Équipe Égypte Nilotique et Méditerranéenne
UMR 5140 « Archéologie des Sociétés Méditerranéennes »
Cnrs – Université Paul Valéry (Montpellier III)

The Construction Phases of the Bent Pyramid at Dahshur
A Reassessment

Franck Monnier, Alexander Puchkov

Citer cet article :

Fr. Monnier, A. Puchkov, « The Construction Phases of the Bent Pyramid at Dahshur. A Reassessment », *ENiM* 9, 2016, p. 15-36.

The Construction Phases of the Bent Pyramid at Dahshur
A Reassessment

Franck Monnier and Alexander Puchkov

FM: associated member of the Équipe Égypte Nilotique et Méditerranéenne – Laboratoire ASM Archéologie des Sociétés Méditerranéennes, UMR 5140, Université Paul-Valéry Montpellier, CNRS, MCC; AP: independant researcher

THE BENT PYRAMID of Dahshur exhibits peculiarities that distinguish it from the other funerary monuments of the Old Kingdom: the sudden changing inclination of the faces, the two internal layouts, both accessible through entrances situated on the outer faces of the pyramid; one on the northern face, and the other on the western face, and finally, the addition of an outer layer built with sloping courses during the construction.[1]

These characteristics have previously been interpreted as demonstrating a desire to express a theme of duality in the architecture, which would have been planned as a whole from the beginning of the construction.[2] The evidence available today, however, makes it impossible to deny that modifications took place during the construction of the building, and that they disrupted the internal arrangements. This fact was brilliantly established by Italian architects Vito Maragioglio and Celeste Rinaldi.[3] This article provides an update of the facts, as well as a reassessment, to produce a coherent and global understanding of this exceptional site.

Description of the Pyramid

The Superstructure

This double-sloping pyramid rises to 104.71 meters, and lies on a square base with sides measuring 189.61 meters on average.[4] It is oriented toward the cardinal directions with a small error varying from 11.8' to 17.3'[5]. The faces bend suddenly at 47.04 meters above the ground, with an angle changing from 54°30'-55° to ~43°-44°.[6]

---

[1] We gratefully acknowledge Valeriy Senmuth Androsov and Olga Kozlova for providing us with valuable pictures of the bent pyramid. We would also like to thank David Ian Lightbody and Delphine Richez for proof-reading the English text of this article.

[2] A. VARILLE, *À propos des pyramides de Snéfrou*, Le Caire, 1947, p. 7-8; J.A.R. LEGON « The Geometry of the Bent Pyramid », *GM* 116, 1990, p. 65-72; M. NUZZOLO, « The Bent Pyramid of Snefru at Dahshur. A project failure or an intentional architectural framework? », *SAK* 44, 2015, p. 259-282.

[3] V. MARAGIOGLIO, C. RINALDI, *L'architettura delle piramidi Menfite* III. *Il Complesso di Meydum, la piramide a Doppia Pendenza e la piramide Settentrionale in Pietra di Dahsciur*, Rapallo, 1964, p. 96-100.

[4] J. DORNER, « Form und Ausmasse der Knickpyramide. Neue Beobachtungen und Messungen », *MDAIK* 42, 1986, p. 54.

[5] J. DORNER, *op. cit.*, 1986, p. 51.

[6] *Ibid.*, p. 54; C. ROSSI *Architecture and Mathematics in Ancient Egypt*, Cambridge, 2003, p. 243.
According to Flinders Petrie, the slope of the lower part decreases appreciably from 55°1' to 54°31' on average

The building is still covered with the greater part of its outside casing. The lower part shows that the courses slope inward with an average inclination of about 6°50' (between 5°36' and 13°27'),[7] whereas the upper part reveals inclined layers of only 3°30' on average.[8]

At ground level the casing blocks rest on foundation stones of variable thickness. The foundations are deeper at the corners of the building (2.50 meters of superimposed squared stones) than along the sides (a single block only), where the additional masonry is substituted with sand and gravels.[9]

According to Josef Dorner's plans, the bedrock seems to be located more than 2.50 meters below the ground level.[10] The observations he made on this matter do not indicate if the transition between these two types of foundation is gradual or sharp.

Fig. 1. The Bent pyramid of Dahshur (photo: Franck Monnier).

from bottom to top (W.M.Fl. PETRIE *A Season in Egypt. 1887*, London, 1888, p. 30). He deduced that the faces were slightly convex (W.M.Fl. PETRIE, *op. cit.*, p. 30; V. MARAGIOGLIO, C. RINALDI, *op. cit.*, p. 58; J. DORNER, « Die Form der Knickpyramide », *GM* 126, 1992, p. 39; J.A.R. LEGON, « The Problem of the Bent Pyramid », *GM* 130, 1992, p. 50), the question arose to know if this convexity was due to either a specific design (J.A.R. LEGON, *op. cit.*, 1992, p. 52) or to a movement of structure (J. DORNER, *op. cit.*, 1992, p. 40). Now it seems clearly that this so-called convexity is far from being uniform. It is very marked on the western face, near the southwest corner, as well as in the center of the eastern face. The edges of the corners are more or less affected by this deformation, other than the northeast corner which is strictly straight. It is false to claim that the faces of the lower part follow a convex profile. At the most, we can perceive various heterogeneous curvatures. These deformities are thus far too irregular to have been the result of a planned design.

[7] W.M.Fl. PETRIE, *op. cit.*, p. 29.

[8] R.W.H. VYSE, *Operations carried on at the Pyramids of Gizeh in 1837, with an account of a voyage into Upper Egypt, and an Appendix* III. *Appendix containing a Survey by J.S. Perring of the Pyramids at Abou Roash, and to the southward, including those in the Faiyoum*, London, 1842, p. 66.

[9] J. DORNER, *op. cit.*, 1986, p. 44-46, fig. 1.

[10] *Ibid*.

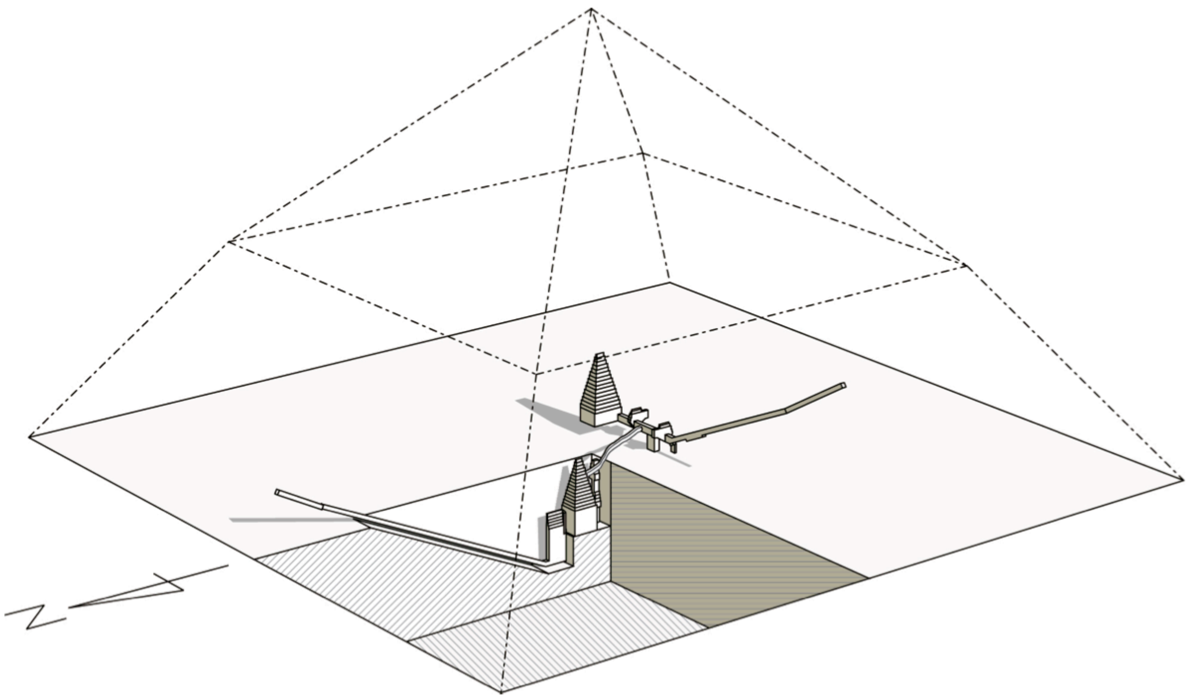

Fig. 2. The internal layouts of the Bent pyramid.

The Inside Apartments

The pyramid is exceptional in that it has two largely separate internal layouts; a lower one with an entrance located on the north face at a height of 11.33 meters from the ground level, and an upper one – a unique case for the Old Kingdom – with an entrance situated on the west face at a height of 32.76 meters.[11] These two systems of apartments both contain a vast chamber which is covered with a corbelled vault.

These different arrangements were connected by a gallery dug through the existing masonry, undoubtedly by the builders themselves at a late stage of the construction work, but before the western access was definitively closed.[12] The premature blocking of the western descending passage, which then forced the builders to reach the upper chamber from the lower system, has found no explanation so far[13] (cf. *infra*).

The north descending corridor consists of a 12.60-meter-long first section with a slope of 28°38',[14] separated from the rest of the passage by a peripheral joint where important fractures appear in the side walls, as well as a sinking of 23 centimeters of the ceiling and the floor with respect to the lower part of the corridor[15] [fig. 10].

[11] J. DORNER, *op. cit.*, 1986, p. 56, fig. 4.
[12] V. MARAGIOGLIO, C. RINALDI, *op. cit.*, p. 66, 104-106.
[13] Vito Maragioglio and Celeste Rinaldi don't express their view on this subject (V. MARAGIOGLIO, C. RINALDI, *op. cit.*, p. 66, 108-110).
[14] This value was determined by Perring (R.W.H. VYSE, *op. cit.*, p. 67) and reproduced by Maragioglio and Rinaldi (V. MARAGIOGLIO, C. RINALDI, *op. cit.*, tav. 11).
[15] *Ibid.*, p. 60-62, tav. 11.

At a distance of 1.40 meters below this joint, other less important cracks as well as an 8-centimeter collapse also affected the sidewalls.[16] From this point, the descending passage penetrates into the pyramid over a 66-meter distance and following a slope of 26°10'.[17] It leads to a narrow but very high hallway covered with a corbelled vault, which is located at 22 meters below the base of the pyramid. Through the south wall of the hallway, at about 6.75 meters from the floor ,[18] a large opening gives access to the lower chamber.

This chamber is covered with a great corbelled four-face vault and reaches 17.30 meters high.[19] Traces of mortar on the walls, up to the level of a small discharging vault, show that the volume was filled with masonry, leaving only the space under the vault completely cleared.[20]

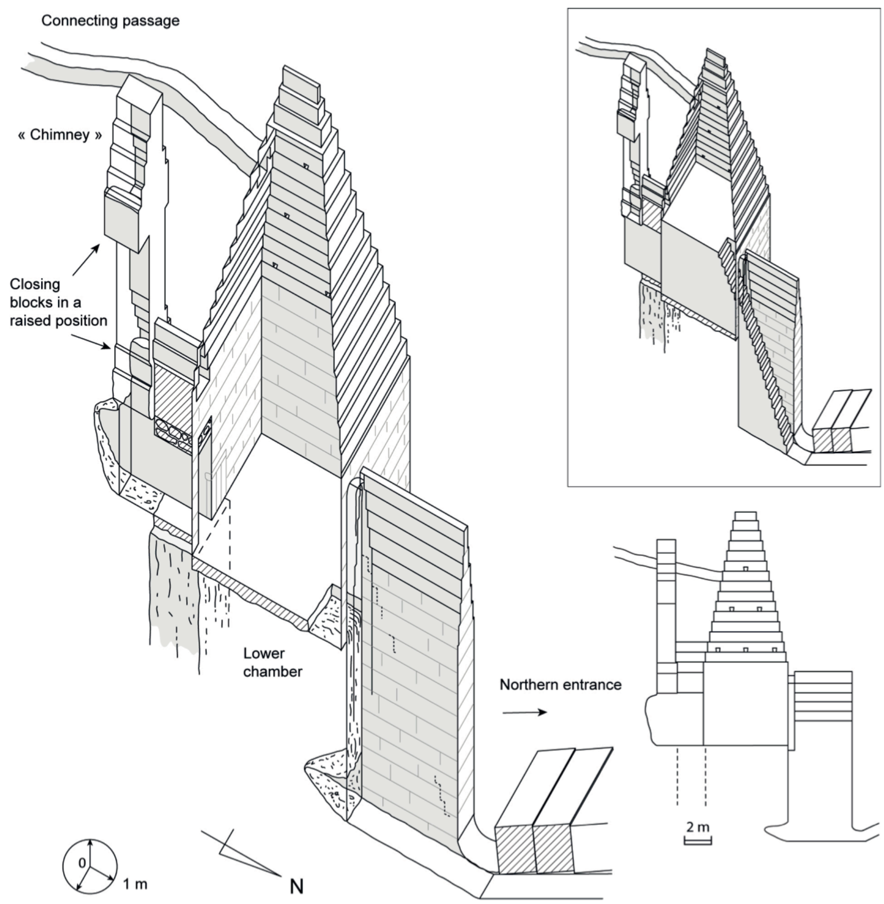

Fig. 3. The lower system.

In the south wall of the chamber, a short passage leads to a vertical shaft. This 'chimney' is 15

[16] *Ibid.*, tav. 11.
[17] *Ibid.*
[18] *Ibid.*
[19] A. FAKHRY, *The Monuments of Sneferu at Dahshûr* I. *The Bent Pyramid*, Cairo, 1959, p. 47; V. MARAGIOGLIO, C. RINALDI, *op. cit.*, tav. 11.
[20] A. FAKHRY, *op. cit.*, p. 47-49; V. MARAGIOGLIO, C. RINALDI, *op. cit.*, p. 64, 102.

meters high and leads to a dead-end which is sealed with two stone butting blocks.[21] Two other limestone blocks are placed on edge and still remain in a raised position inside small lateral cavities. It seems they were planned to seal off communication.

In the south face of the vault of the lower room, and at 12.60 meters above the floor, a gallery excavated through the masonry joins the two apartments and opens into the horizontal corridor of the upper system.

The west descending passage consists of two main sections: the outer one inclined at an average angle of 30°9’ over 21.81 meters, and an inner part inclined at 24°17’ over 45.85 meters.[22] Like in the north descending passage, there is a continuous peripheral joint, situated this time a little bit closer to the entrance, at 10.63 meters [fig. 11].

Shortly afterward, one meter below this joint, a fracture breaks the flat surface of the ceiling which, like the walls, sank by about 5 centimeters.[23] It should, however, be noted that the floor is flat, suggesting that either a re-cutting or the introduction of floor slabs was carried out after the settlement had occurred [fig. 11]. Unlike what we can see in the north descending passage, it is not the outmost section which has slightly sunk, but the core of the pyramid. The inner section of the corridor is seriously damaged. In all other respects, the outer part of the peripheral joint shows no damage or settlement of the masonry.[24]

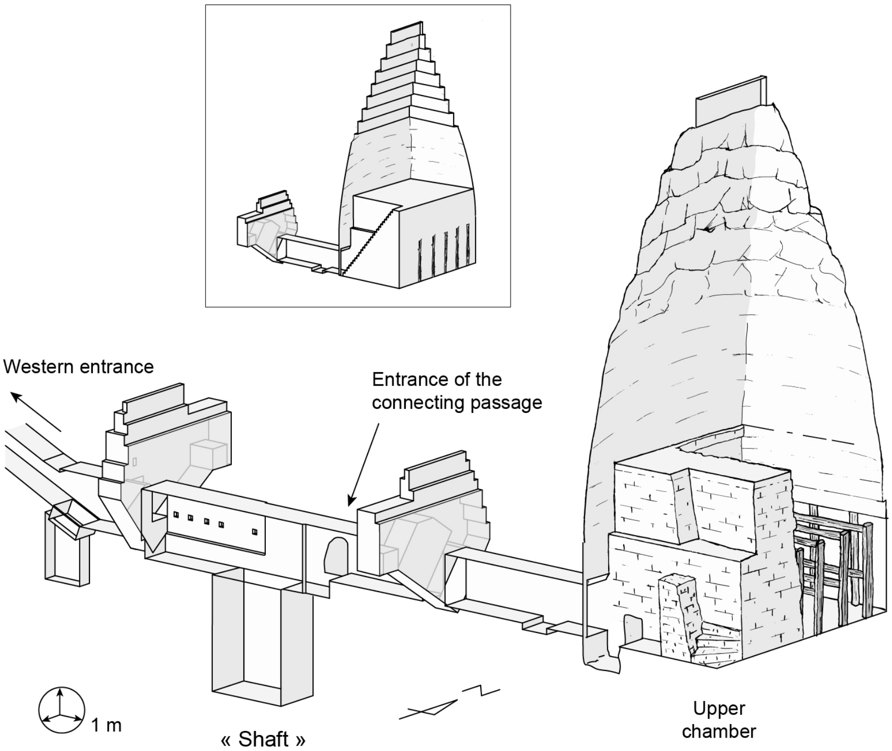

Fig. 4. The upper system.

[21] *Ibid.*, tav. 12.
[22] *Ibid.*, p. 66, tav. 13.
[23] *Ibid.*, p. 66-68, tav. 13.
[24] M. HAASE, « Im Inneren der Knick-Pyramide », *Sokar* 14, 2007, p. 17, Abb. 19.

The descending passage leads to a horizontal corridor which is situated a few meters above the ground level. This one is interrupted by two vertical blocking systems, each featuring a sliding block; only the westernmost has been sealed [fig. 4]. A perforation through that block allows passage to the other side. A plastering of the joints on both sides of the stone indicates that this closing system had been made operational before the descending corridor was plugged.[25] It was then necessary to take the tunnel to proceed to the closing of the upper system, a fact proving that this connection is not the work of looters but the builders themselves.[26]

We reach the upper chamber at the eastern end of the horizontal corridor. The description of this room is far from easy, because of its largely chaotic state of preservation and the insufficiency of the archaeological reports that address it. As a matter of fact, a masonry mass filling half of the chamber has largely been cleared, the original location and the destination of the limestone blocks taken away were not photographed, described or recorded.[27] Furthermore, the available plans and sections do not do justice to the complexity of this structure[28] and do not give rise to new insights on its precise shape or construction history.

The major axis of the rectangular plan of the room, 5.26 meters wide and 7.97 meters long,[29] is orientated north-south. This funerary chamber is covered by a corbelled vault with four faces beginning at 3.20 meters above the floor and rising to a maximum height of about 16.50 meters[30] [fig. 4].

The condition of this roof is so chaotic that it is extremely difficult to discern the levels of the overhangs, in fact the final dressing has not been completed.

A substantial cedar-wood shoring that was set up during the construction takes up the space between the walls of the room [fig. 7]. This framework was discovered during the clearing of the masonry mass that completely filled the funerary chamber up to 6.54 meters.[31] Nearly one quarter of this mass still remains in position. Parts of logs are still set into the stones above the second overhang of the vault. Another one remains in place under the summit, propping up the western and the eastern faces.

The filling mass, just like the wooden framework, was designed so as to leave a passage in front of the entrance. Due to a cutting of the walls and corbellings, the passage extends the horizontal corridor of the upper system [fig. 5]. Inside this high passage, a rubble stone ramp made it possible to reach the platform of the masonry mass. This stairway is partially dismantled.[32]

---

[25] A. FAKHRY, *op. cit.*, p. 52.

[26] We judge that the perfect condition of the ceiling of the horizontal corridor is a strong evidence that this passage is protected by a relieving corbelled vault such as those that have been recently discovered in the pyramid of Meidum (J.-Y. VERD'HURT, G. DORMION, « New discoveries in the pyramid of Meidum », in Z. Hawass, L. Pinch Brock (ed.), *Egyptology at the Dawn of the Twenty-First Century. Proceedings of the Eighth International Congress of Egyptologists, Cairo, 2000*, Cairo, New York, 2003, p. 541-546.

[27] We ignore where they are today, just as we ignore the actual location of the plugging blocks that have been extracted from the western descending passage.

[28] The plans and sections of Fakhry (A. FAKHRY, *op. cit.*, p. 54-58) and Maragioglio and Rinaldi (V. MARAGIOGLIO, C. RINALDI, *op. cit.*, tav. 12, 13) reveal many defects and mismatches.

[29] *Ibid.*, tav. 12, 13.

[30] *Ibid.*, p. 70, tav. 12, 13.

[31] The propping up is much older than the filling because some of its elements are still enclosed in the masonry mass (A. FAKHRY, *op. cit.*, p. 52-59).

[32] A. FAKHRY, *op. cit.*, p. 52-59. A photo is reproduced in the newspaper *The Illustrated London News* (P.A.L. GARNONS WILLIAMS, « In the Heart of a Dahshur Pyramid: Recent Investigations which may lead to the

An in-depth analysis reveals that this upper chamber has undergone some modifications, not only by raising its floor, but also by re-cutting the overhangs of the vault (cf. *infra*).

Additional Comments

A Possible Reason for the Abandonment of the Lower System of Apartments

Some characteristics of the lower system recall the arrangement of chambers and passages in the Meidum pyramid, in particular the short passage associated with its relieving vault, and the 'chimney' which was without doubt initially intended to lead to a burial chamber[33] [fig. 3]. Contrary to a widely held viewpoint then, the lower chamber does not seem to be such a burial chamber, but merely an antechamber.

The evidence which suggests that the architects changed their plans in the early years is the dead-end with the two closing blocks which never played their role, and also the existence of an upper system of chambers and passages.

The two very different locking methods used for the two inner systems suggest that they are the reason why the first one was abandoned. The architect probably judged that the 'chimney' was too perilous to allow access to the funeral procession, and so an alternative arrangement had to be found.

The Rearrangement of the Upper Chamber

We argue that everything seems to indicate that the upper room, before having its props removed and the faces of its walls completed, underwent modifications at a very early phase of the construction. The modifications included the elevation of the floor in two stages,[34] then the cutting of the overhangs in order to flatten the walls of the new burial place [fig. 5-9]. Both levels are indeed characterized by a very thorough paving of the floor and resized walls.[35]

First of all, the decision was taken to raise the floor by filling the space under the vault with small limestone blocks squared and carefully laid with mortar (stage P2). So that the room should still look like a chamber, the workers paved the floor and began to take away the cedar beams propping up the first overhangs, and then re-cut the projections to get nearly flat faces.

This first operation was not finished when they decided to elevate the floor of the chamber once again. The height of the masonry mass was increased up to the fifth overhang of the corbelled vault, and topped up with paving slabs (stage P3). There too, the projections were re-cut up to the ninth one (or maybe the tenth one as the transition is not easily discernible).

The question then arises as to what motivated the architects to raise the floor twice. It is certainly not due to structural problems (cf. *infra*). The raising of the floor led them to smooth

---

Discovery of an Intact Royal Tomb », *The Illustrated London News*, march 22, 1947, p. 305 [fig. 9]).

[33] Vito Maragioglio and Celeste Rinaldi listed the different hypotheses that were made about the role of this communication passage, but without providing a clear-cut answer to this question (V. MARAGIOGLIO, C. RINALDI, *op. cit.*, p. 102-104).

[34] P2 and P3 stages which are indicated on the plans drawn by Vito Maragioglio and Celeste Rinaldi. According to the Italian architects, the vault is in a rough condition, as the final stonecutting has never been made to reveal the projections (*ibid.*, tav. 12).

[35] *Ibid.*, p. 70-72, tav. 13.

the overhangs so that the space thus obtained should look like a burial chamber, and not a simple space under a vault [fig. 8].

If the structure had actually been unstable, the architects would most likely have tried to strengthen the recently smoothed overhangs. But it was not the case. In fact, if the structure was compromised they would not have taken the risk of weakening the vault by resizing the existing overhangs during the construction.

The Lebanon cedar framework is only found in the upper chamber, and precedes the stone filling in the chronology of the construction phases. Its existence can be explained by the fact that the walls of the room, like the corbelled courses, had to be supported for the few months or years which were required to raise them.[36] Its presence seems to show that the changes of plan of this room were decided in the early years of the project, just after the top of the vault had been finished and doubtless during the first stage of the pyramid construction.

Except for the vault, the walls of the lower chamber arranged against the rock of the plateau did not require such reinforcements during their construction.

Fig. 5. The southern part of the upper chamber (the masonry filling with its facing blocks is on the right) (photo: Valeriy Senmuth Androsov).

[36] As the chamber walls were raised at the same time as the courses of the pyramid, the shoring ensured only the support of blocks during their setting. It would not have been strong enough to contain excessive thrust that later enlargements would have provoked, as it has been often stated. If the Egyptians had actually noticed that the walls were moving because of structural strain, the beams such as those we found in the upper chamber would have been useless for resisting it given their dimensions. A masonry filling would have been the only solution suitable. The current stresses are the same as those appearing during the completion of the work, and the almost complete dismantling of this support structure caused neither damage nor settlement in the upper chamber. This proves that the chamber never needed structural reinforcement.

Fig. 6. The vault of the upper chamber (photo: Valeriy Senmuth Androsov).

Fig. 7. Reconstruction of the overhangs that were recut during the raising of the upper chamber floor (photo: Valeriy Senmuth Androsov).

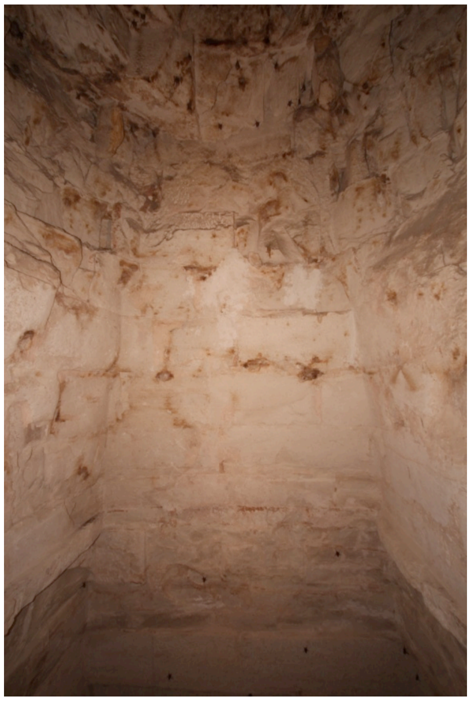

Fig. 8. The corbel vault with its flat faces in the upper chamber (photo: Valeriy Senmuth Androsov).

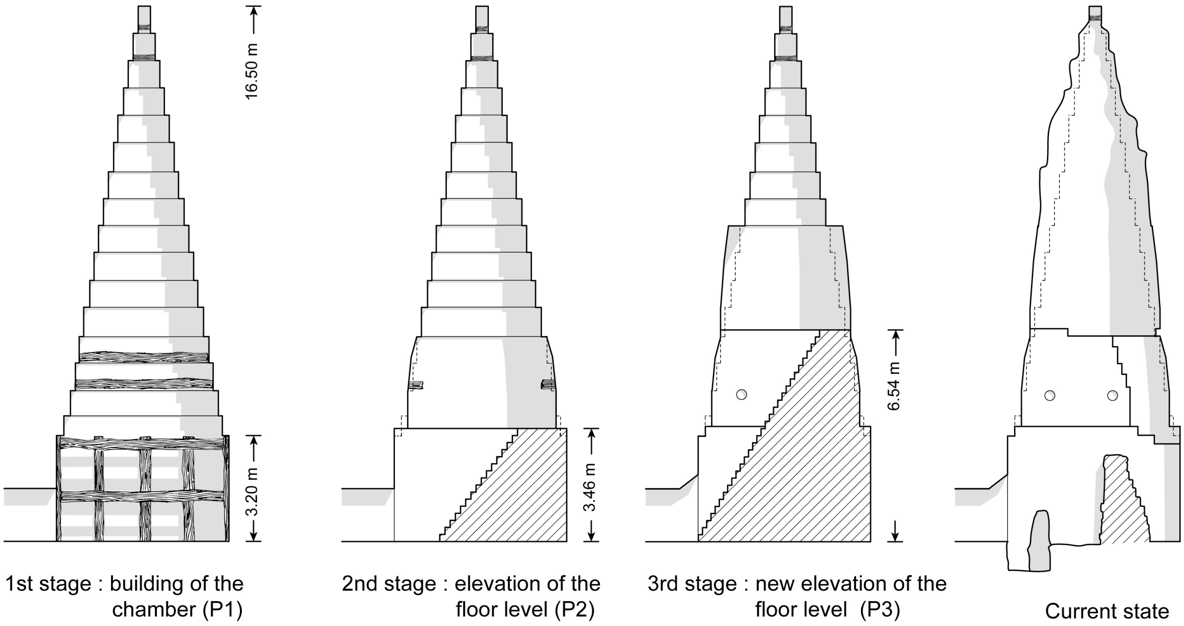

Fig. 9. Reconstruction of the three building stages of the upper chamber.

Internal Damage: the Facts and their Significance

Much has been written about the so-called structural faults located in the lower and upper chambers. Some scholars claim that the walls would have begun to bulge under the weight of the stonework.[37] This would have forced the Egyptian architects to decrease the load which was weighing down on the apartments by decreasing the planned height of the pyramid.[38]

In fact, the lower chamber is in a fairly good condition, although it underwent the construction and the clearing of a temporary partial filling.[39] Only one minor crack deforms the west wall of the room. Furthermore, the corbelled vault is in an excellent state of preservation.

The problems mostly concern some parts of the descending corridors, as well as the upper chamber whose vault is in a very poor condition. The overhangs are hardly recognizable, and the erosion is so extensive that the top of the vault looks like a natural rocky dome.

The presence of a wooden shoring and a masonry filling, both installed by the builders, could indicate at first sight that some settling led the architects to strengthen the structure of the room.[40] The careful fitting-out of the southern part of the room, however, as well as the

[37] « (…) the stoutness of the poles and their arrangement suggest that it was intended to counter lateral pressure on the walls and thus provide support until the floor had been built up. Structural weaknesses must have become apparent while the pyramid was being built, because, as Perring observed, plaster had been used by the builders to fill up cracks which had developed in the walls of the lower chamber, and similar repair work had also been carried out in the upper chamber » (I.E.S. EDWARDS, *The Pyramids of Egypt* (revised edition, first published in 1947), Harmondsworth, 1985, p. 86-87); « Many of the stones in the apartment have given way under the superincumbent pressure, and the settlement must have taken place whilst the building was going on, because of the faulty places have been covered over with plaster » (R.W.H. VYSE, *op. cit.*, 1842, p. 68).

[38] M. VERNER, *The Pyramids*, New York, 2001, p. 177. According to Vito Maragioglio and Celeste Rinaldi, there is no crack in the upper chamber (V. MARAGIOGLIO, C. RINALDI, *op. cit.*, p. 72).

[39] *Ibid.*, p. 64.

[40] D. ARNOLD, *Building in Egypt. Pharaonic Stone Masonry*, New York, Oxford, 1991, p. 234, 240; M. LEHNER, *The Complete Pyramids*, London, 1997, p. 103; I.E.S. EDWARDS, *op. cit.*, p. 86-87.

paving slabs laid on the chamber filling, suggest that this space was still intended to serve its purpose.

The beveled edge of the room's entrance can be linked to the proximity of a stone staircase leading to the top of the mass. This adjustment may have been required so that large-sized furniture could be installed.[41] Consequently, it is clear that the Egyptians still trusted the vault which suffers from no cracks. Similarly, the shored-up walls of the room show no sign of any deformation. No lateral pressure seems be pressing on them.[42]

The highest of the overhangs are extensively damaged today, and great fragments seem to have fallen down from the walls [fig. 6, 8]. Compared to the re-cut and unbroken lower courses, such a condition might seem surprising.

It would appear that the stones of the uppermost courses suffered from serious splitting, although the degradation may not have been sudden. Nevertheless, despite the impression of serious structural failure this degradation is not unusual for the type of stone used (cf. *infra*).

We do not know if this ceiling was still intact at the time of Snefru, but it seems that its reshaping and modifications betrayed the weakness of the material, and that this vault turned out to be a potential danger for the funeral furniture and the royal remains.[43]

From a mechanical point of view, the compressive stresses of a corbelled vault are concentrated on the inside angles of the overhangs, all the more so if the latter are deep, which increases the risk of cracks at these angles. Overall, nothing in these chambers suggests the existence of serious structural defects but rather an accumulation of damage attributable to the re-cutting of the corbels and the nature of the material used. Moreover, it is certain that the modifications were never completed as demonstrated by the wooden log still lying in its housing at the level of the penultimate overhang.[44]

We argue that it is this accumulation of weaknesses that led to the tomb being abandoned[45] in favor of another, new, building site at North Dahshur, the one which was finally going to offer a house of eternity completely pleasing to the king[46] [fig. 6].

Unlike the outer part of the northern corridor, the outer part of the western corridor reveals no settlement.[47] The lower part, where the erosion is dramatic, shows a deterioration process that can also be attributed to the type of rock used in the construction, that is to say a kind of

---

[41] V. MARAGIOGLIO, C. RINALDI, *op. cit.*, tav. 13.

[42] On this point, it goes without saying that the cedar supports would have given in under a such great pressure (K. MENDELSSOHN, *The Riddle of the Pyramids*, New York, Washington, 1974, p. 118).

[43] During the reign of Snefru, the chamber was certainly not in the same condition as during the time of Abd Essallam M. Hussein, when big pieces of rock covered the floor before the Egyptologist began his excavation. The photo taken by him to illustrate *The Illustrated London News* is very instructive in this respect (P.A.L. GARNONS WILLIAMS, *op. cit.*, p. 305 [fig. 8]).

[44] Wooden log which is very similar to that of the apartment in the pyramid of Meidum (V. MARAGIOGLIO, C. RINALDI, *op. cit.*, tav. 4).

[45] The only block which could seal the access (the eastern one) was never set up.

[46] The dates of the quarry marks seem to indicate that the pyramid of North Dahshur was built during the last part of Snefru's reign (R. STADELMANN, « Beiträge zur Geschichte des Alten Reiches. Die Länge der Regierung des Snofru », *MDAIK* 43, 1986, p. 229-240; R. KRAUSS, « The length of Sneferu's reign and how long it took to built the "Red Pyramid" », *JEA* 82, 1996, p. 43-50).

[47] It indicates that the nature of the ground on which the foundations bear is heterogeneous. According to the geologists D. Klemm and R. Klemm, doline-type sink holes which are located in the surrounding area could have amplified the unpredictability of very localized collapses (D. and R. KLEMM, *The Stones of the Pyramids. Provenance of the Building Stones of the Old Kingdom Pyramids of Egypt*, Berlin, New York, 2010, p. 49).

marly limestone with a fine sedimentation bedding. This kind of stone has a much lower degree of cohesion than a fine compact limestone. These limestone blocks extracted from local quarries are subjected to a fragmentation due to atmospheric influence which causes them to disintegrate into very fine chips.[48] We were able to observe these fine geological layers, ready to fall in the first antechamber of the pyramid of Meidum.

A similar degradation occurred in the lower part of the northern descending passage of the Bent pyramid where two kinds of limestone showed very uneven strengths and consistencies.

In the following discussion we suggest that serious settlement of the structure only impacted the monument during the second stage of construction.

Fig. 10. The cracks and settlement in the outer part of the northern descending corridor (photo: Valeriy Senmuth Androsov).

Fig. 11. The peripheral joint in the outer part of the western descending corridor. Settlement and small cracks are visible in the foreground (photo: Valeriy Senmuth Androsov).

[48] *Ibid.*, p. 41.

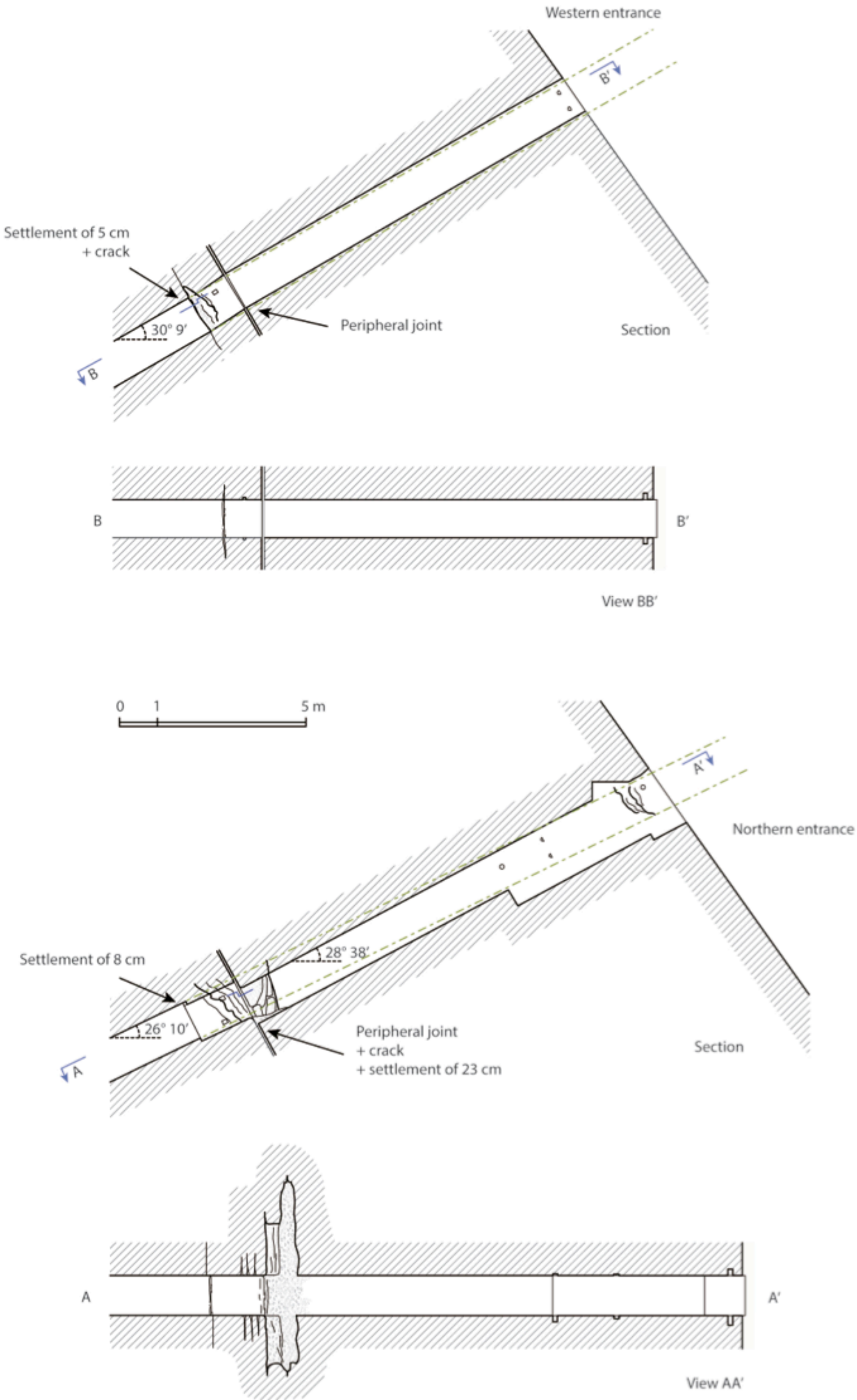

Fig. 12. Description of the cracks and settlement in the outer parts of the descending corridors.

The Bent Shape in Three Stages: a Reassessment

The change in the slope of this pyramid just below the half way point between its base and its summit when complete allows *a priori* two possible interpretations: it was designed in a completely novel way from the outset, or a modification of the pyramidal shape was improvised during the building work.

The hypothesis that this profile could symbolize an expression of a duality is credited to Alexandre Varille[49] who found in the person of John A. Legon his most fervent follower.[50]

This theory would be convincing – indeed, Snefru built two pyramids at Dahshur, the Bent pyramid has two entrances and two internal layouts[51] – if evidence of structural collapse and modifications had not been found inside the building. This theory is also contradicted by the fact that the burial chamber of the lower layout was never built (cf. *supra*).

We will not fuel the debate more by commenting further on this matter; we consider that the architects Vito Maragioglio and Celeste Rinaldi collected enough evidence to demonstrate that the unplanned structural issues were significant.[52] The Bent pyramid was enlarged and it led to unexpected consequences, that is to say cracks and subsidence that forced the architects to give this very non-typical shape to the building.

The Italian architects have therefore made an important breakthrough in the understanding of the history of this monument, but their scenario remains an outline. The full reconstruction of the different building phases is still in need of elaboration.

There is little agreement about the precise dimensions of the initial project, or about how to correlate or explain the peripheral joints and the cracks which are located not far from the northern and western entrances. The cracks are not all in close proximity to these joints, so we have to further analyze the structural situation.

The Italian architects superimposed the western and the northern descending corridors on one cross section in order to identify a relationship between the peripheral joints. They connected the two joints with a line running down to the ground level. They concluded that the joints were originally openings at the face of an earlier phase of the pyramid and so the line equated to the outer form of this early building. They were able to reveal the slope of the first pyramid, about 60°, and the side length of its base, 157 meters[53] (300 cubits). That these peripheral joints give the position of entrances relative to a first project is confirmed by the presence of holes situated some centimeters below their position, the kinds of holes typically found at the entrances of descending passages, and especially at the actual entrance of the Bent pyramid.[54] Moreover, the open fractures in the walls of the northern descending passage reveal the partly smoothed outer face of the original entrance. Its 60° slope confirms the accuracy of their conclusion.

[49] A. VARILLE, *op. cit.*, p. 7-8.
[50] J.A.R. LEGON, *op. cit.*, 1990, p. 65-72; J.A.R. LEGON, *op. cit.*, 1992, p. 49-56.
[51] M. NUZZOLO, *loc. cit.*
[52] V. MARAGIOGLIO, C. RINALDI, *op. cit.*, p. 96-100.
[53] *Ibid.*, p. 98, tav. 10.
[54] *Ibid.*, p. 140-144, tav. 11, 13, 14; W.M.Fl. PETRIE, *The Pyramids and Temples of Gizeh*, London, New York, 1883, p. 145, pl. 11.

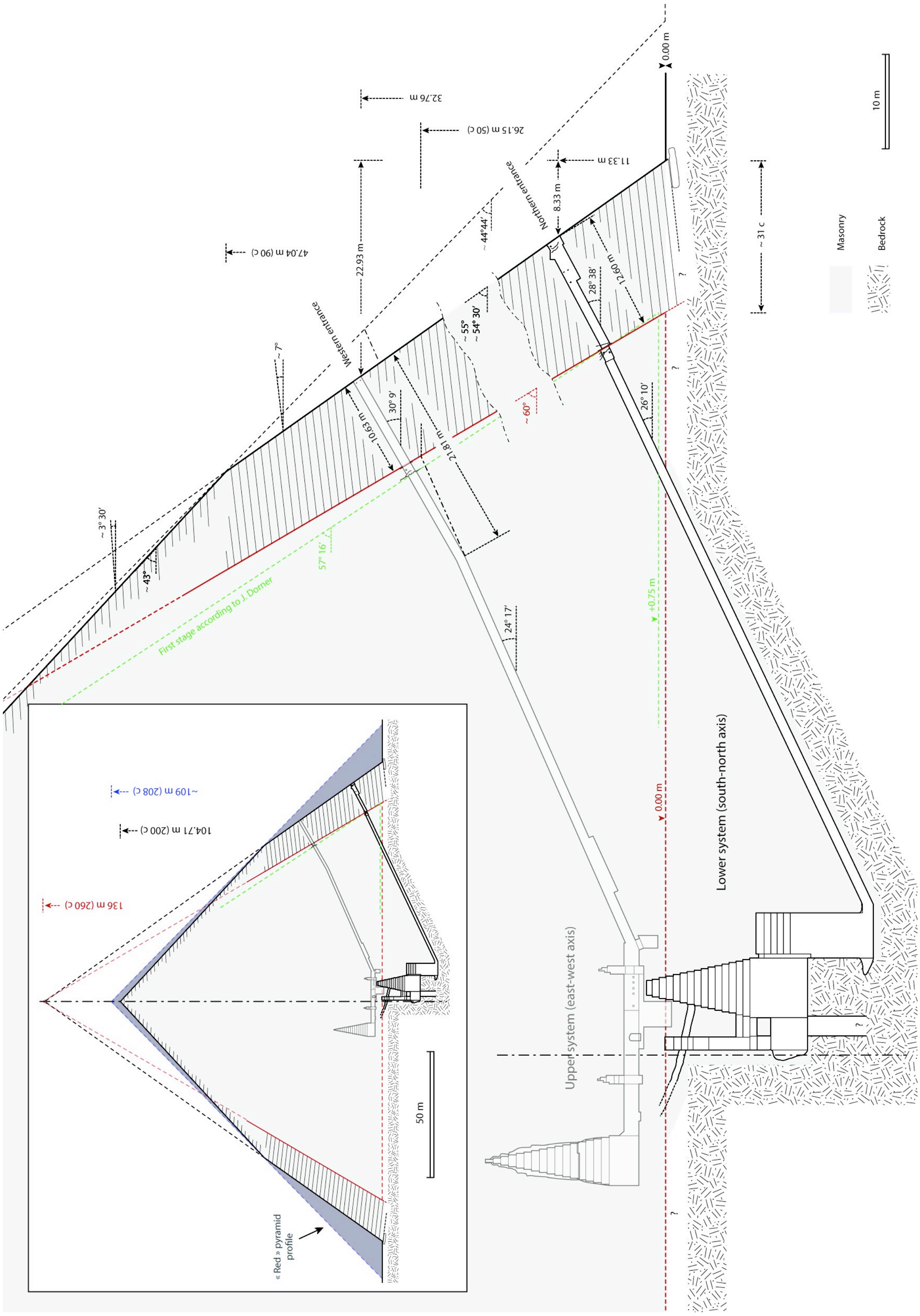

Fig. 13. Architectural details of the Bent pyramid.

For his part, Josef Dorner has followed the plan made by the Italians, not without adding some confusion to what had already been established. Instead of connecting the peripheral joints, the German scholar links that of the northern passage with the cracks which are situated one meter below the western peripheral joint.[55] It led him to reconstruct a 122- meter-high initial pyramid[56] (233 cubits), while the initial pyramid of Maragioglio and Rinaldi rises to about 136 meters high (260 cubits), which is approximately the height that would have been attained if the lower outer slope of the finished building had been maintained up to a summit (258.64 cubits).

We consider it unlikely that the slope adopted for the first project was 57°16' as argued by the German egyptologist,[57] but was rather of 60°. The fracture of the western descending passage, which the scholar associates with the entrance of the first project while ignoring the existence of the peripheral joint and its holes, also finds a better explanation in the building progress, as we will show below.

We know from the engineering analysis then that a first pyramid with a base length of 157 meters (300 cubits) and 60° sloping faces was built before the monument acquired its current shape. Following our discussion, some observations came to light:

- The lower apartments were abandoned and the upper ones were built.
- The floor of the upper chamber was raised twice before the enlargement of the pyramid.
- The first project didn't reach its intended height of 136 meters since the pyramid never exceeded 104.71 meters.[58]
- The framing stones of the initial northern entrance indicate that the pyramid – nevertheless unfinished – already had its facing blocks in position, partly smoothed at least around the exit in order to facilitate the junction with the outer part of the descending passage.

The reasons why the first pyramid was covered afterwards with an additional thick envelope of masonry are unclear. It's certainly not due to internal structural failure as some authors have stated it.[59] The overall condition of the funerary apartments (corridors and chambers) does not reveal anything that would suggest such an explanation. If this had happened, it's doubtful that the overseer of works would have chosen to increase the volume and the mass pressing on the apartments if he had actually diagnosed this kind of structural problem. He would have only increased the risks.

[55] It seems that he was guided by the will to discern some noteworthy measures within the edifice. According to him, the original western entrance would have been situated 50 cubits high, just below the peripheral joint, where there is a crack (J. DORNER, *op. cit.*, 1986, p. 56, fig. 4). This round number of 50 cubits he cares so much about led him to artificially raise the ground level by 0,75 meter at this point. The virtual line extending from the lower part of the western descending passage crosses the outer face of the first project as conceived by Maragioglio and Rinaldi, at a point which is situated 50 cubits above the current ground level. It would then be simpler to assume that the change in slope of the western descending passage was the result of a modification that impacted the entrance level initially situated 50 cubits high.

[56] J. DORNER, *op. cit.*, 1986, p. 57, fig. 5.

[57] *Ibid.*, p. 55.

[58] *Ibid.*, p. 54.

[59] M. LEHNER, *op. cit.*, p. 102-103.

In any case, the addition of an outer envelope was not intended to increase the height of the pyramid, like for the pyramid of Meidum, since both stages would have coincided at the same height.

This period of Egyptian history shows how much the architecture was always evolving, how the architects tried at best to reconcile the religious rules and the language of stone. The pyramid of Meidum was modified three times.[60] The Bent pyramid certainly underwent such modifications. The initial 60° slope was probably considered too steep, maybe for aesthetic reasons, but maybe also for technical reasons. The reasons for the reduction in slope may remain unclear, but we can nevertheless note the measures taken to ensure the completion of the project.

The additional masonry coating was made with sloping courses, just as in the layers of step pyramids, but with a lower inclination of about 7° on average. It was most likely made this way to prevent the blocks from sliding outwards (particularly as the envelope was not bonded with the inner pyramid casing). The base side length of the pyramid was thus increased from 157 meters to 189.43 meters[61].

During the construction of this envelope, the foundations seem to have become unstable and yielded under the increasing loads of the masonry. We have seen that the dimensions of these foundations are heterogeneous, being much deeper at the corners whereas the sides effectively rest on sand only. This heterogeneity is doubtless one cause of the unexpected differential settlement. Cracks and the 23-centimeter collapse at the junction between the two sections of the northern descending passage testify to this outer settlement.

Nevertheless, the peripheral joint of the western descending passage doesn't reveal any sign of unforeseen settlement. However, in this case it is the entire core below the junction that seems to have collapsed by some centimeters.

A priori, the foundations were weak in some areas only and did not affect the western side of the pyramid to the same extent.

A careful observation of the area surrounding the peripheral joint in the northern descending passage shows that the incident was not sudden. Indeed, a small 3-centimeter-deep cutting of the ceiling was carried out after the settlement began to occur[62] [fig. 10]. This proves that the builders were not afraid of a collapse since they even continued to raise the envelope up to 47 meters, taking care to extend the corridor of the upper chamber layout to the current western entrance.

The architects did not abandon the construction site, so it seems that the settlement of the northern section was continuous and progressive, increased by the growing loads but without running the risk of collapsing.[63] Eventually, as the structure did not seem to stabilize, they decided not to increase the weight of this outer coating any more by sharply decreasing the slope of the faces.

[60] L. BORCHARDT, *Die Entstehung der Pyramide an der Baugeschichte der Pyramide bei Mejdum nachgewiesen*, Berlin, 1928.
[61] J. DORNER, *op. cit.*, 1986, p. 55-57.
[62] V. MARAGIOGLIO, C. RINALDI, *op. cit.*, p. 60.
[63] It was a settlement, but not a collapse.

The chosen slope of approximately 43°-44° for the faces of the upper part of the pyramid is very close to that of the 'Red pyramid'. Extrapolating the 'Red' pyramid's slope, 44°44',[64] from the point situated 47.04 meters high produces a 109-meter-high pyramid with 219-meter-long sides.[65] The fact that these values are identical to those of the 'Red' pyramid cannot be a coincidence. It seems obvious to us that the Bent pyramid was not expected to be profiled that way at the end of the whole process, but should have had the shape of a true pyramid, the one that the 'Red' pyramid displays today. We conclude that the Bent pyramid is an unfinished 'Red'-shaped pyramid.

Furthermore, it is likely that the third stage of the project began when the scaffolding (a ramp or a structure of any kind) still embraced the pyramid, therefore when the edifice was to be enlarged again, but with a much reduced slope, it was easier and more economical to finish the entire top first, then, and only then, to clear the scaffolding in order to build the lower part.

Despite these developments, and as discussed earlier, it seems that the deteriorating state of the internal chambers eventually persuaded the architects to abandon construction work on the Bent Pyramid and to build another pyramid a little further north, but with the characteristics (slope and dimensions) which they had previously established at South Dahshur. The remaining scaffolding of the Bent pyramid was subsequently removed and the final outer layer never built.

The slope of the upper part, estimated at 43°-44°, is slightly different from that of the 'Red' pyramid. Given the unusual configuration of the existing lower structure of the Bent Pyramid a slight deviation from any desired value would be expected. As the upper section was extending from a lower section with a different inclination, and as there was no accurate horizontal ground surface to measure from, the resulting low error is in fact quite remarkable. In this way the Bent Pyramid reached its final and current form.

Because of separation between the inner core and the envelope, the weight of the upper part of the pyramid was transmitted to the underlying courses, but without being able to expand evenly through the outermost layer. This uneven distribution of stresses resulted in a more significant settlement of the core in relation to the external coating. This is why the inner section of the ceiling of the western descending passage sank slightly compared to the outermost section. The subsequent levelling of some floor stones, just where the ceiling has collapsed, probably shows that this settlement occurred during the construction of the upper part.

The architects managed to reduce the external settlement, but without being able to avoid this differential behavior between the masonries related to the first two projects. This incident will allow us to place an event in the construction history of the monument (cf. *infra*).

[64] J. DORNER, « Neue Messungen an der Roten Pyramide », in H. Guksch, D. Polz (ed.), *Stationen. Beiträge zur Kulturgeschichte Ägyptens. Rainer Stadelmann gewidmet*, Mainz, 1998, p. 25.
[65] *Ibid.*

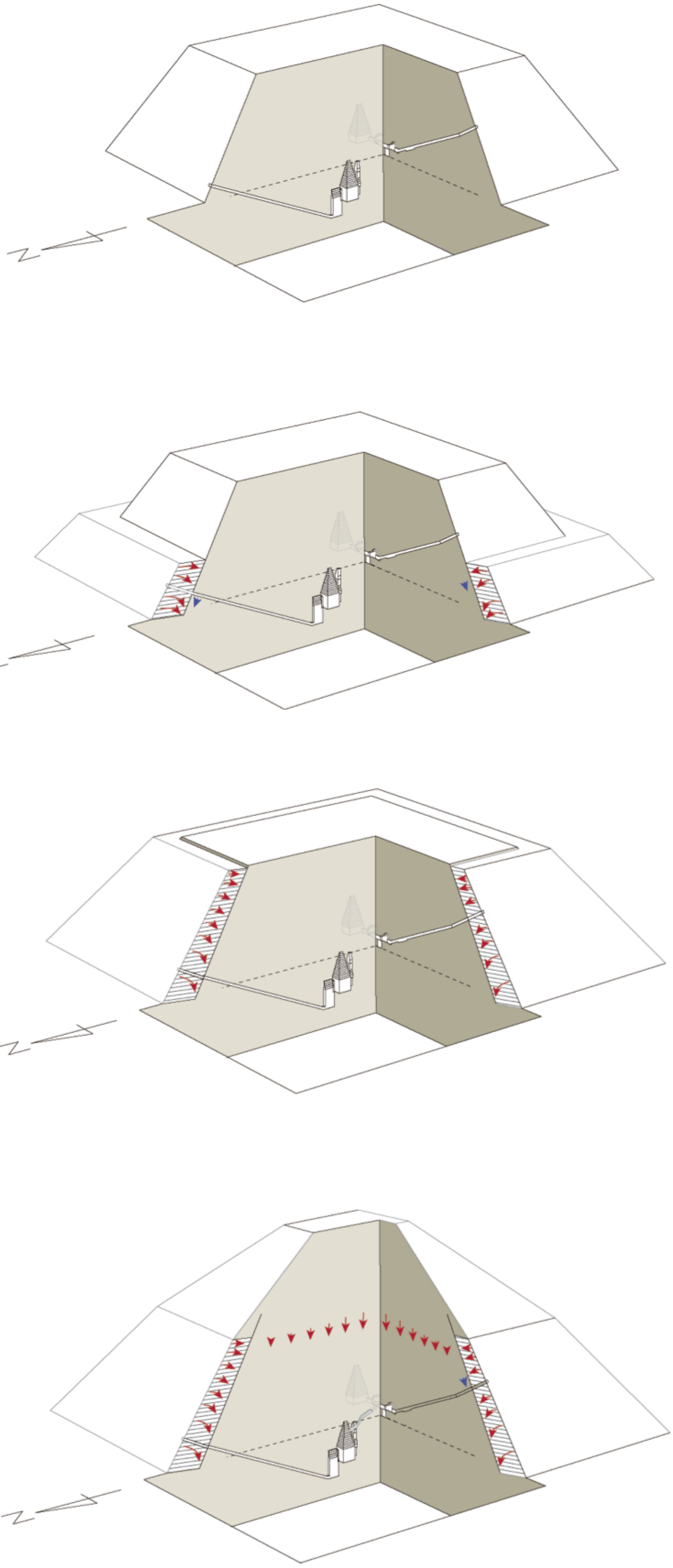

Fig. 14. Behavior of the superstructure during the different building stages of the Bent pyramid.

A Possible Reason for the Plugging of the Western Corridor

Plugging blocks were designed as to fit as closely as possible to the section of the corridor that the Egyptians wanted to seal. The settlements of several ceiling stones in the lower section of the western passage would therefore have had a negative impact on their installation [fig. 11, 15].

We suspect that at some moment between the commencement and the completion of the construction of the upper part of the pyramid, the architects decided to abandon the western access route. Doubtless fearing additional unpredictable settlement, they preferred to give up this communication route into which ceiling blocks had started to collapse [fig. 15]. The continuous splitting and sinking of stones may have been the aggravating factor. They decided to stop using this passage and sealed it up entirely. The blocking-up of the passage would also have helped to stop the settlement, and to strengthen the masonry around the passage.

As the upper chamber was then the only burial place in the pyramid (cf. *supra*), there was a need to find another access route to reach it during the funeral. This requirement explains why they cut a connecting tunnel between the lower and the upper systems. The ‘chimney’ was too high and narrow to undertake passage construction, they rather preferred to dig a new tunnel from the lower chamber at the required elevation.

We consider that the lower chamber was filled with masonry to facilitate the access to the new tunnel and to clear out the excavated materials. This mass was intended to create a staircase from the hallway, only leaving the space under vault cleared in order to construct a wooden scaffold, and maybe another staircase to facilitate the funeral procession.

The upper chamber, in spite of modifications, was therefore always considered functional.

With respect to the western descending corridor into the pyramid, although the transportation of blocking stones must have been facilitated by the presence of the construction ramp at this stage of the building, the task of raising dozens of blocks weighing about 2 or 3 tons up 33 meters, and then, by an unknown method, giving them the required impulse to block the corridor down its whole length, namely 67 meters, was a truly monumental effort!

Fig. 15. Sinking of the ceiling stones in the western descending passage (photo: Olga Kozlova).

Conclusion

By comparing the internal arrangements of the Meidum pyramid and the Bent pyramid, it is clear that the 'chimney' of the lower layout of the Bent pyramid was undoubtedly planned as a route to reach a burial chamber. But for some reason (we think that the invention of a new system of closure was the main cause), this lower arrangement was abandoned and it was decided to build a new one at a higher level, with an entrance in the western face. The burial chamber was made first. Following our new observations, there is no doubt that this upper room was not damaged by overloading. It underwent significant changes, its floor was raised twice, just after its ceiling was installed. The vault was also re-cut twice in order to form new flat walls for the burial space.

Technical reasons including some unpredictable settlement led the architects to reduce the slope of the pyramid's faces from 60° to ~44°, and to abandon the new western access. In order to retain an access route to the burial chamber, the Egyptians cut a connecting passage between the lower chamber and the horizontal corridor. The modifications that had been undertaken since the beginning of the project continued to reveal unpredictable behavior in the masonry including settlement of the outer mantle and surface breakdown of the vault in the upper chamber. The architect was finally forced to leave this site with its bent shape, and to establish a new building project at North Dahshur. This third pyramid of Snefru would benefit from the knowledge developed during the first part of his reign.

Our discussion leads us to propose the following construction sequence and architectural choices for the Bent pyramid:

1. Construction of the first pyramid with 157-meter-long sides and 60° sloping faces.

The internal arrangement was restricted to the lower apartments. The 'chimney' must have been installed for a burial chamber which was never built.

2. Non-completion and abandonment of the lower apartments. Building of the upper system of chambers and passages.

3. Modifications in the upper chamber (raising the floor level twice).

4. When the structure was about 40-50 meters high, the architects decided to enlarge the pyramid by the addition of a 16-meter-thick mantle at the base, with about 55° sloping faces in order to reach the original planned height.

5. Localized collapse in the northern descending passage led the architects to abandon this new project. The slope of the faces were then decreased to about 44°, in order to reduce the total weight of the upper part of the outer mantle. The project was thus modified again with the new objective being the construction of a 'true' pyramid, this time with sides measuring 219 meters and 109 meters high.

6. Owing to continual settlement in the western access passage, the builders decided to abandon this entrance. The lower chamber was filled, the connecting tunnel was dug and the western corridor was sealed. The only remaining access to the burial chamber was via the lower system of chambers and passages.

7. The upper part of the pyramid was completed.

8. The erosion and settlement damage did not stop. The movement in the northern passage increased and the builders could not manage to hide this anymore. The condition of the upper chamber deteriorated and they decided to abandon the site for a new one: that of the 'Red' pyramid.

9. The lower portion of the outer second mantle was never built and so the pyramid obtained its distinctive rhomboid shape.

Addendum

An architectural analysis of the Bent pyramid was released recently by Gilles Dormion and Jean-Yves Verd'Hurt while this article was being published.[66] Even though some of their observations concurred with ours (only in part), their method, their purpose and their conclusions differ substantially from our own. Anticipating the existence of a secret chamber, the work of Dormion and Verd'Hurt seems to have been invalidated by the results of the recent "Scan Pyramids" mission.[67]

[66] G. DORMION, J.-Y. VERD'HURT, *La chambre de Snéfrou. Analyse architecturale de la pyramide rhomboïdale*, Arles, 2016.

[67] Preliminary results available online from: http://www.sciencesetavenir.fr/archeo-paleo/archeologie/20160427.OBS9346/le-coeur-d-une-pyramide-scanne-grace-aux-muons.html [accessed May 20, 2016].

Résumé :

Les particularités architecturales de la pyramide rhomboïdale de Snéfrou à Dahchour-Sud inspirent deux courants d'interprétation. Le premier consiste à y voir l'expression symbolique délibérée d'une dualité et, le second, des modifications en raison de problèmes structuraux survenus au cours du chantier. Cet article fait le point sur l'état de l'archéologie en y apportant des observations inédites et complémentaires. Certains détails jusqu'alors passés inaperçus, ainsi que la pathologie de l'édifice, amènent à confirmer que les bâtisseurs ont apporté plusieurs changements à leur projet, mais aussi à en saisir les raisons. Une révision complète de l'histoire du monument est ainsi proposée en guise de conclusion.

Abstract:

The architectural peculiarities of the Bent pyramid built by Snefru at South Dahshur are the subject of two currents of interpretation. The first one consists of seeing the symbolic and deliberate expression of a duality in the design, and the second one, modifications due to structural problems that occurred during the construction work. This article reviews the archaeological situation by bringing unpublished and additional observations into the discussion. Some details that have been unnoticed by commentators so far, as well as a structural pathology of the building, lead to confirmation that the builders changed their project several times, but also reveal the reasons for these changes. A complete revision of the history of the monument is then suggested as a conclusion.

EN*i*M – Une revue d'égyptologie sur internet.
http://recherche.univ-montp3.fr/egyptologie/enim/

ARTS, LETTRES, LANGUES, SCIENCES HUMAINES ET SOCIALES UNIVERSITÉ PAUL-VALÉRY MONTPELLIER 3

cnrs

UMR 5140 Archéologie des Sociétés Méditerranéennes

ISSN 2102-6629