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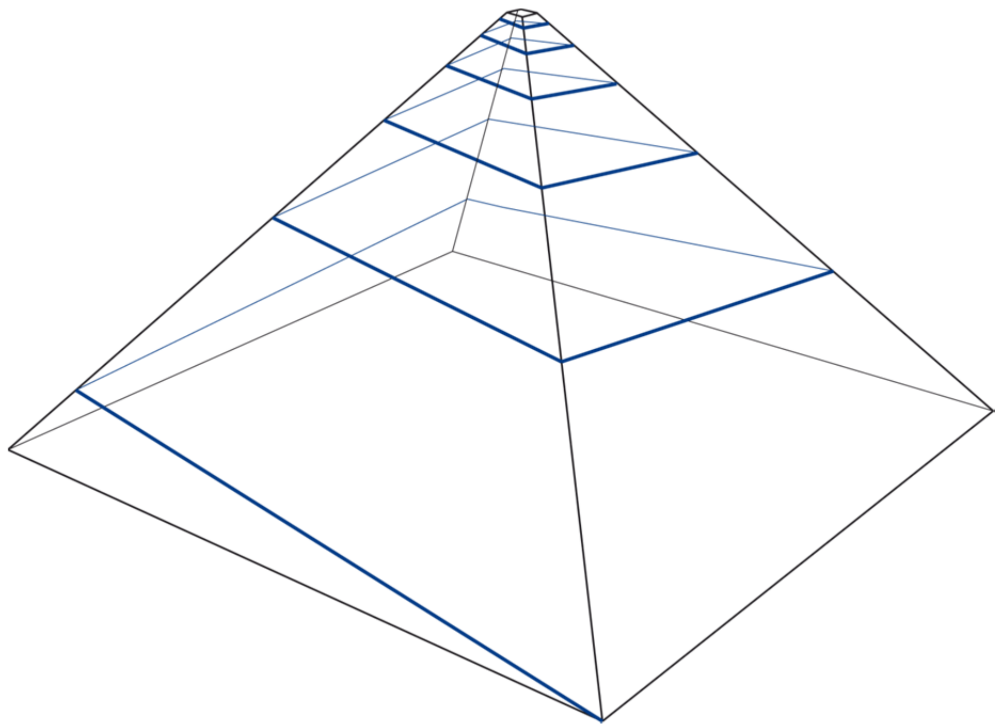
The construction of the Khufu - Pyramid

Six errors of the pyramidologists

and the development of a faultness transport path model



Summary

The number of all the articles published to this day that try to explain the construction of the Khufu-pyramid is enormous. All models developed in it are unfortunately useless. The evaluation of each individual paper would go beyond the scope of this treatise and is not necessary. It is sufficient to identify six essential errors which have led to the fact that no usable models have been developed up to now in order to be able to derive a realistic model.

In this treatise, these six essential errors are identified by means of an analysis carried out with exact scientific methods.

Parallel to the analysis, elements are developed which are assembled to a realistic model of a transport path called *Saumpfad* 1) here, through which all the stones needed to build the Khufu-Pyramid are delivered in the <u>traditional time frame</u>. Its existence is confirmed by archaeological findings. This treatise is a shortened version of the work *Der Bau der Cheops-Pyramide, Analyse und Modellentwicklung* [2], in which all processes are described in detail.

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1) The ancient German word *Saumpfad* contains two meanings: the site (outside the mountain) and the purpose (transport of loads) of the transport path. Owing to its mighty expressiveness, this German word will be adopted to the English text.

Analysis and model development

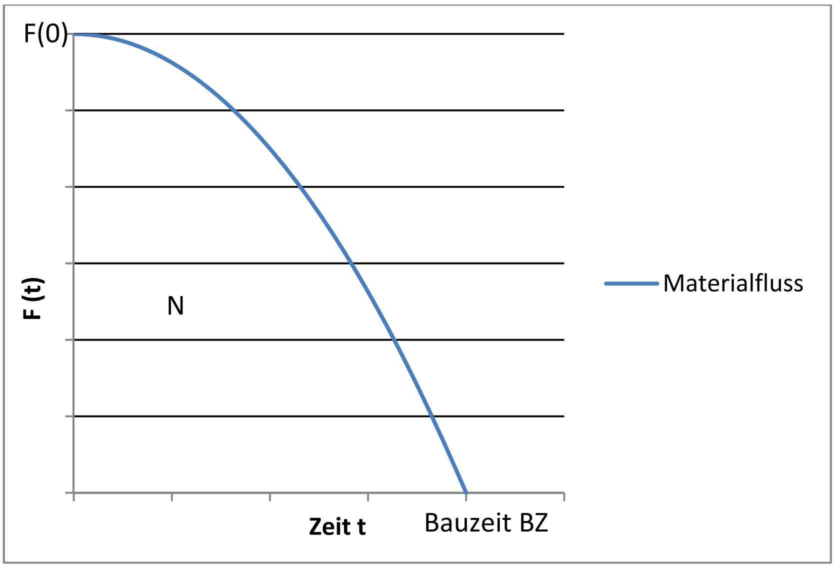
1 The material flow

1.1 Analysis

The number N of stones used and the traditional construction time BZ of the Khufu pyramid are known. From this, the quadratic function F(t) describing the material flow of the delivered stones over the time t can be derived [2], which is shown here as a formula and as a graph.

$$F(t) = \frac{3}{2} \cdot \frac{N}{BZ} \left[1 - \left(\frac{t}{BZ}\right)^2\right]$$

Figure 1: Material flow versus time



In this general form it applies not only to the Khufu pyramid but also to the similar Chephren pyramid. After inserting the number of stones used in the Khufu pyramid $N = 3{,}23 \cdot 10^6$ and the traditional construction time BZ = 20-30 years, one gets the following values:

Construction time of	**20**	**25**	**30**	**Years**
in the first year	174.000	139.200	116.000	Stones

With 360 working days per year, this results in a transport performance of eight or nine hours net working day:

Construction time of	**20**	**25**	**30**	**Years**
8 hours/day	1,03	0,81	0,67	Stone per minute
9 hours/day	0,91	0,72	0,60	Stone per minute

If a ten-day working period with one day off is taken as a basis, the values in the above table change slightly:

Construction time of	**20**	**25**	**30**	**Years**
8 hours/day	1,09	0,87	0,73	Stone per minute
9 hours/day	0,97	0,78	0,65	Stone per minute

These results are rounded and recorded as a necessary condition:

Every minute one stone delivered from the quarry must be lifted by the height h and brought to the next higher level.

The theoretical feeding frequency is therefore one stone per minute.

In practice, the feeding will not take place at exactly equidistant intervals of one minute. The time intervals may vary between 0.8 and 1.2 minutes. But they are not allowed to be significantly higher. A doubling of the feed-in time (one stone every 2 minutes) would mean a doubling of the construction time, i.e. 40-60 years.

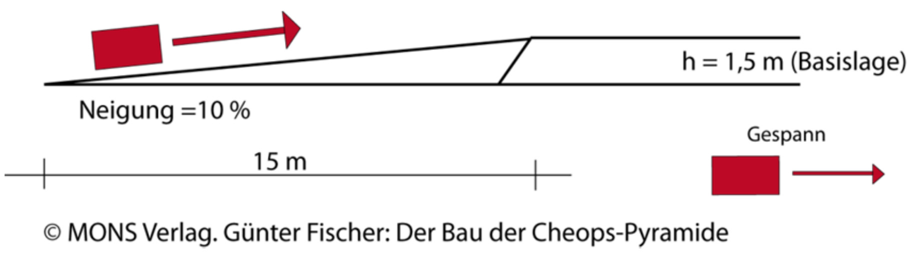
Error Nr. 1: No one of the publications in which lifting devices have been developed as a transport medium satisfies this necessary condition. Their authors have failed to determine the time required by such lifting devices for an elevation. Their use - if it were feasible at all from a structural engineering point of view - would lead to construction times of more than a hundred years. Consequently, all models working with lifting equipment are unusable.

As a consequence, the stone transport must be carried out on a ramp.

1.2 Model development: The carousel

The height of the base stone layer (Basislage) h = 1.5 m is known. In front of this stone layer a ramp consisting of gravel with a inclination (Neigung) of 10% is heaped up.

Figure 2: Ramp in front of base stone layer



Gespann [2)]

The red arrow in the figure symbolizes the motor (lat. motor = traction). These can be workers as well as draught animals. The model applies to both alternatives. In [2] the use of draught animals is preferred, because they enable the pragmatically acting builder to reduce the number of workers on the construction site by a power of ten.

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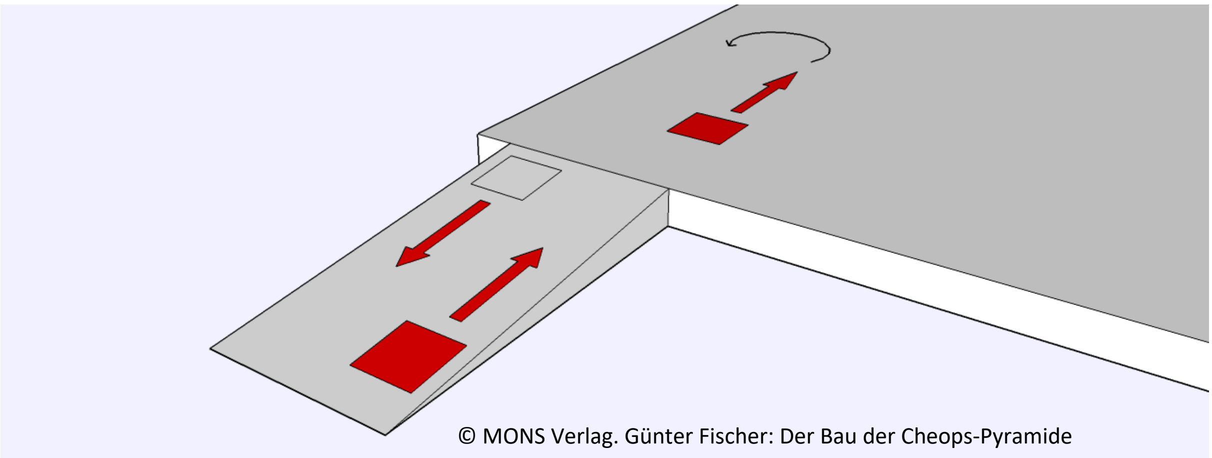
2) The german word *Gespann* includes the two components traction plus transport medium. The traction includes workers and draught animals; the transport medium includes sledges and round timbers. Owing to its mighty expressiveness, this German word will be adapted to the English text.

With a transport speed T = 1 km/h = 1000 m/60 min = 16.7 m/min, each stone can be pulled up to the next higher level in one minute on a ramp no longer than 16.7 m without any problems.

With a unique transport, however, the above necessary condition can be satisfied only once. Only with a rotating system of three *Gespannen* can a permanent transport performance of the feeder service and thus the permanent satisfaction of the necessary condition be guaranteed.

1. a *Gespann* standing on the ramp takes over a stone
2. a *Gespann* has reached the plane and delivers a stone.
3. a *Gespann* is on its way back without load and ready to take a new stone.

Figure 3 : Rotating system of three *Gespannen*



This arrangement is called a carousel in analogy to a fairground carousel that rotates around its axis all day long.

The site management can introduce a replacement *Gespann* into this rotating process at any time without having to interrupt the rotation. The reason for this could be if one of the circulating *Gespanne* weakens or even collapses.

The four parameters that describe the continuous transport of a stone from one level to the next higher level are:

- the frequency,
- the ramp inclination ,
- the transport speed and
- the number of *Gespannen* rotating on the ramp.

This process is repeated 3.23 million times. None of the 3.23 million quadruples will be exactly like any other. Proof of the correctness of the model need not be given for each of these quadruples. It is sufficient to have done it once for the quadruple:

1. Frequency: **one** stone per minute
2. Ramp inclination: **10** %
3. Transport speed: **one** km/h
4. Number: **three** *Gespanne* on the ramp.

2 Transport on the plane surface

2.1 Analysis

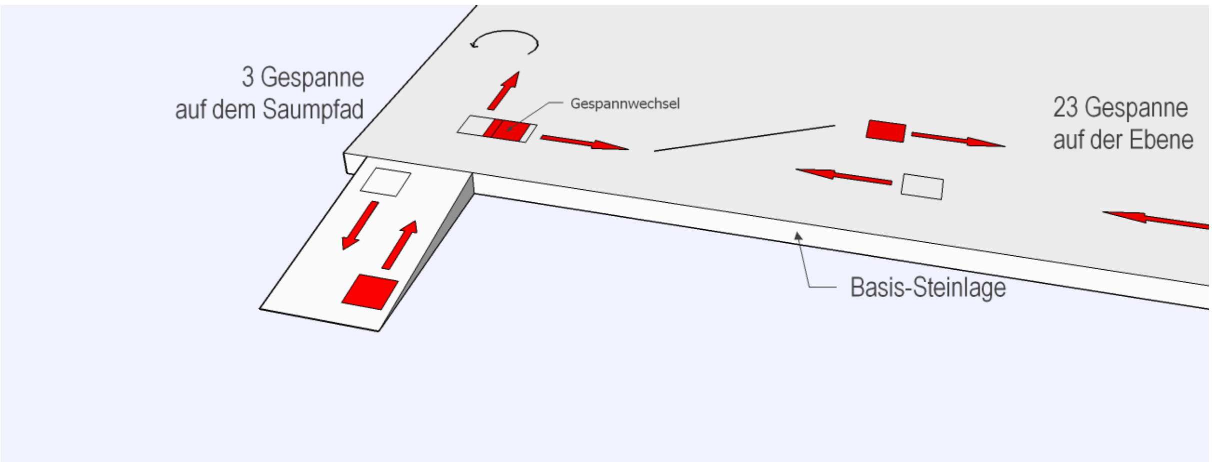
In order to be able to transport all the stones that - as described in model development 1 - have been moved up to the next higher level, a transport capacity on the higher level is required. The generally valid sufficient condition is:

A sufficient number of Gespannen must be provided on each plane surface to ensure that no congestion occurs during the transport flow, but that all stones lifted on the plane surface are immediately carried forward.

Error Nr. 2: In all ramp models published so far except [2] the transport problem is reduced to the motion of the stones on the ramp. The further transport of the stones to their final location on the plane surface, which has to take place simultaneously, is not treated in any of these publications. Due to the missing development of a suitable complex process organisation for the transport of stones, all these models are incomplete and therefore useless.

2.2 Model development: the bucket chain Method

Figure 4: Rotating *Gespanne* on the ramp and on the plane surface



The bucket-chain method has been known since ancient times. Before the invention of the water pump, it was used for fire-fighting operations and is still used today, e.g. in flood disasters when transporting sandbags to secure soaked dams. The modified bucket-chain method on the pyramid provides for the use of rotating *Gespanne* at each plane surface and on each flank of the transport path. With this process organisation, the transport of all stones can be guaranteed at a frequency of one stone per minute to their final location. This method prevents the formation of bottlenecks by dividing the process into autonomous sequences.

3 The Klemm's integral rampe

3.1 Analysis

The parallel structures discovered by the Klemm couple [6] through close observation of the pyramid prompted the two authors 20 years ago to propose an "integral ramp" as a transport path on the Pyramid. They deserve the merit for being the first to have developed the only viable prototype of a transport path. 2018 this idea was taken up by [3]. However, the analysis shows that it is not that easy to realize. The following two figures show vertical sections through a mountain and a pyramid.

Figure 5: Transport path on the mountain

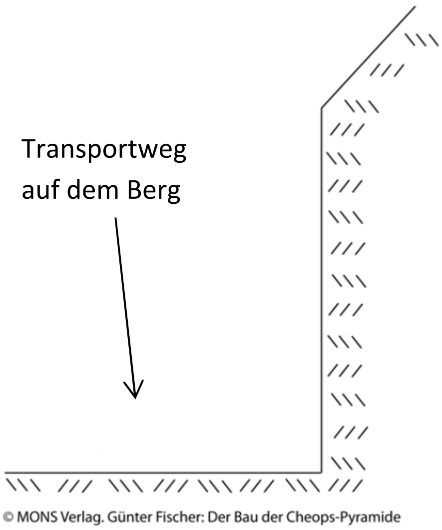
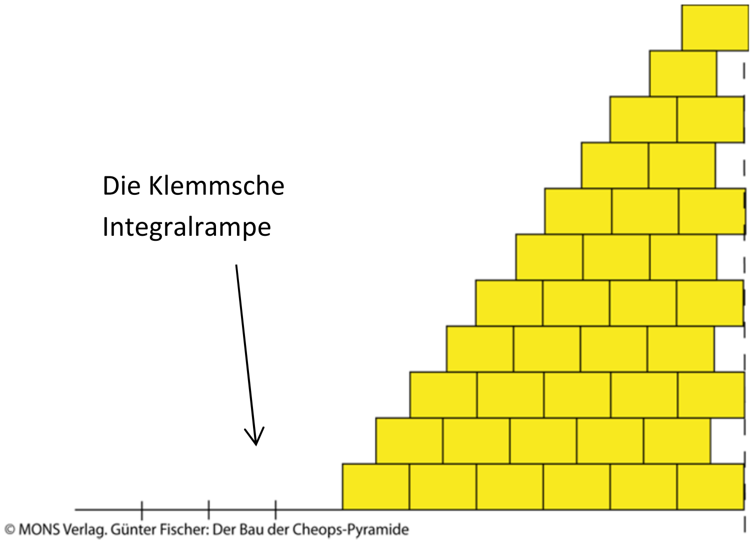


Figure 6: The Klemm's integral ramp

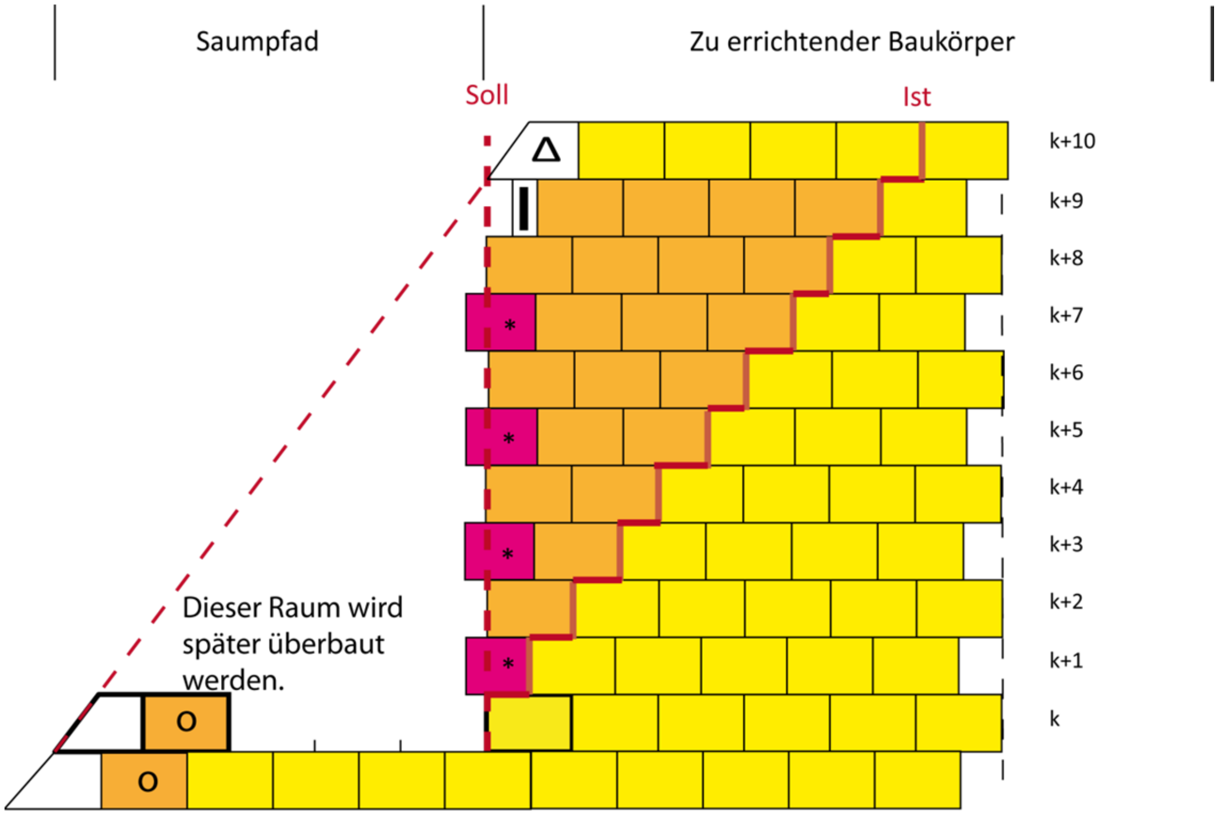


Error Nr. 3: No one has yet recognized that there is a significant difference between a transport path to be built on a mountain and one to be built on the pyramid. The mountain exists. The path will be built afterwards. For building the pyramid, the order is reversed.

With a transport path consisting exclusively in a ramp only the yellow marked stones can be laid. It is the characteristic of pyramid construction that each higher stone layer is built shifted by half a stone.

3.2 Model development: The wall at the back of the transport path

Figure 7: The wall at the back of the transport path



To enable the workers to build the pyramid, all orange colored stones must be laid up to the target line. This requires the installation of the stones marked with *. These must as well protrude from the rear wall to allow the two structures to be connected when the pyramid is built over later.

A flush laying of the *-stones would have the consequence that the later superstructure of the transport path would not be connected with the structure of the pyramid. This could have led to the parallel structures observed by Klemm.

The transport path consists of the four components without which the construction of the pyramid would not be possible:

- the horizontal work surface,
- the inclined plane (= ramp),
- the safety curb stone marked with **o**, and
- the specific wall at the back of the transport path.

The term "ramp" is an inadequate designation for this construct. Therefore, this transport path is called **Saumpfad** . These four components are all equally important for functionality. However, these components differ considerably in the effort required to build the *Saumpfad*. As can be seen from the sectional view in Figure 7, one curb stone must be laid per stone width b, a layer of gravel for the ramp (not displayable in this section) and 24 stones for the construction of the rear wall.

4 The flank change

4.1 Analysis

On each flank change, the transport direction changes by 90°, which makes the transport of especially oversized stones more difficult.
Using the formula for calculating the maximum possible length $L_Ü$ according to [2], the following formula is used:

$$L_Ü \leq 2 \cdot [\sqrt{2} \cdot B - a],$$

where B =3b is the width of the transport path, b is the stone width and a is the width of the oversized stone, it can be shown that the flank change is also possible for oversized stones.

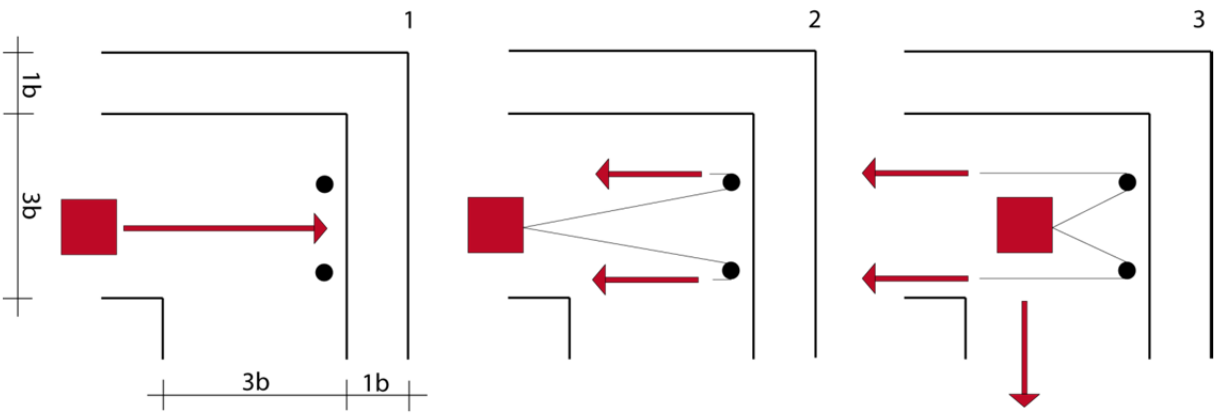
Error Nr. 4: In [7], general and unfounded doubts are expressed as to whether the transport of especially oversized stones is possible at all.

4.2 Model development: the switching platform

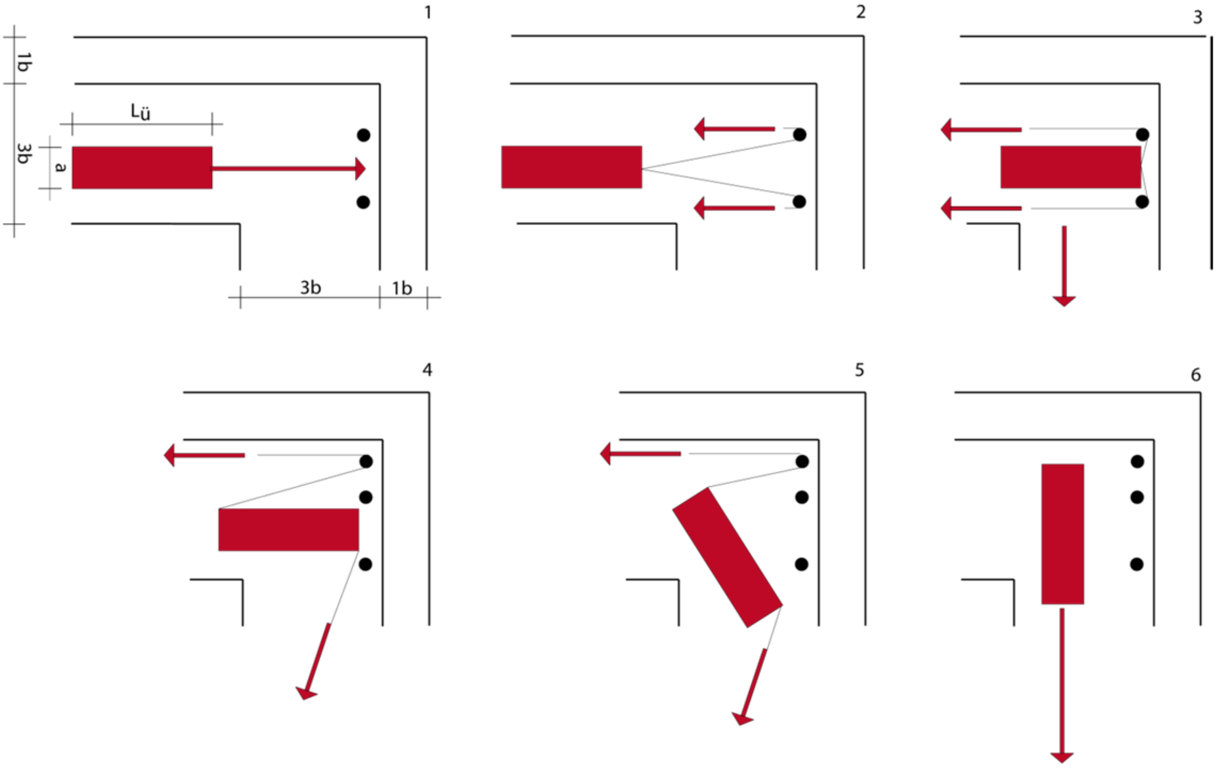
It is proven that only a few reverse posts are required to achieve the flank change. Even oversized stones, such as those needed to build the King's chamber, can be manoeuvred around corners, as shown below.

Figure 8: Stone transport during flank change

1. The transport of standard size stones



2. The transport of oversized stones



Holes at the corner of the transport path, as they are needed for the installation of the reverse posts serving to change the direction of the traction, were found in 2018 during excavations in the Hatnub quarry [1], [4] and can serve as archaeological evidence for the accuracy of the model.

Suppose the transport of the stones has been done by some round timbers, a stone with a weight of 4 tons loads the post with a shear force of 160 kg and a moment < 80 kg m (level arm 0,5 m). This load requires a post with a radius of 4,5 cm.

Suppose the transport has been done by a sledge. In this case the post requires because the higher friction a radius of 9,5 cm.

5 The upper platform

5.1 Analysis

Error Nr. 5: This figure 9, taken from an aerial photograph, shows a formation of the stones, the regular structure of which , nobody has recognized until today although this formation has been known for centuries . To support the analysis, stone numbers, plane surface numbers and two red lines have been added in longitudinal and transverse direction.

Figure 9: Formation of the platform after an aerial view.

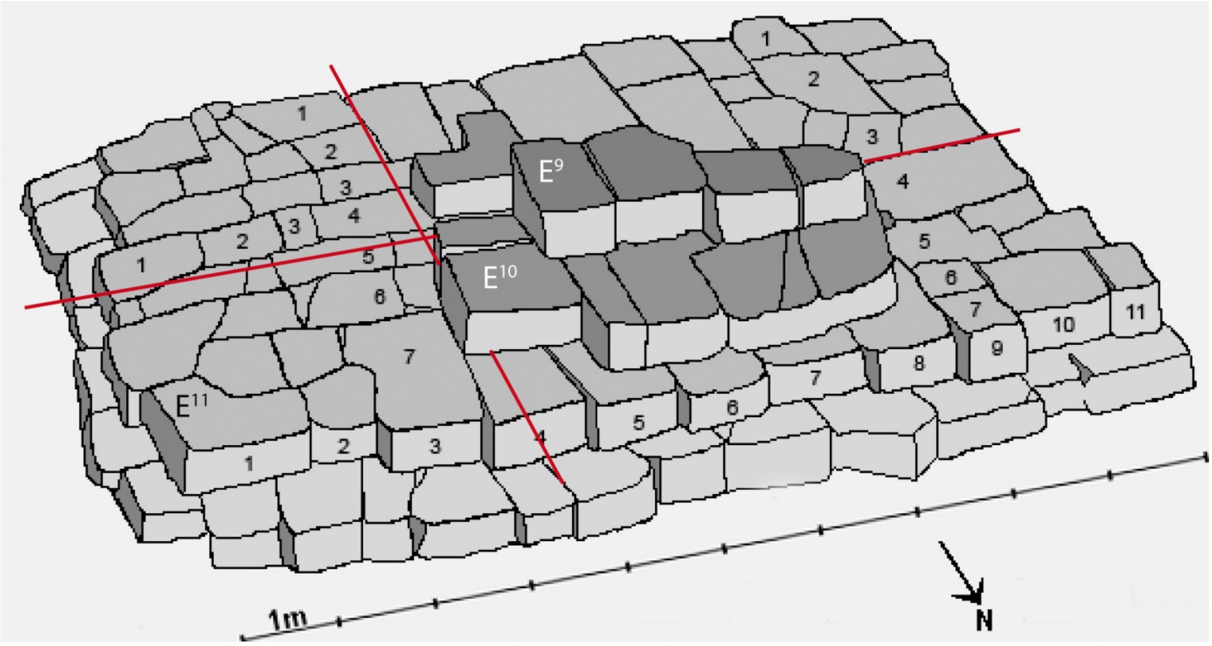


Bild: Maragioglio, V.; Rinaldi, C.: Architettura delle Riramidi Menfite. Le grande piramide di Cheope

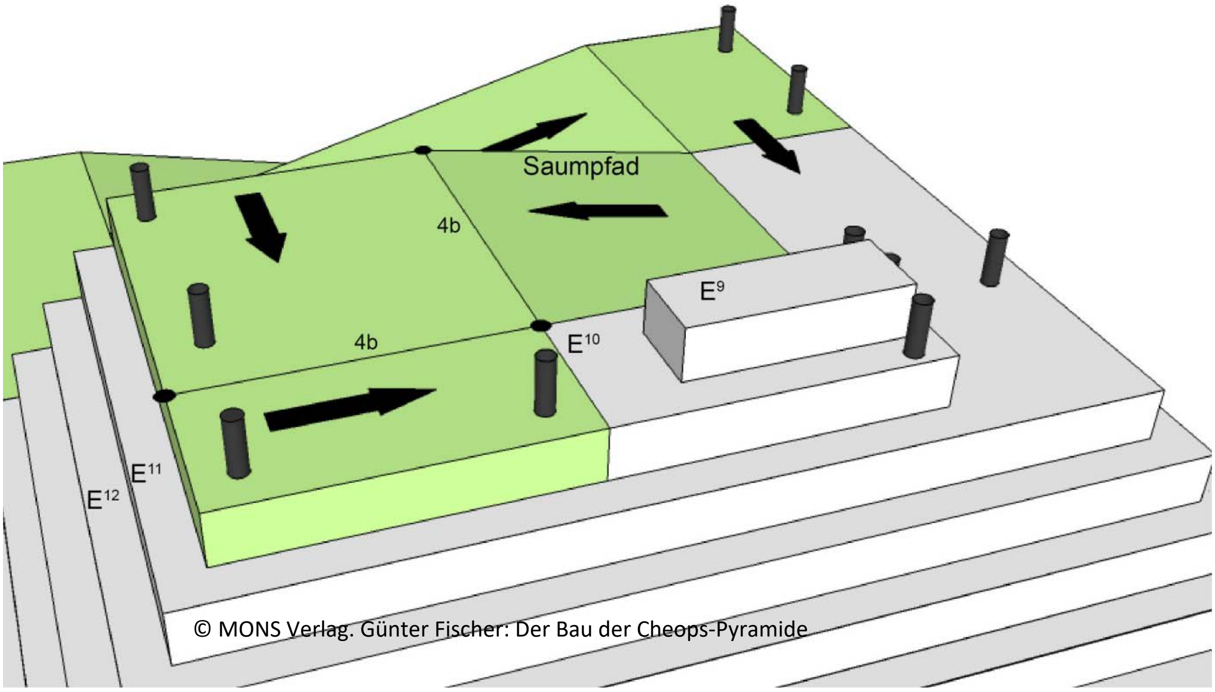
In the south, at the layer E^{11} is missing a 4b wide path. Furthermore two 4b wide horizontal paths can be seen in the south and east.

It is remarkable that despite the different dimensions of the stones, their number per rank is kept. In the 11th stone layer there are 11 stones. In the 10th stone layer, minus the 4b wide path in the east, exactly 6 stones were laid. The laying instructions have been observed until last.

5.2 Model development: the end of the Saumpfad

To illustrate the congruence between the formation of the stones on the platform photographed in Figure 9 and the model, the model is shown in a clear perspective representation in Figure 10.

Figure 10: Modelling the construction of the platform



The light gray tinted modelling of the platform formation is congruent with the aerial photograph shown in Analysis 5. This congruence is a further archaeological proof of the existence of the *Saumpfad*

The gravel layers of the transport path, which were removed by the storms, have been added in light green to the above figure to illustrate the way in which the last stones were pulled up.

6 The top of the pyramid

6.1 Analysis

In the 1993 published book *Der Bau der Cheops-Pyramide – wie die Pharaonen wirklich bauten* [5], it is described in detail how numerous workers are said to have pulled heavy stones up to the top of the pyramid using the rope roll method and to have set the pyramidion in the presence of the Pharaoh. Theoretically such a thing is possible with the rope roll method, if four stairs of about 150 m length and two ropes about 170m length are available.

The question is now: why are these stones no longer up there today?

In order to answer it, mathematics, logic and aerodynamics must be applied in three analytical steps one after the other.

Because the authors did not calculate the construction time (error no. 1),in a the first analysis step has been calculated in [2] the construction time of the pyramid, which would result from the rope roll method. The result is: the construction time would be more than 60 years, which is significantly longer than the traditional construction time of 20-30 years. Conclusion: The truncated pyramid could not have been built with the rope roll method.

In the second analysis step, it is examined whether the rope roll method - if it has not been used for the construction of the stump - has been used for the construction of the pyramid top. This construction site has comparatively small dimensions. Two stairs of about ten metres in length, two ropes of about 15 metres in length, a scaffolding of about 1 metre in height for the positioning of the pyramidion and a frame to be erected outside the structure where all the stones delivered via the *Saumpfad* are temporarily stored.

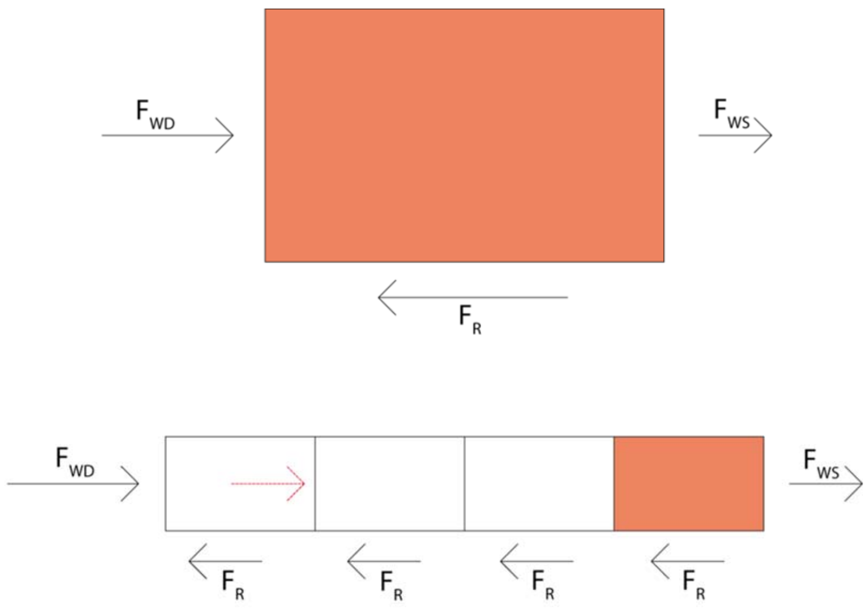
In this step of the analysis, we start from the four stones of the stone layer E^9 that actually exist, which have been standing there for more than four and a half thousand years and resist all storms because their weight and thus their resistance is greater than the wind forces generated by the hurricanes. The proof is provided by means of proof by contradiction that is common in logic.

We start from the correct assumption that the entire top of the pyramid has been built with stones that were pulled up by rope rolls.

The stones pulled up by means of rope rolls are of the same order of magnitude as the four stones still present on layer E^9. If they are of the same weight, the same conditions apply to them. They should still be there today. Because such stones are not there today, the assumption is wrong. It follows that they never stood there.

In the third analysis step, aerodynamics is used for further investigation. A wind pressure F_{WD} acts on the front side of a layer of stones around which there is a flow, and a variable suction F_{WS} acts along the range of stones on the rear side. The suction force F_{WS} in the middle area of the rear range is approximately half as high as the wind pressure F_{WD}.

Figure 11: Effect of the wind forces



For the last stone lying in a range of at least three stones, it applies that no wind pressure acts on this stone, because the frictional resistance of several stones lying one behind the other is greater than the wind pressure, but only the wind suction.

Here as an example for a suction force F_{WS} = 0,5 F_{WD} and a maximum speed of a hurricane of 30 m/sec, the minimum width b of a stone still in a stable position is calculated to b > 10 cm.

As there are no stones of this size on the platform, the entire pyramid top has therefore been built with small stones of a width b < 10 cm.

Error Nr. 6: This proves that the rope roll model developed in [5] has never been used in the construction of the Khufu pyramid. It follows that the claim made in the title that this work shows "how the pharaohs really built" is wrong.

6.2 Model development: the real construction

The final phase of the pyramid construction once again shows how pragmatic the constructor is in his approach, always choosing the path of least effort.

Due to their low weight, these small-format stones can be delivered to the workplace without any lifting or robe roll devices and can be bricked up by the workers without any effort.

The disadvantage of using small-format stones only comes to light when the storms have shredded the protective metal cover and then removed all the stones bit by bit.

Conclusion

It could be proven that neither the numerous published lifting and ramp models nor the rope roll method were used in the construction of the Khufu pyramid. The transport of all stones up to the platform was done by a *Saumpfad* on the pyramid. Its existence is proven by several archaeological finds.

It has also been proved that the top of the pyramid was built with small stones.

Annex

The dissertation of Müller-Römer [7] has not been dealt with explicitly in the above treatise. His model contains the errors 2 and 3 and is therefore unusable.

For the sake of completeness, this appendix will point out another serious error. His model is based on the false hypothesis that the pyramid was built from the inside out, i.e. first the core masonry and then the outer layer of cladding. To install the cladding, he envisages a working platform that would have to cover an area of 86,000 m^2! How these massif stones weighing tons are transported upwards is not explained further. A core masonry built in this way, in which, as is well known, no stone is equal to another in its dimensions, can never achieve the accuracy in lengths and right angles that is characteristic of the Khufu pyramid.

The high dimensional accuracy of the pyramid could only be achieved because it was <u>built from the outside inwards</u>.

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