Surveying errors within the Great Pyramid of Giza

Abstract

The Great Pyramid of Giza is a well known ancient structure which has been extensively surveyed, and the dimensions of its internal architectural features are well established. The original surveying data of the building's architecture was published in the 1800's and the surveying of the pyramid's narrow shafts, which was carried out between 1992 and 2013 using robotic inclinometers, was published in online documents and CAD drawings.

By comparing the original surveys of the pyramid, which contain details of the shafts' start and end points, with the modern robotics surveys it is determined that the two sets of data contain a vertical discrepancy of 1.4 m at the point where the upper northern shaft meets the pyramid's northern face and a vertical discrepancy of 0.67 m on the corresponding point on the south face.

It is shown that these discrepancies are partially caused by a calculation error in one of the original surveys which has then been duplicated in all subsequent works, and partially by an erroneous assumption in the recent robotics survey.

By resolving the calculation error in the original survey of the building it is determined that the position of the internal architecture of the building has been incorrectly surveyed in relation to the central vertical axis of the pyramid and the ground level and that a correction to the position of the internal architecture relative to the external architecture is required.

By resolving the eroneous assumption in the modern surveying of the upper northern shaft it is determined that this shaft is not continous from its lower to upper point and that the architecture in the lower portion of this shaft is significantly different from the currently accepted design.

Surveying errors within the Great Pyramid of Giza

The Great Pyramids of Giza's internal and external architecture is complex, and a complete set of measurements of it can only be compiled by referencing three surveys of the building: the 1993 robotic survey of the pyramid's shafts carried out by Rudolf Gantenbrink[1] ; the 1883 survey by William Petrie[2] ; and the survey by Piazzi Smyth published in 1867[3]. It is important to understand how these three sets of survey data correlate to each other.

Gantenbrink's survey of the upper shafts was published in technical drawings, in which he attached his detailed shafts' survey data to the already established surveyed location of their start points in the upper chamber. William Petrie's survey work covered the Great Pyramid's internal and external features and his detailed publication is the basis of the currently established structure of the building. Piazzi Smyth's work contains detailed measurements of the internal architecture of the pyramid only, and is referenced on numerous occasions in the work of Petrie. Therefore there is a direct connection over the course of 126 years between the first detailed measurements of Smyth and the modern robotics survey data of Gantenbrink. The shaft exit points on the faces of the pyramid determined by the robotics survey are dependent upon the works of Petrie and Smyth.

Using the three sets of survey data a compound CAD drawing of the pyramid's architecture was created in SI units, including the measurements of the heights of the external courses of core masonry. The method that was used to accomplish this was by extracting the numerical data from the surveys of Petrie and Smyth and placing it in a spreadsheet, using a unique cell in the spreadsheet to hold the conversion ratio between the measurement unit of the surveys and the desired SI unit of the CAD drawing, thereby eliminating random transposition errors. Where discrepancies were encountered between the two data sets the measurements of Petrie were used, as he explains in his work that he employed a more robust method of measurement than Smyth.

The shafts' survey data from Gantenbrink's published drawings was then copied onto the CAD drawing by re-scaling his drawing using the measurement marks that he included along the shaft floors in his drawings as a reference.

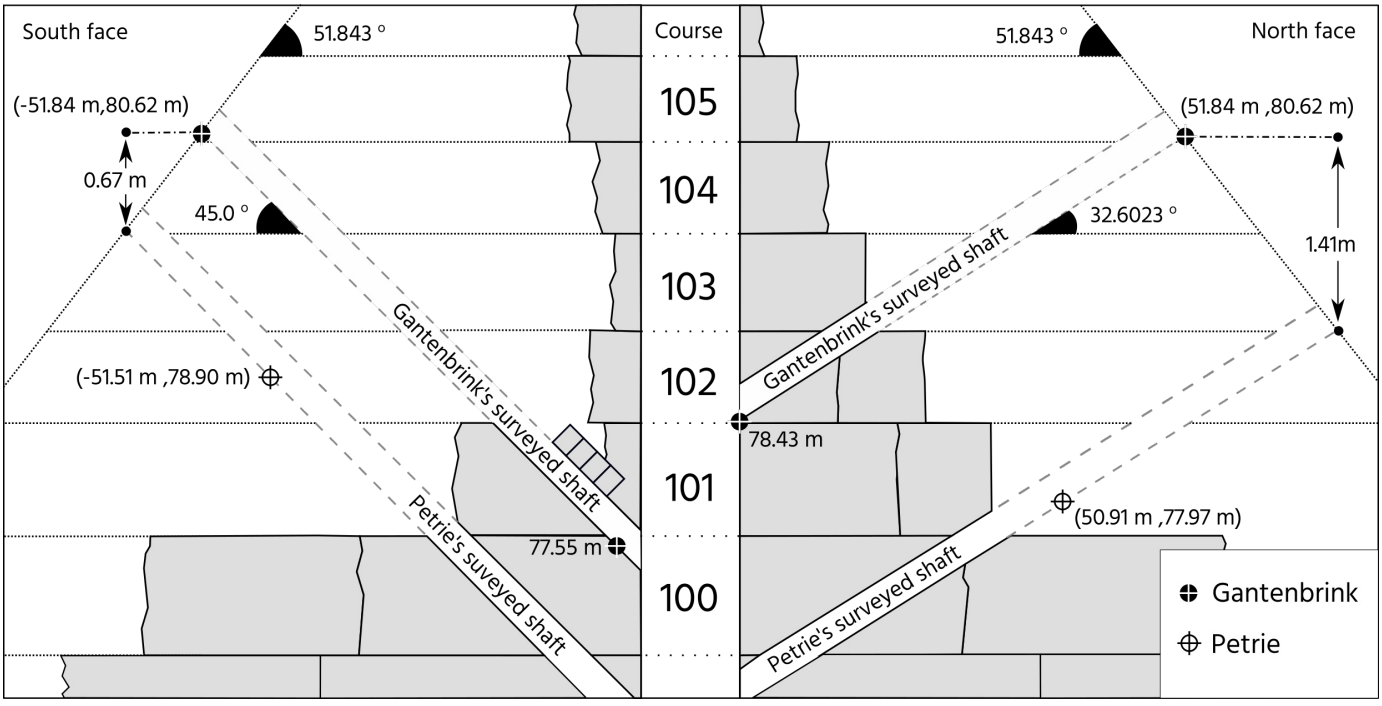

Figure 1 The exits of the Great Pyramid's upper shafts

The upper shafts

Figure 1 shows the shaft exit points on either side of the pyramid, Petrie's station marks, Gantenbrink's surveyed shaft positions, their intersect with the pyramid's faces and his shaft exit heights from the body of his text[4]. To verify the course levels of the shafts exits, HD video footage from a drone flight over the Great Pyramid[5] and photography taken from the ground was studied, and it was confirmed that the shafts exit on the 101st level of the current core masonry on both the north and south side of the pyramid. Figure 1 is therefore a verified technical drawing of the combined surveying data of Gantenbrink and Petrie.

The surveyed shaft positions do not correspond with each other, with a vertical discrepancy of 0.67 m on the south side and 1.41 m on the north side. Also, Gentenbrink's spot heights for the shaft exit points of 77.55 m on the south and 78.43 m on the north are both located inside the pyramid's existing masonry, and Petrie's survey points are located outside the existing masonry.

Because Petrie's surveying of the internal features of the pyramid is known to be accurate and there is no reason to doubt Gantenbrink's modern digital measurements, it was concluded that there must be an error in the positioning of the internal architecture of the building onto which Gantenbrink has attached his shaft survey data.

The plug blocks of the ascending passage

The surveying data for the internal architecture of the pyramid is continuous from the upper chamber down to the bottom of the ascending passage, at which point a series of granite plug blocks prohibit connecting the surveying measurements of the internal features with those of the external features. This section of the pyramid is the only discontinuous section of surveying in the pyramid's passages and the only place that a error could have occurred.

Figure 2a shows our current understanding of the ascending passage. The entrance passage descends into the bedrock of the Giza plateau, and in its roof there is the start of a passage which is blocked by a granite stone, only the face of which is visible. Figure 2b shows a roughly cut tunnel, known as Al-Mamun's tunnel, that leads from the outside of the pyramid and which emerges in two places, the first is in-front of the two granite plug blocks, and the second is in the entrance passage, with a 4 m deep, nearly vertical, hole connecting the two sections.

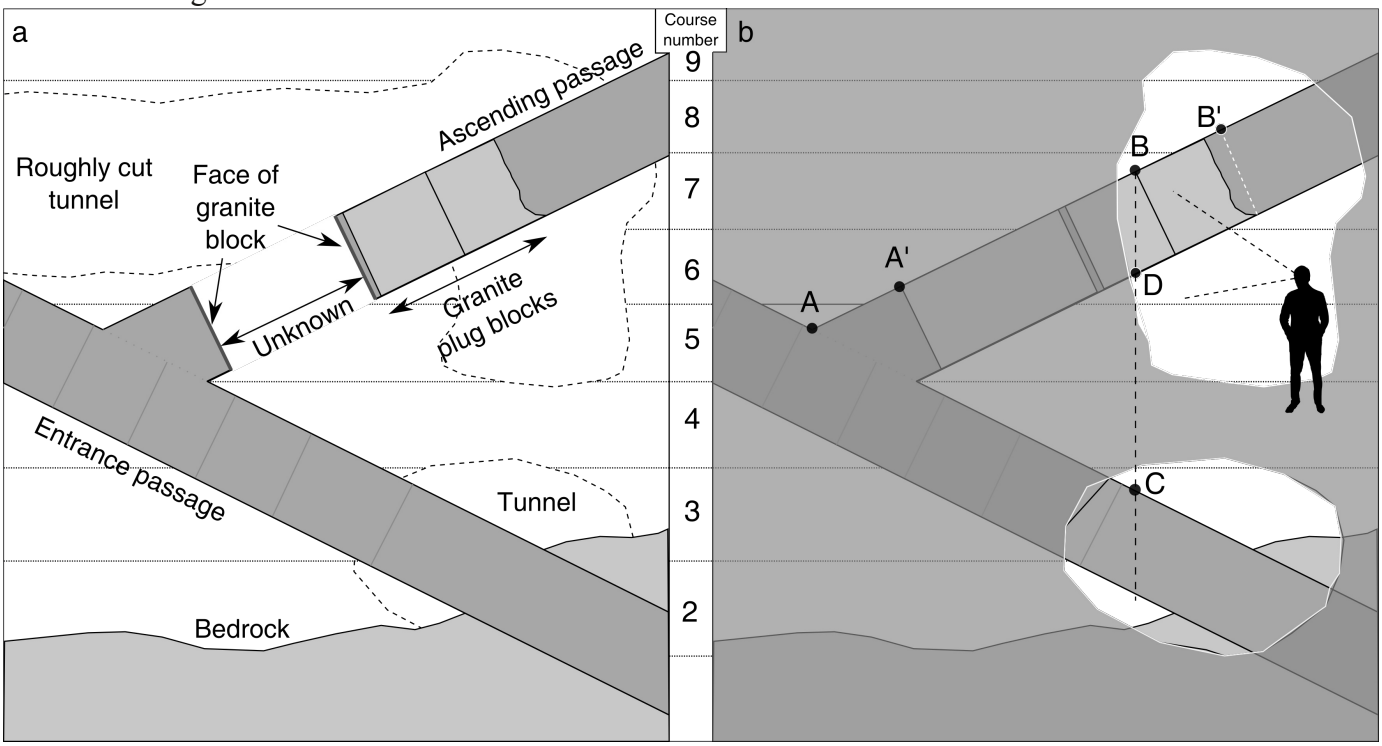

Figure 2 The ascending passage a) Cross section looking east b)View from inside the roughly cut tunnel

In order to connect the external and internal surveying of the pyramid, it is necessary to determine the length of the unknown section of passage, and this task was performed by Smyth[6], and his explanatory diagram is replicated in figure 2b. Point B is the top of the joint between the first and second plug blocks at the passage roof level, from which Smyth dropped a short plumb line. Point D is a point on the end of a long rod which Smyth visually aligned with the short plumb line and which is at least 1.2 m in-front of the plug block face, from which he dropped a second long plumb line. This procedure was necessary because there is masonry directly below the floor of the passage under point B prohibiting a plumb line being dropped more than the height of the ascending passage, and below point D this is no longer the case. Point C is a point in the entrance passage which is the bottom of the long plumb line that was dropped from point D, and that is vertically coincidental with points B and D. Point A is the intersection of the roofs of the entrance and ascending passages, and point A' is the ascending passage roof at the face of the granite stone.

At the time of performing his calculation, it was thought that the entrance and ascending passages were of equal and opposite angle, which they very nearly are, and so Smyth's logic was as follows. The distance AC must be the same as the distance AB and therefore the length of the hidden section of passage plus the second plug block, the length A'B, can be calculated because both AC and AA' can be measured in situ. By carrying out this calculation Smyth determined that the distance from point A' to the top face of the upper block point B' was 178.8 inches, or 4.542 m. This value was then used without question by Petrie, and continues to be the basis of all current drawings and models of the pyramids, including Gantenbrink's.

Smyth's analysis is flawed because he has started with the assumption that the granite block face that is visible in the entrance passage roof and the plug blocks that are visible in the ascending passage are a linear continuation of each other. Although this would appear to be a sensible proposition, there is no evidence to support this assumption, and therefore Smyth's determination of the length across the hidden section of the passage is a meaningless value. Moreover, the ascending passage could be placed anywhere in 3D space relative to the apparent start of the ascending passage in the entrance passage roof.

The only way of resolving the problem incorporated into Smyth's analysis was to take measurements inside the entrance tunnel of the pyramid to determine the position of the plug blocks relative to the outside masonry and then compare the results to the survey publications.

Measuring the plug blocks

In November 2018 a series of measurements were taken inside the carved out entrance tunnel of the Great Pyramid, using an Bosch DE50 laser measurement device. The device was calibrated in situ against a steel tape and was found to be accurately measuring distance to 1 mm, and the rear of the device was permanently modified with a dual axis spirit level which was calibrated against a known horizontal.

The carved out entrance tunnel inside the pyramid contains a modern rigid metal gate which prohibits public access to the entrance passage from the tunnel area, and a location on this fixed object was used as a reference point for measurements. The first measurements taken was the vertical distance from the reference point on the metal gate to the base of the joint between the upper two plug blocks, a distance of 0.75 m +/- 0.01 m. A horizontal laser track was then taken from the reference point, via 3 intermediate points, back to the entrance of the tunnel. This measurement was repeated on four occasions, and the base of the plug block joint was determined as being 0.304 m above the top of the 5th level of core masonry at which height the floor of the tunnel commences, and which is known from Petrie's surveying to be at a level of 6.099 m above the pavement. This gives the altitude of the base of the plug block joint above the pyramid's pavement level as **6.403 m** +/- 0.03 m, that being the combined estimated error resulting from the accuracy of the leveling of the laser track and determining the joint's height above the reference point. The height of the base of this plug block joint in Smyth and Petrie's surveying of the building is **6.69 m** +/- 0.01 m showing that there is a vertical error of 0.29 m +/- 0.03 in the surveying.

The source of the error

Figure 3a is an illustration of the method that Smyth used to project his vertical line from the top of the joint between the two plug blocks into the entrance passage below, the points B and D being the same as those shown in figure 2. He aligned these points visually using the only reference plane available in the rough tunnel, that being the upper face of the second plug block, which is in pristine condition and is exposed due to damage to the back face of the first plug block.

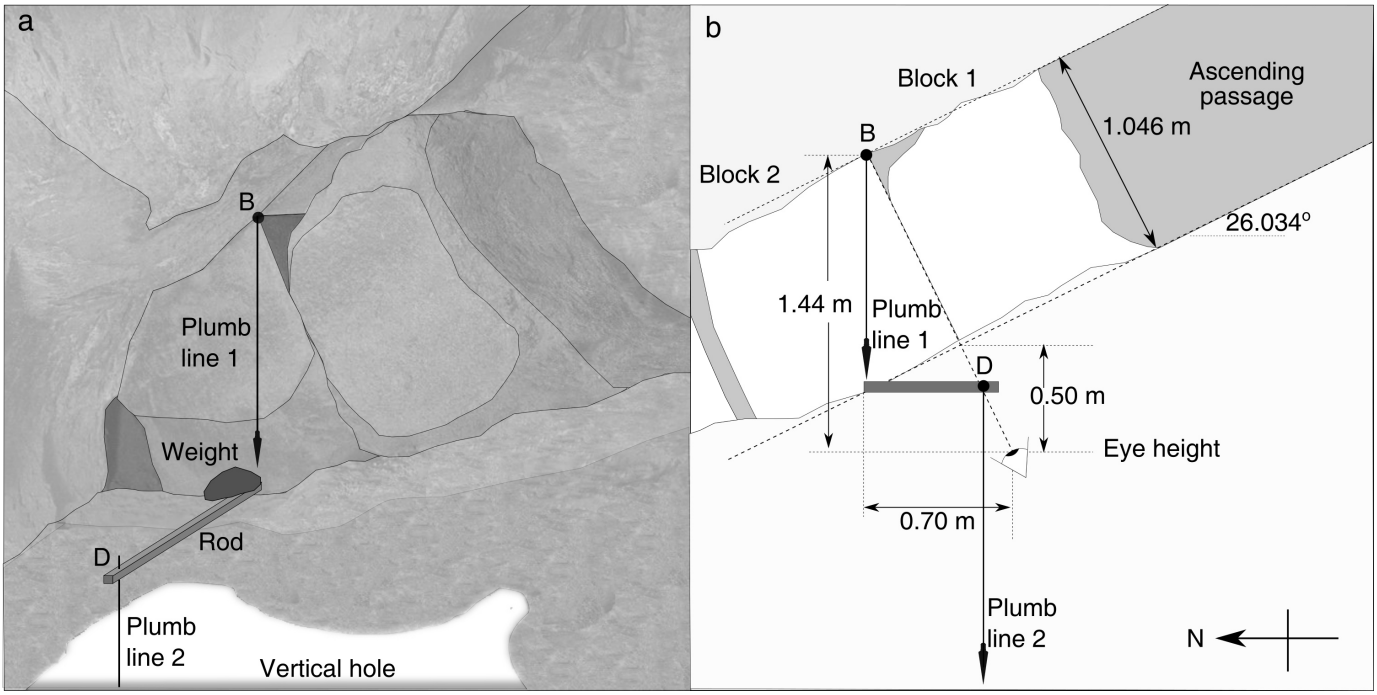

Figure 3 An analysis of the surveying error of Smyth

Standing at the near (west) side of the vertical hole in the floor which descends to the entrance passage, Smyth has aligned himself with the front face of the second plug block by slightly adjusting his standing position from right to left until the block's face just disappears from view. Assuming at that point that he is in line with the joint between the two plug blocks, he has then adjusted the position of the rod onto which the long plumb line is attached so that this plumb line is vertically in line with the short plumb line which is hanging from point B. He has then descended into the entrance passage and marked off the position of the long plumb line in that passage.

The error that he made is shown in figure 3b. When visually aligning himself with the front face of the second plug block he has not taken into account that the plane of the plug block's face, combined with his eye height, will have caused him to be offset to the right of the point B.

Smyth's eye height can be determined because he had a photograph[7] of himself taken outside the pyramid whist holding one of his surveying poles vertically, as a prop, and the major measurement divisions on the surveying pole are visible from which Smyth's height can be estimated as being 1.75m. Standing just in front of the vertical hole in the floor, my eye height was measured against the lower part of the plug block joint as being 0.37 m below it, and so Smyth's eye height must therefore have been about 0.50 m below the same point when making his alignment, as shown on the illustration. By trigonometry, this has resulted in him being 0.70 m to the right (north) of the point B and the long plumb line start point D, which would have been just in-front of him, approximately 0.60 m offset. As there is currently a concrete floor in this section of the tunnel upon which I was standing when taking the measurements, which increases the Smyth's error value, all surveying measurements of the internal architecture of the building must be offset by somewhat more than 0.60 m to the south.

With the angle of the ascending passage being known, this horizontal error of 0.60 m to the south would produce a corresponding vertical error of 0.29 m, which corresponds to the vertical error of 0.29 m that was measured when connecting the inside and outside of the building's surveying.

The error that Smyth made is logical, repeatable and measurable.

The results of correcting the surveying of the internal architecture

A more precise value for Smyth's horizontal error was determined by looking at other parts of the building's architecture which are known to relate to the position of the central vertical axis of the building. Figure 4 shows the lower chamber of the pyramid.

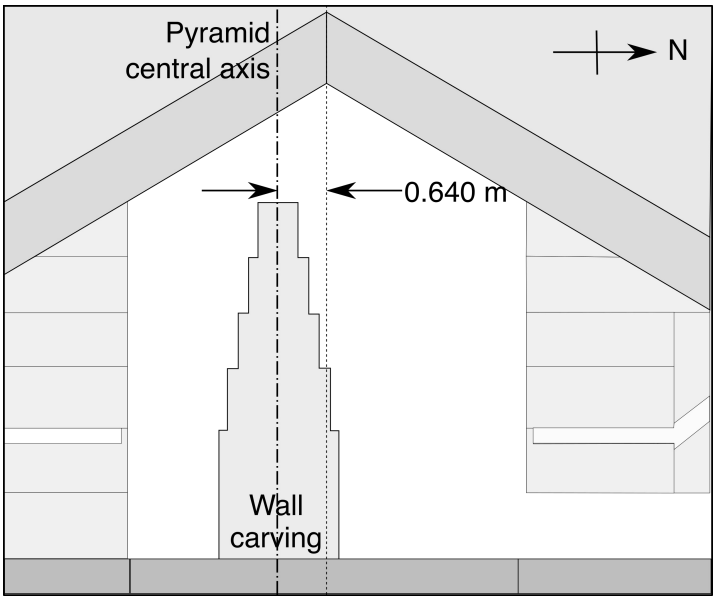

Figure 4 The lower chamber with the correction applied

The apex of the lower chamber roof was surveyed by Petrie as being in line with Smyth's incorrect central vertical axis of the pyramid, and the central axis of the symmetrical wall carving in that chamber was surveyed at 0.64 m to the south of the roof apex. If this value is taken as being the accurate value for Smyth's horizontal surveying error, then the wall carving becomes positioned on the central axis of the pyramid

By relating the surveyed value of the carving's central axis offset against the room's vertical axis to the known angle of the ascending passage, the transformation required to correct the surveying of the internal architecture of the building was calculated as :

North: **0.64 m**
Vertical: **-0.313 m**

Resolving the upper southern shaft

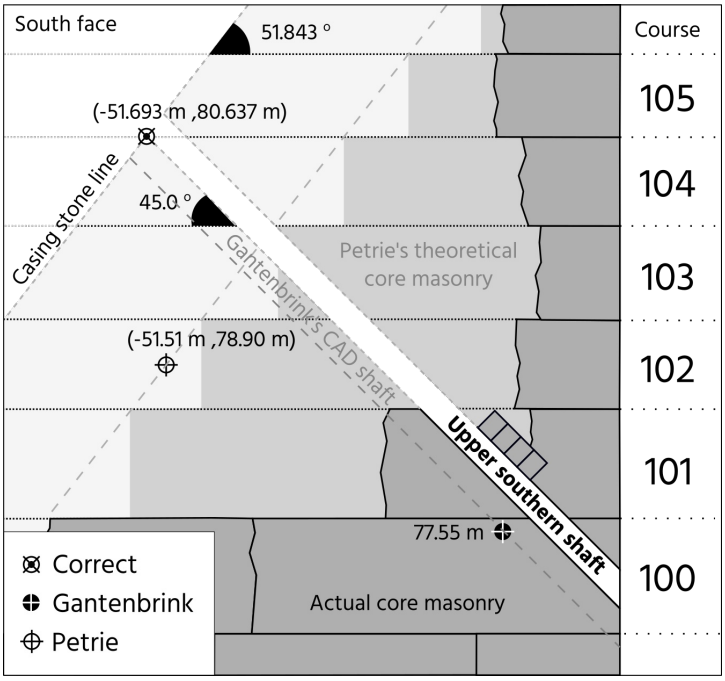

Figure 5 The upper southern shaft exit

The upper southern shaft's surveying by Gantenbrink is continuous from the upper chamber to the outlet on the face of the pyramid and the result of applying the correction to the internal surveying is shown in figure 5. When the shaft is moved down by 0.313 m and to the north by 0.64 m it ends up with the floor of the shaft aligned to the roof of Gantenbrink's original shaft position. With the accuracy of Gantenbrink's surveying not being in question, the discrepancy shown at the outset of this work between the two sets of survey data on the south side of the building was determined as being in Petrie's station mark placement.

In Petrie's text[8] he states that he determined the course of masonry upon which the shafts emerge on the north and south faces by measuring the heights of several courses above and below the exit points, and then he referred to his previous

surveying of the course heights to establish the course number of the exit. By conclusion he did not triangulate the exit points to reference points on the ground, and the horizontal component of his station marks must therefore be a calculated value against the angle of the pyramid's face angle. Upon studying photography[5] of the exit points and Gantenbrink's images[9] it was seen that the southern shaft exit point is inset over 3.0 m relative to the core masonry plane, which corresponds to the CAD drawing with the internal architecture correction applied. Petrie's station mark placement falls on the line of the theoretical core masonry and it was concluded that this point is incorrectly placed.

Resolving the upper northern shaft

When the correction to the internal architecture was applied to the upper northern shaft the discrepancy between Petrie and Gantenbrink's surveying was not resolved. The initial vertical discrepancy of 1.41 m was reduced only by the vertical correction of 0.313 m leaving an error between the two surveys of 1.10 m. and it was determined that this error must be contained within the surveying of the upper northern shaft.

Figure 6 shows our current understanding of the lower sections of this shaft with figure 6a showing the shaft's starting point in the north wall of the upper chamber, and figure 6b showing the tunneled out section directly behind that north wall. These sections of the shaft are made up from 5 blocks of stone, which are numbered in the illustrations.

When Gantenbrink surveyed this shaft he did so in the following manner. First, he manually measured the horizontal section of shaft stone from inside the main chamber, and determined that it was 2.63 m long. Second, he went into the tunnel area behind the north wall and surveyed all of the cut away stones' lengths and angles using manual surveying equipment. Third, he placed his robotic inclinometer device inside the upper shaft-hole in the tunnel and attached it to a cable which had previously been lowered into the shaft from the shaft's exit on the northern face. From outside the pyramid he dragged the inclinometer device up the shaft by pulling on the cable, measuring the distance traveled and the inclinometer angle at numerous points within the shaft. These three sets of data were then joined together to form the basis of his technical drawings.

In order to determine any possible surveying error in the above method it was necessary to work from the outside of the building back in towards the upper chamber, as it was found that there is a subtle but very important discontinuous piece of surveying in the shaft.

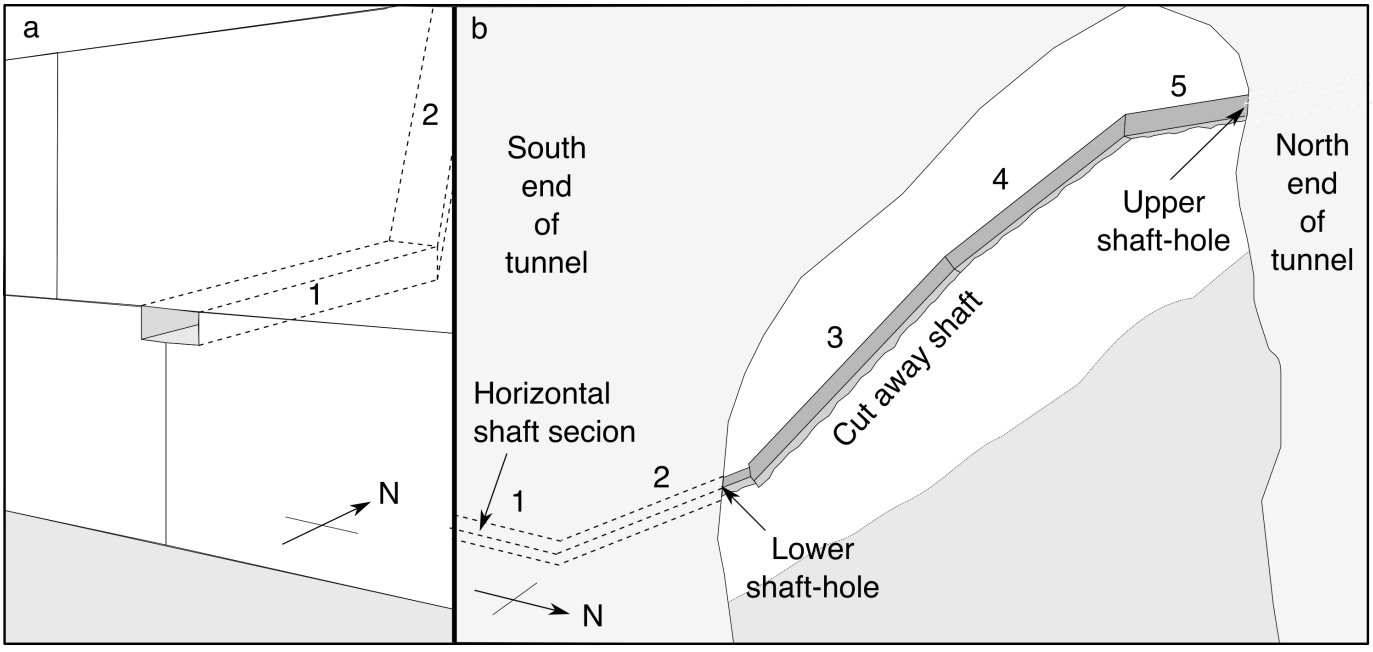

Figure 6 a) North wall of the upper chamber b) The tunnel at the back of the upper chamber north wall

There is no scientific evidence that the first two blocks of stone seen when looking inside the shaft from the main chamber are the same as the first two blocks of stone that can be seen when looking into the lower shaft-hole in the tunneled out cavity behind the north wall. The assumption that they are the same is clearly entirely logical, but not a proven fact because there is no record of anyone ever having inserted an object into the shaft in the main chamber and then later recovering that same object via the lower shaft hole in the tunnel, or visa-versa.

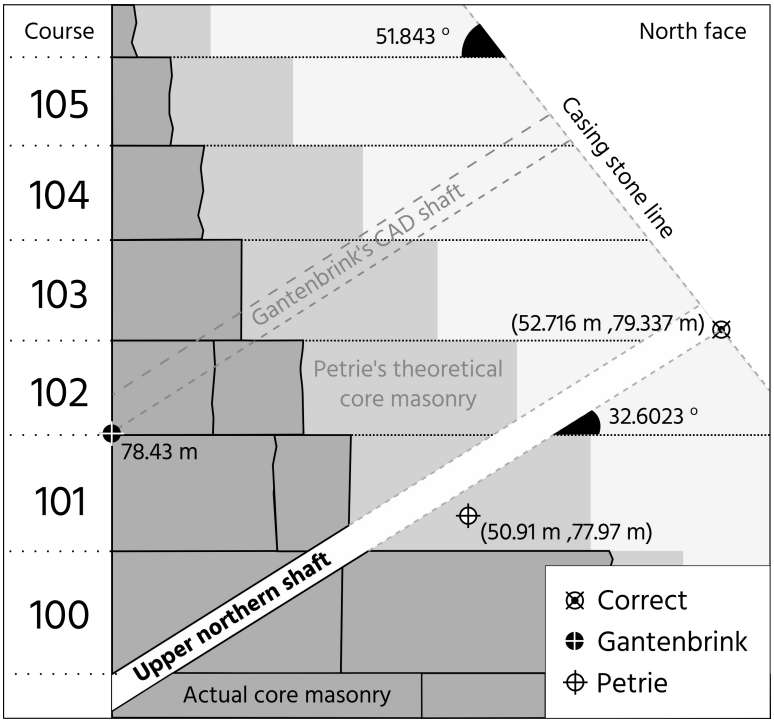

Figure 7 The upper northern shaft exit

Gantenbrink's technical drawings show the termination point of the upper outlet of the shaft on the pyramid's northern face precisely, with the top of the 100th level of masonry clearly indicated. To connect the shaft to the external surveying of the pyramid rather than the internal surveying, the upper northern shaft survey data was re-positioned on the CAD drawing, aligning Gantenbrink's shaft exit level with the level of the exit determined from the photography analysis, the result of which is shown in figure 7.

With the technical drawing of the shaft now correctly positioned in relation to the external surveying data, and knowing that the accuracy of the measurements within it were not in question with a tolerance of a few centimeters linearly and 0.2 degrees angularly, the start of the shaft was resolved.

The result of attaching the shaft survey data to the outside of the pyramid is shown in figure 8. At the lower end of the shaft the floor of the horizontal section of the shaft that is visible from inside the tunnel is 1.04 m above the surveyed shaft's horizontal floor, a distance that corresponds to the surveying error between Gantenbrink's CAD drawing and the actual shaft exit level on the northern face of the pyramid.

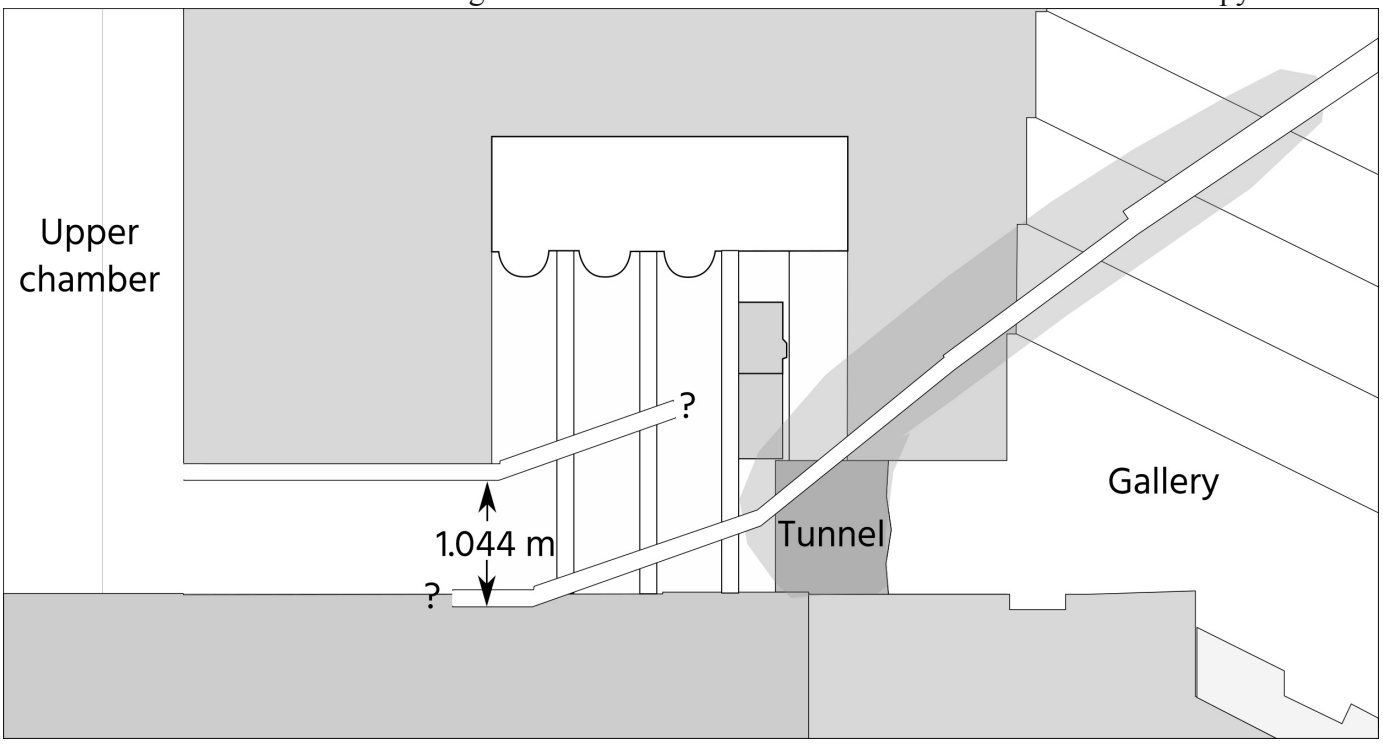

Figure 8 a) The upper chamber northern shaft b) The upper northern shaft end inside the tunnel

The lower northern shaft that starts in the main chamber and the shaft section that is visible on the south side of the tunnel behind the upper chamber's north wall are two distinct features. Therefore they are two sections of the pyramid's architecture which have never been explored beyond their respective bend points, as shown by the question marks in figure 8.

Conclusions

By comparing the published surveys of the Great Pyramid of Giza it has been shown that the all of the internal architectural features of the building on current surveys from the plug blocks upwards are incorrectly placed. The carving in the lower chamber should be positioned on the central vertical axis of the building and the vertical position of the internal architecture on current surveys is set 31.3 cm to high.

It is also shown that the upper northern shaft which starts in the main chamber is not the same shaft as the one located at the south end of the antechamber tunnel behind the main chamber's north wall.

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