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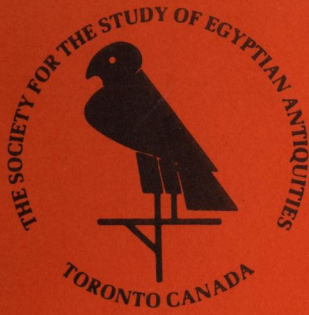
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A REASON FOR THE CORBELLED ROOF IN DYNASTY III AND IV PYRAMIDS*

NABIL SWELIM

The architecture of pyramids shows several methods in the development of roofs placed over chambers, corridors and shafts. These methods range from trunks of trees which were used in the pre- and protodynastic times to granite beams, limestone corbelled roofs and limestone pointed roofs. Together with these types which involved building, there are the rock cut corridors and chambers which required no such roof. Some of them were lined with masonry and this too had its own developments. These developments of the roofs came as a result of requirements, limitations, availability, skill and other factors such as the development in religious traditions, the length of the kings' reigns and the economic situation. But these factors did not have their effect on roofs only; the size of the pyramid was subject to them.

I believe one could divide the pyramids of Dyn. III and IV into two eras: the era of the step pyramids and the era of the giant pyramids. Overlapping these eras is the complete phase of the corbelled roof which is followed by the phase of the pointed roof. The latter phase spans the remaining part of the era of the giant pyramids and almost all the succeeding royal pyramids with only a few exceptions. Roofing with granite beams appears and disappears before and after the phase of the corbelled roof.

* This paper, excluding minor changes, was part of the Third International Congress of Egyptology, held in Toronto, Canada, September 5-11, 1982.

1. The chronology follows my conclusions in, *Some Problems on the History of the Third Dynasty* (Alexandria, 1983). This subject has been briefly mentioned in it, III, 5, F, ii and iii. It comes also as part of my current research on *The Development of the Pyramids and Similar Monuments of Ancient Egypt until the Beginning of the New Kingdom*.

2. Randall-Maciver, David and A.C. Mace *El Amrah and Abydos*, (London, 1902), 27-28, No. B96, 97, 137.

The landmarks of this study are the unfinished pyramid of King Nebkara at Zawiyet el Aryan, Mastaba 17 at Meydum and the Great Pyramid of Khufu. Nebkara's unfinished monument gave reasons to avoid using granite, and Mastaba 17 revealed the advantages of limestone; thus with another influence from mud brick architecture the phase of the corbelled roof was born and so was the era of giant pyramids. The Great Pyramid of Khufu closed that era and opened up the era of the pointed roof. In the meantime granite played an important role on many of these monuments.

Corbelled roofs of mud brick were found at el Amrah by R. MacIver² in 1902, at Raqaqnah by J. Garstang³ in 1904, by G. Reisner⁴ at Nag ed-Der in 1908, and by A. Mace⁵ at the same site in 1909. These tombs were dated by their excavators to Dyn. II and III. According to Reisner in a later study in 1936, the royal tombs of Qaa, Peribsen and Khasekhemwy at Umm el Giaab Abydos had corbelled roofs.⁶

MacIver used various descriptions referring to the corbelled roof without using the term itself. Thus: "bricks over an aperture," "bricks which were supported on other bricks" and "built on the cantilever principal, with courses of bricks overlapping one another until the

3. J. Garstang, *Report of the excavations at Raqaqnah, 1901-2. Tombs of The Third Egyptian dynasty at Raqaqnah and Bet Khallaf* (Westminster, 1904) 23-29, pl. 14.

4. G. Reisner, *The Early Dynastic Cemeteries of Nag ed Der*, Part I. (Leipzig, 1908) 72-82.

5. A. Mace, *The Early Dynastic Cemeteries of Nag ed Der*, Part II (Leipzig, 1909) 2-4, 8-9, 14, 19-20.

6. G. Reisner, *The Development of the Egyptian Tomb down to the Accession of Cheops*, (Cambridge, Mass., 1936) 355.

aperture was spanned." Garstang thought that the corbel during Dyn. III was a "spontaneous, natural and local" phase in the development of the arch, by noting that "a number of smaller tombs (at Raqaqnah) illustrate the development of the corbelled or offset vault from which the arch seems to have naturally evolved in Egypt and Chaldaea." The descriptions of the corbel given by these scholars are accurate but the role of these corbels towards the birth of the arch cannot be. We are in possession of evidence which undoubtedly shows that mud brick arches existed at an earlier date.⁷ Tomb 3500 dating to Horus Qaa at Sakkara had subsidiary graves with barrel vaults found intact by Emery in 1958; this vault was built on the principal of the arch with the bricks on edge, which differs from corbelling. It means that the two methods of roofing, barrel and corbel vaulting, existed side by side at a very early date. Both methods were maintained in later monuments. The brick barrel can be seen at the Ramesseum and elsewhere and the brick corbel in Middle Kingdom private pyramid tombs found by Mariette at Abydos.⁸

The idea of the corbelled roof was adopted from these monuments, no doubt, to furnish the royal pyramid with a new architectural technique of roofing. Limestone was employed in the corbelling system instead of bricks. In pyramid architecture, the earlier system of roofing was by granite beams at the Step Pyramid, but this monument also uses the archaic methods for roofing with wooden logs over eleven shafts under its eastern side. The later system of roofing was by the pointed limestone roof. The earlier method fell into disuse for the duration of the phase of the corbelled roof then reappeared with Khufu, who was responsible also for introducing

the later system of the limestone pointed roof. The following represents the monuments of the phase of the corbelled roof in a chronological order.

1. The pyramid of Meydum,⁹ the burial chamber of King Huni; Dynasty III.
2. Mastaba No. 16¹⁰ at Meydum, the burial Chamber of Nefermaat; Dynasty III-IV.
3. Mastaba No. 9 at Meydum,¹¹ the burial chamber of Ranefer (or Khent); and other tombs at that site; Dynasty III and IV.
4. The Bent pyramid,¹² two chambers, an antichamber and a niche King Sneferu; Dynasty IV.
5. The subsidiary pyramid to the Bent pyramid,¹³ the burial chamber; Dynasty IV.
6. The Red pyramid,¹⁴ three chambers of King Sneferu; Dynasty IV.
7. The Great pyramid at Giza,¹⁵ a niche and the Grand Gallery of King Khufu; Dynasty IV.

Impressive as it is, the Grand Gallery puts an abrupt end to the phase of the corbelled roof, which never reappears in royal monuments. Consequently the Great Pyramid spans the end of the phase of the corbelled roof, the revival of the early granite beam roofing and the newly introduced limestone pointed roof. Of course we do not know at present how Djedefra intended to finish the descending corridor of his pyramid at Abu Rawash; the width of the excavation in which the corridor was built is 5.5-7m — if a grand gallery was planned then the one of Khufu will be considered the penultimate corbel.¹⁶

7. W. Emery, *Great Tombs of the First Dynasty III*, (London, 1958) 102, pl. 116.

8. I. Edwards, *The Pyramids of Egypt* (rpt. 1972, West Drayton, 1947) 245.

9. V. Maragioglio and C. Rinaldi, *l'Architettura della Piramidi Menfite*, Vol. III (Rapallo, 1964), 6-53, Tav. 2-7.

10. G. Wainright in Petrie, *Meydum and Memphis III*, (London, 1910) 18-22, pl. iv.

11. Petrie, *Medum*, (London, 1892) 17, pl. VII.

12. A. Fakhry, *The Monuments of Sneferu at Dahshur*,

Vol. I (Cairo, 1955) surveyed by H. Mustapha, 65 ff, figs. 33-36, pl. VIII.

13. *Ibid.*, 90, fig. 55-56.

14. V. Maragioglio and C. Rinaldi, *op. cit.*, 124-128, Tav. 18-19.

15. Many references, e.g. A. Fakhry, *The Pyramids*, (Chicago, 1974) 115-124.

16. N. Swelim, *Some Problems on the History of the Third Dynasty*, III, 5, F, i.

It must be noted that the burial chambers under corbelled roofs are characterized by the absence of stone sarcophagi in pyramids and tombs of this phase.

In the great pyramid of Khufu a limestone pointed structure was placed above the roof of the pyramid entrance and as roof over the second unfinished chamber (the so-called Queen's chamber). His sarcophagus granite chamber, although roofed five times above it with large granite beams of the earlier tradition and above the relieving chambers, ultimately had a pointed roof of limestone placed above all. The pointed roof became a fundamental part of almost all burial chambers of future pyramids. These roofs occur at an earlier date rock cut at Meydum in Petrie's "Far Western Cemetery" Nos. 55, 56 and 81. Other tombs at that cemetery have pent roofs which may have a connection with pointed roofs.¹⁷ But pointed roofs which have been built of stone are not known before Khufu. Yet one can imagine that a pointed structure was placed as a relieving factor over the chambers with corbelled roofs of the gable form: thus at Meydum, at the pyramid subsidiary to the Bent Pyramid, at the Red Pyramid and possibly above the Grand Gallery of Khufu. The pointed structures do not occur over any entrance except Khufu's and would seem difficult to erect over the cone type corbelled roof of the Bent Pyramid. The problem of stresses on the Lower Northern Chamber may have been overcome by building it in a deep rock cut pit. This method has preserved that chamber. The Upper Western Chamber, however, which was built within the superstructure did not have such protection, consequently it was damaged by the weight from above and the pressure of inclined masonry in the accretion layers on its walls.

Granite has been an important building material in the funerary monuments of the Old Kingdom. Its first appearance was during Dynasty I at the Tomb of Horus Den at Umm el Giaab Abydos. The burial chambers of Horus Netjerykhet under the Step Pyramid and the Southern Tomb were built of that material at the bottom of deep pits at Sakkara. King Nebkara built at the bottom of another great pit at Zawiyet el Aryan a granite pavement with a sarcophagus carved in it, with the intention, no doubt, to build a granite chamber over it. The unfinished rock cut chambers of Horus Sekhemkhet and the Layer Pyramid at Zawiyet el Aryan show no evidence of how they were to be floored, walled or roofed. Judging by the existing examples of their period, one cannot exclude the possibility of using granite for that purpose.

Following the above mentioned pyramids and tombs comes the phase of the corbelled roof where granite completely disappears. The pyramids at Meydum and Dahshur and the one of King Khufu at Giza, up to a certain stage of its construction, clearly demonstrate its absence. As soon as the builders of Khufu's great pyramid had completed the Grand Gallery, granite was reintroduced into the pyramid to build his third chamber. All Khufu's successors used much granite in their pyramids except Khafra who very cautiously employed it in his pyramid; nevertheless, like the other successors of Khufu he used it generously in his temples.

The following figures are only rough estimates of the amount of cubic metres of granite used in tombs and pyramids; these figures do not include granite used in temples, subsidiary pyramids, etc., only in superstructures and substructures.

Horus Den	approx. 18m ³
Horus Netjerykhet	" 100m ³

Pavement of chamber in his tomb at Umm el Giaab¹⁸
Chambers under the Step Pyramid and Southern tomb¹⁹

17. Petrie, *Meydum and Memphis III* (London, 1910) 24-28, pls. XVII, XVIII.

18. Petrie, *The Royal Tombs of the Earliest Dynasties*, Part II (London, 1901) pls. LVIA 1 and 2, LXII. The area paved with granite of 5 inches thickness is 142m² thus 5 inches = .125m x 142m² = 17.75m³. Cf. p. 10.

19. J. Ph. Lauer, "Sur L'Age et L'Attribution possible de l'Excavation monumentale de Zaouiet et Aryan" in *Revue d'Égyptologie*, T. 14 (1962) 26, where he has calculated the total value to be 97m³.

Horus Sekhemkhet	?	Chamber left unfinished
King Nebkara	" 1000m ³	The pavement at the bottom of the pit. ²⁰
Layer pyramid	?	Chamber left unfinished
 No granite in a phase characterized by the corbelled roof and the absence of sarcophagi:		
King Khufu	approx. 1100m ³	The King's chamber ²¹
King Djedefra	?	Probably as much as or more than Menkaura (see below)
King Khafra	" 1650m ³	Lower course of casing and upper descending corridor ²²
King Menkaura	" 11100m ³ or 22000m ³	Sixteen courses of casing and the lower chamber If the whole pyramid was encased with granite ²³

These figures tell us that a great jump in the amount of granite was made by Nebkara for building his burial chamber by using 1000m³ for the pavement alone. More would have been used for the chambers over the pavement; I would imagine that the chambers would be roofed by granite beams like the earlier ones of Netjerykhet and the later ones of Khufu. The great pit would have been filled up in a similar way to the method followed by Imhotep in filling the pit of the Southern Tomb of Horus Netjerykhet.

I would estimate that another 200-500m³ of granite would be needed to complete this substructure, thus a total of 1200-1500m³ of granite. If the corridor (106.2m long and 5.4-6.35m wide²⁴) was to be walled and roofed with granite also the totals would have to be doubled, i.e. 3000m³ of granite.

The quarrying and transportation of this great amount at such an early date of the history of the pyramid builders would have surely lengthened the time of construction of the substructure of the monument. No earlier monument involved stone logistics of that quantity from

such far away quarries in Aswan. This monument chronologically follows the two great enclosures and the two step pyramid complexes at Sakkara.²⁵ These four monuments were supplied with stones for building their nuclei locally and for facings from Tura, which lies on the opposite side of the Nile. The granite supplied to the Step Pyramid was only 100m³, which is only one thirtieth of what was needed for Nebkara's project. Consequently, the logistics of stone brought from far away quarries at the time of Nebkara were still in a state of infancy or immaturity. The short reign of this king brought an end to the work before the superstructure was hardly begun.

Perhaps the successors looked upon this unhappy fate of Nebkara's ambitious project as a realization of the immature methods of granite logistics or perhaps a warning against the use of granite altogether. They had never roofed any monument before to withstand the weight of a pyramid except twice with granite beams at the bottom of deep pits in the time of Netjerykhet. Sekhemkhet's chamber was rock cut; roofing was not needed to withstand any weight. A lining

20. *Ibid.*, Lauer calculated the amount of granite to be 970m³.

21. Calculated from V. Maragioglio and C. Rinaldi, *op. cit.*, Vol. IV, Tav. 7, 8.

22. Calculated from V. Maragioglio and C. Rinaldi, *op. cit.*, Vol. V, Tav. 6, figs. 4-7.

23. Calculated from V. Maragioglio and C. Rinaldi, *op. cit.*,

Vol. VI, Tav. 4, fig. 2 All the sides of the pyramid may have been encased with granite. I have considered 16 courses and the whole pyramid.

24. N. Swelim, *op. cit.*, fig. III, 2, No. 2; this corridor would not be floored.

25. N. Swelim, *op. cit.*, II, 2, C and D, II, 3, A and B.

of granite on the floor, walls and roof would have been similar to the lower chamber of Menkaura, but this was never done. Consequently a solution had to be found. To be able to account for this solution, I will follow some of the facts we can glean from the era of the giant pyramids.

Following the monument of Nebkara and the Layer Pyramid of Zawiyet el Aryan, comes an era of giant pyramids, lasting till Menkaura. The phase of the corbelled roof, with a complete absence of granite and stone sarcophagi, covers the first half of that era, then the pointed roof takes over.

The era of giant pyramids required in the course of their construction a flow of supplies of limestone. As the pyramids became bigger, the nearby limestone quarries did not fulfil the needs. Consequently, new quarries were opened up going further south until Djebel Abu Foda was reached.²⁶ Mr. & Mrs. Klemm and B. Wagner have presented analytical studies concerning the origin of ancient Egyptian stone material; in their report they write that "remarkable (are) the most heterogen localities of origin of the building material of the Cheops pyramid, which apparently is derived from a large number of quarries from Cairo to the area of Assiut."²⁷ Gangs were formed at these quarrying areas, hundreds of barges were carrying the blocks and thousands of masons were at work to keep up a rate of 112.600m³ of limestone supplied annually to the site of construction, or 308.5m³ of stone added to the pyramid every day of the king's reign (considering a reign length of 23 years). These rates were recently worked out by Prof. R. Stadelmann.²⁸ Apparently by the time of the reign of Khufu the facts and estimated figures in our possession today confirm the assumption that a highly organized body of various activities were operating in vigorous harmony — an ancient example of cybernetics.

This state of affairs was reached by trial and error over a period of several reigns of short and long durations. The perfection of the whole operation involving limestone logistics from quarries 400km away may have encouraged a further exploitation to re-establish the tradition of the use of granite in the burial chamber and other parts of the pyramid. The King's Chamber in the pyramid of Khufu must have been the fruit of this exploitation. But the amount of granite in the great pyramid is small in comparison to the amount used in the pyramids of Djedefra and Menkaura (See below).

The unfinished pyramid of Djedefra is disappointingly small, but an enormous amount of granite was used in it for casing and otherwise. I believe that the pyramid of Khafra, which is much bigger, was initially planned with no intention of using granite. In size it has more resemblance to the pyramids of the phase of the corbelled roof. It is true that the characteristics of the corbel and no sarcophagus were given up by now for the newly developed pointed roof and the granite sarcophagus. Yet limestone would still enable the builders of the pyramid of Khafra to free themselves from limitations imposed by erecting a pyramid which employed some considerable granite elements as was the case with his predecessor Djedefra. A small part, however, of the pavement of the burial chamber and descending part of the upper corridor used granite due, perhaps, to a later decision. This amounts to approximately 360m³ of granite and would not create any problems affecting the size of the pyramid. The figure given above (1650m³) includes the first course of the outer facing which uses 1290m³ of small blocks probably left over from the temples of Khafra or from the pyramid of Djedefra. Consequently, Khafra was able to build a pyramid much larger than his predecessor Djedefra and his successor Menkaura.

26. These are cliffs composing the east bank of the Nile south of El Amarna and north of Assiut.

27. D.D. Klemm, R. Klemm and B. Wagner, *First Interim Report on the Analytical Studies in the Research Program*

"Origin Determination of Ancient Egyptian stone material," Munich/W. Germany.

28. R. Stadelmann. "Snofru und die Pyramiden von Meidum und Dahshur," in *MDAIK* 36 (1980), 439.

I think Menkaura could have enlarged his pyramid considerably had he not decided to encase it with granite blocks of a larger size and add a granite burial chamber under the monument. Here one had to realize that the quantity of granite in this pyramid in its present state is ten times as great as that employed by Khufu. If this pyramid, as the case may have been, was to be entirely encased with granite Menkaura would have used 22000m³, i.e. 20 times as much as Khufu. Khafra and Menkaura employed the largest limestone blocks in their funerary temples.²⁹

Nevertheless, the phase of the corbelled roof demonstrates the largest mass of cubic metres of masonry in the history of the pyramids of ancient Egypt. The solution sought by the successors of Nebkara to avoid granite was the exclusive use of limestone. They had no choice but to use it because the other common stone in Egypt, sandstone, is in the area of Djebel El Silsila which is too far south. Consequently the architects had to tackle the problem of roofing with that stone and use limestone beams in the same way as they used granite beams for Netjerykhet and in the same way they would have used granite beams for the chamber of Nebkara. These limestone beams are found in Mastaba 17 at Meydum.³⁰

This mastaba is a remarkable monument with the most impressive burial chamber of all monuments of the Old Kingdom. The mummy was placed in the great granite sarcophagus before the burial chamber was completed and before building the superstructure of the mastaba. The burial chamber was roofed with very large beams of limestone each of a volume of 18.5m³ and a weight of 42.5 tons (at D = 2.3). These limestone megaliths do not occur at any earlier monument for the purpose of roofing. Mastaba 17 seems to have been built in haste to inter someone of the greatest importance after he

had already died, probably a king who was not able to complete his pyramid. Limestone could conveniently be brought from the quarries a little further north on the other bank of the Nile at Tura. Since the weight of the intended superstructure of this mastaba on the roof of the burial chamber is much less than the weight of a pyramid, the builders of Mastaba 17 knew it was safe with limestone beams as roofing.

Could these limestone beams withstand the weight of a pyramid? The consequence was doubtful. Whatever the fears of the pyramid builders were, they must have realized through the experience gained from building the burial chamber of Mastaba 17 that limestone can be employed instead of granite if safety measures are taken. The safety measure was, undoubtedly, adopting the corbelling system already used in mud brick architecture, consequently, the phase of the corbelled roof began. At that point work had started on the burial chamber of the Meydum pyramid. The stone chippings and the builders' waste coming from the pyramid were later supplied to Mastaba 17 as material for building its superstructure in layers.

While an account for the phase of the corbelled roof can be given, the absence of sarcophagi poses a difficult problem. The royal funerary monuments before this phase have shown that Netjerykhet and the owner of the Layer Pyramid at Zawiyet el Aryan did not include sarcophagi for themselves while Sekhemkhet and Nebkara did; the sarcophagi of the last two are most unusual. In earlier royal tombs known to us an absence of sarcophagi can be noted also. The first regular sarcophagi for kings are those in Mastaba 17(?) and in Khufu's Pyramid.³¹ Could we consider that breaking the tradition of using granite was bad enough without adding a sarcophagus? Would these changes be considered revolutionary? Or was the sarco-

29. Four hundred twenty-five tons according to Hölscher, *Chephren*, (Leipzig, 1912) 52, and 220 tons, Reisner, *Mycerinus*, (Leipzig, 1931) 71. Cf. N. Swelim, *op. cit.*, III, 5, F, iii, ns. 1, 2, 3.

30. N. Swelim, *op. cit.*, II, 4, D; figs. II, 4 D No. 1 and 2; III, 4 F, i, c III, 4, F, iii. Originally investigated by Petrie,

Wainright and A. Rowe; Petrie, *Medum*, (London, 1892) 11-13, pls. I, VI, VIII, Petrie, *Meydum and Memphis*, III, (London, 1910) 13-17, pls. X-XIII.

31. I do not consider the two sarcophagi in the gallery connected to shaft No. V under the Step pyramid as kings' sarcophagi.

phagus a bad omen because kings who placed them in their pyramids (Sekhemkhet and Nebkara) never lived long enough to complete them? The question remains unsolved.

To end this short study one may consider that corbelled roofs appeared because kings could not afford the delay caused by the logistics of granite used for burial chambers, roofing beams and other architectural elements of the pyramid. The experience of the unfinished pyramid of Nebkara at Zawiyet el Aryan is, in my opinion, a determining factor. It was decided henceforth to avoid using granite altogether and to replace it with limestone. Limestone beams proved to be durable at Mastaba 17 at Meydum and corbelling must have been employed as a

safety factor against the weight of the pyramid above. The new roofs developed rapidly showing better forms and designs in each monument but suddenly fell into disuse. Limestone, however, enabled the builders to increase the size of pyramids considerably and the era of giant pyramids was born. Khufu and his successor used the pointed roof in chambers which were not hollowed in the natural rock. Moreover, the old tradition of granite beams was reintroduced by Khufu once more. In his time stone logistics were perfected and the amount of granite was comparatively limited; consequently, this reintroduction had little effect on the whole project. Later kings, however, who wished to use more granite in their pyramids were compelled to build smaller pyramids.