Is the Great Pyramid's 'Big Void' in fact caused by two construction space zones flanking the Grand Gallery? Looking for plausible interpretations of the ScanPyramids data set.

David Ian Lightbody[1] April 2018 (WORKING PAPER).

The announcement of the 'discovery' of a new 30m long (minimum) void space in the Great Pyramid of Giza in western Cairo, Egypt, made global headlines November 2017. Reports referenced the Nature article (doi:10.1038/nature24647) which described muon detection experiments carried out by the ScanPyramids team through 2017 to produce a data set which was presented. The article expressed little doubt regarding the conclusions that should be drawn from the results and the size and location of the proposed new space which they labelled the 'big void'.

Due the magnitude of the central claim made, the lack of comparanda for such a void in a similar location in any other Egyptian pyramid, and a significant number of recent cases in which archaeological data sets have been misinterpreted, the scans and the data set were reviewed to see if any other plausible interpretations could be identified.[2] As can be seen from the Nature report, the data collection was carried out with technical professionalism, however, it may be the case that there are additional plausible interpretations of the data set produced, and the initial interpretation may not have been the correct one.

> This article reports a different interpretation of the data set and proposes that the 'big void' may in fact be the result of two zones containing many small construction voids which flank the Grand Gallery (Fig. 1). Geometric calculations illustrated below (Figs. 2 and 3) indicate that the new features on the scans which were interpreted as produced by a single 'big' void viewed from two directions, located 40m out towards the north face of the structure, could in fact have been produced by two smaller void zones closer to the center of the pyramid, one on either side of the Grand Gallery structure. Due to the offsets of the two Nagoya nuclear emulsion detection plates from the center line of the Grand Gallery, which were of a similar magnitude (NE2 – 4 m west, and NE1 - 5.5 m east of the N-S center line), and the inward slope of the sides of the Grand Gallery structure, only one such void zone would be clearly visible on each Nagoya scan. On one side the small voids would be aligned with the detector and would form a zone that was almost a continuous void directed at the plate. On the other hand, the opposing void zone signals would not align with the detector and so the effect of the signals would not be cumulative. In addition, most of them would be hidden behind the signal of the main gallery structure. The attached diagram illustrates how the geometry of the pyramid's internal structure could have contrived to produce the results returned.

Example Configuration

The example illustrated (Fig. 3) demonstrates how such twin void zones would appear across a single section of the muon detection plates located in the Queen's Chamber. The horizontal bands across the top of the diagram represents a section running E-W across both detector plates at NE1 and NE2. The

---

[1] Co-editor, the Journal of Ancient Egyptian Architecture, JAEA. www.egyptian-architecture.com

[2] In Nile Magazine Dec 2016/Jan 2017, in an article entitled *The Quest for Khufu* which addressed the progress of the ScanPyramids project to that point in time, I contributed to the discussion, stating that: "This technology has been used before at Giza, back in 1970, and it has the potential to be improved, but at present, the results remain difficult to interpret. Researchers should be certainly be cautious about drawing any firm conclusions at this stage."

example used for the demonstration corresponds to a plane angled at 63.5 degrees to the horizontal, sloping up towards the northern sky. The floor of the Grand Gallery, on the other hand, is inclined at 26.5 degrees to the horizontal, on a plane sloping up towards the south.[3] Muons travelling down the P2-P1 line at the center of the plane rising to the north would therefore travel perpendicularly down through the Grand Gallery structure (26.5° + 63.5 ° = 90°). The center line of the diagram corresponds to the line running from point P2 on the northern face of the pyramid towards point P1 in the Queen's Chamber. The images at the top of the diagram show how the unexplained void features on the exposures could correspond to Grand Gallery side void zones in this configuration. Both the resulting muon images produced would include one flanking void zone signal, separate from the main gallery signal, while the other flanking void zones would be spread out and hidden behind the main gallery void signal. In this case the simulations are close to what was observed and published in the Nature article. Each muon exposure image included two separate bands of void signal, one aligned with the Grand Gallery void and one additional void signal running alongside it.

It is not intended to suggest that this second interpretation is definitive, as some of the same methodological problems raised by the previous interpretation would then be revisited, but it is proposed that it is another plausible interpretation of the data set that should be carefully evaluated.

Construction logic

The proposal would make good sense from an archaeological and architectural point of view. If twin flanking void zones exist, then these spaces could have resulted from a complex engineering problem. Because the gallery ascends at an inclination of 26.5 degrees, and the external width of the ashlar-built gallery structure most likely contracts inwards as it rises, it would have been challenging to interface the gallery structure with the limestone core structure around it, particularly if the two structures were erected at different times. The ancient Egyptians were adept at cutting sloped faces on stone blocks that inclined in a single plane, as can be seen from the casing stones on the exterior of the pyramid, and inclined box section passages within, but it would have been extremely challenging to cut interface blocks that had faces inclined across two planes at once, or that could be securely interfaced with a complex, unfinished face of the gallery's exterior. As a result, it may have been too labor-intensive to carefully interface the horizontal construction layers of cuboid limestone core blocks with the sloping or unfinished outer surfaces of the gallery structure, and so many small void spaces may have been left behind as the core layers were added.

It is possible that these spaces were filled with a low-density sand or mortar that do not absorb muons to the same extent as the surrounding core blocks, however, at this stage it is difficult to estimate if this could be the case as the ScanPyramids team have not published test results that compare the muon absorption rates of the different materials used to build the pyramid, and which could be used to calibrate predictive models.

[3] An angle of 26.5° is an inclination or gradient of 50%, or 1:2, or a "seked" of 14 using the ancient Egyptians' system of measurement whereby the angle was defined by the run (in palms) for every 1 cubit rise (7 palms). See Gillings (1982), p. 212.

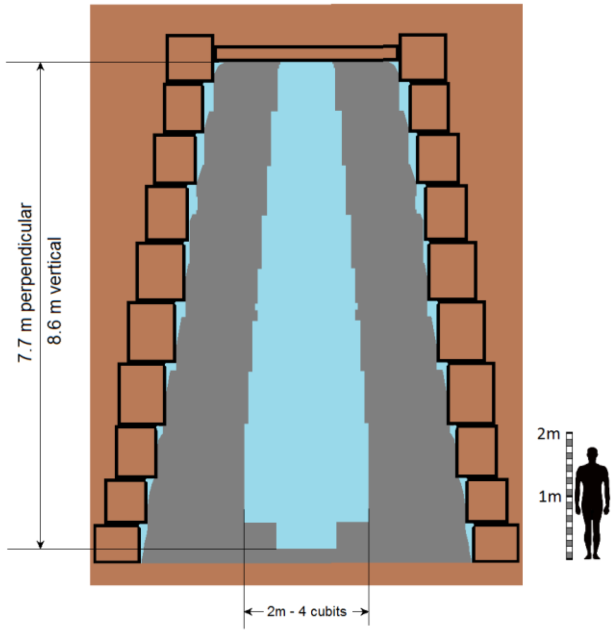


Figure 1. Corbelled ashlar Tura limestone block tunnel-vault Grand Gallery with twin flanking void zones, flanked by limestone core blocks and multiple construction void spaces. (author's diagram).

Structural functionality

The purpose of the main internal space which fills the gallery vault was to protect and preserve the open passage below. While the gallery resembles the corbelled vaults seen in earlier Old Kingdom pyramid structures, it is the unique example of a corbelled vault erected on a slope, and it is significantly narrower than the earlier examples. Just like the so-called King's Chamber which was constructed using Aswan red granite, the finely cut ashlar masonry used to build the Grand Gallery differs significantly from the bulk of the Great Pyramid's limestone core blocks. The walls and ceilings of both the Grand Gallery and the Queen's chamber are constructed with fine limestone from the Tura, Maasara, and Mokkatam quarries near Cairo.[4] This limestone, originally grey-white, has taken on a slight reddish tint, possibly due to a painted finish that was applied after construction was completed, and also due to prolonged exposure to the air and moisture generated by the breath of thousands of tourists. Over time, low iron content in the stone migrated from the interior and oxidized on the exterior surface of the stone where it has formed a smooth patina.

Due to the importance of creating these structurally-strong internal spaces, it is possible that the chambers and the gallery were designed as stand-alone, self-supporting structures that were first created off-site (possibly Aswan for the King's Chamber), before transportation to Giza for installation within the pyramid's core. The architects may therefore have constructed the ashlar block tunnel-like gallery structure with a free-standing section, loaded from the top like a "deck-arch bridge".[5] This could explain why flanking void zones would not be filled with gravel or offcuts of stone, as there was no need to add

[4] Klemm and Klemm (2010).
[5] The top of the Grand Gallery was spanned with slabs rather than tapering to a narrow channel, as was the case with the corbelled vaults in the Red Northern Pyramid. See Lehner (1997), p. 113.

more lateral force to the exterior of the self-supporting structure than was necessary, as the structure was not designed as a fully side-loaded vault.

The result of the above scenario would be twin void zones on either side of the Grand Gallery where it meets the core block layers. Such features could have produced the two unexpected, new, and very long signals seen on the muon detection plates, which run parallel to the long axis of the Grand Gallery.

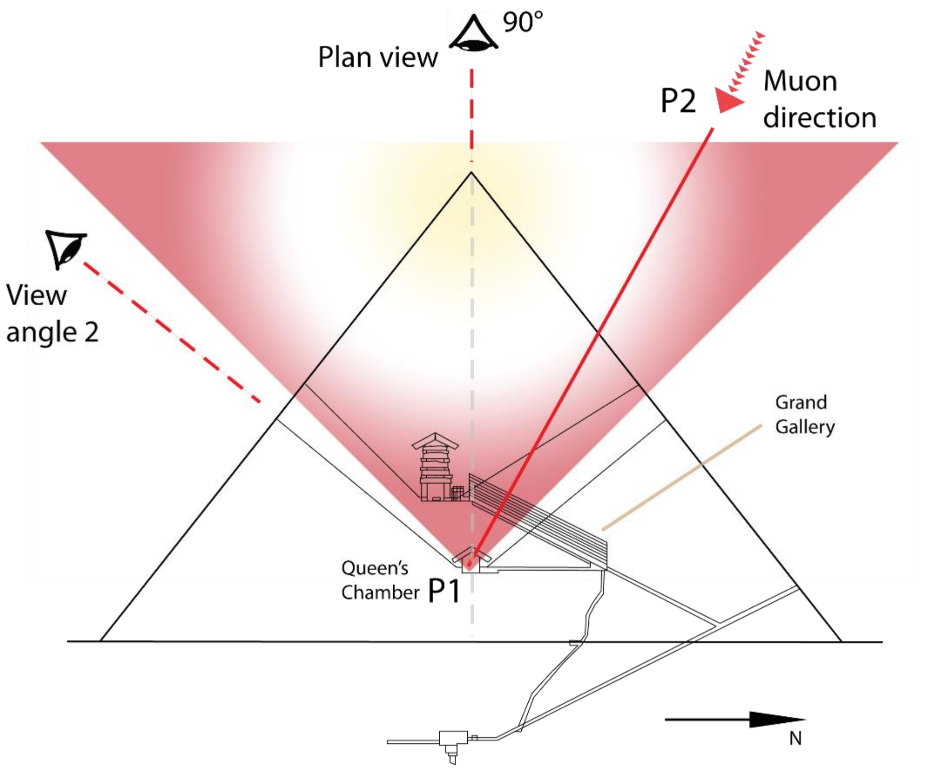


Figure 2. Diagram showing plane of example illustrated in figure 3. Solid red line shows plane 63.5 degrees to the horizontal, sloping to true north and running from P1 to P2. The inverted red triangle represents the zone covered by the Nagoya muon detection plates near P1.

Understanding the experimental context

Triangulation of a single new void location was perhaps an understandable misinterpretation of the complex data set. The same logic can be applied to the hodoscope images taken from locations H1 and H2 in the main Queen's Chamber, which were west of or close to the Grand Gallery center line, which made interpretation even more difficult.

Advanced as the muon detection techniques are, they produce two dimensional images, as opposed to, for example, Ground Penetrating Radar (GPR) which also yields depth signals for every point returned. GPR can only penetrate around 10m of limestone rock, hence 3D GPR scans are unavailable for the more profound depths encountered in a mostly-solid structure of the size of Khufu's pyramid. In addition, it is challenging to interpret 2-dimensional muon images from complex three-dimensional structures. The interpretation of scan results for ancient and singular structures like the Great Pyramid must take place within a context that includes historical, archaeological, and architectural knowledge, experience, and expertise, and a methodical approach.

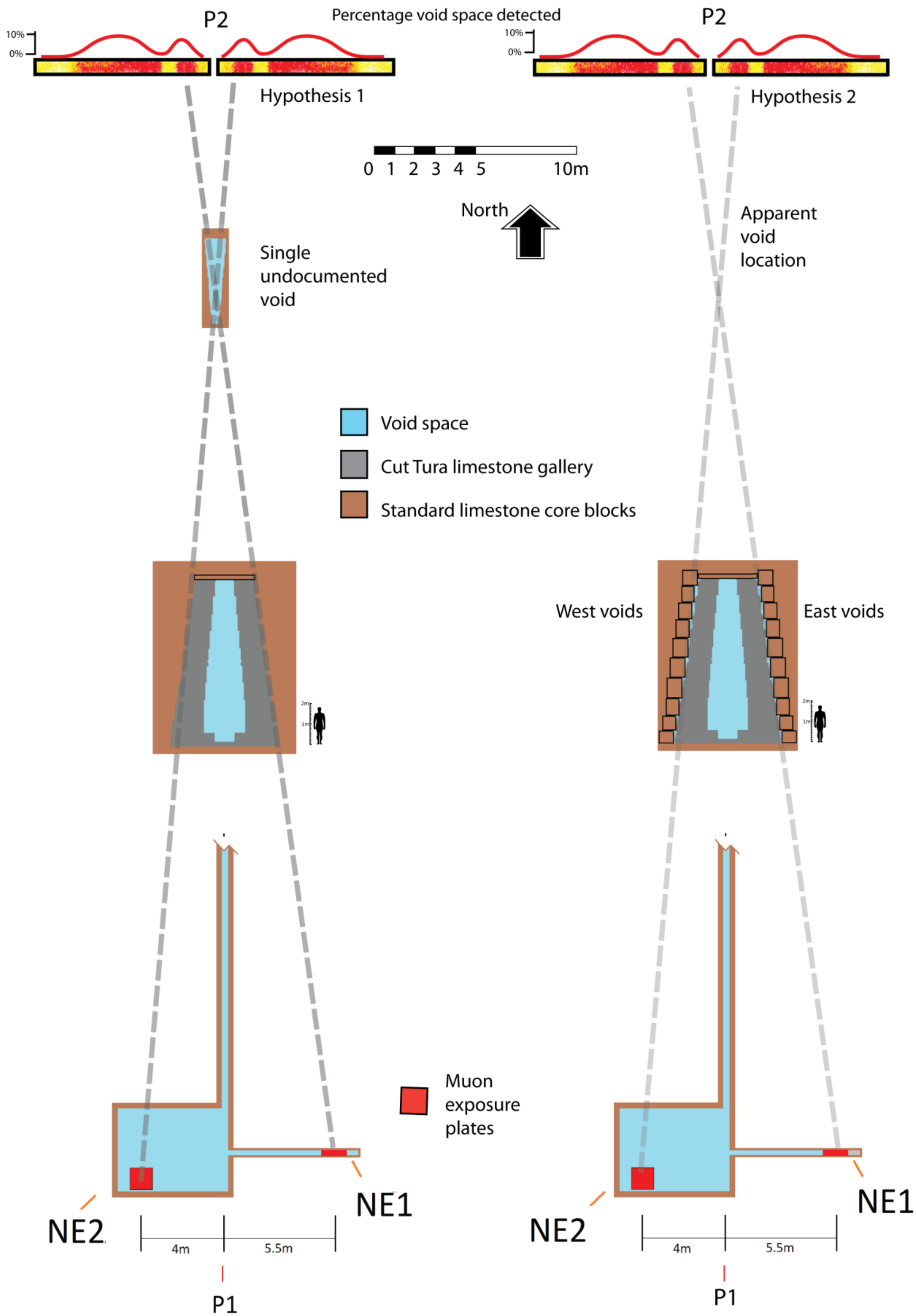
If the scenario described here is correct, an explanation for the CEA gas detector readings taken from points G1 and G2 outside the main entrance to the pyramid is still required, as they apparently showed fluctuations in line with a supposed trangulation location further out towards the north face of the pyramid.

Muon detection images are low in resolution and quality decreases with depth of travel through a structure. A scan taken from a point outside the main entrance facing south at an elevation of around 45 degrees must peer through approximately 250 m of rock before open air is reached. The intervening structure is interrupted by the huge entrance vault which has been partially dismantled. Earlier scans indicated possible low-density zones behind the entrance vault, and there could also be low-density zones above the King's Chamber relieving chamber structures. In addition, there are likely to be many other smaller voids scattered throughout the structure, which Mark Lehner described as being more like Swiss cheese than cheddar. It would therefore be expected (as was found) that significant fluctuations are visible in the data set. It is reasonable to suggest that such fluctuations could have been misinterpreted due to a pre-conceived conclusion based on the preliminary interpretation of the Queen's Chamber scan results. This may not have been the case, but it is the objective of this article to suggest that there are other plausible interpretations of the data set that must be considered and tested before definitive conclusions can be drawn. At the very least, it will give the team an opportunity to test their hypothesis and their data set.

This twin void zone proposal can be falsified using the same non-destructive muon detection technology employed by the ScanPyramids team, for example by repeating one of the Queen's Chamber muon exposures with a plate inclined at 45 degrees towards the north face. This would allow the 90-degree angle coverage of the image to scan the whole of the Grand Gallery, rather than just the upper part. If there are void zones on either side of the Grand Gallery they would most likely continue down to the lower end of the structure, so the flanking void spaces would be visible on new images covering that area, down to a height equivalent to the level of the Queen's Chamber floor. The ScanPyramids team have already produced simulations of what they expected to find based on the previously known structure. A muon scan simulation based on a new model would test how closely simulated results based on the proposed structure would correspond with the observed scans. Finally, it would be straightforward to use GPR to peer through the upper sides of the Grand Gallery, as the method would have the range to detect voids in proximity.

It should be noted that the importance of carefully calibrating and testing readings of this type, and accurate modelling of existing structures was already noted during the earliest round of muon scans undertaken in 1967. [6] During those scans, unknown void spaces were initially thought to have been observed, but after further analysis and calibration this was found not to have been the case.

[6] See Alvarez *et. al.* (1970), p. 838.



P2
Percentage void space detected
10%
0%
Hypothesis 1
P2
10%
0%
Hypothesis 2
0 1 2 3 4 5 10m
North
Single undocumented void
Apparent void location
Void space
Cut Tura limestone gallery
Standard limestone core blocks
West voids
East voids
Muon exposure plates
NE2
4m
5.5m
P1
NE1
NE2
4m
5.5m
P1
NE1

Figure 3. How twin void zones would appear on a single section of an exposure due to muons arriving at an angle of 63.5 degrees to the horizontal from the northern sky, from point P2 on the northern face of the pyramid towards point P1 in the Queen's Chamber, close to where the detectors were set up (NE1 and NE2) The strips at the top show simulated detector scan strips based on sections taken across the actual scan results (author's diagram).

Conclusions

Whatever the positive outcomes with respect to possible new internal spaces or structures, the ScanPyramids team have already made significant discoveries. The negative results from the ScanPyramids project are perhaps most significant. It has now become clear that theories relating to surviving internal spiral construction ramps and hidden chambers near the center of the pyramid must be rethought and possibly abandoned once and for all. Furthermore, they have demonstrated that non-destructive testing and comprehensive publishing of scientific results in peer reviewed journals are effective ways to conduct research into such globally significant historic monuments, although muon absorption rate comparison and calibration measurements for the different construction materials are required. The Scan Pyramids project must be applauded for their progress so far, and more experimental work of this type is required at Giza. Ultimately, however, the priority should be to understand the structures from the point of view of the ancient Egyptian builders and architects who created them.

Bibliography

Gillings, R.J., (1982), *Mathematics in the Time of the Pharaohs*, Dover.

Klemm. R. & Klemm, D. (2010), *The Stones of the Pyramids*, Berlin: De Gruyter.

Lehner, M. (1987), *The Complete Pyramids*, Thames and Hudson.

Alavrez, L.W, J.A. Anderson, J.B. F. El Bedwei, J. Burkhard, A. Fakhry, A. Girgis, A. G., A Goneid, F. Hassan. D. Iverson, G. Lynch, Z Miligy, A.H. Moussa, M. Sharkawi, L. Yazolino, (1970), Search for Hidden Chambers in the Pyramids, in *Science* Vol 167, Issue 3919 pp. 832-839.