How the Pyramid Builders May Have Found Their True North

By Glen Dash

The builders of the Great Pyramid of Khufu aligned the huge monument to true north to within six minutes of arc, or one tenth of a degree. Scholars have described that achievement as “extraordinary,” astonishing,” and “brilliant.” How they managed to do that has long been debated. In this article we will examine four prominent theories, test one, and compare and contrast the others.

Old Kingdom texts, pictorial representations and surviving tools offer us few clues as to how the Egyptians built their pyramids, let alone how they aligned them. I. E. S. Edwards, the former Keeper of Egyptian Antiquities at the British Museum, summed up the situation this way: “Extant Egyptian records, whether written or pictorial, throw no light on the methods employed by the builders of the pyramids either in the planning or in constructing their monumental works.” Scholars, therefore, have had to formulate theories without much help from the Egyptians themselves.

The Imperishable Ones

Why did the Egyptians need to align their pyramids with cardinal points? The answer may lie in their vision of the Netherworld. The “Pyramid Texts,” which were first inscribed on the walls of the burial chamber of the Fifth Dynasty king Unas (c. 2356–2323 BC) describe their view of eternity and the deceased’s connection to the celestial world. Among other things, it was the king’s destiny to “go forth to the sky among the Imperishable Ones” and “go around the sky like the sun”.

The “Imperishable Ones” were the circumpolar stars, so named because they never set below the horizon. The king’s spirit may have been guided on its journey by the orientation of pyramid’s inner spaces. At their northern end, the corridors of many pyramids end in a “descending passageway” angled up at the circumpolar stars “like a telescope” (Figure 1).

While the Pyramid Texts may help us understand why the Egyptians aligned their pyramids to cardinal points, we do not know why they needed to do it with such precision. As Mark Lehner has said, “For the royal designers, such exactitude may have been imbued with symbolic and cultic significance that now eludes us.”

The Vault of the Heavens

To astronomers, due north and south are said to lie on the “meridian line,” a line that connects the geographic South Pole to the North Pole (Figure 2). An observer standing anywhere on the earth’s surface looking north finds the meridian line running between his or her feet. The location directly above the observer’s head is known as the “zenith.” The “meridian circle” arcs overhead connecting north, south and the zenith. The meridian circle lies in a plane perpendicular to the observer’s horizon.

Using these lines and circles, we can locate any star in the sky by its “elevation” and its “azimuth.” We define the elevation as the vertical angle of the star above the unimpeded horizon. We define a star’s azimuth as its angle from due north along the horizon. A clockwise angle is positive, and counterclockwise, negative. We measure angle in degrees and minutes of arc. There are 60 minutes in one degree.

Edward’s Circle

In his book “The Pyramids of Egypt” (1947), I. E. S. Edwards claimed that the Egyptians located the meridian with the aid of an artificial horizon -- a circular wall built around an Edward's Circle.
mounted on a second story porch which held a 3/16 diameter rope about 10 meters in length. However, Edwards never field tested his theory. Therefore, in the fall of 2012, Petrie never field tested his theory. If he had, he may have found it difficult. To achieve an accuracy of 6 minutes of arc, he would have needed to establish the relative positions of the star’s rising, setting and the center of the circle accurately to better than 2 parts in 1000. If his circle were 3 meters in diameter, that translates to a total error of just 6 millimeters. Edward’s acknowledges that in order to achieve that, the wall would have to have been almost perfectly round and level, a feat other scholars have doubted the Egyptians could have achieved.  

Isler’s Shadows

Perhaps the most ancient instrument we have for determining direction is the simple vertical pole. It has long been used in China for that purpose, and is still used by tribesman in Borneo today.

We can use a pole to find the meridian by using the “shadow method” (Figure 4). An observer sets a pole vertically in the ground. The pole is known as a gnomon, Greek for “one who knows.” As the day passes, the observer marks the location of the tip of the sun’s shadow as it moves in an arc along the ground. At the end of the day, the observer fixes a string to the base of the gnomon and draws a circular arc which crosses the shadow pattern at two points. If done over perfectly level ground, the observer will find that a line drawn through the intersecting points will run exactly east-west. The meridian runs perpendicular to this east-west line and can be found by bisecting the angle formed by the two intersections and the base of the gnomon.

Martin Isler, an American sculptor who has written extensively on pyramid building, field tested the shadow method, reporting his results in 1989. To sharpen the shadow, he used a V-shaped slit in a piece of wood which he held upside down (Figure 5). The Egyptians used a similar device, known as a bay, to measure and survey since at least the New Kingdom. In his tests, Isler achieved an accuracy of 19 minutes of arc using a gnomon just 60 cm high.

Petrie’s Elongations

Flinders Petrie, whose seminal 1880-1882 survey of the Great Pyramid is still widely in use today, believed the pyramid builders found due north by following the pole star. In his 1883 book, The Pyramids and Temples of Gizeh, he tersely described the method he thought they used:

“...would not be so difficult. If a pile of masonry 50 feet high was built up with a vertical side from North to South, a plumb-line could be hung from its top, and observations could be made, to find the places on the ground from which the pole-star was seen to transit behind the line at the elongations, twelve hours apart. The mean of these positions would be due South of the plumb-line and about 100 feet distant from it; on this scale 15 seconds of angle would be about 1/10 inch, and therefore quite perceptible.”

A version of Petrie’s method is illustrated in Figure 6. A plumb line is suspended from Petrie’s north-south masonry wall. An observer watches for the pole star to transit behind the plumb line from beyond a low bench which holds a moveable sight. The bench and sight were the suggestion of the Czech archaeologist Zbyněk Žába and makes the observer’s task easier.

The purpose of the whole arrangement is to record the extreme movements of the pole star. Like all other stars of the northern hemisphere, the pole star circulates around the north celestial pole counterclockwise (Figure 7). Today, the pole star is Polaris, about one degree distant from the celestial pole. At the time the Great Pyramid was built, it was Thuban, about two degrees distant. As the pole star rotates around the north celestial pole, it passes sequentially through its highest point in the sky (“upper culmination”), its westernmost point (“western elongation”), its lowest point (“lower culmination”) and its easternmost point (“eastern elongation”).

Viewing the pole star through the sight’s parallel vanes, the observer tracks the movement of the star by moving the sight along the bench from east-to-west or west-to-east until the pole star disappears behind the rope. The star eventually reaches one of its elongations, and when it does, the observer marks the location of the center of the sight on the bench. The observer continues to watch until the pole reaches its other elongation and then marks that location as well. The observer then makes a third mark on the bench precisely between those two. A line drawn between this third mark and the rope should lie on the meridian. Petrie never field tested his theory. Therefore, in the fall of 2012, I did so at my home in Pomfret, CT.”
calculated dates for the commencement of these six pyramids using Spence's methodology. The second and third, the "Bent" and the "Red," at Dashur. The table below compares pyramid building age and included all three pyramids at Giza (Khufu, Khafre and Menkaure) as well.

We can use Spence's theory to calculate the commencement date of other Fourth Dynasty pyramids as well. For any two stars, however, this technique only works perfectly in one particular year. Owing to precession, a wobble in the Earth's orientation as it spins on its axis, the celestial pole moves relative to the stars. In the case of the simultaneous transit of Kochab and Mizar, this movement amounts to 31 minutes of arc per century or about 3 minute of arc per decade. Therefore, if the observer repeated the same measurement ten years later in 2457 BC, his or her results would have been off by about 3 minutes of arc.

To Spence, however, this was an advantage. The effect of precession on the movement of Kochab and Mizar relative to the celestial pole could be used to provide the very date the Great Pyramid was started. To calculate that date, Spence used Josef Dorner’s measurement of the azimuth of the lower edge of the casing on pyramid’s west side. Dorner measured it as 2.8 minutes of arc west of north. The two stars aligned 2.8 minute of arc west of north in 2476 BC. According to Spence, that date, plus or minus five years, was the date the Great Pyramid was started.

We can use Spence’s theory to calculate the commencement date of other Fourth Dynasty pyramids as well. Two bright stars, Kochab in the asterism we now call the Little Dipper and Mizar in the Big Dipper, straddled the celestial pole in the pyramid age. In fact, in 2467 BC a chord drawn through them would have passed directly through the pole (Figure 9). An observer in 2467 BC could have held up a plumb line and waited for the two stars to transit behind it. At that moment, the line between the observers’ pupil and the plumb line would have been the meridian.

The Egyptians, of course, would not have had the advantage my modern ropes and would have to have used Thuban, which was dimmer and farther away from the pole. Nonetheless, I believe they could have used Petrie’s method to find due north to within one to two minutes of arc. Nor would the Egyptian’s have needed a wall and plumb line 50 feet high. Petrie wanted to prove that the Egyptians could have located the meridian to within 15 seconds of arc – one quarter of one minute. However, the Great Pyramid is several minutes of arc off due north. They could have achieved that accuracy with a far shorter plumb line.

Spence’s Transits
Kate Spence of the University of Cambridge thought that the Egyptians may have used a technique known as “simultaneous transit” to orient the pyramids. In her 2000 paper, she noted that two bright stars, Kochab in the asterism we now call the Little Dipper and Mizar in the Big Dipper, straddled the celestial pole in the pyramid age. In fact, in 2467 BC a chord drawn through them would have passed directly through the pole (Figure 9). An observer in 2467 BC could have held up a plumb line and waited for the two stars to transit behind it. At that moment, the line between the observers’ pupil and the plumb line would have been the meridian.

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calculated dates for the commencement of these six pyramids using Spence’s methodology with more traditional dates based on the work of von Beckerath and Stadelmann. Spence cites their work in her paper as a “currently accepted” chronology. Spence’s analysis places the Fourth Dynasty pyramids in their correct order of commencement. On average, Spence’s dates are 74 years later than those the currently accepted chronology. Spence defends the difference stating that, “[E]xisting Egyptian chronologies of this period [which are] based primarily on cumulative reign lengths can only be considered accurate to about +/- 100 years.”

Therefore it is possible that the Egyptians could have aligned the casings of these pyramids with due north using simultaneous transit. However, by applying the same analysis to the descending passageways we can show that these passageways were aligned using some other method. The descending passageways of the Bent and Red Pyramids are aligned to due north with extraordinary precision, -0.5 and +2.9 minutes of arc respectively, even better than that of the Great Pyramid. As seen in the table below, applying the simultaneous transit analysis to the azimuths of the descending passageways produces an order of commencement that is wrong. The analysis would have the Great Pyramid of Khufu being started before Snefru’s last two pyramids. Such an order of commencement cannot be reconciled with the historical record. Whatever method the Egyptian used to align the descending passageways of these pyramids with due north, it was not simultaneous transit.

<table>
<thead>
<tr>
<th>Pyramid</th>
<th>Azimuths of the Descending Passageways (Minutes of Arc)</th>
<th>Date of Commencement According to Spence’s Theory</th>
<th>Date of Commencement According to Spence’s “Currently Accepted” Chronologies</th>
<th>Difference in Years</th>
<th>Order of Commencement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snefru-Medium</td>
<td>-21.6°</td>
<td>2537 BC</td>
<td>2598 BC</td>
<td>61</td>
<td>1</td>
</tr>
<tr>
<td>Snefru-Bent</td>
<td>-11.8°</td>
<td>2505 BC</td>
<td>2583 BC</td>
<td>78</td>
<td>2</td>
</tr>
<tr>
<td>Snefru-Red</td>
<td>-8.7°</td>
<td>2495 BC</td>
<td>2572 BC</td>
<td>77</td>
<td>3</td>
</tr>
<tr>
<td>Khufu</td>
<td>-2.8°</td>
<td>2476 BC</td>
<td>2552 BC</td>
<td>76</td>
<td>4</td>
</tr>
<tr>
<td>Khafre</td>
<td>+6.0°</td>
<td>2448 BC</td>
<td>2520 BC</td>
<td>72</td>
<td>5</td>
</tr>
<tr>
<td>Menkaure</td>
<td>+14.1°</td>
<td>2422 BC</td>
<td>2487 BC</td>
<td>65</td>
<td>6</td>
</tr>
</tbody>
</table>
Snefru-Bent  
-0.5° 2469 BC  2583 BC  114  3

Snefru-Red  
+2.9° 2458 BC  2572 BC  114  4

Khufu  
-5.8° 2485 BC  2552 BC  67  2

Kharfe  
+5.6° 2449 BC  2520 BC  71  5

Menkaure  
+13.3° 2424 BC  2487 BC  63  6

In 1981 Josef Dorner, an Austrian surveyor and archaeologist whose work on the Bent, Red, Great and Khafre pyramids was the source of much of the data Spence used in her work, suggested that these extraordinary alignments could only have been achieved by measuring a circumpolar star at its elongations. In fact, in a 1998 article he noted that the sloping surface of the descending passageways actually made that easier. Instead of needing a plumb line 10 to 15 meters long, the pyramid builders only needed to suspend a short plumb line from the top of the passageway to its base (Figure 10). A shorter plumb line is more stable, producing more accurate measurements. To lay out the descending passageway in the Bent pyramid, for example, the pyramid builders could have started by cutting a trench into the desert floor roughly aligned north-south. They then could have used the circumpolar method to draw a meridian line down the center of the trench. After that, they could have laid masonry walls into the trench parallel with the meridian line to finish the passageway.

At Khufu, things were a bit more complicated since the entire pyramid is built over a bedrock knoll. Here, the Egyptians would first have to have built a rough masonry passageway over the bedrock knoll roughly aligned with due north. Then they could have measured the meridian, and then finished the masonry portion of the passageway with fine stone laid parallel to it. To finish the lower portion of the passageway, they then would have to have bored into the bedrock along a line defined by the angle of the upper passageway. Dorner also believed that the Egyptians could have aligned the casings using the same method, but with a longer and less stable plumb line. He speculated that the use of the longer plumb line could account for the greater error in the casing's azimuths.

Conclusions
The Egyptians most likely used a circumpolar star to align the descending passageways of the Bent, Red, Great and Khafre Pyramids with due north. Petrie believed the Egyptians used Thuban, the pole star of their time. Using Polaris, I have demonstrated that Petrie's technique is practical. As for the casings, the Egyptians may or may not have used the same method. If they did, the longer plumb line required may explain why the casings are not aligned with due north as well as the descending passageways. On the other hand, Spence's data does seem to demonstrate a link between the orientations of the casings and the movement of stars in simultaneous transit. Finally, we cannot completely exclude the possibility the Egyptians aligned at least some their pyramids with due north by using the sun.
Figure 1: Inside the Great Pyramid. The body of the king was laid to rest in the King’s Chamber. Its spirit moved among its internal spaces and may have exited out via the descending passageway. Scholars have attempted to determine the pyramid’s intended alignment by examining the orientation of its casing and its passageways.

Figure 2: Mapping the Sky. The meridian line lies in the direction of due north. Any object in the sky can be located by its azimuth and elevation.
Figure 3: Edward’s Method. Edwards placed an observer inside a circular wall that served as an artificial horizon. An assistant marked the location where a certain star rose and then, hours later, set. Bisecting the angle formed locates the meridian.

Figure 4: The Shadow Method. An observer marks the location of the tip of the shadow on the ground. Over the course of a day, the shadow forms an arc. A string connected to the base of the pole is used to draw a circle which intersects the shadow arc at two points. These run east-west. The line perpendicular to these runs north-south.

Figure 5: Sharpening the Shadow. By holding an ancient Egyptian instrument, a bay upside down, Isler was able to sharpen the gnomon’s shadow. (After Isler 1989, 199)
Figure 6: Sighting Circumpolar Stars. A high masonry wall supports a plumb line which is affixed to the ground. An observer sights the star by adjusting his or her position and moving the sight until the star is occluded by the line. (Illustration by Joan Dash) (Drawing not to scale)
Figure 7: Finding the Meridian. Petrie’s method requires two sightings, one at the star’s western elongation and one at its eastern. The location of the sight is marked on the bench after each sighting and the midpoint determined. The line connecting the midpoint and plumb line is the meridian. (Drawing not to scale)

Figure 8: Testing Petrie’s Method. A wooden pole was substituted for Petrie’s masonry wall. This held a plumb line which was fixed at its base. The observer sights a star through the vanes of the sliding sight.
Figure 9: Spence’s Simultaneous Transit. An observer holding up a plumb line in 2467 BC would find Mizar and Kochab aligned with the meridian. By 2000 BC, the alignment would have shifted east. Spence used this not only to explain pyramid alignments, but to predict the dates the pyramids were built.
Figure 10: Sighting the Descending Passageway. Petrie’s method works best when sighting the descending passageway while it is being constructed. The plumb line required is short due to the passageway’s upward angle of about 26 degrees, which lessens error. Once laid out, the passageway can be roofed, as was the case with the Bent and Red Pyramids, or extended into the bedrock, as was the case with the Great Pyramid.

References

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I am also indebted to Dr. Juan Antonio Belmonte and Dr. E. C. Krupp for their review of this paper and their comments.
I would also like to thank Dr. Peter der Manuelian of Harvard for hand scanning and providing me a copy of Zbyněk Žábá’s important, but hard to find text.

-- Glen Dash

1 Dash 2012, 16.
3 Spence 2000, 320
4 Edwards 1993, 245
5 Lehner 1997, 28
6 Allen 2005, 12
7 Allen 2005, 10-12
8 Lehner 1997, 28
To do this I affixed a carpenter square horizontally on the bench and aligned one leg of the carpenter’s square with the axis of the bench. The other leg of the square then pointed to the north. By eye, I angled that leg towards Polaris, which set the axis of the bench roughly east-west.

To find the meridian, the total station’s telescope is focused on Polaris and the time noted to the second. The azimuth of Polaris at that moment is looked up on ephemeris tables. That azimuth is then loaded into the total station. The total station is then focused on a second star, such as Kochab and the time noted. The total station’s readout of azimuth should then match the ephemeris tables for the second star to within 20 seconds of arc.

The total error can be calculated as follows. The error in measuring the western elongation was 0.82 minutes. This was added to the error in the measurement of the eastern elongation (-1.09 minutes) and the sum divided by two. The error in the estimated meridian was therefore equal to 0.14 minutes or 8 seconds of arc. This was confirmed by actual measurement.

Petrie believed that at the time the Great Pyramid was built, the pole was 5 to 6 minutes of arc west of where it is today. Petrie 1883, 126. We now know that the pole has wandered less than one minute since then.

To calculate a commencement date, we divide the azimuth of the pyramid by .31 to get a number in years which we add to 2467 BC (numerically -2467). Thus, for the Great Pyramid, we divide -2.8 by .31 to get -9. We add this to -2467 to get a commencement date of -2476 or 2476 BC.

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Spence stated that she derived her "currently accepted" chronology by using von Beckerath's chronology (lower estimates) with the exception of the length of Snofru's reign and the dates of construction of his pyramids ... which follow Stadelmann." Spence 2000, 320

Spence reported this number, citing Dorner. However, Dorner reported that due to settling, the original lines of the Bent pyramid could not be determined. Dorner was able to determine the original azimuth of the north side as -8.4 minutes off due east-west. If we assume the base of the pyramid was square, then the best estimate we have for the west side would be -8.4 minutes as well. Dorner 1986, 51

Dorner 1998, 23

The actual azimuth of the east side of the Khafre Pyramid is -6.0 minutes of arc according to Dorner. Spence reversed the sign based on her theory that the measurements for this pyramid were made when Kochab was in upper culmination and Mizar was in lower.

The gap of 74 years has troubled some. Juan Antonio Belmonte has proposed that the Egyptians might have used Megrez and Phekda the Big Dipper instead of Kochab and Mizar. Using those stars moves the commencement date for the Great Pyramid to approximately 2550 BC. Belmonte 2001, S11-S15

Spence 2000, 324

Petrie 1892, 11

Dorner 1986, 42

Dorner 1998, 27

Petrie 1883, 125

Petrie 1883, 125. We have reversed the sign. As noted, Spence reversed the sign based on her theory that the measurements for this pyramid were made when Kochab was in upper culmination and Mizar was in lower.

Petrie 1883, 117

Dorner 1981, 137-148

Petrie 1883, 125

Petrie 1883, 117

Dorner 1981, 137-148

Dorner 1998, 30

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Petrie 1883, 117

Dorner 1981, 137-148

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Establish the relative positions of the west. The leading idea of how the pyramids were built was with out and out manpower. Workers would cut the limestone blocks by hand from a nearby quarry, and the blocks may have been floated to the construction site on barges, then simply dragged using a large number of men pulling on ropes. Moving a small “test” block using the roller method. They have no true ancient hieroglyphs. Their placement on the globe is perfect. It is in the center of all land mass and faces true north at a time when we are supposed to believe they did not have compass technology which could have enabled them to get magnetic north let alone true north. Their measurements and proportions are beyond the current capacity of engineering and indicative of extremely advanced mathematical knowledge.