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# Architectural Ceiling Types and Pressure-Relief Techniques in Chambers and Corridors of Ancient Egyptian Royal Pyramids

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## ABSTRACT

The research discusses the architectural styles of ceilings of corridors and chambers within the main pyramids of kings, excluding queen and Ka pyramids, from the beginning of the Third Dynasty to the beginning of the Eighteenth Dynasty. These ceilings have been classified into four architectural styles. The study examines the architectural methods used to carry, resist, and relieve pressure on the ceilings of those corridors and chambers within the royal pyramids. These methods had varied over twelve hundred years and had demonstrated the ingenuity of the ancient Egyptian architect in addressing the problem of pressure and weight on the ceiling. Some were designed in specific ways and made from strong materials to sometimes carry thousands of tons, while other ceilings were designed with different techniques and more solid materials to endure millions of tons. Despite all precautions, some architects occasionally failed, leading to cracks in the walls and ceilings of some pyramids. They did not give up and attempted to use other methods to solve these problems and made the ceiling capable of carrying and resisting pressure. They often employed more than one method in a single pyramid to ensure their effectiveness and achieve the desired goal.

## INTRODUCTION

The kings of the Old Kingdom built their pyramids in the royal cemetery of Memphis, which extends in the western desert for 80 km north-south. It includes Abu Rawash, which contains Djedefre’s pyramid and unknown one (Valloggia 2001, 1); (Porter & Moss 1974, 1–9) and Giza which includes three main pyramids for Khufu, Khafre, and Menkaure. This cemetery also contains Zawyet El Aryan, which contains two pyramids of Khaba and Nebka (Lepsius 1897, 128–129); (Porter & Moss 1974, 313–314).

The Memphite necropolis also includes Abusir, which contains five main pyramids for the kings; Sahure, Neferirkare, Neferefre, Shepseskare, and Neuserre (Verner 2001a, 5). It comprises Saqqara, which includes thirteen pyramids, ten of which belong to the Old Kingdom kings; Djoser, Sekhemkhet, Userkaf, Djedkare, Unas, Teti, Pepy I, Merenre, Pepy II, and Pyramid 29, attributed to Menkauhor from the Fifth Dynasty or Merkara from the Tenth Dynasty (Chauvet 2001, 176).

The necropolis of Memphis also includes Dahshur, which contains several pyramids, including two main pyramids of Sneferu. The first pyramid was the first planned from the beginning to be a true pyramid (Verner 1997, 174). It was called the ‘Bent Pyramid’ due to the change in the angle of its construction, causing it to become bent or inclined. The second pyramid is called the 'Red, Northern or Complete Pyramid', which took 10, 11 (Romer 2007, 71), or 17 years to be built.

The necropolis of Memphis also includes Meidum, which contains the pyramid of Huni (Porter & Moss 1968, 88–95). In Arabic, it is called the 'False or Lying Pyramid' due to the change in its design from a step pyramid to a complete one.

The form of the royal tomb in the Old Kingdom evolved from a step pyramid to a bent pyramid, then a complete pyramid. The purpose of the pyramid was to serve as a royal tomb, symbolizing the primordial mound, beginning of creation, resurrection process, and representing a ladder for the king's soul to ascend to the sky and settle among the stars of the northern pole (Verner 2001b, 88). It represents the nightly transformation center for the king who has gone to the afterlife, where he will be reborn. The chambers within the pyramid are connected to the ascension process to the sky (the vestibule and the antechamber) and the union of the king with Ra-Atum (the sarcophagus chamber) (Arnold 2003, 183–184). It represents a massive construction project providing job opportunities for various categories and craftsmen and serves as a temple, a ceremonial center, and a sacred place for the king. It embodies the interplay of shadow and light, expresses the union of the horizon with the earth, and enshrines the mystery of death and rebirth (Lehner 1997, 9).

Shepseskaf chose the shape of a mastaba rather than a pyramid. This might be due to his rejection of the sun religion, or he spent time and money completing his father's pyramid, which forced him to change his own pyramid into a mastaba due to the lack of financial resources and time. Some believe that Shepseskaf intended to build a pyramid and he started it but he died before completing it, resulting in it being finished as a mastaba rather than a pyramid (Stadelmann 1991, 152–153). In any case, it is outside the scope of research because it is not a pyramid.

There is a group of stepped pyramids located in Seila at Fayoum, Zawyet el-Maitin at Minya, Sinki at Sohag, Naqada and el-Kula at Qena, Edfu, and Elephantine at Aswan. Most of these pyramids date from the reign of Sekhemkhet to Sneferu's reign. Their purpose is unknown; they might be pyramids for queens located in their birthplace, they could represent shrines linked to the Horus and Set legend, they might symbolize the primordial mound, represent symbols of the solar religion, or perhaps they were commemorations of the king's presence and authority in areas distant from the capital, near regional centers and royal headquarters (Verner 1997, 172–173). These pyramids are outside the study because they lack chambers.

The kings of the First Intermediate Period attempted to construct pyramids, but the short duration of their reigns and their limited financial resources prevented most of them from completing this work. Some pyramids were destroyed, some remain undiscovered, and other pyramids have been found such as that of Ibi at South Saqqara and Khui in Dara near Manfalut in the Western Desert. The tombs of the kings of Herakleopolis have not been discovered, and we do not know whether they took the form of pyramids or ordinary tombs.

The kings of the Eleventh Dynasty (Intef I, II, and III) constructed their tombs at El-Tarif in the form of a portico with rock cut chapels. There is no evidence that their courtyards or facades included mud brick pyramids (Lehner 1997, 165).

Mentuhotep II constructed a funerary complex in a rocky area in the cuddle of the mountain at Deir el-Bahari. It is of a unique stepped design with a temple on top, above part of it which is either a pyramid or a mastaba. Carter discovered a pit in the courtyard that includes an entrance leading to a downward sloping passage carved into the rock about 150 m long and leads to a chamber beneath the southeastern side of the pyramid. In this chamber's floor, there is a vertical shaft leading to another chamber. This 'Horse's Gate Tomb' represents a symbolic tomb (Carter & Maspero 1901, 201–205, figs. 1, 2). We suggest that this tomb or pyramid represents the idea of the southern tomb for Djoser and the ka pyramid for other kings, which lies outside this study that is limited to the main pyramids of kings.

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No confirmed tombs for Mentuhotep III and IV have been found, but they are believed to be in Deir el-Bahari or El-Tarif (Arnold 1991, 16). There is a tomb in Sheikh Abd el-Qurna similar to the tomb of Mentuhotep II, which may belong to one of these kings (Wilkinson 2000, 37, 172, 173, 181) or to Amenemhat I before he left Thebes (Arnold 1991, 16).

The kings of the Twelfth Dynasty built their tombs differently from those of the Eleventh Dynasty and adopted the style of the tombs of the Old Kingdom kings, the pyramid. They incorporated some architectural elements from the Eleventh Dynasty. These were constructed in Dahshur and Fayoum and belong to Amenemhat I, II, III, and IV, and Senusret I, II, III, and Sobekneferu (Grinsell 1947, 157–180).

Despite the large number of kings in the Thirteenth Dynasty, only a few pyramids have been found for them in Dahshur (Porter & Moss 1981, 890) and South Saqqara (Porter & Moss 1978, 434–435). We have not found the tombs of the Hyksos kings, and it is likely that they were not buried in pyramids (Fakhry 1963, 338).

The papyri of the tomb robberies (Abbott, Leopold II, and Amherst VII) mention that the tombs of the kings of the Seventeenth Dynasty, which are six or seven, take the form of pyramids in the Dra' Abu el-Naga area to the west of Thebes. These pyramids have been subjected to theft and destruction and were constructed with mud bricks from the inside. There are some obstacles in studying these pyramids as the old official excavation reports conducted in that area were not published, and there have been undocumented and unauthorized excavations by some residents of el-Qurna village. It seems these pyramids were small in size. The last king to be buried in a pyramid was Ahmose I in the Dra' Abu el-Naga. This pyramid has not been examined from the inside. He also built another pyramid for himself in Abydos made of stone blocks and sand from the inside and had a good limestone outer casing, but it lacks chambers and corridors (Lehner 1997, 188–190). After him, royal tombs were no longer in the form of pyramids but were instead carved into the rock.

Based on the information we have about the pyramids, this research will address and analyze the styles of ceilings in corridors and chambers and the methods of supporting and reducing pressure on them within the pyramids of the kings, excluding those of the queens and the Ka pyramids, from the beginning of the Third Dynasty until the beginning of the Eighteenth Dynasty. This period is referred to as the ‘Pyramid Builders’ Age’ (Verner 2001b, 88). This lasted for approximately 1200 years.

The selection of this research topic stems from several key motivations. First, there is a noticeable lack of specialized studies that thoroughly investigate the pressure-relief techniques applied in the ceilings of corridors and chambers within royal pyramids. The studies conducted on the pyramids by archaeologists—whether those who carried out excavations or those who focused on examination and description (Perring & Engineer 1839); (Vyse 1840); (Perring 1842); (Petrie 1888); (Petrie 1890); (de Morgan 1895); (de Morgan 1903); (Borchardt 1907); (Borchardt 1909); (Borchardt 1910); (Petrie et. al. 1912); (Petrie et. al. 1923); (Jéquier 1933 ); (Jéquier 1935); (Jéquier 1936); (Maragioglio & Rinaldi 1962); (Fakhry 1963); (Maragioglio & Rinaldi 1965); (Maragioglio & Rinaldi 1966); (Maragioglio & Rinaldi 1967); (Stadelmann 1991); (Arnold 1992, 97); (Edwards 1993); (Lehner 1997); (Verner 1997); (Hawass 2010); (Hawass & Smith 2018). These studies are mainly concentrated on describing the pyramids. They occasionally mentioned one or two pressure-relief methods, usually in a direct manner during the description of a specific pyramid, and these references have been cited in this research where relevant. Among the best studies that addressed some pressure-relief methods are those by Arnold concerning Pharaonic Stone Masonry (Arnold 1997) and The Encyclopedia of Ancient Egyptian Architecture (Arnold 2003). However, none of the previous studies focused on compiling all the pressure-relief techniques, tracing their historical development, or analyzing them comprehensively. Moreover, many of the methods identified in this current study were not mentioned in those references as pressure-relief strategies but have been inferred and interpreted as such through this research.

This gap highlights the need for a deeper understanding of the architectural and structural evolution of pyramids, particularly when considered in relation to geological, functional, and religious influences. Furthermore, the study aims to shed light on the remarkable engineering ingenuity of the ancient Egyptian architect, especially in managing massive stone elements under the challenging conditions of the desert. By exploring these aspects, the research also seeks to explain the varying degrees of preservation among pyramids—why some have withstood the test of time, while others have suffered collapse or severe damage. Ultimately, the study offers a fresh analytical perspective that enhances our comprehension of the architectural philosophy and intentionality behind ancient Egyptian pyramid construction.

This study is expected to provide a clear classification of pyramid ceiling types by dynasty and function, reveal how materials and pressure-relief methods affected structural stability, and highlight key factors—like seismic activity, groundwater, and religious symbolism—that influenced design choices. It will showcase the ancient Egyptians' engineering brilliance in balancing durability with meaning and offer a valuable reference for scholars in architecture and archaeology.

The importance of this study lies in highlighting the brilliance of ancient Egyptian architects and their ability to overcome major structural challenges in pyramid construction, especially in protecting inner rooms from collapse. It also contributes to understanding the relationship between site selection, material quality, and architectural development. Moreover, it enriches modern research in historical architecture and showcases the ancient Egyptians' accumulated knowledge in engineering and geology.

## 1. ARCHITECTURAL CEILING TYPES OF CHAMBERS AND CORRIDORS IN ROYAL PYRAMIDS

The ceilings of chambers and corridors in the royal pyramids take several different architectural styles. The study has been able to categorize them into four types:

### 1.1. Vaulted Ceiling

This style was known in some buildings made of mud brick since the First Dynasty in houses, storerooms, and tombs as a ceiling for rooms, corridors, and stairs (Arnold 2003, 252). Its purpose was to prevent the heavy weight above the ceiling from breaking it. This design appeared in royal pyramids in the limestone burial chamber of Djoser's pyramid (Verner 1997, 164) and the pink granite burial chamber of Menkaure's pyramid. This last one was designed with several layers of granite and was carved into a vaulted shape (Maragioglio & Rinaldi 1967, 46) **(fig. 1).**

This vaulted ceiling was also found in the Fifth Dynasty in the corridor, separating the antechamber and the burial chamber of the pyramid of Djedkara. It is also found during the First Intermediate Period in the descending corridor leading to the burial chamber inside a pyramid or tomb of Khui (Arnold 2003, 66, 71–72).

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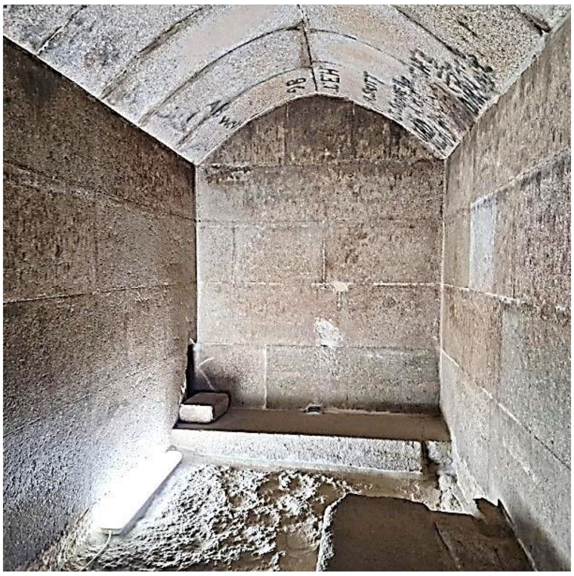

**Fig.1.** Vaulted ceiling of the burial chamber of Menkaure (Photo: The author).

It continued into the Middle Kingdom in the horizontal corridor leading to the first side chamber and the pink granite burial chamber of Senusret II's pyramid (Petrie et. al. 1923, 6, pl. xxv). This style also appeared in the ceiling of the central limestone chamber and the granite burial chamber in Senusret III's pyramid (de Morgan 1903, 89–90, fig. 133), and the limestone burial chamber of Amenemhat III's pyramid at Dahshur (Lehner 1997, 180). The burial chamber of the southern pyramid at Mazghuna, whose owner is uncertain but possibly Amenemhat IV (Porter & Moss 1968, 76), or a king from the Thirteenth Dynasty (McCormack 2010, 70), was carved into a quartz block with a flat ceiling topped by a limestone vaulted ceiling (Petrie et. al. 1912, 46, pls. xl, xli).

### 1.2. Stepped Ceiling

The stepped ceiling consists of several rows of stones used in the walls of the chamber or corridor, where each upper row protrudes inward relative to the row below it at a certain rate until reaching the ceiling. The purpose of this method was to reduce the size of the ceiling and relieve pressure on it, distributing it to the side walls to prevent collapse. This style first appeared in the mud brick tombs of the Second Dynasty at Naga ed-Deir and el-Amra. It later appeared in royal pyramids in the burial chamber of Huni's pyramid. It was built at the base level of the pyramid with limestone walls and a stepped ceiling totaling seven steps (Arnold 2003, 60, 145).

This type of ceiling continued during the reign of Sneferu. The first, second, and burial chambers of the Bent Pyramid were constructed with limestone and had a stepped ceiling. The northern entrance leads to a descending corridor, leading to a front chamber. This chamber rises 12.60 m and has a stepped ceiling on the four walls, with each step increasing by 15 cm from the one below it, making the chamber's ceiling 30 cm x 1.60 m. There is an opening at a height of 6.25 m in the southern wall of the first chamber that leads to the second one with a stepped ceiling. This chamber has two passages in its southern wall; the lower one leads to a shaft that rises up and leads nowhere. The upper passage leads to a horizontal corridor extending from east to west, which is the western entrance of the pyramid. This last corridor contains two terraces and there is a burial chamber behind the second terrace to the east, with a stepped ceiling (Mustapha 1952, 599, fig. 4, pls. 4–6) **(fig. 2).**

**Fig.2.** Stepped ceiling inside the bent pyramid of Sneferu (Photo: The author).

Sneferu applied the same idea when constructing the northern pyramid. The first, second, and burial chambers were all built from limestone. The entrance leads to a descending corridor, which leads to a horizontal corridor, and then to the first chamber. This chamber extends from north to south, with a stepped ceiling featuring eleven steps, measuring 12 m in height, 9.30 m in length, and 3.60 m in width. There is an entrance in the southwestern corner of the first room leading to the second chamber, which is similar to the first. It includes an entrance in its southern wall, but at a height of 7.5 m, accessible by a wooden staircase newly constructed for ease of visitation, leading to a horizontal corridor that leads to the burial chamber. This chamber extends from east to west and has a stepped ceiling with fourteen steps, measuring 15 m in height and 9.30 m in length (Perring 1842, 16).

The architect of the Great Pyramid at Giza adopted the idea of the stepped ceiling in the Grand Gallery that extends from the ascending corridor to the portcullis room in front of the burial chamber of Khufu. The gallery was constructed with high quality of limestone, measuring 47 m in length and 8.5 m in height. It has a stepped ceiling consisting of seven layers, with stone rows gradually receding inward by 7.5 cm from a height of 1.8 m on the gallery's walls. This continues up to the seventh layer of the side walls, narrowing the gap between the stones towards the ceiling, which makes the ceiling width about one meter (Edwards 1993, 93).

### 1.3. Gabled Ceiling

Every two stones lean against each other in an opposing manner, forming a triangle or pyramid from the top, while each stone at the bottom supports itself on the side walls. Initially, these stones from the bottom did not rest horizontally over the walls of the room. The purpose of this design was to alleviate the pressure of the pyramid's weight and distribute it from across the ceiling and the walls instead of placing the weight solely on them, which could lead to cracking and collapsing (Arnold 1997, 191).

This method began in the ceiling of the descending corridor of the main entrance of Khufu's pyramid **(fig. 3)** and the queen's chamber. The queen's chamber is located halfway between the northern and southern faces of the pyramid. It is lined with white limestone and has a ceiling in the form of a limestone gabled shape with a height of 6.23 m. This chamber was the first to be built in a pyramid with a gabled ceiling. Subsequently, the ceiling of the fifth chamber of the pressure relieving chambers above Khufu's burial chamber followed the same design (Dormion 2004, 154, 259).

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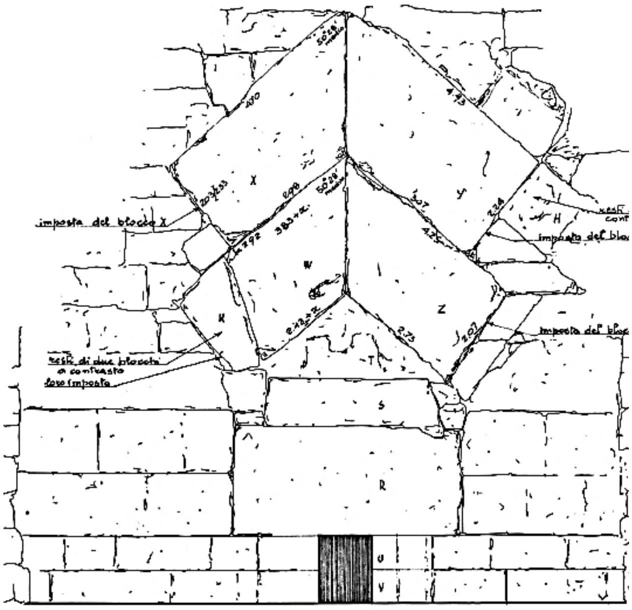


**Fig.3.** Gabled ceiling of the main entrance and corridor of Khufu's pyramid (Maragioglio & Rinaldi 1965, pl. 2)

This gabled style continued to be used as a ceiling for the burial chamber and the antechamber in the pyramids of some kings of the Old Kingdom, including Khafre from the Fourth Dynasty at Giza (Maragioglio & Rinaldi 1966, 56), then the kings of the Fifth and Sixth Dynasties at Saqqara and Abusir (Arnold 1997, 191); (Hellum 2007, 107); (Lehner 1997, 141–148), and some kings of the Middle Kingdom, like the upper ceiling of the corridor and burial chamber of Amenemhat II's pyramid at Dahshur (de Morgan 1903, 39, figs. 77, 80, 81).

### 1.4. Flat Ceiling

A flat ceiling refers to a ceiling that has a flat or level shape and consists of blocks of limestone, granite, or sandstone placed flat and level or carved into the rock to take on a flat level shape.

This style is found in most of the lower passages of pyramids, some rock-cut chambers, and some constructed rooms. It was found in the passages beneath the Step Pyramid of Djoser at Saqqara (Firth & Quibell 1935, pls. 10, 13, 14, 18); (Hawass & Smith 2018, 60), the descending passage and the incomplete rock-cut chamber inside the Great Pyramid (Maragioglio & Rinaldi 1965, 30), and in the pink granite burial chamber of Khufu **(fig. 4).** It is considered the only chamber from the Fourth to the Sixth Dynasties with a flat ceiling and not in the form of a gabled ceiling (Lehner 1997, 111, fig. on p. 112). The ceiling of the descending passage and the serdab or niche chamber that appeared within the pyramids since Menkaure (Maragioglio & Rinaldi 1967, 42) onwards in the Fifth and Sixth Dynasties took on a flat shape (Piankoff 1968, 11, Plan A and B ); (Megahed et. al. 2017, 49). Similarly, the burial chamber of Ibi at South Saqqara took on the same shape (G. Jéquier 1935, 3–4, pls. i, ii).

This style continued in the Middle Kingdom in the lower ceiling of the passage and burial chamber of Amenemhat II's pyramid (de Morgan 1903, 39, figs. 77, 80, 81), the burial chamber of Amenemhat III's pyramid at Hawara (Edwards 1993, 237), the southern pyramid at Mazghuna, (Stadelmann 1991, 250), and the pyramid of Khendjer at South Saqqara (Grinsell 1947, 153)

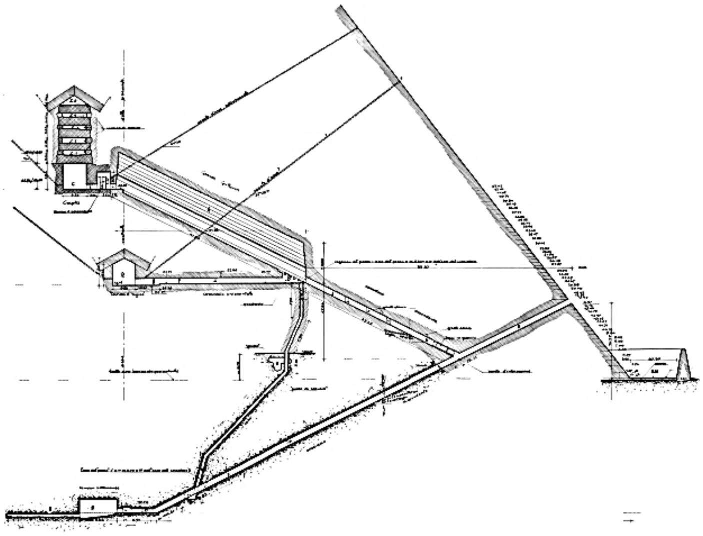

**Fig.4.** Flat ceiling of the descending passage, rock-cut room and burial chamber of Khufu's pyramid (Maragioglio & Rinaldi 1965, pl. 3)

## 2. PRESSURE-RELIEF TECHNIQUES ON THE CEILINGS OF ROYAL PYRAMID CHAMBERS AND CORRIDORS

The ancient Egyptian architect adopted a set of innovative architectural means and methods to resist pressure on the ceilings of chambers and corridors inside the pyramids. Some burial chamber ceilings reached about 90 tons, in addition to the weight of the pyramid body above them. Verner mentions that some ceilings were designed in a certain way and from strong materials to sometimes withstand 5,000 tons (Verner 1997, 254). Other ceilings were designed with different methods and from more durable materials to withstand much more, as happened in Sneferu's Northern Pyramid at Dahshur, where the ceilings of corridors and chambers inside carry the weight of about 2 million tons of stones.

We can study the royal pyramids from the inside to understand and collect these pressure-relief Techniques innovated by these genius architects:

**2.1.** Some corridors and chambers were carved deep into the rock, making their ceilings rocky. A rocky ceiling is capable of carrying the pyramid's weight, especially if the rock is good, strong, and solid. This occurred in the entrance corridor and h1allways of Djoser's pyramid (Hawass & Smith 2018, 60). There is an entrance carved into the rock on the northern side in the funerary temple leading to a corridor and then to the burial chamber. There are four rock cut hallways around the burial chamber. They are connected to corridors and are prepared to place funerary furniture and numerous vessels. They carved eleven shafts on the eastern side that connect to horizontal corridors as tombs for family members and storage for funerary furniture (Bard 2008, 129) **(fig. 5).**

This idea was also found in the pyramid of Sekhemkhet. There are stairs leading to the pyramid entrance on the northern façade. It includes a descending corridor 60.96 m long with a vertical shaft at the top of the corridor. The corridor leads to an unfinished carved burial chamber. There are two corridors at the end of the stairs, one to the east and the other to the west, leading to the entrance that is surrounded by approximately 136 U-shaped rooms (Goneim 1956, 104, 141).

The same idea was repeated in the pyramid of Khaba. The entrance of the pyramid is located northeast and consists of stairs with 36 steps carved into the rock. These steps lead to a descending passage going west, ending in a shaft carved into the rock that leads upwards to an upper passage heading south, but unfinished. Returning to the depth of the vertical shaft, one finds a lower horizontal passage heading south, then more stairs, and then a horizontal passage leading to the burial chamber (Stadelmann 2007, 247). Its

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dimensions are 3.63 m in length, 2.65 m in width, and 3 m in height. The burial chamber is located 26 m below ground level (Reisner 1936, 135).

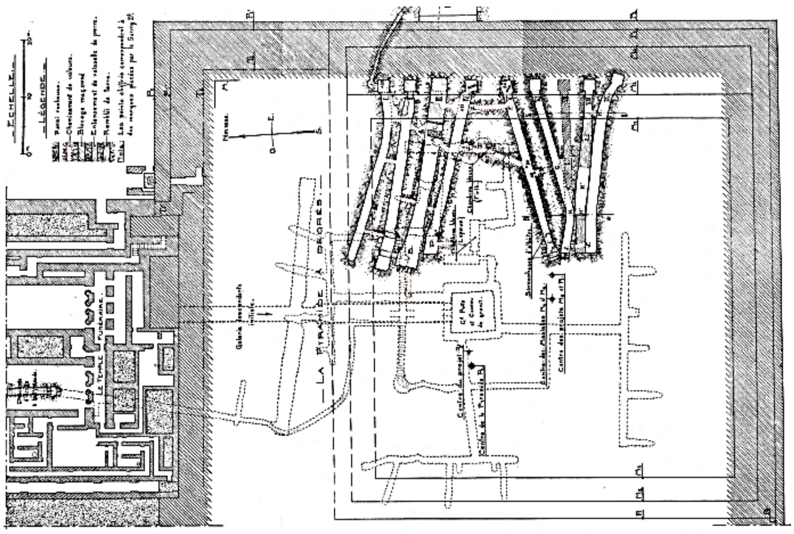

**Fig.5.** Djoser's pyramid from inside (Firth & Quibell 1935, pl. 23).

Khufu applied this technique in the descending passage and the rock chamber. The descending passage extends from the original entrance at a height of 17 m above the ground and is 1.09 m wide, 1.20 m high, and 105 m long. It reaches the depth of the pyramid's floor and continues to descend carved into the rocky floor with a rocky ceiling for a distance of 30 m below the pyramid's floor. Then it extends a further 9 m horizontally to reach the rock chamber. There are longitudinal grooves on its walls that were preparations for removing the remaining rocks and completing the chamber (Maragioglio & Rinaldi 1965, 30).

Khafre imitated his father in carving a rock cut part in his pyramid. It is the lower entrance, passages and chambers. He carved the lower entrance into the mountain's base a few meters from the pyramid's side, leading to a rock cut descending and horizontal passages with a rock chamber with a gabled ceiling (representing a serdab or an offering store) in the west. Then the horizontal passage continues and leads to an ascending passage connecting with the southward horizontal rock passage, which leads to the burial chamber. Its lower part was carved into the rock (Maragioglio & Rinaldi 1966, 52–56). This idea was repeated in the rock cut descending passage within the pyramid of Userkaf (El-Khouly 1978, 35–43).

The concept was not absent in the Middle Kingdom. Some rulers of the Twelfth Dynasty (Amenemhat I, Senusret I, Amenemhat II, Senusret II, and Senusret III) carved burial chambers into their pyramids at great depths into the rock near the groundwater level (Lehner 1997, 171).

The idea wasn't limited only to the burial chambers, as it can also be found in the entrance and the passage leading to the burial chamber in the pyramid of Senusret II at Illahun. A large vertical shaft is located southeast of the pyramid between the enclosure wall and the southern side of the pyramid. This shaft contains a burial chamber for one of the princesses (Tomb No. 10 by Petrie). This burial chamber has a vertical shaft in its floor, leading to a northward horizontal rocky passage. This passage reaches a rectangular chamber with a vaulted ceiling and a niche containing a vertical shaft going downwards. The vaulted chamber leads to a northward ascending passage reaching a second chamber to the west. The passage continues north and eventually leads to a rectangular chamber, oriented east-west. This room leads to another passage and then the burial chamber. This chamber has an entrance in its southeast part leading to a passage and then to another chamber (Petrie et. al. 1923, 9–11, pl. viii).

The idea is also found in the entrance and passage leading to the burial chamber in the pyramid of Senusret III at Dahshur. There is a vertical shaft located in the courtyard northwest of the pyramid between the enclosure wall and the western side of the pyramid, leading to an inclined corridor heading east, then south, reaching three chambers (de Morgan 1903, 87–90, fig. 132).

The concept wasn't absent in the Second Intermediate Period either, found in the burial chamber of the pyramid of Intef VI at Dra' Abu el-Naga. Its entrance was carved in the floor of the antechamber or temple courtyard where steps lead to the rock-cut burial chamber below the pyramid. It also appeared in three unidentified royal pyramids in the same cemetery. The rock cut entrance is in the funerary temple courtyard and leads to a hall with four columns, with a shaft 10 m deep, leading to a passage and then to the burial chamber (Lehner 1997, 188).

**2.2.** The construction of ceilings, walls, and floors of corridors and chambers inside the pyramids with hard, thick stones was to resist the immense pressure on them. These good stones aided the walls in supporting the ceiling. Weakness in the rock in certain areas was the reason for lining the floor and walls of the burial chamber with hard stones. The used stones included good limestone, granite, and quartz, while alabaster and sandstone were used minimally.

The use of stones in construction began from the First Dynasty onwards. Stones were first used for floor paving in Den's tomb at Abydos where granite was used (Arnold 1997, 141). The expansion in the use of stone began in the Third Dynasty (limestone and granite) for building corridors and burial chambers inside pyramids and covering the pyramid's exterior. Some estimate the amount of granite used in the pyramid of Khufu, whether for walls, ceilings, floors, and barricades, to be around 8,000 tons (Romer 2007, 157). The expansion in the use of quartz in pyramids began from the reign of Amenemhat III onwards (Arnold 2003, 230).

Examples of ceiling, wall, and floor corridors and chambers constructed from hard stones include the entrance, descending corridor and chambers of the Red Pyramid, which were built of good quality white limestone (Perring 1842, 16). Khufu built his burial chamber entirely of pink granite, measuring 10 m from east to west, 5 m from north to south, with a height of 5.974 m. The walls consist of five courses and the ceiling is nine massive granite blocks (Kanawati 2005, 55). Each block exceeds 5.5 m in length and weighs between 25 and 40 tons.

Djedefre applied the same idea in the corridor and burial chamber of his pyramid. The entrance leads to a descending corridor 49 m in length and 7 m wide carved into the rock and lined with limestone and granite. The corridor leads to a rectangular burial chamber 22 m long, 9 m wide, and 9 m high, lined with 2-meter thick limestone or granite. The chamber's lining was removed during the reign of Mohamed Ali. Khafre did likewise; the upper entrance leads to a descending corridor lined in walls and ceiling with pink granite. This corridor leads to a horizontal rock-cut corridor that leads to the burial chamber constructed and roofed with limestone blocks (Maragioglio & Rinaldi 1966, 12, 14, 52).

The idea continued in the application in the foundations and flooring of the burial chamber of Nebka, which were paved with strong limestone and granite blocks (Gundacker 2009, 26–30). Each block weighs nine tons to support the walls, which in turn support the ceiling. The walls of the burial chamber were constructed with granite and sandstone (Barsanti & Maspero 1906, 257–286).

Menkaure applied the same idea in the descending corridor, vestibule, and burial chamber. There is an entrance in the middle of the north façade of the pyramid, 4 m above

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the floor level. It leads to a descending corridor 31 m made of granite, then a limestone vestibule, followed by a horizontally rock-cut corridor. This corridor leads to a rectangular chamber that includes in the western part a passage. This passage is connected to a descending staircase, leading to six niches and then to the burial chamber. This burial chamber is carved into the rock 15 m below the pyramid floor and its walls and ceiling were constructed of granite (Fakhry 1963, 214). This king used granite more than any other. It was costly to cut and transport compared to limestone (Lehner 1997, 135).

The idea spread during the Fifth and Sixth Dynasties, as seen in the descending corridor, vestibule, horizontal passage, antechamber, and burial chamber in the pyramids of Userkaf, Sahure, Neferirkare, Neferefre, Neusere, and Pyramid 29 (Hawass 2010, 156). It also appeared in the descending corridor, vestibule, horizontal passage, antechamber, burial chamber, and serdab inside the pyramids of Djedkare (Maragioglio & Rinaldi 1962, 21–28), Unas, Teti, Pepy I, Merenre I, and Pepy II (Jéquier 1936, 5–6). The floors and walls of these structures were made of high-quality limestone from Turah, with parts or all of the corridors covered in granite or limestone. Notably, the western wall of Unas' burial chamber was built from alabaster (Hays 2009 , 215–216).

The idea continued during the First Intermediate Period, specifically in the burial chamber and serdab in the pyramid of Ibi. The walls and ceiling of these chambers were constructed from high-quality limestone (Jéquier 1935, pls. i, ii); (Baker 2008, 302). Additionally, the concept was found in the last part of the corridor and burial chamber inside the pyramid or tomb of Khui, which were built using recycled limestone from previous tombs (Fakhry 1963, 294).

The idea gained acceptance and application in the Middle Kingdom, particularly in the descending corridor inside the pyramids of Amenemhat I and Senusret I at Lisht. The entrance leads to a descending corridor carved into the rock, lined with granite blocks at that of Amenemhat I and by limestone at the beginning then granite in the case of Senusret I. There is no information concerning the burial chamber of the two pyramids as groundwater has filled them (Gauthier & Jéquier 1902, 87, fig. 106); (Lehner 1997, 171).

The concept is similarly found in the walls and ceilings of corridors and chambers inside the pyramids of Amenemhat II (Arnold 2003, 13) and Amenemhat III at Dahshur and Hawara (Edwards 1993, 237), which were built from good limestone. The walls and ceilings of the storeroom and antechamber of Senusret III's pyramid were constructed from good limestone (de Morgan 1903, 87–90). The burial chamber in the pyramids of Senusret II (Petrie et. al. 1923, 6) and Senusret III was built from pink granite. The burial chamber in the southern pyramid at Mazghuna was made from a block of quartz surrounded by walls and ceiling of limestone (Stadelmann 1991, 251).

**2.3.** The architect built the entire pyramid from inside and outside from good quality limestone, as was the case with the pyramid of Pepy I in South Saqqara. It became a target for reuse by neighboring locals (Vyse 1840, 51). In this way, this pyramid differed from others as it was customary to build the chambers and corridors inside pyramids with good quality limestone and also cover the pyramid from outside with the same material sourced from Turah and el Masara.

**2.4.** Constructing each wall of the long walls of the burial chamber inside pyramids from a single block of good stone was used to achieve stability and durability for the walls and to make them capable of carrying the ceiling and resisting pressure. Pepy II's burial chamber followed this way in the north and south walls, where each wall was built from a single block of good limestone (Arnold 2003, 193).

**2.5.** Strong and solid mortar was used in the Old Kingdom pyramids to bind the stones, create adhesion between them, fill the gaps and joints in the stones and between them (Arnold 1997, 118), and act as a divider protecting the walls from cracks and fissures. It was usually placed beneath the stones, except in corridors it was placed vertically between the stones to prevent their descent. This mortar was a mix of gypsum and sand mixed with water to be strong and solid material. It was also used as a filler for cracks and voids in the stones in the walls and ceilings, as happened in some pyramids (Huni and Bent Pyramid). Some believed that the architect used in the construction of the Giza pyramids strong mortar comprising cement made from limestone powder mixed with water and gravel (Harrell 2012, 5–6). The ancient Egyptian realized that when the stones of the walls were cohesive with each other, they became stable and capable of carrying the ceiling and making it able to withstand the pressure above.

**2.6.** The groove method and the round or square tongue, to connect the stones in the casing and side stones of some pyramids and to fix the pyramidion from the Fourth Dynasty onwards (Arnold 1997, 127, 132), were used in our opinion to reduce pressure by dispensing with mortar.

**2.7.** The mortar was absent in the pyramids of the Twelfth Dynasty. The reason for that, from our perspective, is that it represents an additional weight and pressure on the ceilings. They used the dove tail technique, where two adjacent stones are fixed, and then a shape resembling a dove tail is carved at the edge of each stone in the middle, and a wooden piece shaped like a dove tail is used to connect the two stones and is adhered with gypsum (Arnold 1992, 97). Its use began at the valley temple of Khafre and continued in the temples of Userkaf, Sahure, Neferirkare, and Unas. It was limited to weak parts like lintels and made of copper or bronze fixed with nails. Its use increased in the casing of all pyramids of the Twelfth Dynasty and it might be used in the inner building stones (Arnold 2003, 60–61). Sand was used between mud bricks instead of mortar. Senusret III constructed his pyramid from mud bricks without mortar, placed sand between the bricks, and then covered it from the outside with good limestone firmly connected via dove tail technique (de Morgan 1895, 48, fig. 108) **(fig. 6).**

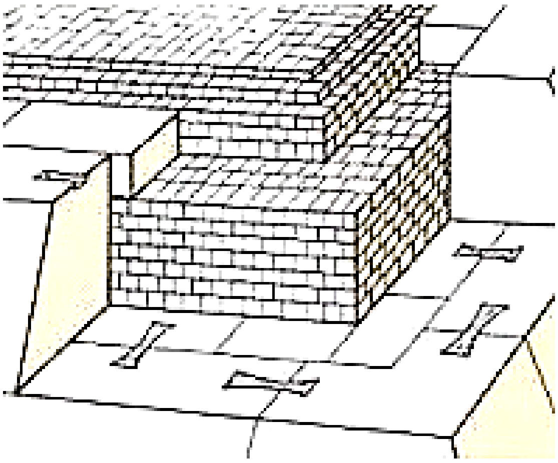

**Fig.6.** Dove tail technique in Senusret III's pyramid (Verner 1997, fig. on p. 422)

**2.8.** Building stones in the lower part of the pyramid are massive blocks to create a sturdy, precise, crafted base capable of supporting what lies above. Architects realized this from their experiences in the two pyramids of Sneferu (Hawass & Smith 2018, 67).

**2.9.** Building stones in the upper part of the pyramid are smaller than those in the lower part, making them lighter on the ceilings of corridors and chambers inside pyramids. This appeared in the Bent Pyramid (Fakhry 1951, 513), where the thickness of the outer casing stones near the base was 178 cm and near the top was 61 cm (Petrie 1888, 29–30). In the Red Pyramid, the thickness of the stones near the base was about 91.5 cm while near the top was 61 cm (Perring 1842, 15). Architects who constructed the pyramid of Khufu used

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stone blocks having a height of 148 cm with each weighing three tons in the lower part, and 50 cm high weighing one ton in the upper part. Similarly, the stones in the upper part of the pyramids of Khafre and Unas were smaller than those in the lower part.

**2.10.** Utilizing the rock outcrop and shaping it as steps to be a part of the pyramid structure helps stabilize the building in place and adds sturdiness against any form of earth movement resulting in cracks and fissures in the chamber and corridor ceilings. This rock outcrop appeared in the pyramid of Khufu (Hawass & Smith 2018, 69) **(fig. 7)**.

**Fig.7.** Rock outcrop as part of the pyramid structure of Khufu (Photo: The author).

**2.11.** Reducing the size of the pyramid alleviated the burden on the ceiling of the chambers and passages inside it. Since the reign of Khafre onwards, the size of the pyramids began to decrease, but the size and decoration of the mortuary temple increased (Lehner 1997, 135). It was planned for Khafre's pyramid to be larger than its current size; evidence of this is the existence of the lower entrance of the pyramid on the ground in front of the pyramid, about 30 m from its body. This design was overlooked and built at a smaller size (Verner 1997, 226). An unknown pyramid next to Khendjer's pyramid was planned to be bigger than what was actually built, with its side measuring 78.75 m (Cimmino 1996, 298). It was the largest pyramid from the end of the Twelfth Dynasty until the end of the Thirteenth. Given its size, layout, and quality, it is likely attributed to an important king from that period (Stadelmann 1991, 251), perhaps Sehetepkare Intef (Ryholt 1997, 194, 244), Neferhotep I, Sobekhotep IV (McCormack 2008, 207), or Djehuti (Theis 2008, 101) from the kings of the Second Intermediate Period.

The pyramids are ordered by height as follows: Khufu – Khafre – the two pyramids of Sneferu – Senusret III – Amenemhat III at Dahshur – Djedefre – Menkaure – Huni – Senusret I – Djoser – Amenemhat III at Hawara – Amenemhat I – Neferirkare – Djedkare = Teti = Pepy I = Merenre I= Pepy II – Niusere – Userkaf – Senusret II – Sahure – Unas – Khendjer – Ameny-Qemau – Ibi – Intef VI – Ahmose at Abydos.

The pyramids are ordered by the length of the base as follows: Khufu – Red Pyramid– Khafre – Nebka (Baka) – Bent Pyramid – Khui – Huni – Djoser – Sekhemkaw – Djedefre – Senusret II – Neferirkare = Senusret I = Senusret III = Amenemhat III in Dahshur and Hawara – Menkaure – Shepseskare – Khaba = Amenemhat I – Niusere – Sahure = Djedkare = Pepy I = Merenre I = Pepy II = an unknown pyramid next to the pyramid of Khendjer – Teti – Userkaf – Neferirkare – Unas – two pyramids of Mazghuna = Khendjer = Ahmose at Abydos – Menkauhor = Ameny-Qemau – Amenemhat II – Ibi – Pyramids of Dra' Abu el-Naga (Intef VI and Kamose and others).

**2.12.** The stones of the core of pyramid or the pyramid from inside are small in all periods. Each stone is usually carried by two persons except for the Fourth Dynasty. In that period, the stones were large and required more people to carry them and different methods in the process of transferring and moving them (Arnold 1997, 159). The smaller stones exert less pressure than the larger stones.

**2.13.** The ancient Egyptian architect constructed the core or body of the pyramid from light materials such as soil, construction debris, and mud bricks and coated it from the outside with good limestone, or built the entire pyramid with mud bricks. This might require building stone structures called 'radiating walls' in the bodies of the pyramids as some kings did (Senusret I, Amenemhat II, and Senusret II). Some kings dispensed with these radiating walls to reduce the further pressure on the ceilings, as Senusret III did in his pyramid at Dahshur. We see from our perspective that the soil, construction debris, mud bricks, and radiating walls are lighter on the ceilings of rooms and corridors than the solid construction composed of stone blocks that were used in construction next to and above each other. Verner suggests that it is as an economical method and suitable way to deal with the intermittent earthquakes that occur in Egypt (Verner 1994, 139).

Mud bricks were used in the construction of pyramids since the First Intermediate Period and became a basic material in the Twelfth Dynasty. This was not only to reduce cost and effort but also because of the availability of clay layers near the sites of those pyramids at Lisht and Fayoum (Verner 1997, 396). Mud bricks were a mixture of brown or gray-black Nile silt, sand, plant fibers, and stone fragments. They were made in wooden molds and left in the sun to dry (Arnold 2003, 34).

We can count the pyramids that were built from sand, soil, and mud bricks and used the radiating walls. It is possible that Khufu used radiating walls filled with sand in the body of his pyramid (Verner 1997, 195). Sahure and Neferirkare built external pyramid walls from huge stone blocks and inner walls from smaller stone blocks around the corridor and burial chamber and filled the space between them with stone fragments, pottery shards, sand, debris, and silt to expedite completion. It is possible that the pyramid of Neferirkare was built in the same way (Verner 1994, 139). Teti used local stones, debris, and soil in constructing the body of his pyramid (Lehner 1997, 156). The exterior casing of the pyramid or tomb of Khui was made of mud bricks and filled internally with sand (Arnold 2003, 66).

The pyramid of Amenemhat I at Lisht was constructed internally with local limestone blocks and filled with sand, soil, and mud bricks (Lythgoe 1907, 113). The pyramid of his successor, Senusret I was constructed internally by building radiating walls filled between them with mud bricks, sometimes lesser stones, construction debris, and sand. Eight massive walls and eight shorter walls were built inside the pyramid of Senusret I, forming several small chambers made from good quality limestone, which were filled with gravely sand (Fakhry 1963, 309-310). Amenemhat II built his pyramid at Dahshur internally with radiating walls and chambers of limestone filled with sand and soil (Grinsell 1947, 161).

The pyramid of Senusret II was constructed internally in radiating walls of limestone, with gaps between them filled with mud bricks. The pyramid's body was completed with mud bricks (Petrie et. al. 1923, 3). He was the first king to construct his pyramid internally with mud bricks (Arnold 2003, 35). Senusret III built the body of his pyramid from differently sized mud bricks and placed sand between the gaps without radiating walls. The exterior was coated with good limestone (de Morgan 1895, 48, fig. 108). The pyramid of Amenemhat III at Dahshur was built internally with mud bricks in the form of steps (Vyse 1840, 71). The body of the pyramid does not include radiating walls to strengthen the building, unlike his predecessors since the beginning of the Twelfth Dynasty (Verner 1997,

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396–397, 422). Amenemhat III built the body of his pyramid at Hawara with radiating walls filled between them with mud bricks (Edwards 1993, 238) **(fig. 8).**

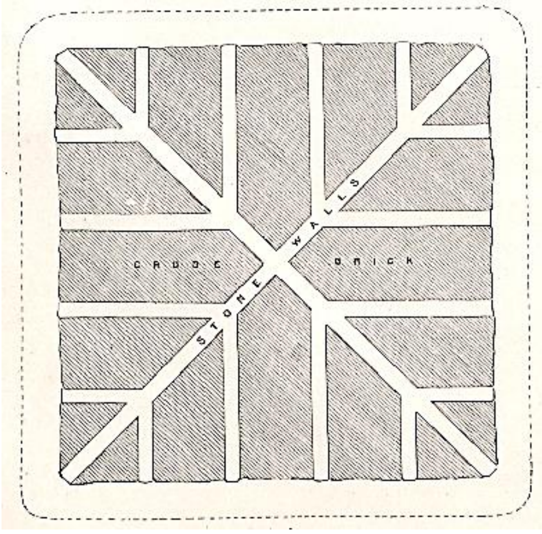


**Fig.8.** Radiating walls in the core of Amenemhat III's pyramid at Hawara (Perring 1842, pl. xviii, fig. 2)

The construction of the southern pyramid of Mazghuna was not completed, with only two courses of mud bricks remaining from the pyramid's body (Petrie et. al. 1912, 41). The body of Khendjer's pyramid (Arnold 2003, 122) and another unidentified pyramid next to it were built from mud bricks. All the pyramids of the Seventeenth Dynasty were built entirely from mud bricks at Dra' Abu el-Naga (Fakhry 1963, 339).

**2.14.** The external casing made of limestone from the Mokattam hills was abandoned in the pyramids of the Seventeenth Dynasty at Dra' Abu el-Naga and was replaced with a layer of plaster (Lehner 1997, 188). We observe that the external high quality of limestone casing of the pyramid represents a burden and weight on the body of the pyramid, chambers, and passages inside it. It often had large sizes, was made of heavy materials, inclined inward towards the center of the pyramid, and added extra weight.

**2.15.** Creating empty chambers between ceilings and/or filling them with small-sized stone pieces were used to lighten the load on the main stone blocks and to provide space in case of earthquakes and movement of the main blocks. This occurred in the burial chamber of Djoser at Saqqara, which has a flat lower granite ceiling, then an empty space, followed by a domed upper ceiling of limestone (Verner 1997, 164). Similarly, the idea is found in the pyramid of Khufu at Giza, where above its burial chamber are five closed chambers from all sides, hollowed in the middle with a height of one meter (Maragioglio & Rinaldi 1965, 24).

Neuserre applied the same idea in his pyramid at Abusir. The ceiling of the burial chamber consists of three layers of high quality of Turah limestone on top of each other, shaped in a gabled form and is separated by small-sized stone pieces (Borchardt 1907, 103) **(fig. 9).**

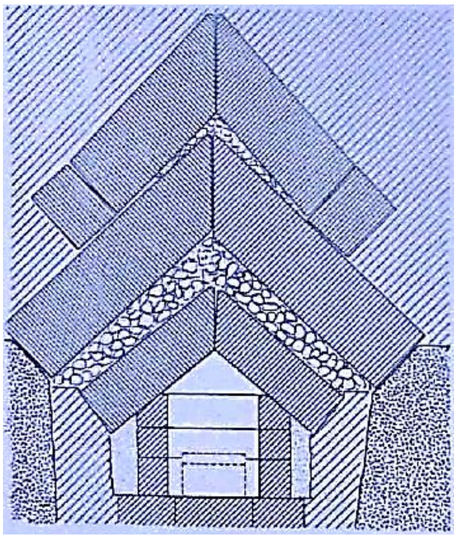

**Fig.9.** Ceiling and walls of Neuserre's burial chamber (Arnold 1997, fig. 4.129).

The idea was repeated in the Middle Kingdom in the passage and burial chamber of the pyramid of Amenemhat II. The ceiling of the chamber and passage is flat and is followed by an empty space, then a gabled ceiling to lessen the upper pressure (de Morgan 1903, 32–35, figs. 77–81). Amenemhat III followed the same approach in his pyramid at Hawara. The first ceiling of the burial chamber is flat, composed of three massive quartz blocks and is followed by an empty space. There is another ceiling from high quality limestone in a gabled shape, topped by a vaulted ceiling made of mud bricks. Mud bricks are found in the empty space between the second and third ceilings (Petrie 1890, pls. iii, iv); (Petrie et. al. 1912, xli).

**2.16.** The Egyptian kings built their pyramids at a high place away from the Nile flood and groundwater and selected a strong rocky base that is, as much as possible, capable of carrying the weight of the pyramid. They constructed foundations as a stone base for the body of the pyramid if the ground is weak. They chose the Western Desert as a place to build their pyramids for doctrinal and religious reasons. However, it was not practically successful due to the lack of good limestone and the weak ground compared to the Eastern Desert, which has good stones and a stable and strong ground (Arnold 1997, 159).

There are no foundations for the pyramids of the Third Dynasty, because the architect relied on the inward tilt of the stones as a means of stability and firmness for the structure. Khaba decided to build his pyramid on the edge of a high rocky hill at Zawyet El Aryan (Reisner & Fisher 1911, 56). Huni built the inner part of his pyramid at Meidum on rocky ground, while the outer part was constructed on sand (Mendelssohn 1974, 84). The rock in that area was poor (Rowe 1931, 6).

Sneferu chose Dahshur to construct his two pyramids in the depths of the desert at elevated locations away from flooding. After experiencing the Bent Pyramid, builders noticed that the foundation consisted of sand and weak rock was unable to support the pyramid's weight. They attempted to address the cracks in the casing and within the pyramid by adding construction around and creating a foundation consisting of five rows of stones at the corners to a depth of 3 m, placed below the pyramid's side walls (Arnold 1997, 110). When building the Red or Northern pyramid, the builders decided to place a foundation of several layers of good-quality limestone to prevent the sinking problem (Petrie 1888, 26). Foundations in the Old Kingdom were usually composed of three layers of stones: the lower foundation, the foundation itself, and the floor slabs or paving (Arnold 2003, 94).

Builders learned from previous experiences at Dahshur pyramids that the chosen location for pyramid construction must be solid rock and must have a strong foundation to


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support the structure (Hawass & Smith 2018, 67). The Giza plateau is considered one of the best locations for constructing pyramids. Nowadays, with the rise in groundwater levels, moisture never reaches the underground parts inside the pyramid (Fakhry 1963, 177). This was among the reasons why Khufu abandoned Dahshur and chose the Giza area for building his pyramid, due to the lack of adequate space for constructing a large pyramid, insufficient limestone in the area, and unstable ground composed of gray clay. Therefore, he decided to choose another location. It was the rocky prominence in the desert near Giza, characterized by strong, solid rock terrain and abundant good limestone (Verner 1997, 194). The base and part of the pyramid's interior were formed from the rocky ground up to a height of 6 m in some parts (Lehner & Hawass 2017, 214). A flat layer beneath the casing was sufficient in a shallow ground cavity in the Giza pyramids (Arnold 1997, 110).

Djedefre chose a hard rocky prominence in Abu Rawash, which is about 155 m above the level of the Nile Valley (Maragioglio & Rinaldi 1966, 10). When Sahure decided to build his pyramid in Abusir, he chose a location that was only about 20 m above the Nile Valley. The ground was not suitable, so the architects made a base consisting of at least two layers of good stones to build the pyramid on them. The same idea was implemented in the pyramid of Neferefre (Verner 1997, 283, 304). Neferirkare chose the highest point in Abusir, which rises 33 m above the valley level, to ensure that his complex dominated the surrounding areas (Krejčí 2000, 476). Neuserre built his pyramid on a layer of limestone as a foundation topped by another thin flat layer. The thickness of the two layers together is 1.20 m (Arnold 1997, 111). Pepy I chose his location in Southern Saqqara, away from the hustle and bustle of the Djed-sut neighborhood in the capital adjacent to the pyramid of Teti (Malek 2003, 104), on a high rocky outcrop (Lehner 1997, 157). Pepy II built his pyramid on a high hill in Southern Saqqara. Cracks occurred during construction, prompting him to try to strengthen the base of the pyramid by building a wall around it and covering it with stone blocks up to the height of the enclosure wall (Arnold 2003, 173).

The builders of the Middle Kingdom pyramids (Amenemhat II, Senusret II, Senusret III, and the owner of the southern pyramid at Mazghuna) dug a trench around the pyramid and made it a base for placing one to three layers of stones beneath the pyramid's casing. This was done to strengthen and stabilize not only the casing but also the entire pyramid, especially since the pyramid was constructed with lower-quality materials (Verner 1997, 399). Clean, sifted, dry sand was placed in the trench to provide protection against groundwater and earthquakes. It was also to fulfill a religious purpose, as it symbolized the eternal mound on which sanctuaries should be constructed. Since the Twelfth Dynasty, it was customary for the foundations to be stones reused from earlier buildings. The ground was leveled by spreading blocks and small stone pieces from reused materials over the surface. This did not add strength and durability to the construction, as these pieces were small and uneven, causing varying pressure and cracks in the blocks above them (Arnold 1997, 112–113).

Amenemhat I built his pyramid at Lisht on an elevated rocky platform. The temple was constructed on another, lower platform higher than the causeway (Lythgoe 1907, 113). Similarly, Senusret I built his pyramid on a prominent elevated hill, 2 km south of his father's pyramid, with the body of the pyramid constructed on a terrace of stone blocks (Verner 1997, 399).

Architects aimed to avoid mistakes made during the construction of Amenemhat III's pyramid at Dahshur when building his pyramid at Hawara. They employed all precautions to protect the pyramid from cracks, collapse, and theft. They chose a more suitable ground than at Dahshur and built it on a desert plateau over a layer of stones as a foundation. The pyramid of Intef VI was built at Dra' Abu el-Naga in western Thebes on a high rocky protrusion above the base on which the temple was constructed (Lehner 1997, 182, 188).

Most kings of the Twelfth Dynasty did not adhere to this rule, but they built their pyramids in low-lying areas near the valley on weak base and foundations. Amenemhat II chose a location at the edge of the desert near the valley rather than deep in the desert (Petrie 1888, 26). Architects selected an elevated section of yellow limestone rock on the edge of the desert and shaped into four steps to serve as the base and body for the pyramid of Senusret II at Illahun (Petrie et. al. 1923, 3). Senusret III chose the desert edge near the valley, north of Dahshur to construct his pyramid on clean sand and gravel (Perring 1842, 15).

Amenemhat III began constructing his pyramid at Dahshur from his first year until the fifteenth year of his reign (Haney 2018, 545). He decided not to be buried in this pyramid and to build another pyramid at Hawara. This decision was due to technical reasons, as the pyramid was built on a weak soil foundation of compacted mud in the Dahshur desert. Additionally, the pyramid was constructed near the valley and lake of Dahshur, which he wanted to be an advantage and benefit to him. It is closer to sea level than any other pyramid at an elevation of about 33 m above sea level. When groundwater rises due to high sea levels, Nile floods, or water from the Dahshur lake, it reaches the pyramid base and increases its instability (Lehner 1997, 179).

The southern pyramid at Mazghuna was built on gravel soil (Petrie et. al. 1912, 41). Furthermore, Ameny-Qemau constructed his pyramid near the lake of Dahshur (Swelim & Dodson 1998, 319).

**2.17.** Most of the chambers were carved into the rock below the ground level of the pyramid (Arnold 1997, 120), often in the form of an open trench to the sky, with walls and ceilings built from stones as did Neferfre **(fig. 10)**. The rock around the chambers was to withstand the pressure and alleviate it from the walls. The chambers at or above ground level within the pyramid's core were rarely constructed, as it was found in the pyramids of Sneferu, Khufu, Sahure, and Neferirkara (Verner 1997, 455). This increases pressure on the walls and ceilings of the chambers and makes them prone to cracks and breaches, as happened in the Bent Pyramid and Khufu's Pyramid. This last pyramid features a crack in the ceiling near the southern wall (Maragioglio & Rinaldi 1965, 48).

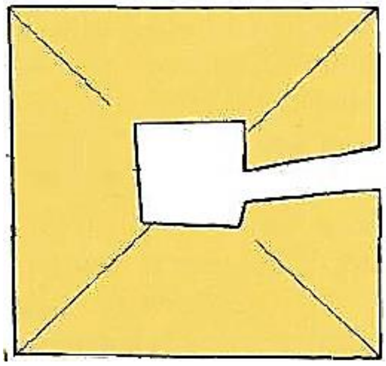

**Fig.10.** Pyramid of Neferfre (Lehner 1997, fig. on p. 146).

**2.18.** The architect created the base and foundation of the pyramid from solid stones beneath the floor of some chambers. Djoser's burial chamber rests at the bottom of the shaft on 24 small distinctive columns made of local stone (Arnold 1997, 109). Nebka carved his burial chamber into the rock, open to the sky, and lined its floor with four layers of granite and limestone (Reisner 1936, 135) to make it capable of supporting the walls. These walls would be strong enough to carry the ceiling, which in turn would be capable of carrying the pyramid's weight.

**2.19.** The builder carved the burial chamber as a single block of solid stone or carved its floor and walls as one single block, with the ceiling composed of two or more blocks made from the same solid stone. This was a security measure against theft and caused that the solid


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stones withstand the pressure exerted on it. This tradition first appeared in the Late Middle Kingdom in the burial chamber of Amenemhat III’s pyramid at Hawara, where a rectangular pit was dug into the rock and lined with limestone. A massive block of quartz weighing 110 tons was placed in it, with the burial chamber carved inside, and three large quartz blocks were placed as the ceiling of the chamber (Edwards 1993, 239) (**fig. 11).**

The idea was repeated in the burial chamber of the southern pyramid at Mazghouna (Stadelmann 1991, 251) and Ameny-Qemau’s pyramid at Dahshur (Swelim & Dodson 1998, 324). They were carved into a single block of quartz. Khendjer adopted the same idea for his burial chamber in his pyramid. He carved the chamber into the rock, placed a massive block of quartz hollowed out in the middle to form the burial chamber, and placed two massive quartz blocks as the ceiling of the chamber (Arnold 1997, 75, 130). A similar method is found in the burial chamber of an unknown pyramid near Khendjer’s pyramid. It was carved into the rock and had a massive block of quartz hollowed out in the middle to form the burial chamber with a sarcophagus. Three massive quartz blocks were placed as the ceiling of the sarcophagus (Jéquier 1930, 110).

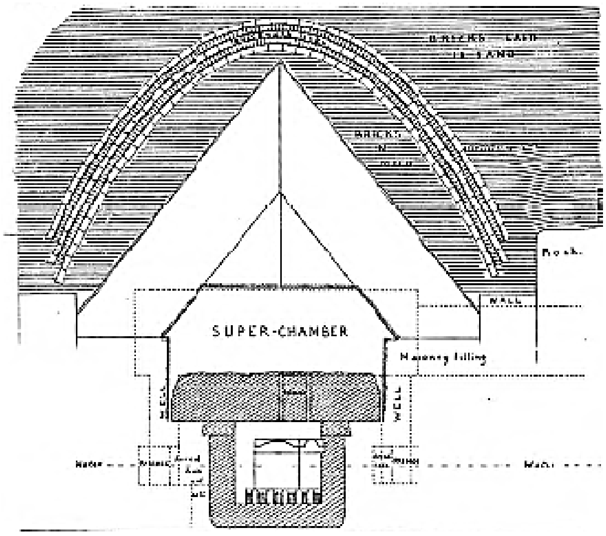


**Fig.11.** Burial chamber of Amenemhat III at Hawara (Petrie 1890, pl. iv).

**2.20.** Reducing the number of passages and chambers inside the pyramids is important because a large number of them can weaken the base and body of the pyramid, making it unable to support the weight of the pyramid above. Some pyramids contained only one chamber, such as the pyramids of Khui and Amenemhat II. Other pyramids had two chambers, like the pyramid of Djedefre, Sahure, Neferirkare, Neferefre, Neuserre, Ibi, Khendjer (Jéquier 1933 , pl. viii), and the southern pyramid at Mazghouna (Stadelmann 1991, 251).

Most pyramids from the beginning of the Fourth Dynasty contained three chambers: an antechamber, the burial chamber, and a storage room or serdab. This became the prevailing pattern in the Old Kingdom (Lehner 1997, 111) and was seen in pyramids of Sneferu, Khufu, Khafre (with a rocky chamber in the horizontal passage and a burial chamber that divided into two chambers but the dividing walls disappeared), Userkaf, Pyramid 29, Djedkare, Unas, Teti, Pepy I, Merenre I, Pepy II, Senusret III, and an unknown pyramid next to the pyramid of Khendjer at South Saqqara.

A large number of passages and chambers appeared in the pyramids towards the end of the Middle Kingdom to mislead thieves, complicate matters for them, and secure the pyramid against theft, but this contributed to the weakening of the construction (Lehner 1997, 185, 187). This occurred in Senusret II’s pyramid, where beneath the body of the pyramid are four chambers, along with two chambers and a niche and three shafts outside the body of the pyramid (Porter & Moss 1968, 106). There is also an entrance in the southern part of the passage between the burial chamber and the forward chamber that leads to a passage encircling the burial chamber and opens onto it in the northwest. This northern passage might have been used by the soul to move northward toward the chapel and the northern polar stars. The passage surrounding the burial chamber might have made it like an island, linking it to Osiris. The numerous, winding passages resemble the paths and passages of the afterlife (Lehner 1997, 176, 179). The number of chambers even increased to seven in the northern pyramid at Mazghouna (Cimmino 1996, 294–295), attributed to Sobekneferu (Porter & Moss 1968, 76), or one of the kings of the Thirteenth Dynasty.

The number of chambers reached approximately 24 as Amenemhet III's pyramid at Dahshur. It included many passageways and chambers beneath its eastern and southern sides for the king and two queens **(fig. 12)**. The idea of the southern tomb of Djoser and the subsidiary pyramid was later replaced by six chapels carved beneath the southern side of this pyramid of Amenemhet III. This increased the weakness of the pyramid's base that already fragile, made it unable to support the body of the pyramid, and led to cracks and fractures. This pyramid is the most chamber-containing pyramid since the Third Dynasty. So, the king abandoned the pyramid and decided to build another one in Hawara. The architects learned from the chamber multiplication mistake in the pyramid of Dahshur and decided to reduce the number of chambers at Hawara to only five chambers (Edwards 1993, 240).

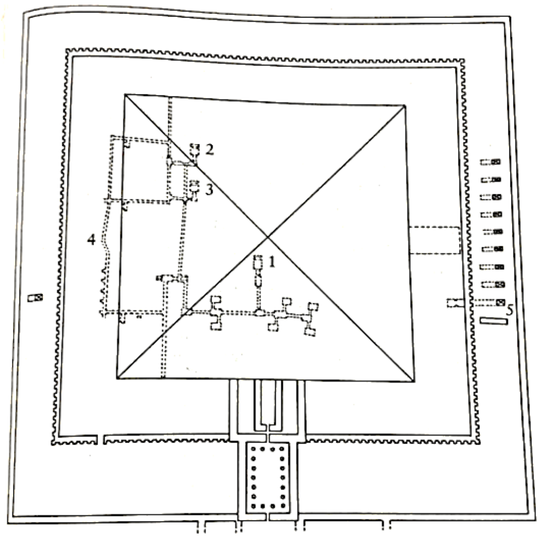


**Fig.12**. Pyramid of Amenemhat III at Dahshur (Verner 1997, fig. on p. 425).

**2.21.** Building a stepped ceiling aimed at relieving pressure on the ceiling and dispersing it to the sides to prevent collapse. This was evident in the burial chamber of Huni (Hawass & Smith 2018, 62), all the chambers inside the two pyramids of Sneferu **(fig. 2)**, and the Great Gallery inside Khufu's pyramid (Stadelmann 1991, figs. 22, 24, 28, 30).

**2.22.** Constructing a single gabled ceiling, made from a single layer of stones, aimed at distributing the weight and pressure from the construction above (Lehner 1997, 111). This appeared in the ceiling of the Queen's Chamber and the ceiling of the fifth chamber in the pressure relieving chambers above Khufu's burial chamber (Perring & Engineer 1839, pls. ii, viii); (Dormion 2004, 259) **(fig. 4)**.

**2.23.** The architect built two gabled ceilings with two large layers of Turah limestone, stacked one above the other and the top one is bigger, aimed at increasing safety in relieving pressure on the ceiling. This style was seen in the ceiling of the burial chamber and the antechamber of Userkaf (Stadelmann 1991, 159).

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**2.24.** The ancient Egyptian builder constructed three gabled ceilings with three layers of large stones stacked on top of each other, where each upper layer consists of larger stones than the one beneath it. This aimed at increasing safety in relieving and dispersing pressure on the ceiling. This style appeared from the early Fifth Dynasty onwards and was found in the burial chamber of Sahure's pyramid (Borchardt 1910, 68, pl. 12), and in the burial chamber and antechamber of the pyramids of Neferirkare (Borchardt 1909, 39–40, fig. 47), Neuserre (Perring 1842, 6, pl. vi) **(fig. 9)**, Djedkare (Megahed et. al. 2017, 50), Teti (Arnold 2003, 243), and Pepy I (Lauer 1976, pl. 154 ).

**2.25.** There is a single vaulted ceiling of some burial chambers and corridors in royal pyramids (Menkaure **(fig. 1)**, Djedkare, Senusret II, Amenemhat III at Dahshur, and the southern pyramid at Mazghuna) and the central chamber of Senusret III's pyramid. The vaulted ceiling was used to prevent the massive weight of the pyramid resting above the burial chamber from breaking it.

**2.26.** The architect constructed two ceilings, a flat one topped by a vaulted one. This appeared in Djoser's burial chamber. Here, a pit was carved into the rock 28 m deep. At the bottom, a rectangular burial chamber of granite stones was constructed. Above it is another chamber with a now-ruined vaulted limestone ceiling (Fakhry 1963, 60). A similar design was found in the burial chamber of the southern pyramid at Mazghuna. It was carved entirely out of quartz with a flat ceiling topped by a vaulted limestone ceiling (Stadelmann 1991, 250) **(fig. 13).**

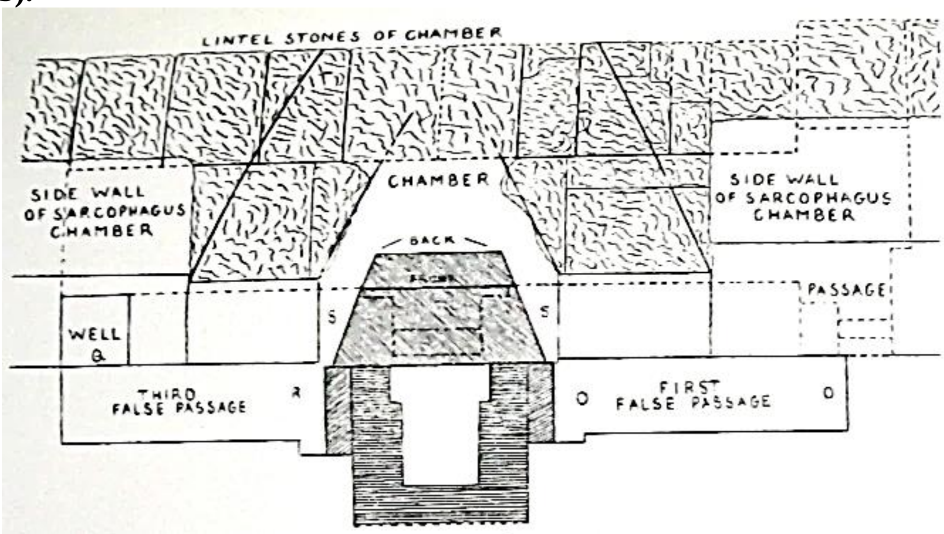


**Fig.13**. Ceiling of burial chamber of the southern pyramid at Mazghuna (Petrie et. al. 1912, pl. xl)

**2.27.** The ancient Egyptian built two ceilings, a flat one topped by a gabled ceiling, as in the corridor and burial chamber of Amenemhat II's pyramid. The flat ceiling is topped by an empty gap, then another gabled ceiling to relieve upper pressure. This gabled ceiling of the burial chamber is composed of six double blocks leaning on each other (de Morgan 1903, 32–35, figs. 77–81) **(fig. 14).**

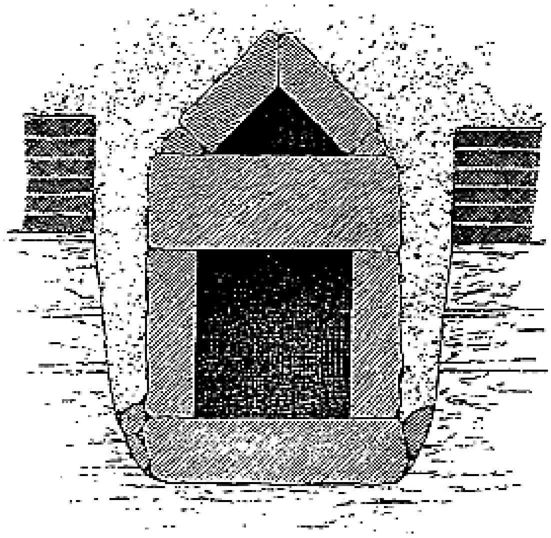

**Fig.14.** Flat and gabled ceilings of the corridor and burial chamber of Amenemhat II's pyramid at Dahshur (de Morgan 1903, fig. 80).

**2.28.** The ancient builder constructed three ceilings for the burial chamber. These are a flat one, topped by gabled and vaulted ceilings. This is found in the burial chamber of Amenemhat III at Hawara **(fig. 11)**. The architects dug a rectangular pit, lined it with limestone, placed a massive quartz block inside, and carved the burial chamber. Then they placed three massive quartz blocks as a flat ceiling of the chamber. They made a gabled limestone ceiling above it, then a vaulted mud brick ceiling on top (Edwards 1993, 237–240). Similarly seen in the burial chamber of Khendjer (Arnold 2003, 122).

**2.29.** The architect built three ceilings for the burial chamber. These are a vaulted one, topped by a gabled one and another vaulted ceiling. This type appeared in the rectangular granite burial chamber of Senusret III's pyramid. It includes a vaulted granite ceiling, topped by a gabled limestone one and a vaulted mud brick one. (Lehner 1997, 177).

**2.30.** The builders of Giza pyramids constructed three ceilings, consisting of a flat one, topped by two gabled ceilings. This was evident in the descending passage of the main entrance of Khufu's pyramid, where the original entrance to the pyramid is 17 m above ground level. Above the entrance passage are a flat limestone ceiling topped by two layers of large limestone blocks in a sloped gabled ceiling shape, each layer 2 m thick (Arnold 1997, 191) **(fig. 3).** This roofing system possibly extends along this descending passageway down to the ground level of the pyramid (Haase 2004, 13). Similar construction is found in the descending passageway from the main entrance of Khafre's pyramid (Maragioglio & Rinaldi 1966, 52).

**2.31.** A unique design was used in the passage of Neferirkare's pyramid (Verner 1997, 293). It is constructing three ceilings, consisting of a flat limestone one, topped by a gabled stone ceiling, and followed by a third layer of reeds (Perring 1842, 6). Perhaps the purpose of the reeds was to protect the ceiling from cracks and fractures (Arnold 2003, 35).

**2.32.** A flat rocky ceiling that covers a rock cut chamber or passageway was used to carry weight and pressure of the portion above it, especially if the rock's nature was solid and good. This style is found in many lower passages and chambers of pyramids carved into bedrock **(fig. 4).**

**2.33.** A unique style is found in Khufu's burial chamber. They constructed six ceilings. Five of them are flat and the sixth is gabled. The ceiling of the burial chamber is built from pink granite in a flat style rather than a gabled shape. Above this ceiling, five limestone rooms are stacked on top of each other, enclosed on all sides. These rooms are one meter high each and were intended to relieve the weight of the pyramid from the flat ceiling of the

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king's chamber. Four of them have a flat pink granite ceiling similar to the burial chamber's ceiling, but the fifth room has a gabled granite ceiling (Maragioglio & Rinaldi 1965, 24) **(fig. 4).**

**2.34.** Sometimes the ceiling was made to rest on rock instead of walls, believing that the rock was stronger and could carry more weight than the walls. This was found in the third, vaulted mud brick ceiling of Amenemhat III's pyramid at Hawara, which is 7 m high (Arnold 2003, 14) **(fig. 11).**

**2.35.** The stones of the vaulted ceiling were connected at the edges in a zigzag pattern rather than a straight line. So, the edges interlock and do not fall due to applied pressure. This occurred in the ceiling of the chambers in the pyramid of Senusret III and Amenemhat III at Dahshur (Arnold 1997, 199) **(fig.15).**

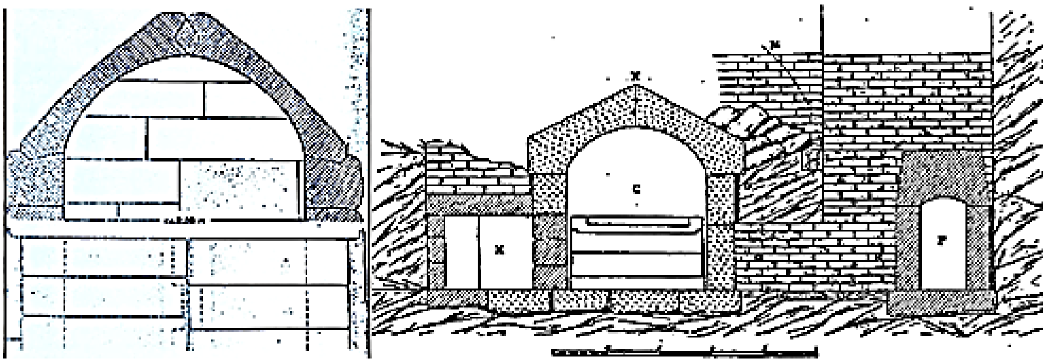

**Fig.15**. The edges of the vaulted ceiling of burial chamber of Senusret III at Dahshur are connected with each other in a zigzag pattern (de Morgan 1903, fig. 133)

**2.36.** The Egyptian architect built front walls as a lining for the internal walls of the burial chamber that support the ceiling. The reasons for this are to ensure that these external walls do not carry any pressure to prevent breaking or cracking and from our perspective, these front walls act as reinforcement and support for the walls that carry the ceiling behind them. This is found in the burial chamber of Neuserre (Arnold 1997, 191).

**2.37.** The passageways inside the pyramids were filled with stones to secure what was valuable and to hinder thieves. Another purpose might have been to protect the ceiling from cracks and fractures. This happened in the western entrance passage and the rooms inside the Bent Pyramid. This entrance is located 33 m above the base and leads to a descending passage 64.63 m long and 1.10 m high. This passage leads to the burial chamber and includes two barriers. The entire passage was filled with massive stone blocks that are not easy to move. Small flat limestone stones were found filling the rooms (Fakhry 1951, 510, 512).

This way was repeated in the ascending passage of Khufu's pyramid. It is located 27.4 m deep from the main entrance inside the pyramid and adjoins the descending passage with a height of 1.2 m and a width of 1.05 m, extending 37.7 m long. This passage leads to the Grand Gallery and the horizontal passage leading to the Queen's chamber. The passage narrows at the beginning to about 0.97 to block stopper stones. After the burial was completed, this passage was filled with granite blocks stored in the Grand Gallery. Some of which were found in the lower part of this passage (Perring & Engineer 1839, 2, pl. ii). The number ranges from 25 to 26 blocks (Arnold 2003, 126). It is likely that the descending passage in the pyramid of Teti was filled with stone blocks broken by thieves.

This idea was also found in the Middle Kingdom, where the upper descending passage in the pyramid of Senusret I at Lisht was filled with granite blocks and sand was placed at the end of the passage to prevent the granite blocks from falling into the chamber (Arnold 1992, 101). There is a passage directly connecting the burial chamber and the entrance passage in the pyramid of Senusret III at Dahshur, blocked with stones (de Morgan 1903, fig. 132); (Perring & Engineer 1839, pl. viii) **(fig. 16).** Most of the chambers and passages inside the pyramid of Amenemhat III at Dahshur were filled with limestone and mud brick to preserve the pyramid from collapse due to the cracks and fractures that occurred in it. Likewise, some passages and shafts, in the pyramid of the same king at Hawara, were filled with stones (Fakhry 1963, 323–325).

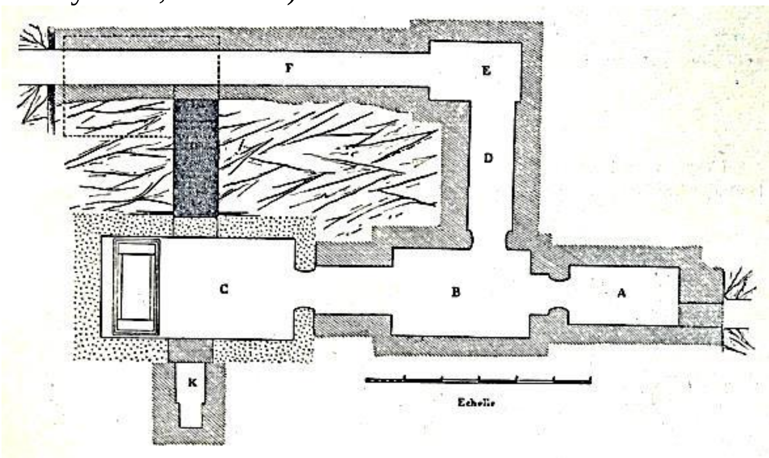


**Fig.16**. Passage connecting the burial chamber and the entrance passage in the pyramid of Senusret III at Dahshur, blocked with stones (de Morgan 1903, fig. 132).

**2.38.** Wooden cedar beams were used to tie the top of the walls and reinforce them. This was either an attempt to prevent cracks and fractures in the ceiling and walls, or a desire to reinforce the pyramid against the cracks that had already occurred (Mendelssohn 1974, 80, 115). This is found in the burial chamber of Huni's pyramid and Bent Pyramid **(fig. 17)**, as well as some chambers of Amenemhat III's pyramid at Dahshur.

**Fig.17**. Wooden beams in the burial chamber of the Bent Pyramid (Photo: The author).

**2.39.** The mud brick arches supported by props resting on the walls were used to carry the vaulted ceiling. This is seen in the entrance passage of the tomb or pyramid of Khui at Dara near Manfalut (Kamal 1912, 128, fig. 1) **(fig. 18).**

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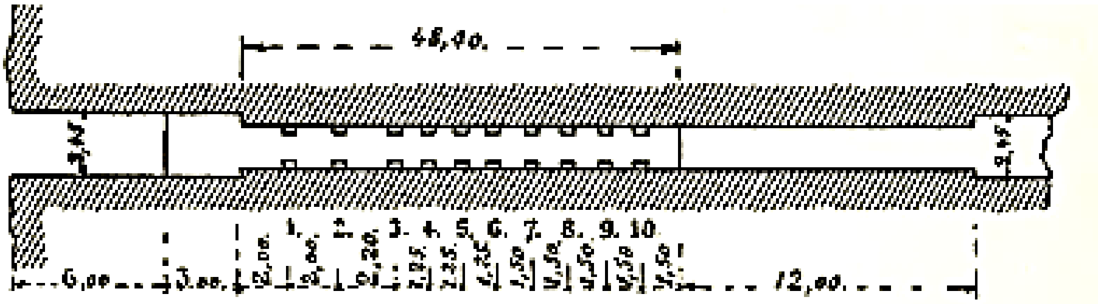


**Fig.18.** Entrance passage of the tomb or pyramid of Khui at Dara (Kamal 1912, 128, fig. 1)

**2.40.** The stone blocks in the ceiling are thick to withstand the pressure on them and not too long to avoid breaking from the weight on them. This happened with the ceiling blocks in the burial chamber of Khufu, which are 2 m thick and 5.25 m long (Arnold 1997, 183). Moreover, these stone blocks in the flat ceiling are not excessively long or deeply recessed in order to reduce their weight and not to be an additional burden on the walls, increasing the pressure on them. This was observed in the ceiling of the chambers in the Pyramids of Senusret III and Amenemhat III at Dahshur (Arnold 2003, 47).

**2.41.** Changing the angle of pyramid construction and reducing it were used for fear of the bigness of the building and the occurrence of cracks in the ceilings and walls of chambers. This happened in the Bent Pyramid of Sneferu at Dahshur where builders initially started with an angle of inclination of 60 degrees, and midway through the construction, they found cracks had occurred in the external casing. At that point, they decided to add a construction around the pyramid with a thickness of 15.75 m at a lower angle of inclination, 54 degrees. However, it was too late as cracks and fractures had occurred in the internal chambers. They attempted to control these cracks by several methods, including filling them with plaster, placing new casing on the walls, and using imported cedar trunks to support the walls. None of these attempts succeeded, and they decided to further reduce the angle from 54 to 43 degrees, so the pyramid became bent or curved. Had they not changed and reduced the angle, this pyramid would have been the largest one in Egypt. This change also occurred in Amenemhat III's pyramid at Hawara, which was constructed with a building angle of 48 degrees, lower than his pyramid at Dahshur (56 degrees). They were afraid that the collapse and cracks, which occurred in his pyramid at Dahshur, happen again in second pyramid at Hawara (Arnold 2003, 13).

**2.42.** The architect changed the construction method followed in the Third Dynasty. This method had the stones and mortar tilt inward to achieve sturdiness and support the structure and to ensure the coherence of the stones, not to fall (Hawass & Smith 2018, 59). This was evident in the pyramids of Djoser, Huni (Verner 1997, 163), and Khaba (Reisner & Fisher 1911, 56) **(fig. 19).** It continued in the lower part of the Bent Pyramid. When the angle was changed due to cracks and fractures, architects noted that tilting the stones and mortar inward increased the pressure on the internal chambers and corridors, thus builders placed the stones and mortar horizontally to alleviate the pressure (Hawass & Smith 2018, 62). This last method became prevalent in the Red Pyramid (Perring 1842, 15) and most subsequent pyramids. Djedefra returned to the old style with the inward-tilting stones in his pyramid (Lehner 1997, 120).

**Fig.19.** Stones and mortar tilt inward in Khaba's Pyramid (Photo: The author).

**2.43.** The granite portcullis or barrier was used to block the horizontal passage of the pyramid and to prevent thieves from entering the pyramid. It is viewed from our perspective as helping to support the ceiling. This is especially relevant since this part often had its walls and ceiling constructed from granite around the portcullis, taking the shape of pliers or jaws. The walls and ceiling of the horizontal passage behind the portcullis were built with granite to prevent thieves from breaking through the ceiling of this passage and entering the burial chamber. The portcullis was often sculpted from granite and sometimes from quartz. The number of these portcullises in a single pyramid ranged from one to four, either adjacent or spaced apart at the beginning or near the end of the same passage, or in two passages. The common pattern was two or three barriers. These barriers appeared in pyramids from the Bent Pyramid onwards. They were placed in the ceiling and dropped using pulleys, cylinders, rollers, or operated like the concept of a sliding door as in the Middle Kingdom, where they were moved on a wooden rod or on a sloped floor (Arnold 2003, 179, 224).

We can identify pyramids with a single barrier as that of Khafre, Sahure, Neferirkare, Ibi, and Ameny-Qemau. Pyramids with double-barrier are exemplified by the Bent Pyramid, Userkaf, Pyramid 29 of Lepsius, Amenemhat II, the two pyramids of Mazghuna (each barrier in a corridor) and Khendjer.

Three barriers appear in the pyramids of Khufu, Menkaure, Neuserre, Unas, Teti **(fig. 20)**, Pepy I, Merenre I, Pepy II, and Amenemhat III at Hawara.

**Fig.20.** Granite portcullis in the horizontal passage of Teti's pyramid (Photo: The author).

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Pyramids with four barriers include the pyramid of Djedkare, where the first barrier is located at the beginning of the horizontal passage made up of three barriers, followed by another barrier near the end of the passage consisting of a single barrier (Verner 1997, 326). There was a plan for an unknown pyramid next to Khendjer's pyramid to contain four barriers (McCormack 2010, 80).

Senusret II did not adhere to the idea of barriers, as evidenced by the absence of them in his pyramid. The reasons for that are that the architects changed the entrance location from the normal location (north) of the pyramid to a new and unexpected location (south), from the body of the pyramid to a distant location, and closed the main shaft of the entrance to use it as a tomb for one of the princesses. Similarly, Senusret III did not adhere to the concept of barriers, because his architects changed the entrance location from the north of the pyramid to the west and from the body of the pyramid to a distant location in the ground (Arnold 2003, 215).

**2.44.** The niche walls of the serdab, which appeared inside pyramids from Menkaure onwards, help to support the room's ceiling and carry the pressure of the pyramid's weight along with the outer walls as we suggest. This view is confirmed by the fact that the ancient Egyptian architect followed several methods, such as using the gabled, vaulted, and multiple ceilings to protect the ceiling of the antechamber and burial chamber from the pressure above them. The niche walls of the serdab are sufficient as an auxiliary means for the walls to support the flat ceiling of the serdab and withstand the pressure on them.

**2.45.** The drainage of water that falls on the pyramid's body was to prevent it from seeping inside the pyramid or its base and weakening it. There is a well 40 m deep in the northwest corner of the courtyard surrounding the mortuary temple of Teti. It is surrounded by a limestone wall (Verner 1997, 344). It is likely used either to store water for pyramid construction and daily rituals or to drain water falling on the pyramid (Firth & Gunn 1926, 9–10). A rock cut trench was found around Senusret II's pyramid and filled with sand to absorb rainwater (Lehner 1997, 175), preventing it from adding extra weight and pressure on the ceiling.

**2.46.** A well was dug to measure, identify, and monitor the groundwater level so that the chambers could be constructed away from the groundwater level. The ancient architect wanted to be sure that these rooms were strong, stable, and capable of carrying the ceiling and the ceiling itself was away from the groundwater level to be able to support the pyramid's body. This was done in the niche of Senusret II's pyramid, which includes a vertical well descending downward. We haven't reached its depth yet due to groundwater (Petrie et. al. 1923, 6) **(fig. 21).**

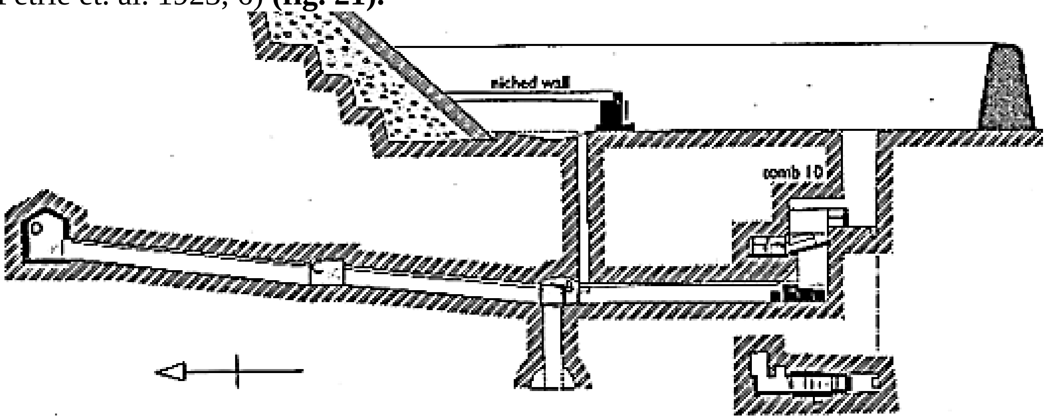


**Fig.21.** Vertical well in Senusret II's pyramid at Illahun (Arnold 2003, fig. on p. 215).

Amenemhat III built his burial chamber at Hawara near ground level, away from groundwater. It seems that the proximity of some Twelfth Dynasty pyramids (Amenemhat

I, Senusret I, Amenemhat II, Senusret II and III) to the valley and carving some burial chambers underground level deep in the rock, close to groundwater, may have been due to the king's desire for connection and proximity to the realm of Osiris (Lehner 1997, 171, 182). The rise of groundwater in the burial chambers of Amenemhat I and Senusret I was the reason for digging that well in some subsequent pyramids.

**2.47.** Changing the burial chamber's location from the pyramid's central axis to one of the sides might have been intentional from our viewpoint, not an architectural error as some believe. This was to relieve pressure on the ceilings of the rooms and corridors inside the pyramid since they are topped by less weight from the pyramid's body compared to the rooms directly under the pyramid's center. This occurred in Senusret II's pyramid, where the burial chamber and passages are in the pyramid's southeast section rather than its vertical axis (Porter & Moss 1968, 106). Similarly, the burial chamber and passages of Senusret III's pyramid are in the northwest section (Fakhry 1963, fig. 112). It is also found in Amenemhat III's pyramid in Dahshur, where the king's passages and rooms occupy the southeast, while the queen's passages and rooms occupy the southwest (Petrie 1890, 5, pl. ii) **(fig. 12).**

**2.48.** The architect avoided multiple entrances and preferred a single main entrance with a descending passage. Multiple entrances and passages caused structural weakness for the pyramid. This mistake was done by Sneferu in his southern pyramid and Amenemhat III in his first pyramid at Dahshur and forced them to abandon their pyramids. Sneferu's southern pyramid contained two main entrances. The northern entrance leads to a descending passage, then to two rooms and the burial chamber. The western entrance leads to a descending passage, then a horizontal one and the burial chamber. Cracks appeared inside the pyramid. Amenemhat III's pyramid at Dahshur contains two entrances, one for the king in the southeast and another for the queens in the southwest. Each entrance contains descending stairway, then a horizontal passage leading to various passages and rooms beneath the pyramid base **(fig. 12)**. Cracks and fractures appeared in the pyramid.

## CONCLUSION

The analysis of ceiling types across pyramidal architecture from the Third to the Eighteenth Dynasty reveals four primary structural styles: vaulted, stepped, gabled, and flat ceilings. Among these, the gabled and flat types dominated due to their structural efficiency and symbolic significance. While vaulted and stepped forms appeared sporadically, their limited use suggests experimentation or context-specific functions. The stepped ceiling may have required significant effort during construction, making it less favored by ancient Egyptian architects, while the vaulted ceiling was likely considered insufficiently safe to withstand the pressure placed upon it—especially in burial chambers or main corridors—which also limited its use.

The ancient Egyptian architect employed various methods to reduce the pressure on the ceilings of chambers and corridors within pyramids, aiming to protect them from collapse and ensure their ability to bear the weight above. These methods involved careful selection of the pyramid's foundation, the floors, foundations, and walls of internal rooms and corridors, as well as the number, shape, and thickness of the ceilings and spaces between them. Pressure relief was also achieved through the strategic positioning and number of chambers and corridors, the construction techniques and materials used, the size of the stones, the pyramid's core and casing, its overall size and angle of construction, and surrounding elements such as trenches, shafts, and basins. Additional measures included the use of stone portcullises, filler materials, ceiling supports, and wells to monitor groundwater levels and avoid its impact on structural stability.

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Some pressure-relief techniques appeared only during specific periods or were used exclusively in a single pyramid, either due to their high cost—such as constructing an entire pyramid from high-quality limestone as Pepy I did—or because the required conditions weren't available, such as the good and solid rocky outcrop shaped into steps within Khufu's pyramid. The variety of techniques used within a single pyramid reflects the ancient architect's careful efforts to protect the structure and fulfill the belief in the pyramid as an eternal home. This explains the remarkably preserved condition of the Giza pyramids, as the Giza Plateau offered one of the best locations for pyramid construction. Among the reasons Khufu abandoned Dahshur in favor of Giza were the limited space for a large pyramid, the scarcity of quality limestone, and the unstable clay-rich ground. Instead, he chose a rocky desert prominence near Giza with a solid, durable foundation and an abundant supply of good limestone. Even today, despite rising groundwater levels, moisture does not reach the parts of the pyramid below ground level.In the three Giza pyramids, all four ceiling types were employed, along with Twenty-four distinct pressure-relief techniques (numbers 1, 2, 5, 6, 8–11, 13, 15, 16, 20–22, 25, 30, 32, 33, 37, 40, 42–44, 48), Twenty-Two of which were found in Khufu's pyramid alone.

There were some architectural errors in pyramid construction, such as adding many entrances, corridors, and chambers, which weakened the structure, as well as building on unstable ground near the valley. Some features considered by researchers as mistakes—like placing the burial chamber to the side rather than beneath the pyramid's central axis—are, in our view, intentional and clever decisions aimed at reducing the load on the chamber by distancing it from the heaviest pressure point. Ancient Egyptian architects learned from past errors and avoided repeating them in later constructions. For instance, they addressed the flaws of the Bent Pyramid when designing the Northern Pyramid, avoided the mistakes of Sneferu's pyramids when building Khufu's pyramid, and corrected issues seen in the Black Pyramid of Amenemhat III while constructing his pyramid at Hawara. Architects also responded quickly to issues during construction. When cracks appeared in the Bent Pyramid's outer casing, they added a 15.75-meter-thick layer at a reduced angle (54°), but internal cracks had already begun. They attempted several solutions—filling gaps with plaster, adding new wall casings, and using imported cedar beams to support the walls. When these failed, they changed the pyramid's angle to 43°, resulting in its bent shape. They also observed that inward-leaning stone and mortar placement increased pressure on internal spaces, so in the upper part of the Pyramid, they shifted to horizontal layering to reduce stress. Similarly, cracks during the construction of Pepy II's pyramid led architects to reinforce its base by building a surrounding wall and covering it with stone blocks up to the height of the enclosure wall.

Some architectural elements used as pressure-relief methods served multiple purposes simultaneously. For example, stone portcullises and the stone-filled corridors inside pyramids were not only intended to block tomb robbers after burial, but also functioned structurally by supporting corridor ceilings, absorbing pressure, and preventing cracks. Likewise, the niche walls in the serdab chamber, besides dividing the room into niches, helped carry the ceiling and shared the weight of the pyramid with the outer walls. The well next to some pyramids may have been used to store water for construction or daily rituals, and possibly to drain rainwater falling on the pyramid, which could otherwise weaken the structure. Carving the burial chamber as a single block of solid stone—or carving its floor and walls from one block with a ceiling made of two or more slabs from the same material—was both a security measure against theft and a structural solution, as the solid stone could bear heavy pressure. Using the natural rocky outcrop shaped into steps as part of the pyramid body accelerated construction, helped anchor the structure in place, and added stability against seismic shifts that might otherwise cause cracks in ceilings and corridors. The construction of frontal and facing walls in burial chambers served as a lining for the main and inner walls that supported the ceiling. This design ensured that the outer walls did not bear any vertical pressure, preventing them from cracking or breaking. From our perspective, these facing walls also acted as reinforcement, supporting the load-bearing walls behind them that carried the ceiling.

The religious significance had a stronger influence than practical considerations in the selection of pyramid locations. The ancient Egyptians chose the Western Desert for constructing their pyramids based on religious and ideological beliefs, despite it being a less practical choice due to its lack of quality limestone and weaker ground stability compared to the Eastern Desert, which had more suitable building materials and stronger terrain.

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# الطرز المعمارية للأسقف وتقنيات تخفيف الضغط عليها في الغرف والممرات داخل الأهرامات الملكية المصرية القديمة

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## بيانات المقال

**تاريخ المقال**

تم الاستلام في ١٥ مايو ٢٠٢٥

تم استلام النسخة المنقحة في ١٢ سبتمبر ٢٠٢٥

تم قبول البحث في ٣ نوفمبر ٢٠٢٥

متاح على الإنترنت في ١١ نوفمبر ٢٠٢٥

## الكلمات الدالة

الأهرامات – المقابر الملكية – السقف – الضغط – الممر الهابط – الحجرة الأمامية – حجرة الدفن – السرداب – مقبي – جمالون – متدرج – مسطح.

## الملخص

يتناول البحث الطرز المعمارية لأسقف الممرات والحجرات داخل الأهرامات الرئيسية للملوك دون الملكات ودون أهرامات الكا منذ بداية الأسرة الثالثة وحتى بداية الأسرة الثامنة عشرة. وقد تم حصر تلك الأسقف في أربعة طرز معمارية. وتم دراسة الوسائل المعمارية المتبعة لتحمل ومقاومة وتخفيف الضغط على أسقف تلك الممرات والحجرات داخل الأهرامات الملكية. تنوعت تلك الوسائل على مدار ألف ومائتيَ عام وأظهرت مدى براعة المعماري المصري القديم لمواجهة مشكلة الضغط والثقل الواقع على السقف. فقد صُممت بشكل معين ومن مواد قوية لتتحمل أحياناً آلاف الأطنان، وصُممت أسقف أخري بأساليب أخرى ومن مواد أكثر صلابة لتتحمل ملايين الأطنان. ورغم كل الإحتياطات لم يوفق بعض المعماريين أحياناً وظهرت بعض الشروخ في الجدران والأسقف في بعض الأهرامات. ولم يستسلموا وحاولوا اتباع وسائل أخرى لمعالجة تلك المشاكل وجعل السقف قادراً على تحمل الضغط ومقاومته. كانوا غالباً ما يتبعون أكثر من وسيلة في الهرم الواحد لضمان فاعليتها وتحقيق الهدف المرجو منها.