper by Wilson *et al.*[1], just published in *Proceedings of the Royal Society*, reports on just such an apparent case in cichlid fishes from Nicaragua. The contribution is all the more interesting because it seems that sympatric speciation is taking place. This is the controversial hypothesis which holds that one species can split into two without the benefit of geographical barriers to prevent interbreeding.

The celebrated evolutionist Ernst Mayr built a persuasive case that speciation can occur only when geographical barriers enforce non-random mating while new species are emerging[2]. This is allopatric speciation, and Mayr's view became the orthodoxy for many years. There is now growing evidence, however, that sympatric speciation can happen in the right circumstances[3]. The study by Wilson *et al.* breaks new ground by providing the first example of replicated sympatric speciation: one species splitting in two several times independently. If confirmed, these natural replicates would offer a unique opportunity to identify the factors that trigger sympatric speciation.

The cichlid fishes are particularly attractive for speciation studies. The 700 species are remarkable for their diverse colours, shapes and sizes, and behaviours (which include complex courtship and parental care). Cichlids can speciate rapidly: the 300 species in Lake Victoria, east Africa, may have descended from a single ancestral cichlid in only the past 12,400 years[4]. Further, these fish may be prone to sympatric speciation. A remarkable case involves cichlids from isolated crater lakes in Cameroon[5]. Genetic data show that nine species living in Lake Bermin are each other's closest relatives, implying that they speciated there. The lake is only 0.6 km^2 in surface area and 14.5 m deep, making it implausible that geographical barriers were involved.

Wilson *et al.*[1] studied cichlids in four lakes in Nicaragua. Each lake has two types of fish that differ in colour — a 'normal' morph and a 'gold' morph. In two of the four lakes, Wilson *et al.* found statistically significant differences between the nuclear and/or mitochondrial gene frequencies of the morphs. Further, mitochondria from the different morphs within each lake are statistically more similar to each other than to those from different lakes, supporting the authors' interpretation that sympatric speci-

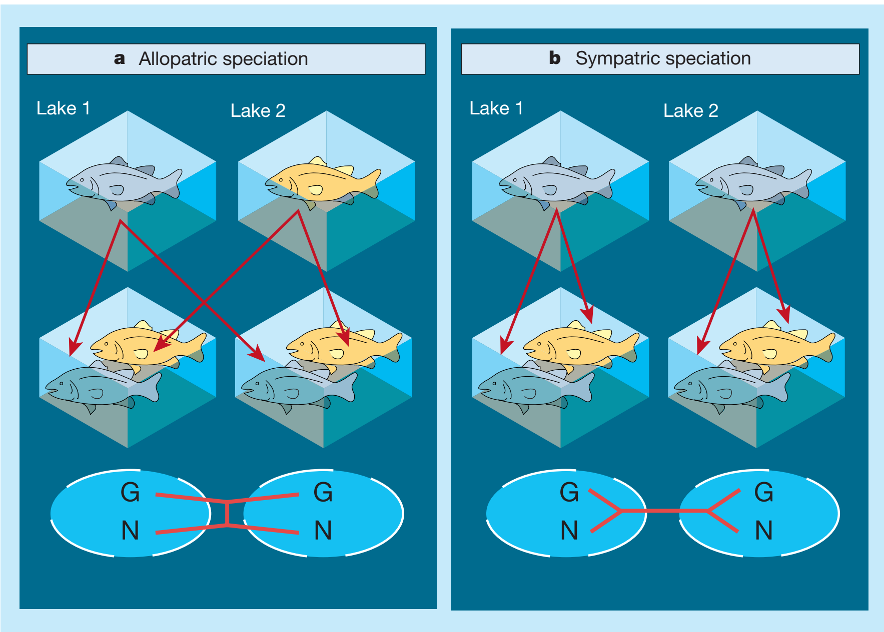

Figure 1 **Molecular signatures of speciation: possible outcomes of genetic analyses of cichlid fish in two Nicaraguan lakes.** a, **Allopatric speciation, in which species form while a geographical barrier is present and then come into contact secondarily.** b, **The corresponding pictures for 'replicated sympatric speciation', where new species form independently within each lake in the absence of geographical barriers. At the bottom is the gene tree for genes from gold (G) and normal (N) individuals sampled from the two lakes that would be consistent with each course of events. The gene trees reflect the historical relations of the populations. Under allopatric speciation** (a), **genes from the gold forms in different lakes will be more similar than genes from the gold and normal forms within each lake. The opposite is true under sympatric speciation** (b).**Wilson and colleagues' data**[1] **tend to support this second pattern, and the view that sympatric speciation has occurred.**