ZEITSCHRIFT
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HERAUSGEGEBEN VON

FRITZ HINTZE UND SIEGFRIED MORENZ †

96. BAND

ZWEITES HEFT

1970

AKADEMIE-VERLAG · BERLIN

IN ARBEITSGEMEINSCHAFT MIT J. C. HINRICHS VERLAG · LEIPZIG

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INHALT

Miszellen:

Eusebius hat uns eine neuplatonische Interpretation des heiligen Tieres von Elephantine bewahrt[35]. Nach ihm weisen die Hörner auf die Konjunktion von Sonne und Mond im Zeichen des Widders. Die blaue Farbe des Götterbildes symbolisiert die Kraft des Mondes, die in dieser Konjunktion das Wasser besonders anzieht. Natürlich sind manche Deutungen der antiken Schriftsteller übertrieben und wirken gekünstelt, doch zeigt das archäologische Material der Spätzeit immer deutlicher, daß sie oft nicht bloße unbegründete Erfindungen sind, sondern letzten Endes aus ägyptischen Priesterkreisen stammen.

WIESŁAW B. KOZIŃSKI

The Investment Process of the Cheops Pyramid (Some Problems)*

I.

1. The present paper concerns an example of a well organized and highly succesful building activity, dating back from 4500 years ago, and records a high organizational capability of the human mind, manifested at the time when the modern facilities, at our disposal today, were lacking.

The investment cycle for the construction of the Great Pyramid – the topic of the present study – is but one link in an important process from which has been derived the term "Pyramid Age". The singularity of this particular process lies, among other factors, in our being able to pursue successively the principal stages of evolution of this vast cyclic investment programme.

2. It was initiated during the rule of the IIIrd Dynasty. The total volume of the enterprise undertaking was to be some two million cubic meters; work were continued for some 55 years, yet none of these pyramids were brought to completion.

While the IVth Dynasty ruled, constructional work on at least seven royal pyramids was maintained. No less than five of them reached completion, the first king of IVth Dynasty brought to completion three pyramids with a total volume of more than 3 million cubic meters. Chu-fu, the second king, built the largest of all pyramids: it is also the one most accurately and carefully built. Its volume is some 2.6 million cubic meters, and it took 23 years to put it up.

All in all, the IVth Dynasty managed to build more than 8.5 million cubic meters of pyramids during a period of 119 years. Only one king of this Dynasty omitted building a pyramid.

The Vth Dynasty began the construction of 8 pyramids, with a total volume of somewhat less than 1 million cubic meters; this work lasted 149 years. The VIth Dynasty began the construction of four pyramids, with a total volume of somewhat less than half a million cubic meters; this work lasted 164 years.

While the IIIrd Dynasty ruled, some of the functions performed had not yet been given formal titles[1], but it is probable that during the time of the IVth Dynasty all the most important functions were attested by formal titles. During the reign of Vth and VIth Dynasties titular functions are distinctly recorded[2]. The VIth Dynasty rule brought a loosening of the national structure.

[35] Porphyrios: De imaginibus Eusebius. Praep. ev. ed. Gaisdorf (III, 12). Th. Hopfner, Fontes historiae religionis Aegyptiacae, Bonn 1922—1925, 471.

* Vorgetragen bei der Ägyptologischen Arbeitskonferenz zu Leipzig im Mai 1968.

[1] A. M. Murray published their list: Index of Names and Titles of Old Kingdom, London 1908. Later publications are: K. Bauer, Rank and Titles in the Old Kingdom, Cambridge 1960; W. Helck, Untersuchungen zu den Beamtentiteln des ägyptischen Alten Reiches, Glückstadt 1954; I. Pirenne, Histoire des institutions et du droit privé de l'ancienne Égypte I, Bruxelles 1932, and H. Junker, Giseh, I—XII, Vienna 1929—1955.

[2] H. Junker, op. cit.

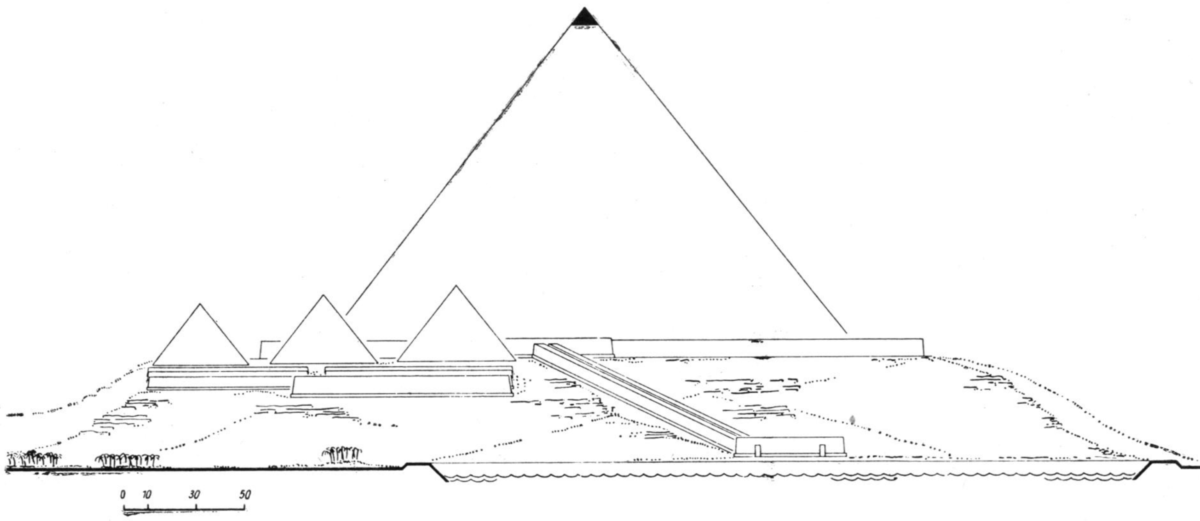

Fig. 1. Great Pyramid complex (reconstruction)

3. The reason for selecting the group of the Great Pyramid for our investigations was: its age, its size and the quantity of accounts available on this object, for example, by Herodotus[3], from funerary inscriptions, etc. (Fig. 1).

4. The gaps in our reconstruction due to missing data we have filled-in by such interpretations as seemed the most suitable among those justified from a technical point of view, for instance, as to the work done by fellahs we assumed in our calculations that this work has been uniformly cyclic during each building season. This conjecture seems admissible in view of the undeniable technical finesse exercised by the builders of the Great Pyramid. We limited our reconstruction of ancient organization to discovered elements.

5. The determination of the purpose for the building of the pyramids was changing in the space of centuries. The XIXth cent. brought the theory dominating up to now, of the religious end of the pyramids, i. e. securing a safe tomb. Middle Ages considered as economic-social purpose, Pliny[4] pointed out a political end etc.

On the basis of all facts known at present we can state that the builders of the first pyramid did not increase at all the security of underground tomb by a fourfold rebuilding of the traditional mastaba and transforming it into a pyramid. It does not seem probable that the King Snefru built three pyramids for himself for religious reasons. The religious theory is not able to explain why the builder of Great Pyramid obtained the security of the tomb of Queen Hetep-heres by hiding the place, not by the superstructure. Why Chu-fu took care of a splendid finish of pyramid and ceremonial causeway and neglected the finish of his sarcophagus, although it stood on its place in pyramid for at least the last six years of building. Finally, why the powerful lock inside the pyramid was never finished and used, while the outer lock was fully realized. The conclusion that the Great Pyramid has never become the tomb of its investor was drawn first by Diodorus Siculus[5]. In conclusion – we have to state that the religious end of constructing – with reference to the Great Pyramid at Giza should be considered as titular one, as a pretext for gaining other ends.

Despite the appearances the presumption that the builders of the pyramids did not leave any written account on the aim of building is not exact. The political importance of these investments is denoted by the original names of the pyramids: "the place of splendor of King Snefru", "King Snefru is great", etc. Also the names of working teams employed at building, such as "Chu-fu inspires love"[6], "Chu-fu is powerful", etc., seem to denote the political-educative importance of

[3] Herodotus, History XX, 124.
[4] Pliny, Nat. Hist. XXXVI, 16.
[5] Diodorus Siculus, History I, 63—64, for G. I. Grinsell, Egyptian Pyramids, Glocester 1947.
[6] G. A. Reisner, Mycerinus, Camb. Mass, 1931, p. 275.

the building process. The account of Herodotus that the workers received food from the state, completed by Petrie that the work was done, in principle, during the technological involuntary unemployment in agriculture, lead to the conclusion that the building process had social-economic aims.

It can be noticed that this idea was clearly presented in Polish literature in a book by Marcin Bielski published in Kraków in the year 1551[7]. The opinion of J. M. Keynes is similar. (The General Theory of Employment, Interest and Money, London 1946, p. 131.)

6. The investment process of the Great Pyramid was executed ca. 4558 years ago. The Turin Papyrus determines the period of the reign of the pyramid investor as 23 years. Manetho, 1000 years younger suggests 40 years more. The first account agrees with Herodotus. The pyramid was built for 20 and the ramp for 10 years. From the viewpoint of technology these two periods should partialy overlap. 20 years cycle of construction agrees also with Diodorus.

The Great Pyramid was built ca 60 years after that of Zoser. A quick development of organization of big investment process is an evidence of abilities of really old builders.

7. In principle all basic technological processes applied at the construction of pyramids were laborious, simple and known to us. If we accept the perfect accuracy of execution of a huge mass of prefabricated products as an indicator of general quality of production – taking into account the mean level of technology and tools of copper age – we have to assign the results obtained to the "human factor", to efficiency of motivation and effective organization of work.

8. The technical basis of the Egyptian middle and long-range transport of the Pyramid Age was only sliding of goods by teams of people pulling ropes.

In transportation limited to workshop and mounting purpose the levars were used. If the fulcrum is good a levar enables 20-fold levarage, which was enough for pyramid builders. For example the lifting up of the pyramidion required elevation od 146 m by means of ramps and scaffoldings. The scaffolding, most probable not a crane has been applied. The scaffolding of short wooden beams similar to that described by Herodotus is applied commonly up to these days, for example it was used in the rebuilding of Poniatowski viaduct in Warsaw in 1946. The analogy is supported by fact that the ancient Greeks did not separate strictly scaffolding from machine.

The total displaced mass reached ca 7.000.000 tons of big blocks, having often a high standard of finish, thus very susceptible to damage. In addition to the transportation of goods, every year a quantity of ca 100.000[8] and later of 360.000[9] of working personnel was displaced.

When from contemporary point of view estimating the transport of the pyramid construction, we should set a highest value on its organizational aspect.

9. The extremely high quality of surveying and of the stonecutter's handicraft, who prefabricated the casing stones was summed up by Petrie as follows: "Building precision was the most perfect in Great Pyramid . . . the average mistake on the side length of 230,4 m is 1 : 4000. This is the quantity, which would arise in measure made of copper at the temperature difference 15 °C. This ist the work rather of opticians than of stonecutters"[10]. In the case of the Great Pyramid the solution of such a difficult problem as e. g. the meeting at the corner of 2 planes of oblique elevations at the angle of 51° 52′, and the prefabrication of casing, above all a diorite five-side pyramidion, without the substitute of a workshop draft seems incredible. The only material durable enough for this and available in ancient Egypt was stone. The workshop drafts was a model necessary, corresponding in a scale to the required under 0,5 mm accuracy of the casing. In the light of actual mason practice the model should have been executed in the scale ca 1 : 5. In this case the design-model primarily executed should have the measure of a side of the base ca. 35 m. The final design-model should have the measure of a side of the base ca. 46 m (Fig. 2).

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[7] "They did so to keep the people busy, as they were afraid of it idling the people might have taken to the bad". M. Bielski, Chronicle of all World, Kraków 1551.

[8] Herodotus, op. cit. XX, 125.

[9] Diodorus, op. cit. I, 63—64.

[10] W. M. F. Petrie, The Pyramids and Temples of Gizeh, London 1888, p. 88, and after him Edwards, Eg. Pyr. I, p. 229.

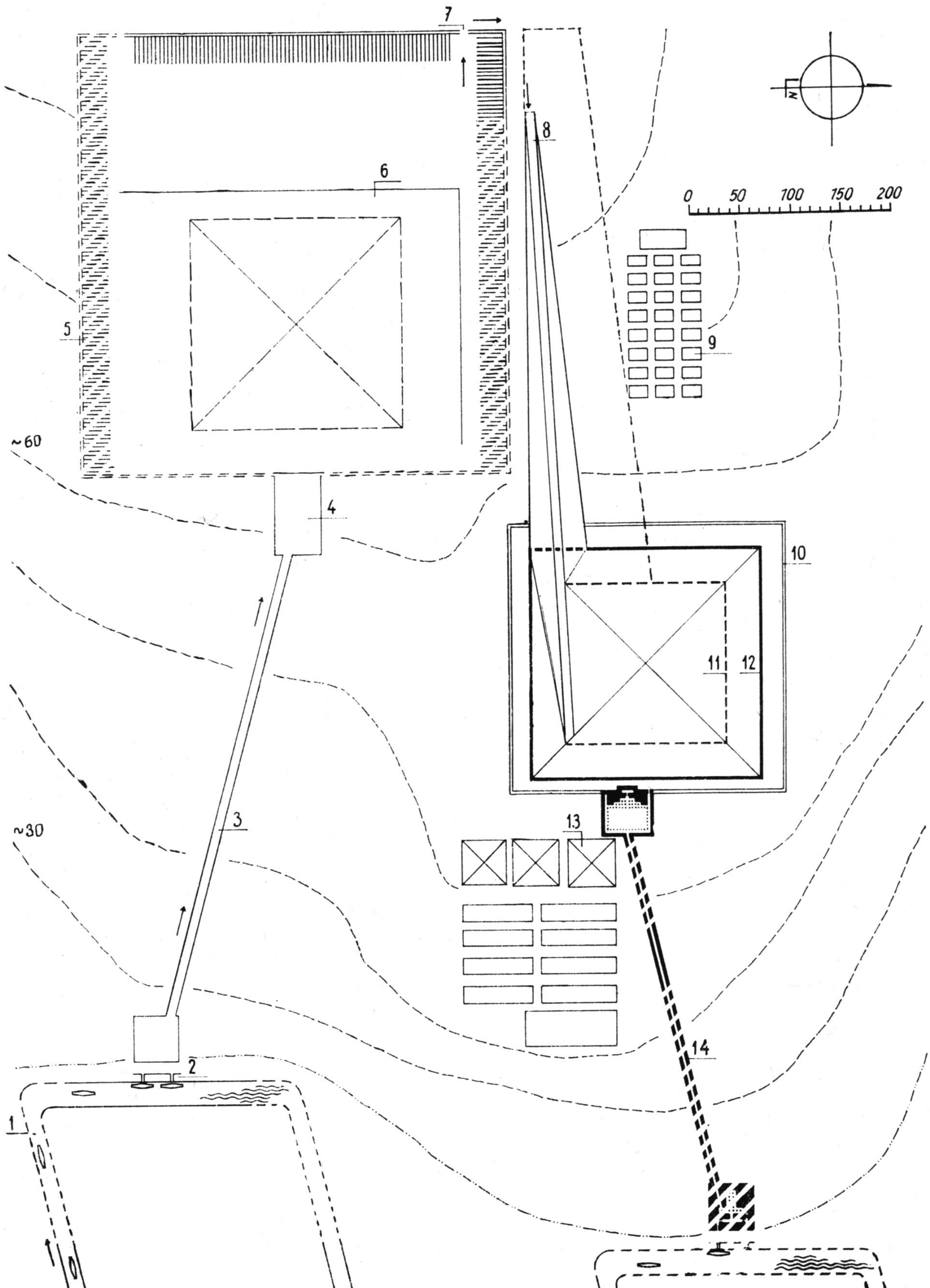

Fig. 2. Site-plan of the Cheops pyramid in ca. 20th year of the construction. — 1., 2., 3., 4. The IInd construction transportation system of Cheops pyramid changed in the temple and ramp complex of Chephren. — 5. The dwellings of craftsmen. — 6. The desert workshop. — 7. The workshop gate. — 8. The west ramp. — 9. The cemetery of the Cheops time. — 10. The builders yard wall. — 11., 12. The pyramid in construction. — 13. The design models. — 14. The Ist transportation system changed in the Cheops temple and ramp complex.

Adopting the hypothesis that the so called subsidiary pyramids were used as workshop model-designs seems to condition the technical probability of prefabricating precision elements.

The relics of these 3 subsidiary pyramids in spite of the damage and inexact measurements, permit to notice a gradual growth of size in the direction from the south to the north. From the analysis of location it appears that the southern, smallest model pyramid was the earliest. The model of the 2^{nd} design was probably the central pyramid.

The northern, appears the biggest, it is most damaged. Its location edged between the tomb of Hetepheres I and temple of Chu-fu seems to be compulsory. Reisner had discovered the traces of shifting it south wards after starting the foundation works. The workers preparing the place for building met evidently unexpectedly the entrance to the tomb of Queen mother.

This proves that this pyramid was the latest.

10. It was possible to move the prefabrication works from Giza to Aswan for the King's Chamber. The precision of execution of granite elements is an evidence of infallible using up the information sent on almost 1000 km distance. The comunication service met the requirements with precision. Its effectiveness rested however not on the communication technique, in fact a simple one, but on the ability of the executors and their organization.

11. It is doubtless that the pyramid is a work of many thousands of people. Petrie's view, that a great majority of these people were employed at building only in the flow season seems indisputable. Seasonal gathering and feeding of enormous human masses was an amazing organizational achievement, indeed, but this problem is not the subject of my study.

Looking from the viewpoint of work organization it seems that the efficient work of a great number of workers, mostly seasonal, on a strictly limited working space would not be probable without the existence of a settled organization composed of specialists of various classes, passing from one construction of a pyramid to the next one, for example from Maidum to Dahshur [11]. This was confirmed by archaeological research. Such a permanent organization – the building enterprise, does not gather only technical and organizational experiences, but must have a seat and material basis, also a topic of this paper.

The differentiation of functions of preserved titles, terrain and technology are an evidence of organizational division in at least five automatic units in the nature of enterprises:

The enterprise of the direct construction of the pyramid, probably with a section of land and water transport, acting partly seasonally.

The enterprise of casing prefabrication called "The desert workshop" at Giza [12] divided into 2 parts: northern and southern [13].

The enterprise of the state quarry at Tura. The enterprise of the state quarry at Aswan, a separate one in view of a long distance.

The enterprise of tunnelling works and construction of the necropolis. The secret of the location of the tomb of Queen Hetepheres I kept to the pyramid builders is an evidence of the independent activity of this absolutely separated organizational unit.

This organization integrated of 5 parts would be at present undoubtedly called "United Works and Constructors of Pyramid".

12. The relics of courtier titles and builder's marks on the blocks of stone show the organizational systems applied at pyramid building [14]. The continuity of exploitation of the underground quarries at Tura with a limited working space made the use of slave work for example of prisoners possible. In the builder's yard of the pyramid the conditions were different.

Up to the end of the VI^{th} Dynasty there was no account about slave labor [15], on the contrary, a decree of Men-kau-re protected the workers from forcing them to do more work than provided for

[11] A. Varille, A propos des pyramides de Snef-ru, Cairo, 1947, p. 10.

[12] Reisner, op. cit. p. 83.

[13] W. Helck, Bemerkungen zu den Pyramidenstädten im Alten Reich, MDAIK, 15, 1957, 93.

[14] A. Rowe, in Reisner, op. cit. p. 275, and Grinsell, op. cit. p. 85.

[15] J. Pirenne, Histoire de la civilisation de l'Égypte Ancienne, Neuchâtel-Suisse 1962, p. 183.

in the contract. The number of the pyramid building crew was changed at least four times. During the period of building of the Hetepheres tomb and of preparatory works it was relatively small. During the execution of the Ist design it increased many times. Another time the crew increase during the execution of the IInd or on the beginning of the IIIrd design. Petrie mentions that there were traces of speeding up the building (Fig. 3, 4).

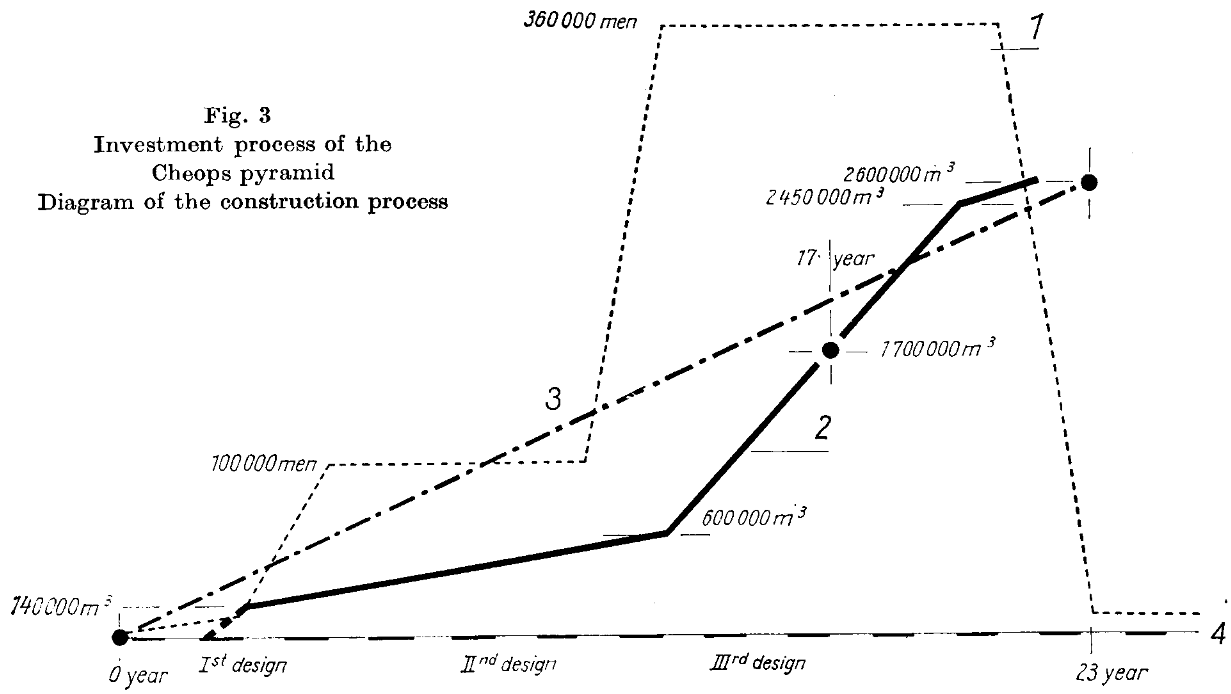

Fig. 3
Investment process of the
Cheops pyramid
Diagram of the construction process

1. employment number curve
2. mean increment of the pyramid volume
3. real increment of the volume
4. years of the Cheops reign

On the basis of calculations it seems right to admit that the account of Herodotus about 100.000 workers refers to the employment in the course of the execution of the Ist design, while the crew mentioned by Diodorus – 360.000 worked after the increase of the building speed. Taking into account a tendency of increase the building rate along with the reduction of working space it is probable that in the last period the principle of using up the forced labour only in flow seasons was given up, and the building was continued all year long. In such case we can admit for example 60.000 people worked out of building place at Giza, and the rest within 3 seasons of the year, in contingents à 100.000 people.

II. The Description of the Investment Process of the Great Pyramid

1. The course of the process reveals points obviously determined by two coordinates: the advancement of the construction expressed by means of the volume and the time in which it has been achieved (Fig. 5). The process began by ascension of Chu-fu to the throne, at this moment the construction did not exist. The investment cycle ended after 23 years, simultaneously with investor's death, the construction was finished in its essence. The date of the 17th years of king Chu-fu's reign placed on stone above the King's Chamber is of decisive importance to reconstruction of the process course. The rendering of the process course curve more accurate was made possible as a number of events which fell within the limits of the three above mentioned points, left quali-

tative traces on the construction. Simultaneously these events were subject to technical, technological, situational, etc. conditions (Fig. 4). They could be expressed by means of clear analogies. For example the dates of the 21^{st} and 22^{nd} year of Sneferu's reign found on blocks of casing on the north pyramid of Sneferu at Dahshur, distant one from another by half the height of the pyramid [16]. Thus it has been ascertained that a period of 2 years was enough to cover with a course of casing stones a construction not significantly smaller than the Great Pyramid.

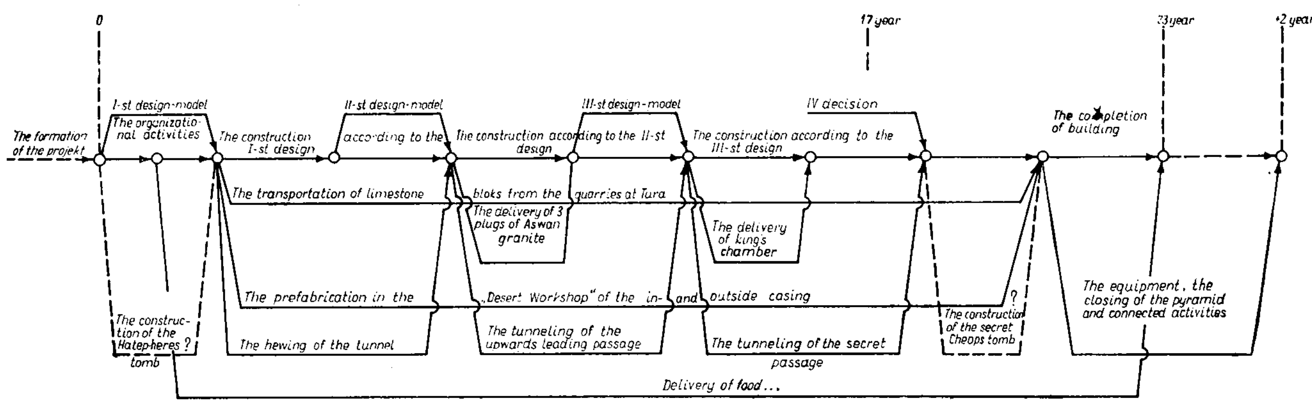

Fig. 4. Condensed network of the Cheops pyramid investment process

2. Parallel to the basic constructional process were three supplementary with a considerable degree of organizational and technological autonomy. The supplementary process of fine prefabrication of limestone casing started at Tura and occured at Giza with no evident complications, a result of accumulated experiences.

The second complementary process, the fabrication at Aswan, probably had not a sufficient tradition. It seems that in the course of studies it has been possible to ascertain traces of mistakes in the organization for example some fragments unfinished or missing because of shortage of time.

The third complementary process occured nearly all the time invisible. It utilized mainly the technique of tunneling which was strictly connected to the tombs. The team was composed of "necropolis officials" and "necropolis workers". A strict professional ability to keep a secret, for example the hidden tomb of Queen-mother was characteristic to this activity.

3. The normalized course of construction between the 5^{th} and 7^{th} year has been perturbated by the 1^{st} change in the design. The level of construction is marked by 1^{st} superstructure chamber, the outline of the pyramid left traces: the first unfinished set of ventilation shafts and the middle 2^{nd} model.

4. The II^{nd} disturbancy in progress of construction occured between the 10^{th} and 12^{th} year of reign. It was expressed by a new design, organizational and constructive activity: the arising of the 3^{rd} model, construction or lengthen of the Grand Gallery and the transfer of a part of labors to remote Aswan. Deglomeration, right from the technical point of view, probably failed in organization.

The design of the King's Chamber complex can be separated into several elements. The Grand Gallery could be planned as the access to the King's Chamber as well as it could be constructed in on cycle with Queen's Chamber. In the second case, its principal purpose would be the storing of granite plug blocks.

It has been assumed that the III^{rd} design – included the King's Chamber with the usual construction of the single granit vault and the pointed limestone roof, and the II^{nd} ventilation system. It has been also assumed that within this design the north ventilation shaft reached the King's

[16] Edwards, op. cit. II, p. 230.

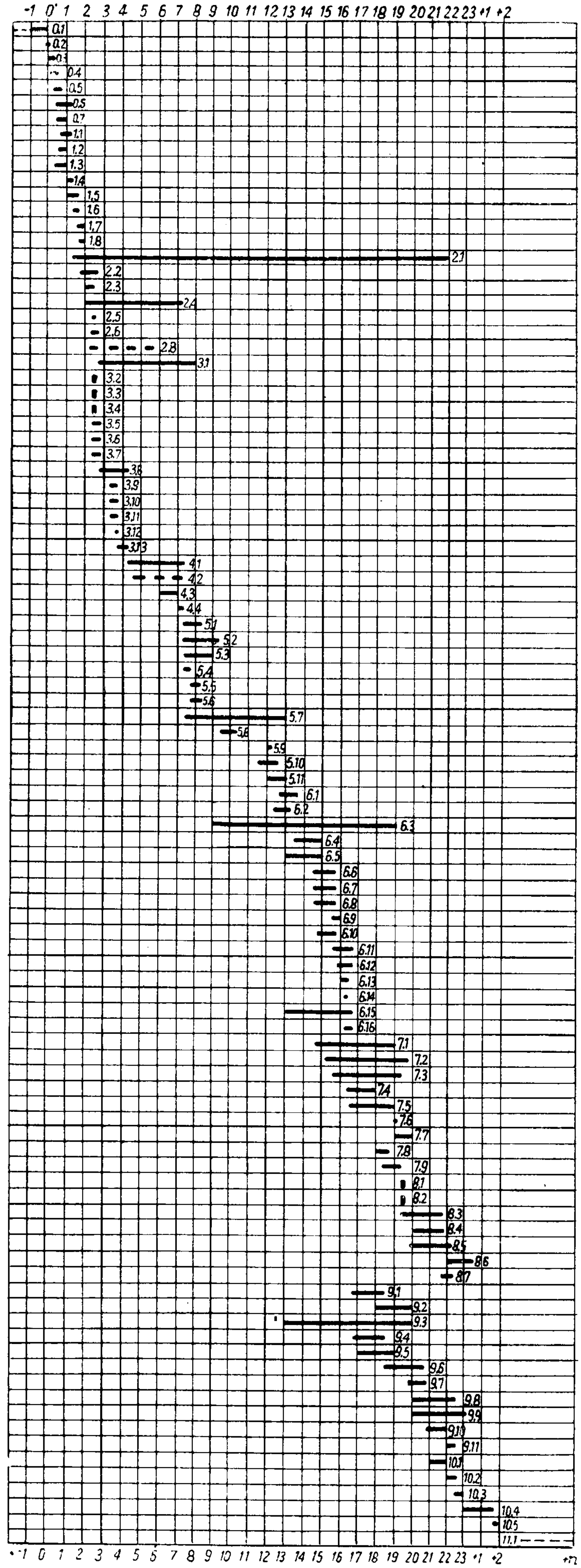

Fig. 5. The labor timetable of the Cheops pyramid construction

Chamber and the flat granite ceiling slabs were within the core of the construction without crossing the relieving joint. It is difficult now to find whether the delays in the labour timetable arose already at this stage or else.

5. The great, difficult, atypical and interconnected labours could be the reason of the perturbation and delays discovered. The most easy way of hiding them was the elongation of the Grand Gallery beyond primary intention. As a result, among others, the north ventilatory canal ceased to reach the chamber. The careless bringing of the King's Chamber into the relieving joint encircling the core of the pyramid had some important consequences. When danger has been noticed and estimated, the unfinished granite stones, possibly destined for closing of the Gallery have been used in a hurry to strengthen fivefold the ceiling. This construction is unique and this seems to be a characteristic feature of mistakes corrected. The repeated use of granit elements could not correct the constructional error.

6. After the 18^{th} year the bursting of the granite ceiling beams that were rigid attached to two opposite joint planes, occured with appropriate rumour, then no doubt the decision has been taken: to finish the external part of the pyramid at all costs and to resign of using the internal part. It seems that the above mentioned unfinished sarcophagus, without a lid is the proof of such a decision. The account of Herodotus that the assembly of the casing has been accomplished beginning from the summit is really probable in view of labour time table, avoiding of damages resulting of the settle of the masonry. The assembly of the casing has been finished in about the 22^{nd} year of construction.

7. Small finishing works have been probably done by the functionaries of Chu-fu pyramid foundation during the two years of the reign of Chu-fu's succesor. The great dimension of its property allow the assumption that the crew was sufficiently numerous.

8. Among the objects that shaped the process of construction there are the canal-system connecting the building-yard with the river. Looking from the summit of the pyramid or at the map an outstanding set of strait parallel canals can be seen, nearly perpendicular to the river. Neigh bouring irrigation units have different systems. As a result the conviction is gained that the canals existing are the successors of ancient transport system. The quayside and the transversal canal in the direction N-S has been found in front of the lower temple of Khephren.

9. During the accomplishment of the I^{st} design the convenient tract to the pyramid was so called Chu-fu causeway. It has at least been proved by Perring that an unusual haste can be observed in the arrangement of the King's Chamber and that the supply of elements occured from the west, i. e. from Lybian Desert and not from the Nile direct. Traces of a great and sufficient long western ramp can be observed. With the progress in con-

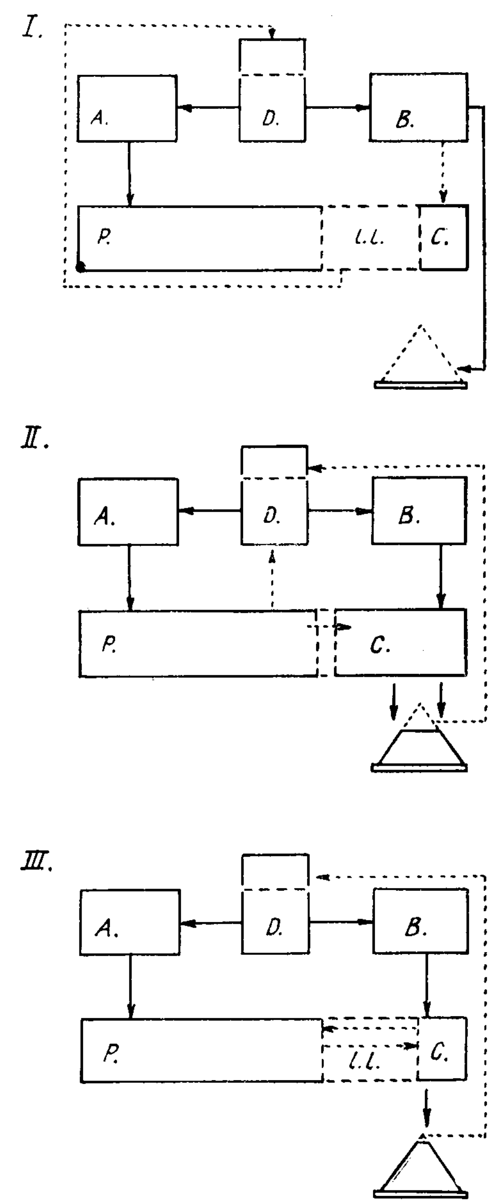

Fig. 6. The social-interlinks diagram at the pyramid construction
The I^{st}, the II^{nd}, the III^{rd} stage of the process
A. administration (scribes etc) — D. decisions (king, chief of all works . . . etc) — B. builders, architects, craftsmen — l. l. unemployed — C. crew of workmen

struction the prefabrication came to be main technological problem. Its characteristic technological feature, as the technique of test assembly was used, had to be an exact horizontal stable plane similar to the base of pyramid in shape but slightly larger than it. Close to pyramid there is only one such surface under the later constructed pyramid of Khephren. The identification of the "Desert workshop" leads to the statement that substructure of the Khephren causeway served as second transport tract for the Chu-fu construction.

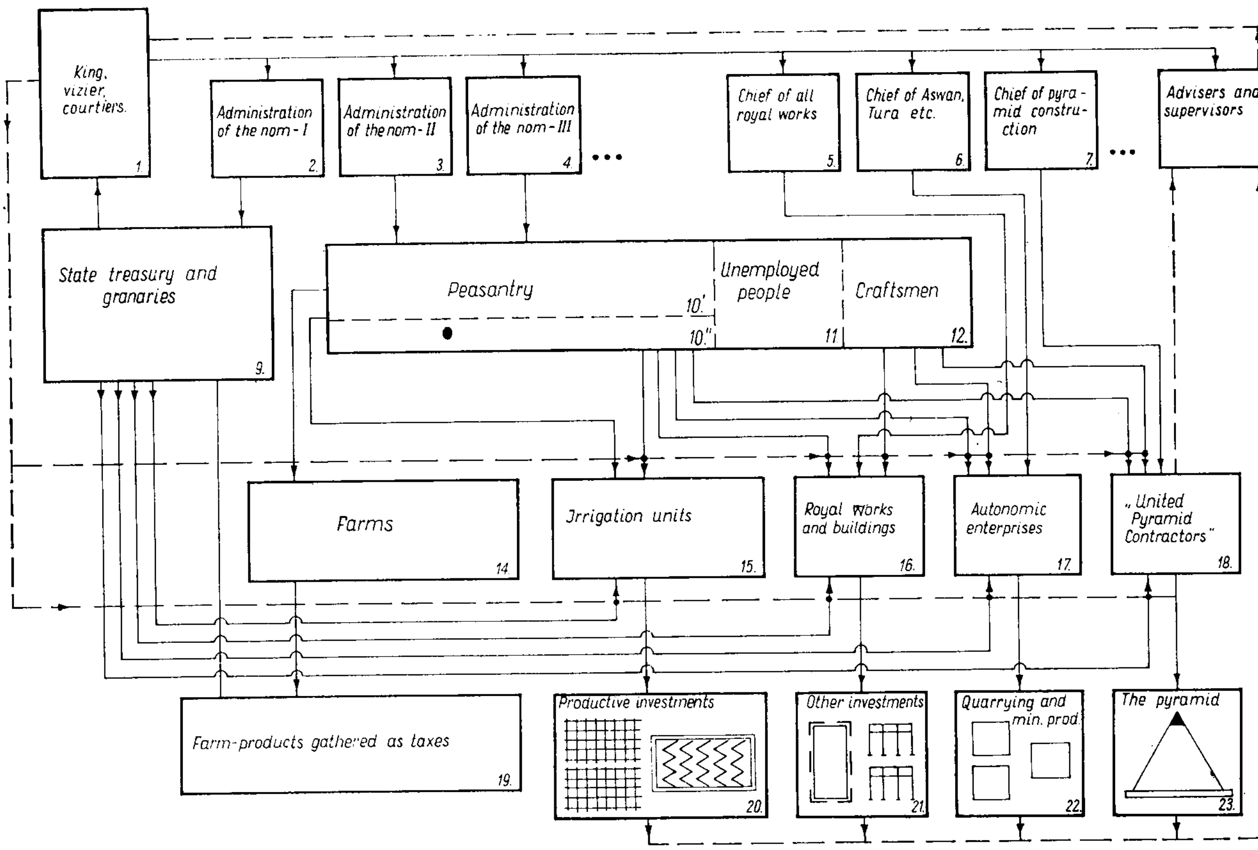

Fig. 7. Principal interlinks of the "United Pyramid Contractors" enterprise and the invested pyramid complex (reconstruction)

10. The placement of "desert workshop" causes the necessity of paying special attention to its surrounding to the so called workers barracks. Its purpose was discussed[17]. In view of work-organization it seems that both opinions were right. A permanent crew of the workshop needed lodging in winter, when the stores were empty, in summer when the stores had to be filled with food for the great number of seasonal workers the nights are hot, it is better to spend them in open space.

The middle (west) building is nearly complete. The north and south wing have been probably dismounted in time of Khephren on the east parts. In the present state the separation of those 3 buildings is not logic a. s. c.

11. For gaining a relatively comprehensive picture of the superintendance of process, the incentives and interlinks of the diagrams in Fig. 6, 7 can be used. We must associate the very high efficiency achieved by "Pyramid Builders" with the effect of a well devised system of incentives of a "practical" kind and of moral posture. Although this factors are manifested in ancient remnants, the author does not discuss it, because it is beyond his professional limited scope of architecture.

[17] The construction was studied by: A. Mariette 1850—1854, W. P. Petrie 1880, L. Borchardt in 1894 and did not propose its reconstruction.