X
The Grand Gallery

What is most striking is the size of the Grand Gallery; not only does the length from the north wall to the south wall correspond to 47.84m, but also its height, measured along the axis of the gravitational force, is 8.60m.
However, if we consider a section perpendicular to the slope the height is 7.70m.
The floor consists of a large central groove exactly two cubits (105cm) wide, flanked by two platforms, both a cubit (52.5cm) high and just as wide.
The floor of the groove is perfectly aligned with the Ascending Corridor, along which the three granite blocks obstructing the lower entrance to the pyramid were slid down.
The work is spectacular and breathtaking as it is majestic (photo **C01-C02**).
Its maximum width, measured from above the two platforms, is exactly four cubits (2.10m). I am convinced that, within the central groove, the sealing granite blocks were first raised and then slid down, while the two lateral platforms would have accommodated two rows of standing men for pulling.
The sidewalls rise vertically for 180cm (161.5cm perpendicular to the slope) before starting to close in, with the projection technique.
The first two rows of the blocks are simply stacked precisely in order to allow the men on the platforms to freely work.
The narrowing toward the ceiling starts with the third block layer only, projecting inward by a palm (7.5cm) on both sides.
This laying technique, consisting in placing the new layer of blocks protruding slightly inwards, continues for all orders of successive blocks.
With each successive layer, the two rising walls move closer to each other forming a structure capable of withstanding a considerable force of vertical compression.
It is, as said, the first ingenious experiment suitable for protecting a cavity from the weight of all that is above.
Leaving to others the analysis of the structural problems, now let's take a look at the other features of this extraordinary uphill path.
Starting right at the Quadrivium, we find in the platforms a whole series of pits, dug adjacent to the walls and arranged head-on in pairs (the twin of one is found at exactly the same height on the other platform) (photo **C01**).

These pits are equidistant from each other and are in the form of a parallelogram, having two long sides parallel to the gallery slope and the two short sides as per the gravitational force (drawing **C03**).
All the pits are 2p (15cm) wide and have a depth of 17cm (measured perpendicularly to the slope = 2p + 1digit).
The length of the pits, however, is not fixed: there are "short" pairs of pits (length 1c = 52.5cm) and "long" pairs (length 1c + 1p = 60cm).
In the drawing **B07** the letters P and G identify the short and long pits respectively.
The number of these pits is considerable: there are 27 pairs, distributed along the whole length of the Grand Gallery plus a final pair, this time a prismatic shape, located on the top landing, back from the step edge and closer to the south wall.
Imagine yourself at the lowest point, right at the Quadrivium, and start climbing, carefully observing the pairs of pits.
The first two pairs are anomalous compared to all the others: all four are "short" pits, i.e. one cubit (52.5cm) long.
Only from the third pair (a "long" one) will the alternating of long-short pair start, and that will end with a "long" pair, set at a distance of 82cm from the edge of the "big step" at the upper end of the Grand Gallery.
These 25 central pairs differ from the first two by another peculiarity: at their center are dug, into the side walls, niches in the shape of true right-angled trapezoids, with the slanted side parallel to the platform floor and the vertical sides aligned with the axis of the gravitational force (so skewed with respect to the Grand Gallery floor) (fig: **C03**, **C04**).

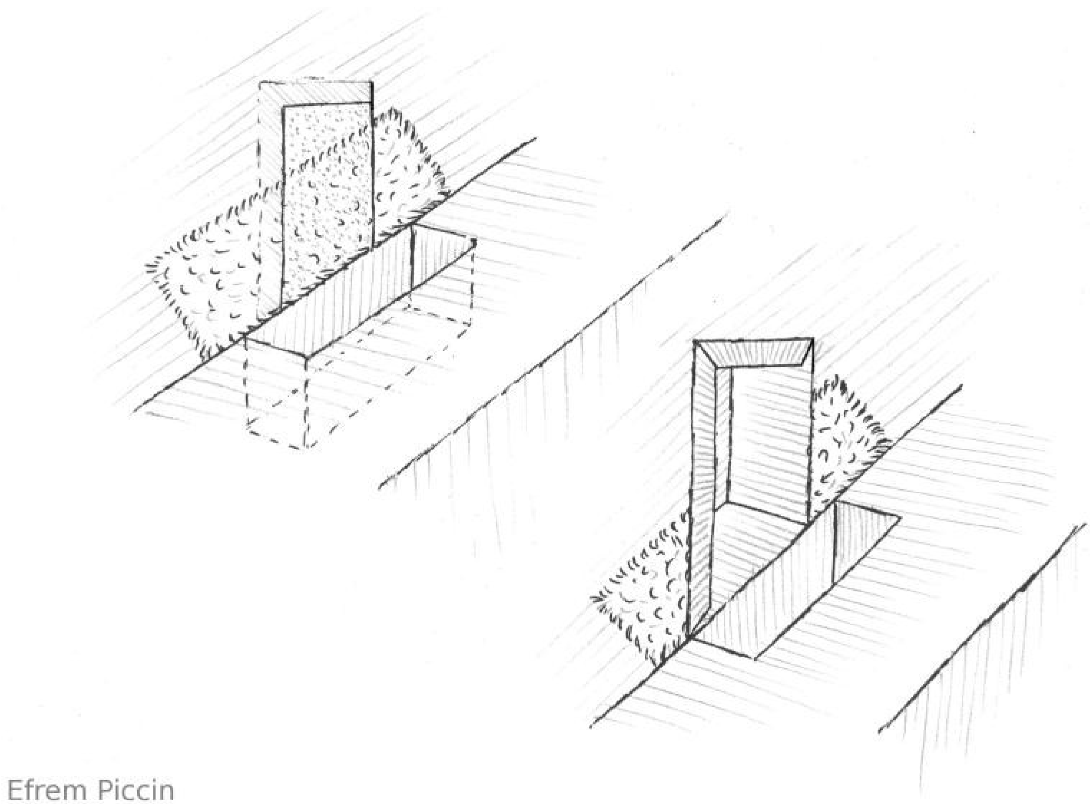

Figure 3: The Pits and Niches

These niches are all the same size: the heights respectively of 60cm (1c + 1p) and 45cm (6 palms), the width 27cm (1/2c) and the depth 22cm (3p). They are all filled with poor quality limestone pillars, also trapezoidal, and undersized compared to the cavity. So, if it were not for the mortar (also poor) that holds them in place, they would be easily dislodged from their setting (?...!).
The base of the niche is coplanar with the platform plane.
It doesn't end there. One of these niches, the seventh on the right going up, is empty (photo **C05**), since the pillar has been removed (I think that its sister, in the opposite platform, had the pillar removed as well, but refilled by a recent restoration). This is why it was possible to observe a further detail that can be assumed also for all the others: the upper horizontal edge of this niche and the vertical lower edge (i.e. to the north) are specifically beveled by a fine machining process (again fig. **C04** and photo **C05**).

At this point I want to say that all the well-finished details belong to the initial project. However, coarse workings were made for later overcoming unforeseen difficulties.
On these bases, I suppose the two beveled edges of each niche had a particular goal in the original design (?...!).
There are also other complications: at the 25 pairs of niches described above, we find chiseling, not “by design” type, on the body of the pillars and the adjacent walls.
It is a rush job done without taking special care, removing from the walls about 1-2cm of limestone.
The long side of these rectangular removals runs along parallel to the slope, (see again photo **B07**, **C03** and **C04**) crossing over the pillar body, while the short one is perpendicular to it.
Top of the chiseling is at a height of about 20cm from the pavement (although I should check on site).
A few easier details regarding the general description of the Grand Gallery and we're done: at exactly half of its height, at the level of the fifth block layer, there are two grooves (one per side), 16cm (> 2p) high and 2cm (> 1digit) deep, running along the full length of the gallery.
Also, in this case we can distinguish a fine machining (by design) overlapped by coarse chiseling mainly at the top and bottom areas, arranged perpendicularly to the gallery slope.
In the original project, in my opinion, the two grooves had to accommodate a long plank, stuck with wooden wedges, intended to be a storage "loft" for all the required materials (not in immediate use) such as ropes, beams, tools...
This loft also helped to hang up the lamps: it is unimaginable that the little floor space available was used for them.
Let us now summarize briefly.
Beginning to climb from the lowest point (the Quadrivium,) we come across two pairs of short pits without niches. 25 pairs of pits alternately long and short follow these, with central niches fitted with pillars and chiseling on the sidewalls. Finally, at the top landing, again a pair of short rectangular pits, with no niches or chiseling, set back from the edge of the big step, which is the top end of the Grand Gallery.

The entire Grand Gallery, measured between the extreme north and south, is 47.84 meters long and this is not a "standardized" measurement, not a integer multiple of cubits, which did not fail to amaze me a lot: I would have bet about it, but...
I then tried another approach: the top landing is 155cm (3c) long. The big step is 90cm (1c + 5p) high, clearly standardized measures. Applying the Pythagoras theorem, I calculated the hypotenuse of this triangle: 1.79m. Subtracting this from 47.84m, the result is 46.05m between the two platforms and 46 meters are equal to 88c exactly! This was enough to understand that Hemiunu had fixed *a priori* the length of the section required for all the 25 sealing blocks (that is all).
For the height of the Grand Gallery, however, I was not able to find any measurements related to multiples of the cubit, but I was not particularly surprised. It is reasonable to fix all the measurements while setting a problem, but the solutions are not always related to whole numbers: the result is what will be, especially if it is not important for the project.
I remembered, however, what was already fixed: the ceiling width (2c), the number of the projections (seven) and their extent (1p). There must be some kind of freedom!
Now I try to explain the reason, hoping you will share it, why the length of the Grand Gallery is 88 cubits exactly.
Hemiunu must have used much of his intelligence in projecting this detail. Furthermore, there are more structural complications, which I have not mentioned yet, but which will leave the best architects of the day speechless. First, the ceiling of the Grand Gallery, as I said, is exactly two cubits wide, half the width of the base: it consists of large limestone blocks placed transversely to the Grand Gallery, as logical. However, to avoid them bearing pressure on each other, thus creating an accumulation of force that could induce the whole ceiling to slide, they exert their pressure on the longitudinal blocks of the side walls, having shallow grooves, with a saw-toothed profile, on their top surface: each ceiling block fitted into its individual groove.
It is not enough: even the blocks of the projections, may be induced to slide towards the bottom. So at the bottom end of the Grand Gallery (north side of the pyramid) this is discouraged by making sure that the blocks transfer their load alternately to the transverse blocks of the north wall and to others located beyond; this by inserting narrow blocks in between the projection blocks crossing the North wall.

Alas, I realize that this is something terribly complicated to explain, maybe add a drawing, but it is really difficult to understand.
However, what I consider important here is to convince you that the architect has everything planned and calculated, leaving nothing to chance.
I have already said that almost all scholars of the Great Pyramid are convinced that the initial project had been changing during the working progress. I also said that I think this idea is nonsensical, unworthy of common sense in general, and in particular, the building of the Grand Gallery would have been impossible without a farsighted, overall approach, since its construction in the body of the pyramid required complex structural arrangements, starting from much lower levels.
Let us return to the 88 cubits length. Please carefully follow the explanation: since you are convinced perhaps you will be hooked for the rest of the journey.
Of course, during this explanation, as soon as you understand one thing, immediately two new questions will come knocking at the door of your mind at least.
The same thing happened to me during the six months or so when I was subject to the " pyramid delirium". It was the most intense experience of my life; the pyramid had consumed my every breath. I slept with a small voice recorder on the nightstand to record my ideas on it, whispering under the bed sheets not to wake my wife, looking at me as if I were a sick person.
I realize that my arguments could also be very indigestible for a reader not inclined towards technical matters. In that case, my story may be enjoyed as a novel without going into too many details.
Let's return inside the Grand Gallery to measure the distance between the center point of the pits (and niches): the average measurement of 3c + 2p (172cm) is obtained, which corresponds exactly to the length of the granite block we used as a sample earlier (170cm long, equal to 3c + 1/4c) plus a little more, just enough to allow a minimum gap (a digit extra).
So here an idea rose that I have for sure to share with many others: the whole Grand Gallery was conceived as a gigantic "loader", holding 25 granite blocks that would, sliding down, have definitely sealed the pyramid.
Why 25 blocks? In the Grand Gallery there are 27 pairs of pits. If we assume (as suggested by some authors) that the pits serve to accommodate the interlocking wooden beams, inserted from the rear to ensure the stability of the blocks, certainly the number of blocks should be 27!

But I do not think so, and I recommend you to look beyond the obvious. Consider the highest among all the pit-niche pairs, the one just beyond the big step on top of the Grand Gallery. It is 82cm from the edge of the step and could not, in any case, act as a "stopper" to another block simply because there is a lack of the necessary space for the block itself there.
On the other hand: 82cm + half of a pit (30cm) - 52.5m x tan 26.5 ° = 85.8cm, is equal exactly to half of a block length.
I had to subtract 52.5cm x 26.5°tan (= 26.17cm) because the block has a rectangular shape and its lower edge can only lean against the lower edge of the big step, creating a gap at the top by the amount indicated (photo **C06**).
If you imagine that 25 consecutive pit-niches (going downward from the big step) are in some manner connected to one block at its center, we will have 25 blocks, the number suggested. But then what is the purpose of the first two pairs of pits without the niches at the bottom? And what is the reason of the last pair at the top landing? (?...!).
It is necessary, at this point, go over a bit of physics and in particular the properties of the vectors (photo **C07**).
If we consider the granite block that I use as a "sample," its volume corresponds to 1.7 x 1.19 x 1.4 = 2.18m^3.
Assuming the specific gravity of granite to be 2.7, we get a very considerable total weight for the block: 2.18 x 2.7 = 5.680T = 5680kg!
Imagine this block at the bottom of the Grand Gallery, ready to be manually dragged up close to the "big step."

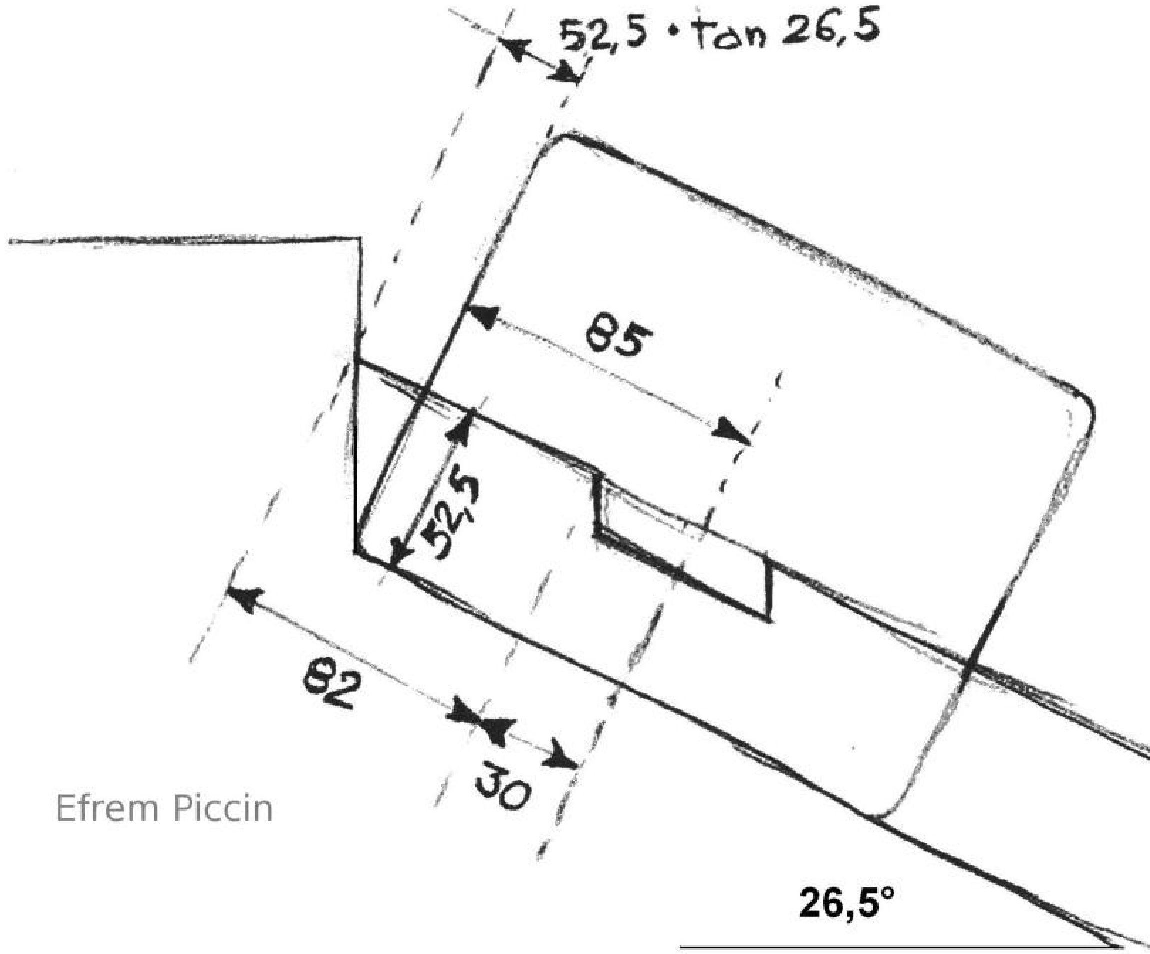

Figure 4: The big step

We have already seen that a right-angle triangle having an angle of 26.5° has a special relationship between its two shorter sides—one is double of the other.
Positioning a block on the hypotenuse of a triangle such as this and then using the parallelogram rule to split its weight force into vector, one perpendicular to the slope plane and the other parallel to it, we have two forces whose values can be calculated by minimal trigonometry (forgive me the word).
F normal = 5680 x cos26.5° = 5680 x 0.895 = 5083kg (about 5000kg.)
F tangent = 5680 x sin26.5° = 5680 x 0.446 = 2534kg (about 2500kg.)
The **F** normal is that part of the weight force compressing the surfaces, in contact with each other. It is, multiplied by an appropriate coefficient (which, in this case, is about 0.5) the sliding friction.
The **F** tangent, however, is that part of the weight force acting parallel to the slope, tending to spontaneously slide the block down. In static conditions, it will be

resisted by friction, but since we are close to the critical conditions, the equilibrium will be very unstable (just a slight tremble would be enough to trigger the sliding).
In such conditions we can assume the value of the frictional force is of the same magnitude as the tangential force, so it is reasonable to attribute to friction also a value of approximately 2500kg (**F** friction = **F** normal x coeff. of Friction = 5000Kg x 0.5 = 2500Kg).
To drag the block uphill, a force of 2500kg needs to be applied to neutralize the **F** tangent, and another 2500kg force is necessary to overcome the friction (pointing in this case downwards), which would lead to an overall force of 5000kg! (again photo **C07**)

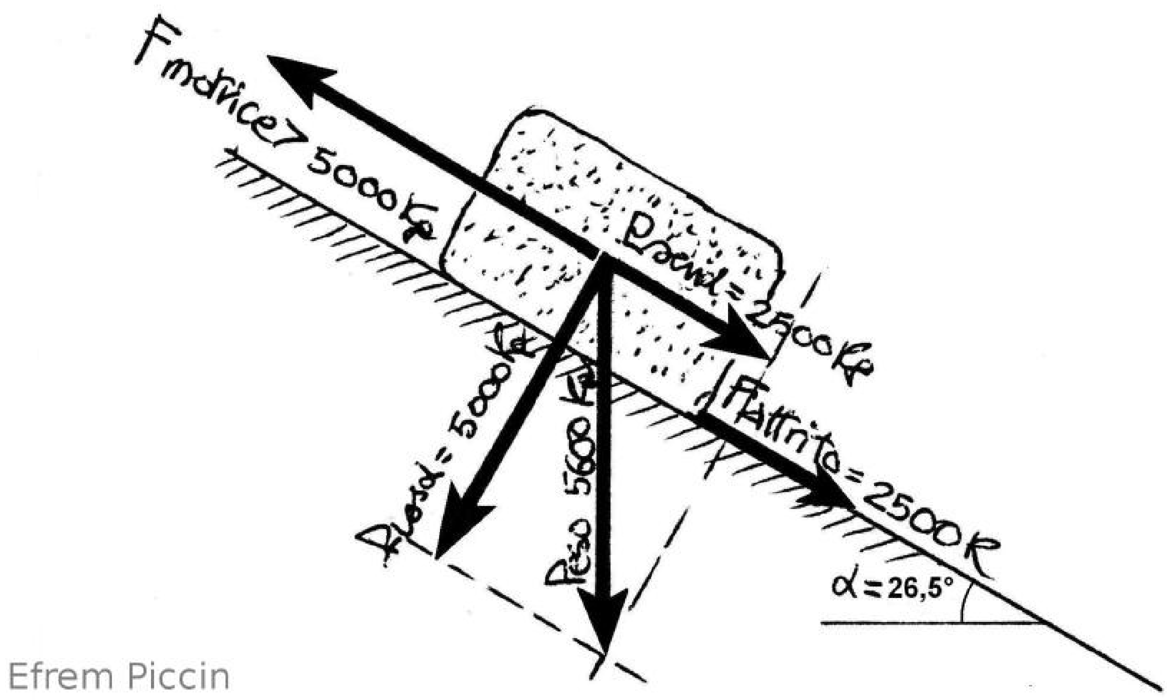

Figure 5: Vector Diagram

Reflect upon these numbers: you need to be convinced they are absolutely true!
All the rest is a consequence of these values. Let us see: how many people will be required to produce this effort?
Imagine a well-chosen, deeply motivated team of strong men: the "special corps" of Hemiunu. It is reasonable to expect during an effort like this that every man can,

discontinuously, pull a weight of thirty kg at least, but not more, especially if this effort will be long-drawn-out.
5000: 30 = 166 ... say 170 men.
It is a small crowd; we also have to add more people for different purposes: workers for ropes and lights, others for water, coordination... let us say, at least 200 men were simultaneously engaged in the enterprise.
Of these, at least 30 would be located here and there, but the 170 workers required for towing, divided into two groups of 85 men each, must be arranged on both platforms.
I tried it out in the classroom with my students, and a square area having sides a cubit long, was enough to accommodate a man at work. Of course in the right position, in close contact, slightly sideways, with their feet placed in herringbone pattern with respect to their neighbors. It may be somewhat of a tight fit but acceptable.
Hereupon the two platforms should be minimum 85 cubits (44.6m) long versus the real length of 88 cubits.
Maybe Hemiunu had planned to put 88 men on each platform pulling 28Kg each (I do not know the weight unit used at the time...).
I think this was the reason to establish the overall length of the Grand Gallery: I do not believe the data could work so well with each other by pure chance.
So 25 blocks were necessary to fill the whole Grand Gallery (the Quadrivium, as entrance to the Queen's Chamber, would have to remain free) (?...!).
Someone could advance an objection: why to work in so harsh conditions, when it would be possible to place the blocks in place while the Grand Gallery was still under construction?
There are two reasons, one of which is much more important than the other. For now, I will talk of the less important one.
It would be a serious mistake to place the blocks on the "loader" so early: Hemiunu knew very well that the pyramids have later minor settling and unexpected trouble... so if any bump will be formed in the Grand Gallery floor under a block...!
The sliding of the blocks, at the appropriate time, cannot and must not be hindered at all. Moreover, as I have already said, there are evidences, at the lower corners of the groove inside the Grand Gallery, showing us a continuous maintenance work. Certainly Hemiunu was frequently checking the alignment of this area.

Let us go back to the first block waiting at the Quadrivium. We also have 170 men ready for pulling, plus 30 for additional jobs... and a ridiculous air supply (do not forget, too, the oil lamps).
The awareness that the air will be terribly short and time precious is the reason why the pits are alternate short and long (?...!) (still waiting to read the part relating to the service shaft).
But first let us calculate the amount of available air. The volumes of the internal rooms are distributed as follows:
King's chamber: 320m^3
Great gallery: 700m^3
Ascending corridor: 50m^3
Horizontal corridor: 42m^3
Queen's chamber: 165m^3
The total is 1275m^3. (I have not considered the Descending Corridor nor the Subterranean Chamber because I think their air cannot be used, even if...)
Obviously we cannot imagine starting the job with 1200m^3 of fresh air (men take time to enter and take position) and we cannot even think of consuming the whole air available inside. Even the so-called ventilation ducts will help little or nothing in the face of the needs of 200 men.
I have checked: an athlete, seriously engaged in a continuous work, can consume 100 to 200 liters of air per minute. Not to exaggerate, let's take the lowest value:
200 men x 100liters/min = 20,000liters/min
1,200,000liters: 20,000liters/min = 60min!
One hour of theoretical time. Probably no more than 30 minutes actually! (even if there will be also a modest air circulation).
Certainly Hemiunu knew the risks associated to the low availability of air: after all the tomb excavation techniques were in use.
Precisely for this reason he had optimized the towing work, planning every single detail to minimize the required time.
When the block begins its journey uphill there is no problem: all men engaged in the towing are in front but, as the block rises, the number of useful men will decrease because those on the platform overtaken by the block cannot help any more. Though...
At the era the wheel was unknown, but there is evidence of hard rocks, properly hewn, which were used as rudimentary pulley blocks, kept wet during the work.

This system, already used on flat surfaces, has been improved here to allow a reverse pulling uphill.

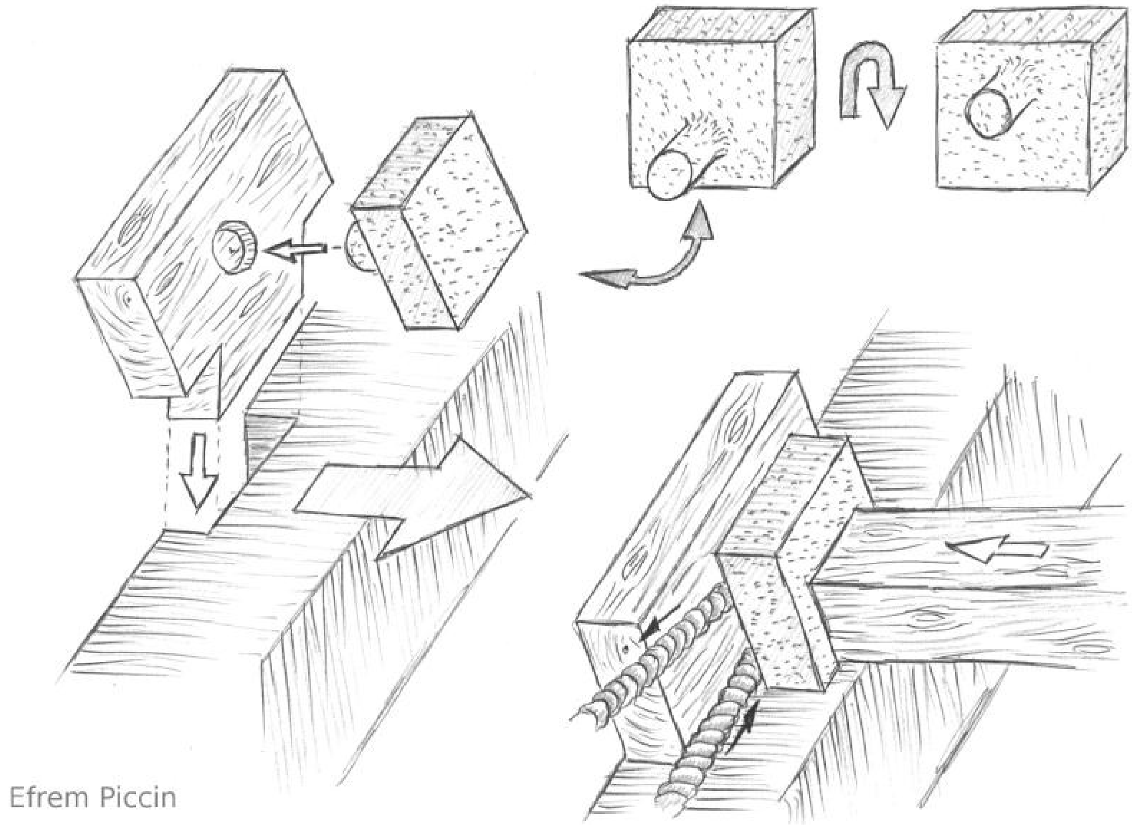

Figure 6: Yokes and Pulleys

In this way the whole team will help, including the workers behind the block.
According to my hypothesis, the pulley-stones were resting on the two platforms with the hub inserted into wooden (or limestone) yokes, shaped ad hoc and inserted into the pits. The two parts of the device were held compressed against the walls by using wooden beams, placed across the platforms, kept firmly in position by sturdy wooden wedges (fig. **C08**).
Let’s go back to the first block ready at the Quadrivium.
How it reached so far is somewhat problematic. (?...!) But since we are describing the working in this part of the pyramid, we start with the block there, pulled uphill by 200 men.
The enterprise was not only difficult, but also very dangerous. If, for any reason, a rope will break, the monolith might fall down with terrible consequences. A

disaster like that definitely had to be avoided, and I think I got a convincing solution, offering all the necessary security.
Obviously I used my imagination to figure out what I would have done in the same situation, but since it works and fits well with the plan...
Remember that the first two pairs of pits are short ones and without niches and chippings. I imagine their purpose was to provide four immediate anchor points for two strong wooden beams, placed behind the blocks, ensuring the safety measures against an unfortunate slip of the block. The beams had to be two because, as the block climbs upward, they will be straightway installed in the first pair of pits available behind, still keeping the second one in a lower position to have an additional slide arrestor.
To improve the safety, I imagine that, on the way up, the empty space behind the block was promptly filled with suitable wooden spacers (propped to the back beam) to immediately stop the block in the unlikely event of a rope breaking.
The safety beams placed crosswise on both platforms should have a thickness of at least 3p (22.5cm) so as to be in line with the block axis which is 2c + 2p (120cm) high, 1c below the platform level and 1c + 2p (67.5cm) above.
A beam of the thickness indicated would be perfectly aligned with the block center of gravity, deterring any dangerous trend to tip over.
To anchor the beams I had first thought to provide two supports similar to the yokes shown in the drawing **C08** (and in the photo-sequence of the model), suitable to fit into the pits. This solution, however, seems not practical requiring a truly remarkable tree and the two end supports could be induced to give way under strain as per the grain of the wood.
Perhaps the solution can be simplified: two suitable stones will be be inserted into the pits, providing the support to the beams themselves.
These stones may be similar to the short type yokes described above.
Working in this way the stones, to be fitted into the pits, were manufactured for the "short" type, but to be used even in the "long" ones.
Up to this point we have described the back safety measures and, partially, the towing method. Keep in mind that everything is subject to availability of air: no time can be lost. All must be done in a hurry. If necessary, work may be suspended, the safety beam inserted behind and the premises evacuated until the air supply is renewed.
When time is precious, it is senseless to waste it by stopping the block to move up the pulley system. The previous installation of additional pulleys upstairs is not

practical as well, due to the delay to remove and re-install the ropes (which are at least a hundred meters long).
Much better to design a continuous working system, without any pause, that is, I guess, what Hemiunu was able to do.
My colleague Saraò had built, on my instructions, a wonderful model of the Grand Gallery, all in limestone and granite where the entire device becomes understandable. The model was in our school premises, but now we are not in touch, so I cannot show pictures of it, which is too bad.
However, years have gone by since then: I have built a wooden model of my own. I shall use photos of this to show you how this device works.
In reference to the my model pictures, it is possible to see that, there are three pulling ropes, embracing the block from behind, since the beginning. I used three colored ropes, hoping to make the functioning more understandable.
Exclusively men, located on the platforms upward, will use the blue rope for the direct pulling. The red and the yellow ones are used for the reverse pulling, acting in succession to each other, never at the same time.
I do not have all the niches in my model. For the sake of simplicity I have limited myself to put together the beginning and the end of the Grand Gallery, omitting the twenty pairs of central pits. In the first picture of the sequence I imagine the block at the Quadrivium, with the two safety beams already in place.
While the block rises, a team of workers will install, into the next upper pits, another pair of pulley-stones. These, however, are different from the previous ones, having the groove for the rope slightly lower (or higher), depending on the type of stone and pit. In the time required to fix this new pair of pulley stones properly, the block will have reached the pair of pulleys used at the moment.
It will then be necessary to disassemble them and to move them up, over the two just prepared (certainly suitable for alternation described above).
No need to dismantle and reinsert the ropes: just the rope loops moved up and placed in position before installing the beams.
Two sets of ropes, dedicated to the reverse pulling, acting alternatively, are required to allow the people to work with one or the other, without having to move or losing continuity.
At the same time the third rope will be still used for the direct pulling uphill. As the block going up, people overtaken by the block will leave the direct pulling rope for the reverse one, without moving.

By operating in this way, hopefully, the block never stop moving. This saves a lot of burdensome exertion that would be necessary to restart the pulling, since the static friction higher than dynamic.
I think you begin to realize why the alternate pits, long and short: the tall pulley-stones (for the long pits) have the scrolling groove positioned higher than the lower ones (for the short pits) and the height difference is equal at least to the rope diameter. In this way there is no overlapping of the ropes while working, no dangerous rubbing and it will be easy for the men to move their hands from one rope to the other without interruption, since the reverse pulling ropes are very close to each other (figs. **C09**).

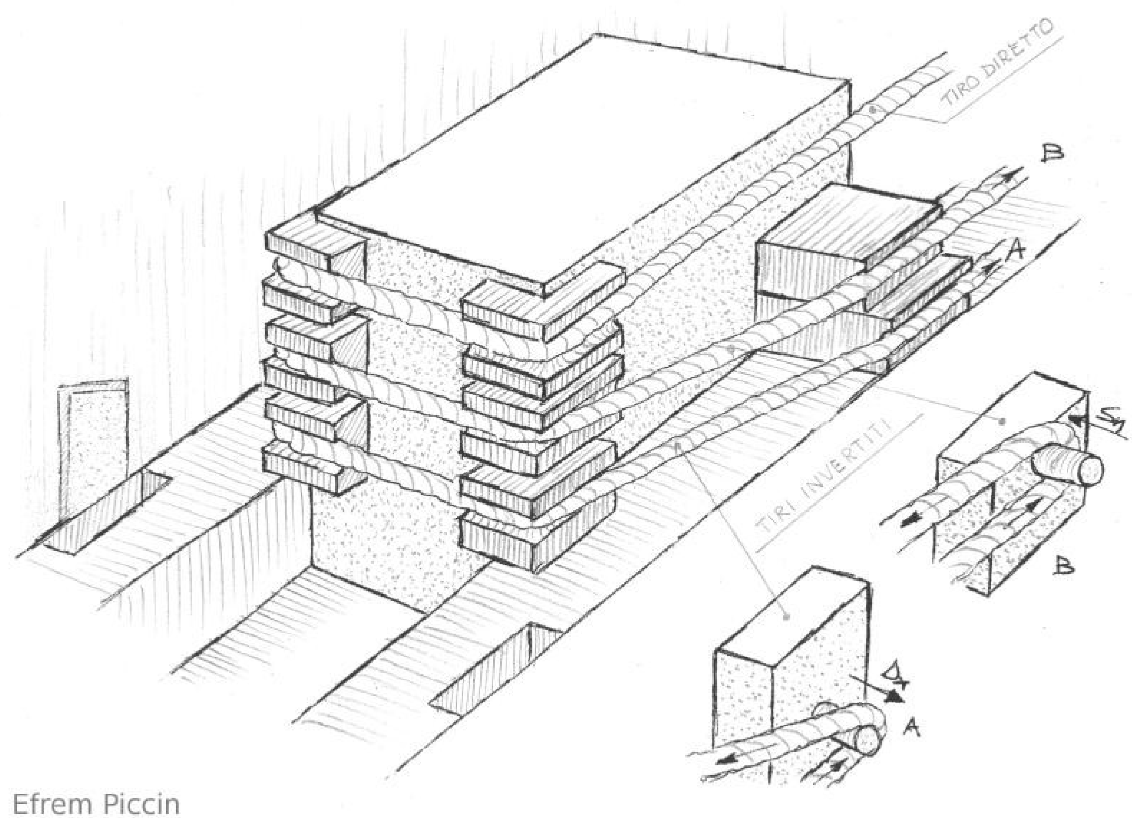

Figure 7: Rear ropes

I have actually figured pulley-stones of one type only, suitable for high or low position, just rotating them. I realize that this is an invention of my own, but the idea of a single type of stone simplifies the work and much more. Who knows...

On the other hand, there must be two kinds of wooden (or stone) yokes to hold the pulleys on site: the longer type will fit in the larger pits and the short ones for the small pits.
It sounds complicated but becomes easier to understand with a working model.
Returning to the towing: the ropes work in pairs. There will be three pairs of ropes working simultaneously, wrapping from behind the block. The yellow and red ropes work with the pulley stones, while the blue one is for direct pulling.
All the men working have to stand on the two platforms.
Their action might be more effective if they were standing in the central groove instead, considering the small steps carved centrally all along its bottom, as reported in a drawing made during Napoleon's expedition.
The explanation for the presence of these steps, dug in the central part of the groove floor, will be given elsewhere (?...!). To continue: if the men were placed within the central groove, their position would be half a meter below the two platforms. In this case the towropes would disrupt the pulley crew and, perhaps, have been damaged by rubbing onto the back transverse beams.
Since the ropes are wrapped around the block from behind, they should be suitably protected from the dangerous abrasive action of the rear corners of the block. In my design I protected them by using appropriate wooden edge-covers with a semicircular groove to insert the ropes. As there are three ropes, so a total of six protecting devices will be used. Considering the block is 120cm high, but 52cm below the platform level, the remaining 70cm outside are available for these devices.
Agnese made an investigation about the ropes in use at the time.
The result was that even a normal coconut fiber rope, having a diameter of 6 to 7cm, could bear the effort.
But I guess Hemiunu must have used the best of the best (linen?) in ropes for the towing, and six edge-covers, each 2p (15cm) high, having a central groove 1p (7.5cm) wide for the rope, looks reasonable.
Going back to the block, towed just beyond the second pair of short pits with direct pulling only (?...!), ready for the big climb.
It is easy to understand the reverse pulling is useless so lower: it will start from the third pit, the first having side chiseling.
The lower edge-protector for the rope cannot be installed now, because the safety beam from behind, so just two edge-protectors have to be installed right above it.

The ropes have obviously to be positioned higher over the platforms and this is the reason why the first pair of pit-niche is suitable for the high yokes.
As the block starts moving up, away from the back beam, additional edge-protectors can be inserted, at the platform level, for a new rope going to a pair of low pulley stones.
From this moment on, all the safety beams, inserted behind, will rest against the edge-protectors and not against the granite block itself.
In my model, I have also provided side grooved wooden spacers to keep the ropes away from the block, aligned with the pulley-stones grooves (again fig. **C09**).
Anchoring is not necessary for these new spacers. Although free, they will be held in place by the pulling ropes in their grooves.
Even these spacers will be of two types: having the ropes to work side by side, it is essential that one sticks out more (rope A, low pulley) than the other (rope B, high pulley). That means that one spacer must be wider than the other by a palm (7.5cm).
Let‘s say at once: more than one thing did not work properly, when closing the pyramid.
The yokes used to hold the pulley-stones in position, probably were not fitted in the right way into the pits and, under stress, they ended up being pulled out from their spot.
(August 2009: while going over things since my wooden prototype was ready, I observed that in the model, the tension in the ropes causes the yokes to be spontaneously dislodged from their housing...).
For this reason Hemiunu was forced into improvising, making the rectangular chippings close to the niches in an attempt to improve the yoke grip against the walls.
Approximately 2cm of limestone was removed on both sides; the yokes would be slightly wedged into the sidewalls and the problem should have been resolved.
To understand the nature of this new difficulty, it will be necessary to resort once again to the parallelogram rule (fig. **C10** A, B).
Looking at a pulley-stone, there are two ropes: a lower one, parallel to the platform, which represents the block resistance (F2) and the other, returning downward to the hands of men (F1), not parallel to the platform (at least 70cm higher).
Doesn’t matter if high or low pulley, the two ropes will never be parallel, having always a small acute angle in between.

Since each rope will exert an identical force (F1 or F2), using the parallelogram rule, the resultant force R acting on the pulley stone (figs. **C10** A), will be never parallel to the platform, but along the bisector of the small angle.
This was the only mistake done: splitting this force in two directions (fig. **C10** B), one parallel to the platform (Ft) and the other as per the gravitational force (Fn), we find that, while the first is neutralized by the action of the pit dovetail (-Ft), the second is not countered by anything and, although considerably less, it nevertheless has a significant value. In maximum effort conditions (using reverse pulling only) can even reach a 700kg value (shared between the two pulleys).
At the same time, the two parallel and opposite forces Ft and -Ft, while neutralizing each other, do not act on the same straight line of action and this generates a torque causing the wooden yoke to rotate clockwise.
Since there is a minimum gap between the parts, this effect will be added to the previous one, uprooting the yokes from their housing which required the late "chiseling" works on the walls.

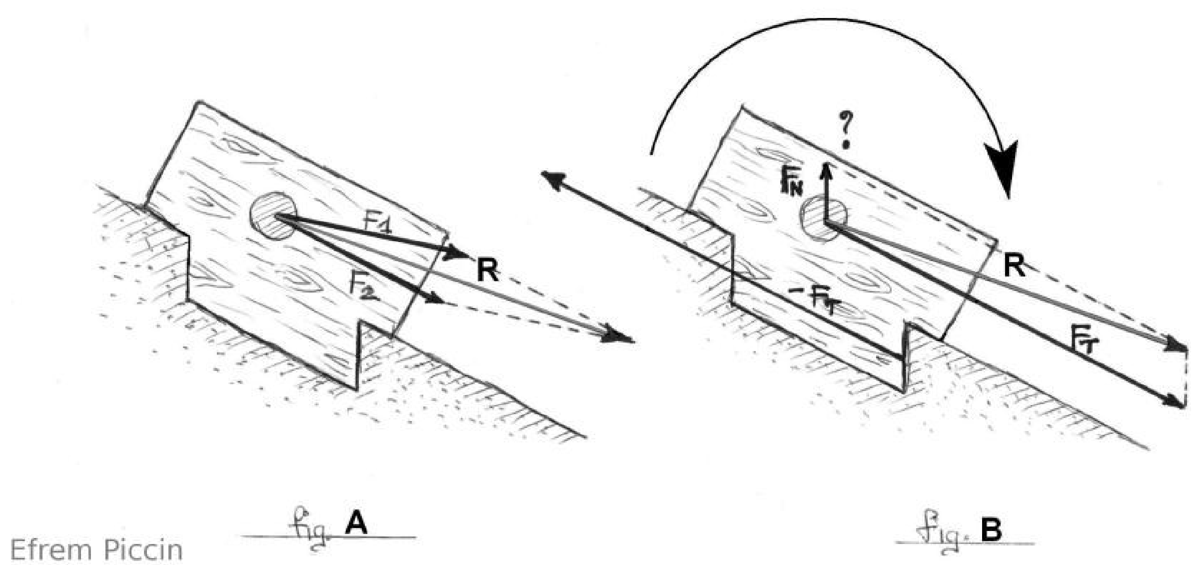

Figure 8: Interlock

Having to use two different types of yokes, one higher than the other, due to the symmetrical pulley-stones, also the rectangular chiseling on the walls should be of a different height depending on whether the pit is short or long.
I do not have any measurements of these details and, even by carefully observing the photos, I am unable to figure out if the height difference exists or not.

I guess no one has ever bothered to confirm so modest a detail; it may also very well have gone unnoticed. But if instead the chiseling should be at the same height, it means the yokes had the same size and the difference in height is coming from the shape of the pulley-stones.
Going on with this climbing process, to get the block close to the big step, the last couple of pits, rectangular and close to the south wall on the top platform, comes into play.
It will take two different yokes, fitted in the pits, long enough to reach the edge of the big step facing the Grand Gallery (photo **C20**).
They also have the high pulley-stones, but placed on the step edge, just in front of the block. Also here there will be the transverse beam to keep the yokes and the pulley-stones compressed against the walls, so the ropes are free for the last pull, entirely reverse.
Grooves carried out hastily to facilitate the insertion of a transverse beam, placed higher with respect to the jamb of the passage, can be observed on the top landing walls. In my opinion, two vertical beams were fitted under this, to hold in position the pulley heads inserted into the pits, avoiding them from popping out.
I hope to attach the picture sequence from my model describing first the insertion of the beam bridge in the Quadrivium and the filling up of the space upward (sequence **B09**.... **B21**), then the sequence of the climbing block, starting from the third pair of pit-niches (**C11**...**C24**).
You can watch the changing between the red and yellow towropes, the installation and removal of the side yokes while the granite block advances. Please note the ropes cannot rub together and to insert them up into the next pair of pulley-stones, it will be sufficient to slide up the eyelet, without to stop the tow.
I realized that I made a small mistake in making the photo sequence: while the red rope going up to the last yoke, located above the big step, the rope eyelet passes under the previous pulley-stone whereas it should have passed over it (photo **C21**).... Please be understanding about the quality of the photos and the "do it yourself" working method.