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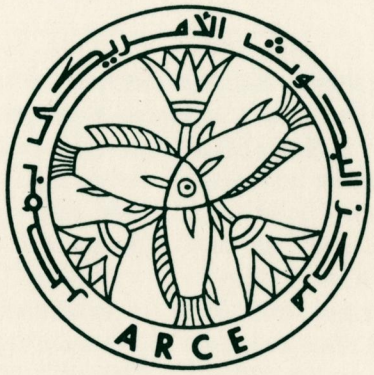

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Some Observations on the Layout of the Khufu and Khafre Pyramids

MARK LEHNER

The accuracy of the leveling and orientation to north of the Great Pyramid has long been admired and the focus of much discussion as to how this could have been achieved by the ancient builders. The question is all the more puzzling in that the accurate layout of the pyramid is a kind of "chicken and the egg" problem. The survey of a true square oriented to the meridian is most accurately done on a leveled surface, but where the surface is to be finely leveled depends on the exact position of the true square. This at least was the case with the two largest Giza pyramids, for the fine leveling which is so admired was not carried out over the entire area to be occupied by the pyramid base, but only as a narrow panel which would receive the lowest course of the pyramid casing.

The following observations were noted during the years I worked in the area on the ARCE Sphinx Project. Preliminary measurements and notes were made for this discussion, but the evidence deserves a more systematic recording and study than that which has prompted the tentative interpretations in the last part of this report.

1.1. Bedrock Core Massif

A large massif of bedrock was left in the core-base of the largest Giza pyramids. At the Great Pyramid, this is indicated by the beginning of the bedrock in the so-called "service shaft" (running from the bottom of the Grand Gallery to the Descending Passage) which is some seven meters higher than the leveled perimeter of the pyramid; the surface of the bedrock in the Descending Passage, 3 m. higher than the base of the pyramid; and by bedrock showing in the SW, NW, and NE corners at the outside of the pyramid (Maragioglio and Rinaldi 1965, 12–13). At the NE corner the bedrock shows to a height of about 4 m. above the base.

At the Second Pyramid a stepped square bedrock massif was also left for the lower part of the core (Maragioglio and Rinaldi 1966, 44–47). It can be seen at the NW and SW corners at a height of more than 4 to 5 m. It is probably more regularized than the bedrock massif at the base of the Great Pyramid.

A significant consequence of the massif for the layout of the pyramids was that the square of the base could not be controlled at the outset by measuring the diagonals. Around the base of the massif at the Khufu pyramid, only an approximate leveling was done in a narrow panel for the perimeter foundation platform, upon which the true baseline of the pyramid was founded. At the Khafre pyramid, the bedrock socle for the bottom casing course was hardly leveled at all, and the true pyramid baseline is only a cut in the granite casing blocks.

1.2. *Lines of Holes at the Khufu Pyramid*

Goyon (1969, 71–77, fig. 3) pointed out the existence of small holes sunk into the rock surface off the NW and NE corners of the Great Pyramid, which, he argues, were for fixing the corners by means of intersecting circle arcs (*ibid.*, 74, fig. 2). The hole at the NW corner is rectangular, measuring 42 × 58 cm. and 42 cm. deep. It is 3 m. west of the NW corner of the pyramid and aligned to its north side. A similar hole (58 × 68 cm., 87 cm. deep) exists 4.98 m. east of the NE corner and aligned to the north side of the pyramid. The third hole, which is round, is 5.25 m. north of the NE corner and aligned to the east side of the pyramid. Goyon then mentions a whole series of holes, generally the same size and shape as that off the NW corner, forming a line 3 m. from the base of the foundation platform of the pyramid along its entire east side (pl. Ia). These, he suggests, could have been for "piquets" or "chaises" at intermediate points between the corners upon which the stretching of the cord for the traverse could have been carried out. Such points could have maintained the orientation and direction of the line and avoided errors of distance caused by sag in the measuring cord. Goyon makes a brief mention of an alignment of holes, occurring in pairs, in the rock floor off the east side of the Second Pyramid (*ibid.*, 73, n. 3).

The series of holes around the Great Pyramid was also noted by Maragioglio and Rinaldi (1965, 66–67):

> Roughly rectangular or roundish holes, with sides varying from 35 to 65 cms. and from 40 to 60 cms. in depth, were cut out of the rock along all four sides of the pyramid and about six cubits from its base. They are regularly spaced (about 3.5 m.) and were filled with stones and mortar before the pavement was laid. An interesting fact is that the end holes of each row are exactly in line with the corner sides of the pyramid foundation platform.

Lines of holes like those which Goyon pointed to along the east side of the pyramid are also observable on the east end of the north side, the ~~north~~ east end of the south side, and about the ~~east~~ north half of the west side. It appears as though they originally described a square 3 m. from the edge of the foundation platform on all four sides. Where the bedrock surface is exposed and they cannot be readily traced, as on the west end of the north side, they may have been obliterated when the rock floor was recut for laying the court pavement. Most of the holes are square or rectangular, and, while their sizes vary somewhat, most are about the size of the hole Goyon described off the NW corner. The distances between them vary, according to Goyon (1969, 76), from 3.4 to 4 m. Measurements I took, from center to center, between some at the south end of the east side give 3.7, 3.9, 3.5 m. (pl. Ia); near the center of the east face: 3.52, 3.65, 3.67, 3.75, 3.66, 3.85 m.; and at the east end of the north side: 3.7, 3.6 m. These measurements give an average of 3.68 m., which is equal to 7 cubits. Being located 3 m. from the edge of the foundation platform, the holes describe a square around that of the pyramid base of about 237 m. to a side. 3.68 m. average spacing allows 64.44 spacings, × 7 cubits gives a layout square possibly intended for an approximate 451 cubits to a side. On the other hand, the side of 237 m. for the square divided by .5232 m. (Petrie's pyramid cubit) gives just under 453 cubits.[1]

1.3. *Lines of Holes at the Khafre Pyramid*

In addition to Goyon's observation, patterns of holes at the Khafre Pyramid were also mentioned by Maragioglio and Rinaldi (1966, 74–74) who stated that "roughly rectangular or roundish holes with sides of about 40 cm. were cut in the rock along the four sides of the pyramid and about 9.5 m. from its base. They are regularly spaced (about 5 m.) and were filled with mortar and

stones cut *ad hoc* before the pavement was laid."

The most consistent series of holes at the Khafre pyramid are situated along the raised edge or bevel cut into the bedrock floor which marked the outside of the pyramid enclosure wall, 13.5 m. from the pyramid base as defined by the bottom of the granite casing blocks or, where these are lacking, their rock-cut socle (fig. 1). Along this line, the holes occur in pairs (fig. 2:A). The first hole of each pair is about 20 cm. from the enclosure wall cutting while the second of each ranges from 85 cm. to 105 cm. from the line. The two holes of each pair are usually staggered with respect to each other by a distance ranging from 20 cm. to 1.64 m. The diameters of the holes range from 30 to 47 cm. Many are filled with mortar or have been fitted with a stone; those that are not are generally filled with sand, so it has not been possible to measure their depth. In contrast to those which surround the Great Pyramid, these holes are almost always round. The distance between the holes on each of the double lines most often ranges from 5.2 to 5.3 m., although the variance in the spacing can be as much as from 5.12 to 5.87 m. (fig. 2:A). In fig. 1 the amount by which the pairs of holes are staggered and spaced has been kept more or less constant; in actuality this amount varies by as much as is shown in the top rows in fig. 2:A, which is the greatest variance I have noticed, at the north end of the west side of the pyramid.

The pattern and its variations are described on the basis of preliminary measurements. Therefore fig. 1 is an idealization of the pattern. Here the variations in the spacings between the holes have been averaged out to 5.5 m. It seems that a rough spacing of 10 cubits was intended. The square described by the outer enclosure wall line, along which the holes are positioned, is about 242.5 m. (215.5 m. for the base of the pyramid plus 13.5×2) to a side. An average of 5.5 m. per spacing allows for 44 spacings per side. If it was generally intended to have spacings of roughly 10 cubits, this gives an ideal length of 440 cubits for the sides of the layout square. However, 440 cubits—the intended length of the sides of the Great Pyramid—is actually a little more than 230 m., not 242.5 m. which gives an actual 463 cubits. On the north side, I have paced off 46 spacings.

On the east side of the pyramid, the rock surface is very poor and quite worn toward the south end (where large locally quarried blocks make up the foundation) making the outer line of the enclosure wall harder to trace. However, it can be discerned as the N–S line at which the rock floor begins to slope away to the east. Holes can be seen here and there flanking the line, although not as consistently as on the other three sides. The line runs to the west end of the mortuary temple which is 11.60 m. from the pyramid base.

It is on the east side of the pyramid, where the outermost series of holes is hard to read, that a more regular and well-defined line of double staggered holes runs 9.1 to 9.9 m. from the pyramid base (fig. 1). It must be this series which is referred to by Maragioglio and Rinaldi as being 9.5 m. from the base. On the other three sides of the pyramid, alignments of holes are also seen about 9.1 to 9.9 m. from the pyramid base, but there it is the closer series that is less consistent and well defined.

1.4. Corner Trenches

In the court of the Khafre pyramid, at the NW, NE, and SE corners of the line corresponding to the outer side of the enclosure wall, there are long trenches cut in the bedrock and oriented N–S (fig. 1). These are laid perpendicular to the north and south sides of the court and 7 m. from the corners of the court as defined by the outer line of the enclosure wall. Such a trench probably also exists at the SW corner, which is still encumbered with sand and debris. Here, at

the appropriate place, there is a long, sanded-up depression lined with pavement slabs which is probably the trench.

The trenches at the NE and NW corners were noted by Maragioglio and Rinaldi (1966, 74, Tv. 5), although they seemed to have missed the one showing today at the SE corner. They suggest that the trenches were for draining off rain water which came down off the face of the pyramid. Against this, it might be pointed out that the ends of the trenches pointing away from the pyramid, particularly that at the NW corner trench, are cut fairly vertical, which would not be expected to facilitate the outward flow of water.

The trench at the NE corner is 6.4 m. long and 2.65 m. at its widest. It is somewhat irregularly cut. That at the NW corner has a deeper trench within the overall cutting (it has not been possible to determine the depth of the trenches, as they are now filled with sand). This deeper trench is cut fairly regular and measures 6.05 × 1.0 to 1.15 m. From its south end, a shallower cutting extends another 4.44 m. and broadens out to 2.83 m. The SE corner trench is 1 m. wide at the south end and maintains this width for a length of 3.20 m. Then it broadens out into a shallower extension to the north another 5.3 m. long and 2.7 m. wide. The south end of the trench at the SE corner, and the north end of the trench at the NE corner, fall nearly on the outer line of the enclosure wall and the series of holes which flank it. The north end of the NW corner trench extends another 1.62 m. beyond this line.

At the Great Pyramid, elements similar to the trenches at the Second Pyramid are not as obvious. Maragioglio and Rinaldi (1965, 66-67) stated:

> All around the pyramid can be seen the levelled rock on which the pavement slabs were founded and it shows a marked impluvium in the middle: we believe the pavement slabs followed the same impluvium. In the northwest and southwest corners of the surrounding court the rock was cut in order to accommodate limestone channels which passed under the temenos wall. They served to drain water away from the surrounding court and conveyed it toward the northwest and southwest corners due to the before mentioned impluvium.

I have not been able to positively identify the channels which these authors mention at the Great Pyramid. The area off the SW corner of the pyramid has again become sanded over, and only the very shallow SW corner socket of the foundation platform is just barely visible. There are cuttings off the NW corner of the pyramid which look like those for receiving the court pavement slabs, but which are somewhat broader and deeper. These form a rectangular sunken area beginning some 3 m. from the corner socket of the foundation platform, extending about 10 m. N-S, and running E-W nearly to the edge of the modern road which cuts this corner of the pyramid court. This area has been cut down some 16 cm. deeper than the surrounding cuttings for the individual pavement slabs. From the south end of the deeper cuttings, there is an ancilliary cutting which looks like it could be a narrow trench or channel running westward under the modern road, but this is largely sanded up today. This may be the channel mentioned by Maragioglio and Rinaldi, but it does not correspond significantly with the trenches at the Khafre pyramid.

There is a cutting in the NE corner of the pyramid court which does correspond more to the trenches at the Khafre pyramid (pl. Ib). This is a series of square dressings in the rock floor, 24 cm. deep at its north end, which is on line with the north limit of the pyramid court as defined by the bedding in the rock floor. Here the cutting is 4.63 m. wide. Exactly like the trenches at the Khafre pyramid, the east side of this cutting is 7 m. from the corner of the pyramid court. The cutting extends southward for 4 m., at

which point a narrower extension, 2.2 to 2.3 m. wide, continues southward for another 4.95 m. Just where this narrower extension begins, there is a pair of very small holes, 20 to 27 cm. in diameter and 60 cm. apart from center to center, in the middle of the cutting. The far SW corner of the cutting is 6 m. NE of the survey pin in the outer corner of the NE corner socket of the foundation platform. The SW corner of the cutting is also 3 m. directly east of the round hole described by Goyon (see above, p. 8 here) which is aligned to the east side of the pyramid. Thus, the narrow leg of the cutting has its west side on line with the series of holes running parallel to the east side of the pyramid, 3 m. from the edge of the foundation platform.

At 2.3 m. north of the north end of the cutting, there begins a channel, 1 m. wide and oriented N–NE, which has been cut deeply into the rock with regular straight sides (pl. Ib). The rock separating this channel from the cutting in the court is raised 25 cm. Therefore the channel would not likely have served to carry rain water from the court and the NE corner cutting. Although this channel looks similar to the NW corner trench at the Khafre pyramid, it shows little correspondence in its position (being outside the court proper) or orientation.[2] Such a correspondence is seen more in the broader and shallower cutting inside the court, 7 m. from its corner.

It appears that the trenches at the Khafre pyramid and the cutting in the NE corner of the Khufu pyramid court align with the diagonals of the pyramid at their farther ends pointing into the court. It should also be noted that the trenches and the cutting at the Khufu pyramid begin at their shallowest on this end facing into the court, and just at the lowest point of the trough, or "impluvium," mentioned by Maragioglio and Rinaldi.

There may be similar cuttings to that at the NE corner of the Khufu pyramid court at the other corners. Some clearing would have to be done to find them. On the other hand, it might be that since they are shallower than the trenches at the Khafre pyramid, they were cut away when the rock floor was recut to receive the court pavement slabs.

1.5. Court Trough

At both the Khufu and Khafre pyramids, there is a gentle but clearly discernable trough fashioned in the bedrock, most pronounced at the corners of the pyramid enclosure, and extending from the base of the pyramid to the inner baseline of the enclosure wall. The trough, or "impluvium," as Maragioglio and Rinaldi called it, appears to phase out very gradually toward the center of each side of the court.

In the Khafre pyramid court, the bedrock trough begins just at the line of the socle for the lowest course of granite sheathing, dips as low as 40 cm.,[3] and terminates on its outer side just before the inner line of the enclosure wall, about 9.6 to 9.9 m. from the casing socle (fig. 2:C). Between the outer edge of the trough and the outer line of the enclosure wall, the bedrock surface is well leveled (much more so than for the casing socle) for a width of about 3.6 to 3.9 m., which is the approximate width of the enclosure wall.[4] Beyond the outer line of the enclosure wall on all sides of the pyramid, the rock floor shows a radical slope away from the pyramid court.

At the far north end of the west side of the pyramid, a third line of holes with more irregular and wider spacings (5.76, 5.56, 5.91 m., etc.) runs along the vague line of the outer side of the trough. While the trough is more obscure along the length of the east side, it is about at the distance of its outer edge from the pyramid base (here 9.1 to 9.9 m.) that the double line of more regular holes referred to by Maragioglio and Rinaldi (1966, 74) and Goyon (1969, 73, n. 3) occurs.

The corner trenches begin, at their ends facing the diagonals of the pyramid, at or near the low point of the trough, and extend to the outer line of the enclosure wall and the series of holes alongside it. The trough

has been observed at the three corners of the Khafre pyramid court where the rock floor is well exposed. At the SW corner, which is more sanded up, there is a place at the west end of the south side where it appears that the extant pavement of the court fills in the dip and levels it off. Maragioglio and Rinaldi state that the court pavement followed the same "impluvium" as the bedrock floor underneath and therefore are able to suggest that its purpose was to drain off rain water. There are places on the west side of the Khafre pyramid where the extant pavement does show the trough slightly. One wonders if this could be due to settling of the pavement over time (some of the slabs are founded on mortar and limestone chip filler). Even if the surface of the pavement preserved the trough cut in the rock floor in order to drain off rain water after the pyramid court was complete, this does not negate an earlier function for the trough in the bedrock at the stage when it was just being prepared for the layout and leveling of the pyramid.

A similar dip in the profile of the rock floor is also seen at the exposed corners of the Khufu pyramid court. There the surface begins dipping immediately along the line of the foundation platform, upon which the true leveling and true base of the pyramid was placed (fig. 2:D). At the NE corner looking west along the north side, and at the NW corner looking south along the west side, the pattern is easily discerned (the other two corners are more encumbered with sand). The trough begins immediately along the line of the foundation platform, sinks about 40 cm. at its deepest, and extends about 9 m. from the pyramid platform before the surface rises again. It is important to note that, as opposed to the system at the Khafre pyramid, this puts the line of holes around the Khufu pyramid, 3 m. from the foundation platform, within the trough rather than alongside it.

At the west side of the pyramid it appears that the extant court pavement slabs largely leveled off the dip of the rock floor, although a slight trough may have been preserved. Along the north side of the pyramid, just beyond the rise from the trough, can be seen the edge of the earlier cutting which first roughly cleared the area of the pyramid court, after which the trough was more finely fashioned. Particularly toward the center of the north side along this outer line, the original removal channels for roughly working the rock surface to create the limit of the pyramid court can yet be seen.[5] Close along this line ran the inner enclosure wall, about 10.20 m. from the pyramid base and 3.15 to 3.60 m. thick at the bottom (Maragioglio and Rinaldi 1965, 66–67; Lauer 1947, 246).

At both pyramids the pattern of the trough is obscured somewhat by the recutting of the floor to lay in the individual court pavement slabs.

2. *Interpretation*

In considering how the Khafre pyramid was laid out and oriented to north, it must be kept in mind that the true baseline was only a cutting in the lowest course of the granite sheathing. Each granite block was cut at the base to meet with the slabs of the court pavement to be laid in later (cf. Maragioglio and Rinaldi 1966, Tv. 6, figs. 2–7). Thus the baseline was formed gradually, and laboriously, as each heavy granite block was levered into place and trimmed, or initially only marked (as at the unfinished granite casing of the Men-kau-re pyramid) to conform with the bedding and slope lines. How could the baseline have been carefully aligned and oriented to true north during this process?

At the Khufu pyramid the true baseline was laid down on the .52 m. thick foundation platform of fine white limestone, upon the surface of which (and not on the bedrock floor) the extremely fine leveling was carried out to where the north side is off true level from the south side by less than 1.5 cm. on the average (Cole 1925, 4). It seems clear that

in both cases there needed to exist some kind of *outside datum or refrence system* for the alignment, orientation, and leveling while the first blocks were being laid into place. It might be suggested that the lines of holes, the trenches, and the bedrock troughs in the pyramid courts are what is physically evident for such a reference system.

We must refer again to the "chicken and the egg" aspect of laying out the pyramid and its surrounding court. The survey of a true square oriented to the meridian is most accurately done on a leveled surface, but the narrow panel to be only approximately leveled for the baseline around the core massif depends upon the position and orientation of the true square. The ancient survey must, therefore, have been carried out as a kind of *successive approximation* which was ever more refined as the original dressing of the surface proceded.[6] It must be remembered that the project was begun on a surface at least several meters higher than the present court levels of the pyramids; indeed the original bedrock surface at the west-NW part of the Khafre pyramid site was a good 10 m. or more higher than the court.

If it is correct to see in the line of holes, trenches, and the court troughs the evidence of the layout of these pyramids, they would mark the final determinations for the outside reference system. At the Khafre pyramid, the reconstruction which follows assumes that the long trenches at the corners of the court and pointing toward the diagonals of the pyramid are a first approximation of the layout square which functioned to roughly define the court, the line of the enclosure wall, and the eventual pyramid baseline. They left about 6 m. margin, north to south, and between 1 to 2 m. margin east to west, for defining the layout square. Thereafter the three separate lines of holes were established, each more precisely oriented and aligned, making successive layout squares. The holes, while forming a line, leave enough leeway for a surveying assistant to move a pin back and forth into a more precise alignment being sighted by the traditional bay and plumb line (Borchardt 1899; Edwards 1961, 257-59, figs. 53-54).

It is clear that the *spacing* between the holes at both pyramids, while fairly regular, made no pretense to accuracy. The spacings themselves were not, therefore, meant to measure off the distance or the length of the sides of the layout square or the baseline of the pyramid. Their main function was to provide, as Goyon surmised, an approximate line in which the more accurate alignment could be posted by stakes and pins which would carry the line. The measure of the sides could then be carried out on this leveled line stretched from stake to stake, and the base of the pyramid established by perpendicular *offset measures* in an implied grid control network around the base of the bedrock core massif.[7] This solved the problem of stretch and sag in the measuring cord, and that of maintaining the correct alignment when marking off great distances in increments.

In a method of successive approximation, this operation had to be carried out more than once and in tandem with the progressively finer leveling of the court around the core massif. It might be emphasized once more that only a narrow panel of bedrock around the bedrock core massif needed to be leveled, and this was only approximated. The bedrock socle for the lower granite casing course at the Khafre pyramid, and to a lesser extent that for the foundation platform at the Khufu pyramid, show variations in the depth of the cutting to accommodate the various thicknesses of the slabs laid upon it. To the outside of this panel, the trough in the rock floor gently dips down, while to the inside the squared bedrock core massif rises up in the pyramid core body.

It has been suggested that the leveling for the pyramid base was achieved by means of an enclosure formed around the perimeter by banks of Nile mud. The area was then filled with water and the rock beneath was cut to a uniform depth below the surface of

the water in a series of small trenches. When the water was drained the remaining rock could then be cut away to the depth of the "facing surfaces" established at the bottom of the trenches (Clarke and Engelbach 1930, 62; Edwards 1961, 255). This would demand teams of men hammering and chiseling in the very water which was to serve as a reference for the leveling. The surface of the water would be greatly disturbed and get clouded up with mud as it washed off the embankments—a very awkward and impractical situation.

The trough in the rock floor at the corners of the two largest Giza pyramids suggests an alternative. Once the bedrock core massif was isolated and the confines of the court roughly established, the shallow dip was cut into the rock floor at each of the four corners. This gentle trough gradually phased out in depth toward the center of each side of the court. When it was filled with water, the bedrock floor at the base of the core massif was trimmed down near to level with the surface of the water at each corner of the pyramid. The work was done beside, rather than in, the water for the bedding of the foundation platform at the Great Pyramid, and for the actual casing socle at the Second Pyramid. Beyond the outside edge of the trough, the rock surface was leveled with reference to the surface of the water for the bedding of the enclosure wall. The trough is still most pronounced at the corners of the pyramid. It is possible that after it had been formed at the corners and filled with water, the ends of the dip pointing toward the centers of the roughly laid-out court were extended by gradually dressing the rock surface ahead of the water until its "fingers," which gradually flowed with the progress of the dressing, met at just over zero depth at the center of each side of the court.

On the basis of the features so far described, actual steps in the layout and leveling of the two large Giza pyramids will be suggested. This may prove to be a bit premature and overly itemized. The actual role or sequence of each feature may not be correct. However, it is given as a working hypothesis in the hope that future investigation can be done on this evidence.

2.1. Layout and Leveling of the Khafre Pyramid

The steps are described with reference to fig. 2:C which is a composite, schematic profile based on measurements taken at the NW corner of the pyramid. The features described above are all represented.

1. Isolation of the bedrock core massif and the rough dressing of the surface for the pyramid enclosure.

2. Excavation of the long (N-S) rock-cut trenches in order to roughly establish the corners of the layout square. These gave a margin of about 6 m. (N-S) for establishing the north and south sides (sighting in the east-west direction) of the pyramid court and layout line. This could have been done by moving a pin or stake along the trench until the desired alignment was achieved. The stake could have been set in mortar or mud fill in the trench. Once these preliminary corners had been established, the layout square could be more refined and expanded by measuring equal offsets from the stakes.

3. A first, inner layout square was projected from the points in the trenches. This layout square was marked by the first series of holes describing a line around the four sides of the massif. This line runs 9.1 to 9.9 m. from what would be the baseline of the pyramid. This preliminary layout square is indicated by a dashed line in fig. 1 and the hole (3) in fig. 2:C. From these lines a very rough approximation of offsets may have been done for the socle of the pyramid base. A major purpose of this first line may have been to define the outer edge of the court trough.

4. The layout square was expanded by about 4 m. on each side, and marked by the outermost line of holes. The second square was more accurately aligned and oriented

than the first square, and the spacing between the holes was more regular, approximately 10 cubits.

5. From the more accurately surveyed outer layout square, the line of the pyramid base, or of the socle for the first casing course, was more precisely established by means of offsets for the sides of the base, and by intersecting circle arcs and diagonal controls for the corners.

6. A shallow dip or trough was formed in the rock floor at the four corners between the line for the pyramid base and the earlier, inner layout line (step 3). This dip extended for several decimeters along each side of the roughly established pyramid baseline.

7. At the ends of the corner-trenches facing into the layout square, each trench was extended in a shallower cutting to the lowest point of the trough. The ends of these extensions would also closely align with the diagonals of the pyramid.

8. The dip was filled with water. The centers of the sides of the court were approximately leveled by dressing the rock surface from the ends of the dip so that the water would gradually flow from the corners to meet in the middle, leaving a dip in the floor at the center of the sides of only a few to zero centimeters.

9. The panel of rock floor between the pyramid baseline and the bedrock core massif was cut down near to the water level as a socle or bed for the first course of granite casing. Along the outer side of the trough, a wider panel was leveled which would, at the end of the project, receive the foundation of the enclosure wall.

10. The outer line of the enclosure wall, which would mark the limit of the pyramid court, was cut and refined as a raised edge or bevel in the rock floor. The rock surface beyond this line was cut to slope away from the pyramid court on all sides.

11. Along the line that would be the outer side of the enclosure wall, another series of holes was cut between the line and the outermost layout square marked by the second series of holes (step 4). The spacings of the third intermediate line were staggered slightly with respect to the second outermost line and may give closer approximations to 10 cubits. This line may be more accurately aligned and oriented than the two earlier lines of holes.

12. A wooden stake was fitted into each hole of the layout square. The stake could have been cut off at the top to a height corresponding to the surface of the water filling the court trough. This could have been done by sighting across the tops of the wooden stakes set in the holes of the first layout square (step 3) which were immediately at the edge of the water, as well as with the water surface in the trenches at the four corners which took the water level out to the outer line of holes. The tops of the stakes then gave a level line the length of the four sides of the layout square. The line could have been oriented more accurately on the stakes by pins. String tied to the pins and stretched taut between the stakes would have given a finer leveled, accurate datum all around the pyramid court. From this datum, the pyramid baseline could have been determined to its final accuracy by offset measures and, for the corners, intersecting circle arcs and diagonal controls.

13. Starting at the corners, the first course of granite casing stones was laid in. The bedrock socle for the casing was cut to considerable variations in depth as seats for the individual casing blocks. The front lower edges of the casing blocks were often cut vertically where they would meet the pavement slabs of the court. Or, where the bedrock socle was left high enough, the lower granite corners were cut to the acute pyramid angle to meet the pavement. Because of the probability that the fine court pavement was laid in at the end of the project, and given the example of the unfinished granite casing at the Men-Kau-re pyramid, it is likely that the actual cutting of the casing was the last thing done, from the top down as the access ramps were removed. In this case fig. 2:C is

a bit misleading, since step 13, the final *cutting* of the pyramid base, would have been one of the very last steps in the entire building of the pyramid, when it was too late to do anything about the inaccuracies in the baseline.

At the Third Pyramid, as is the case "in all unfinished masonry in Egypt which has come down to us, the blocks were laid with the faces rough and fine-dressed afterward" (Clarke and Engelbach 1930, 125). At the same time an examination of those blocks reveals that the true slope of the pyramid has been fashioned already as the line in each block, on both the vertical and horizontal or bedding faces, separating the bulbous, rough, unworked face from the finely formed rising and bedding joins. It was left only to free the slope of the pyramid by cutting away the protruding excess stone. Had the slope of the pyramid not been carefully fashioned already in the undressed granite casing, when it came time to cut away the excess stone it could easily have developed that an insufficient margin of stone had been left to make up the plane of the pyramid face. This would have left gaps at the joins in the face, which would necessitate patchings and mortar fill. Therefore, step 13 as shown in fig. 2:C should be understood as the formation of the plane of the pyramid face in each individual granite block, even though the freeing of that plane may have been one of the very last steps.

14. Given these considerations, Maragioglio and Rinaldi (1966, 100) may be right in seeing the finely leveled top of the first course of granite casing as the zero level of the Khafre pyramid, at least for the practical initial building purposes, since this plane would have been formed at the outset, well before the casing was dressed. Referring to fig. 2C, it may be that there was a step in the layout and initial construction which required stakes in the holes equal in height above the surface of the water to the desired height of the first course of granite casing, which could be leveled by sighting across the tops of the stakes, as shown for the lower baseline of the pyramid.

In this way the layout and leveling of the pyramid was achieved by a kind of successive approximation. The only point to add is that on the east side of the pyramid the outer series of holes is hard to read. As noted, the line runs to the west end of the mortuary temple which may have been laid out about the same time as the base of the pyramid. For this reason, on the east side the operations listed above may have been carried out from the intermediate layout line, marked by holes 9.1 to 9.9 m. from the pyramid base. Here, this inner line of holes appears more evenly spaced at roughly 10 cubit intervals, is more consistent, and is more clearly a double line than the step 3 inner series on the other sides.

It might be objected that the discussion has glorified into the layout lines of the pyramid mere sockets for scaffolding to dress the enclosure wall, since they flank its route exactly. Similar holes found by Hölscher in the court of the Khafre mortuary temple seem to have received scaffolding for dressing the statues which stood there (Hölscher 1912, 74–76, Abb. 68–69, Bl. XVIII; cf. Reisner 1931, 272). The holes around the pyramid could have served this function after the pyramid was finished and the court cleared of ramps, foothold embankments, and debris. However, the pyramid layout requires some system of datum lines and points that would allow for successive approximation of its accurately oriented and finely aligned base. This layout line would have to be run on a level plane and this is lacking along the base of the Khafre pyramid until the first course of granite casing was laid down. To cut the true base level on the casing requires an outside datum or reference system, and the series of holes is what is physically evident for that operation.

It might be added that a line of similar holes, with spacings of about 10 cubits, passes down the center of the Khafre causeway for most of its length. These could not

have functioned as scaffolding for finish work, but probably defined the axis of the causeway before its Turah limestone blocks were laid over the ramp prepared in the bedrock or from large locally quarried blocks. Finally, the series of holes around the Great Pyramid does not correspond to the path of the enclosure wall, and, as this must have been the precedent for the layout system at the Second Pyramid, it establishes the primary function of the holes and lines as being connected with the layout of the pyramid.

2.2. Layout and Leveling of the Khufu Pyramid

The method used for the layout and leveling of the base of the Great Pyramid was similar to that used at the Second Pyramid and also involved successive approximation. The difference is that the Great Pyramid was founded on a platform of fine white Turah limestone slabs about .52 m. thick. The first task, therefore, was to provide an outside datum to which the layout and leveling of the platform could be referenced.

The suggested steps for this operation are shown in fig. 2D, which is a schematic profile obtained from measurements at the NE corner of the pyramid, at the far east end of the north side.

1. Isolation of the bedrock core massif and the rough dressing of the floor to define the pyramid court.

2. It is possible that the layout square was first roughly established by trench-like cuttings at the four corners of the court, into which points could be moved about until the approximate orientation was achieved. The evidence for such trenches is not as clear as at the Khafre pyramid. However, the cutting off of the NE corner of the pyramid, 7 m. from the NE corner of the court, may have functioned as such a layout trench (pl. Ib; see p. 9). Perhaps with points established in corner trenches or cuttings, the layout square was roughly surveyed and marked by the series of holes spaced at 7 cubits on the average. The alignment and orientation of the square could have been refined already by stakes and pins in the holes.

3. From points along the layout square, the line for the base of the foundation platform was roughly established by means of offset measures of 3 m. for the sides of the platform, and by intersecting circle arcs and diagonal controls for the corners (Goyon 1969, 74, fig. 2). For establishing the corners, fixed points outside the layout square could have been set by other holes. The outer limits of the court may have been more precisely established once the layout line was marked.

4. At the corners, a dip or trough was formed in the rock floor about 9 m. wide and starting from the line marked for the foundation platform. The trough was extended for several decimeters along each side of the square laid out for the platform at the base of the bedrock core massif. When the dip was formed, the upper part of the holes marking the layout square near the corners was cut away.

5. The trough was filled with water. The centers of the sides of the square defining the pyramid court were approximately leveled by dressing the rock surface from the projecting ends of the trough so that the water would gradually flow just behind the dressing from the corners to meet in the middle of each side of the court. Again, some of the holes of the layout square may have been cut away at the top in this operation.[8]

6. Perhaps about the same time, the rock panel between the trough and the bedrock core massif was generally leveled, with reference to the surface of the water, as the bed for the foundation platform. The floor of the court to the outside of the trough was also leveled with respect to the water surface. This would become the bed for the enclosure wall. Since the series of holes marking the layout square fell in the dip, it may have been necessary to re-establish holes which

were partially cut away in step 5, and to refine the layout lines, in which case the water would have been drained off after step 6.[9]

7. At the corners of the square marked for the foundation platform, sockets were cut for the large slabs of the four corners (Borchardt 1926, 15, Abb. 2). At the SW corner, the leveling operations required that the floor be built up with limestone pieces to receive the corner slabs of the platform which was then left in a socket only 2 cm. deep (Maragioglio and Rinaldi 1965, 12–15). The large slabs for the platform corners were roughly shaped and laid into the sockets. The rest of the foundation platform, working outward from the corners, was laid down with fine joins between the slabs, while the top and front edges were left in the rough.

8. The holes marking the layout square were re-established if they had been cut away in steps 4 to 5.

9. The stakes were reset in the holes and the alignment and orientation of the square was improved.

10. The dip was again filled with water sufficient to fill the tapering ends of the trough to meet in the center of each side of the court. This re-established an absolute level around the undressed foundation platform. The water would have come right to the base of the platform and to the two outer faces of each of the four broad corner slabs.

11. The tops of the stakes protruding from the water were each cut at the same height above the water surface as the desired surface of the foundation platform (fig. 3). Pins set in the tops of the stakes gave the final adjustments to the alignments and orientation of the sides of the layout square. The pins described a level line running around all four sides of the platform. A string could have been stretched taut from one pin to another to define this line better.

12. The top surface of each of the four broad slabs marking the platform corners was easily leveled by measuring up from the water surface which came up against each slab on its two outer faces. The front edges of the slabs were accurately dressed at a slight batter along a cut measured by offsets from the layout square. The corners could have been rechecked by intersecting circle arcs and diagonal measures from points along the stretched line.

13. From the facing surfaces (Clarke and Engelbach 1930, 62) established on the tops and front edges of the corner slabs, the rest of the foundation platform was leveled and cut along a straight line to a slight batter. This was done with reference to the pins and the stretched line at the desired level on the stakes which projected from the water. Given the distance from the "leads" established at the corners, the center parts of the platform could have been leveled by sighting from the stretched line and pins, across the water surface, to a rule held vertically to the surface of the water at the edge of the platform and marked with the desired height (just less than one cubit). This gave a facing surface, or "lead," along the edge of the platform from which the back parts could be leveled with aids like a stretched line and "boning rods" (*ibid.*, 105–6, fig. 113), and/or a triangle fitted with a straight edge and plumb line (cf. Reisner 1931, 78; Goyon 1977, 166, fig. 56).[10] After the platform was leveled, the outer face could be cut to a fine line determined by offsets from the line of the layout square.

14. Once the foundation platform had been dressed, the actual baseline of the pyramid could be established on its finely leveled surface which, with its straight edge, might itself now be used as a datum. The true square for the baseline of the first course of casing could have been refined by offsets of slightly varying lengths from the edge of the platform (cf. Maragioglio and Rinaldi 1965, 12–13).

2.3. Orientation

As the layout lines were run several times in successive approximations of the pyramid

base and enclosure, the sightings for true north, whether stellar or solar (with shadows, cf. Borchardt 1926, 13 n. 2; Maragioglio and Rinaldi 1965, 100–2), could have been done at each stage in the layout with increasing accuracy.

It is possible that parts of the enclosure wall were built about the same time as the preliminary layout and functioned in the orientation. Since its inner face would have been based nearly at the outer edge of the trough in the court, while its outer face came to the layout line marked by the series of holes (in the case of the Khafre pyramid), the height of the wall could have been determined uniformly with respect to the surface of the water which filled the trough in the court, and with respect to the level line marked by the series of pins in the holes of the outer layout line at the Khafre pyramid. Once it was dressed, the top of the wall would have given another level plane, higher than that of the layout lines on the floor, around the entire circumference of the pyramid court.

It has been suggested that true north was found for the orientation of the pyramid by building an artificial horizon, consisting of a circular wall, over which a northern star could be sighted in its rising and setting by an observer sitting in the center of the circle (Edwards 1961, 259–61, fig. 55). The bisection of the angle formed by the two marked points and the observer station would be true north. The artificial horizon is required, because any irregularities in the natural horizon would throw off the alignment. "For the whole of its circumference, the top of the wall must be on an absolutely level plane," for which Edwards suggests a reference to water filling temporary mudbanks along the wall (*ibid.*).

If a straight section of wall would have sufficed, it is tempting to see the leveled enclosure wall as having something to do with the artificial horizon required to obtain true north. Again, there is a kind of "chicken and the egg" problem here. The enclosure wall, being parallel to the sides of the pyramid, requires, at least approximately, the north alignment, while the north alignment requires a leveled wall. For the orientation to north, segments of the enclosure wall could have served, again, a method of successive approximation.

At the Khafre pyramid, the astronomical sightings might have been included with the layout steps outlined as follows:

a. For steps 1 and 2, a preliminary section of the wall could have been built at the far east end of the north side of the area for the pyramid court, which had been approximately laid out and dressed down. This segment of wall, laid east-west, would have been perpendicular to the NE corner trench which ran to it. The wall segment would have been longer than the 12–14 m. from the outer (east) limit of the court to the east side of the bedrock core massif. The top of the wall was approximately leveled with simple, conventional means, such as a large triangle fitted with a plumb line and straight edge. Because the wall was not absolutely leveled with respect to a water surface, the meridian obtained by sighting over it to the rising and setting of a northern star was only approximate. The N–S orientation was marked by stakes in the trenches at the NE and SE corners of the court, and projected to the NW and SW corners where matching trenches were cut and the line marked by stakes.

b. For steps 3, 4, and 5, the north orientation was transferred to the layout lines and rough determination of the casing socle by offset measurements from the line between the stakes in the trenches. Along the east side, step 3 produced the first of two regular lines of holes from 9.1 to 9.9 m. from the pyramid base (fig. 1). The first run may have been rechecked for the orientation again by sighting over the wall at the north end of the court. As this line was run twice (once at 9.1 and again at 9.9 m. from the pyramid base), it may have been the master line for the meridian at the Khafre pyramid.

A sighting to the north along the west side would have faced the high bedrock ledge left by the quarrying which created the pyramid enclosure and the bedrock core massif. This could have been avoided if the wall was high enough and the observer close enough to the wall so that the ledge could not be seen. However, the closer the observer was to the wall, the shorter became the length of the meridian line obtained, and the less accurate the extrapolation of this line to any great distance. This would certainly have been a problem with "a circular wall with a diameter of a few feet" (Edwards 1961, 260). At both the Khufu and Khafre pyramids, the east side gives a more or less unrestricted view to the northern and southern horizons.

c. Once steps 6 to 9 had been completed, the top of the wall segment at the NE corner of the court could have been more finely leveled with respect to the surface of the water filling the court trough. The orientation, laid down for the length of the east side by the second series of holes, could have been transferred again by perpendiculars to the NW and SW corners, and then to the final layout line 13.5 m. from the pyramid base. The alignment could have been checked and refined once more just prior to steps 13 and 14, the laying in of the lowest course of granite casing and cutting the true pyramid baseline. As the work of laying in and marking the bottom granite casing progressed, the orientation formed into the granite was controlled by offsets from the outer layout lines, as described.

After the first casing course had been laid and marked, with its top surface leveled, the rest of the enclosure wall could have been built. If the whole of the enclosure wall was leveled at the top with respect to the datum lines on the floor, it would give a level plane around the pyramid. This might have been valuable for offset measures to align and orient the crucial first few courses at the base of the pyramid which would establish the diagonals (to avoid twist) and the slope of the faces.[11]

At the Great Pyramid a similar method of aligning the layout square to true north could have been used, although there it was somewhat simpler and more efficient since there is a single series of layout holes. The preliminary wall segments, only approximately leveled, could have been used to obtain an approximate meridian for steps 1 to 4, while in steps 6 to 13 the orientation could have been refined by astronomical sightings over the wall which was more accurately leveled at the top with respect to the water surface in the court trough.

Borchardt (1926, 11, n. 2) gave a table of stars which may have been used for obtaining the meridian at the time when the pyramid was built.

3. *Future Research*

It might be suggested that this interpretation of the bedrock cuttings in the floor around the pyramids of Khufu and Khafre is what might be expected of the ancient Egyptian builders, even when they erected smaller temples or other structures on the flood plain or low desert: staking out the limits of the enclosure, cutting the soil for a foundation, and leveling, as they did in their fields, with channeled water. The difference is the immensity of the undertaking at the two largest Giza pyramids, and the fact that they were working in bedrock rather than soil, necessitating cutting holes for the stakes.

Nevertheless, a good deal more recording and surveying of these features should be done to substantiate the interpretation given here. There are many other holes and cuttings in the rock floor of the pyramid courts besides those most obviously patterned which have been discussed. Detailed large scale plans should be made of all such features in the pyramid courts and immediate surrounding area, which may be carefully contoured to check the hypothesis that the troughs were used with water for leveling the casing or platform socle and the bed for the enclosure wall. Fissures should be plotted since they might present a serious impediment to

the water-leveling hypothesis; if they could not be adequately sealed the water might have drained away.[12] The holes should be checked by theodolite for the accuracy of their alignments, and for the accuracy of the perpendiculars they describe at the corners of the court.

If it is correct that these features are what is left of the ancient survey of the Khufu and Khafre pyramids, it would be a note of caution to future excavation at other pyramids where similar evidence might exist. Where pyramids are founded on the natural desert *tafl* or gravels, the holes of the layout lines, if they exist, might be nothing more than small post holes in the soil, their position indicated merely by fill of a different character. If it is not looked for, such evidence might easily be destroyed in the process of excavation.

NOTES

[1] Based on his measurements of the Great Pyramid, Petrie (1883, 31 and *passim*) derived the cubit of 20.6 inches (.52324 m.). Lauer (1947, 253–55, fig. 17) employs a cubit of .524 m. in his analysis of the Khufu mortuary temple and when giving the dimensions of pyramids in cubits (1974, 342–43). According to Rowe (1931, 23, pl. X) the cubit used at the Medum pyramid was .525 m., which he seems to have based on the measure between leveling lines with cubit notations on the masonry of the pyramid. Carter (1916, 150, n. 1; Carter and Gardiner 1917, 136) derived a cubit of .5231 m. from measuring actual cubit rods in the Cairo, Turin, and Liverpool museums and taking the average. The metric value of this "royal cubit" has not been taken too strictly beyond the second decimal point in most of the cubit values given in this discussion.

[2] A suggestion which will be developed in a separate discussion is that the long channel, oriented north–NE, may indicate preparations for a causeway departing from the NE corner of the pyramid court, like that at the Bent Pyramid of Dashur. If so, the preparations were abandoned when the course of the present causeway was decided upon.

[3] This amount of dip is based upon a very rough measurement taken with a line level at the NW corner of the Khafre pyramid. Similar rough measures were taken at the NE and NW corners of the Khufu pyramid.

[4] Maragioglio and Rinaldi (1966, 72–74) give a width of 20 cubits (about 10.47 m.) for the courtyard, and state that the base of the enclosure wall must have turned the corner to meet flush with the pavement slabs. The foundation of the wall was, therefore, a little wider than the base of the wall which was about 6 cubits (3.14 m.) thick.

[5] Beyond the cutting for the limit of the court, at the east end of the north side, there are additional series of smaller holes sunk into the rough bedrock surface (emphasized in pl. Ib). They are fairly regularly spaced and form E–W lines. Similar series of holes occur within the area of the court at the far west end of the north side. Here they are more irregular in their spacing and alignment, but they generally correspond the path of the enclosure wall. Those beyond the court might be the remains of a preliminary layout to determine the extent of the court. If so, they would have been an earlier step than those described in the successive approximation of the pyramid and its enclosure.

[6] I would like to thank architect Ian MacKinley of Oakland, California for his comments on the features in the floor around the two largest Giza pyramids and on the successive approximation used in the layout of modern structures. I would also like to thank ARCE Fellow Timothy Mitchell for his very practical anecdotes about leveling a tract of ground without surveying instruments in order to flood it with water for an ice skating rink.

[7] James Allen first suggested to me that the lines of holes around the Khafre pyramid might be for offset measurements to determine the pyramid base. This article has benefited from many discussions with Dr. Allen about the features of the bases of the Giza pyramids.

[8] Goyon (1969) measured depths of 42 to 87 cm. for the holes off the NW and NE corners of the pyramid. If all the holes are within this range of depth, it is not likely that they would have been completely obliterated when the trough, some 40 cm. deep at the most, was cut and extended.

[9] It would be nice to see some facility for draining the water out of the court trough when necessary. Perhaps the channels which Maragioglio and Rinaldi saw off the NW and SW corners of the Khufu pyramid court (see above, p. 00) had this function. At the same time, we are not dealing with a great deal of water considering that the troughs have little depth. The water might have easily been scooped out and pushed away with whatever residue being allowed to evaporate. Evaporation might present a problem for the idea that water in the trough served as a datum, as Dr. Gerhard Haeny (personal communication) has pointed out.

[10] For an example of how the leveling and slope of individual blocks could have been controlled using red pigment, see Haeny (1969, 39–40, Abb. 3).

[11] Petrie (1883, 99) noted corrective leveling lines on the 5th course of the nucleus masonry at a height of 10 cubits along the west side, and running along the 10th course at a height of 20 cubits (cf. Maragioglio and Rinaldi 1966, 46–47, 100).

[12] This would have been a problem given any reconstruction of leveling operations in which it is assumed that water was used as a datum.

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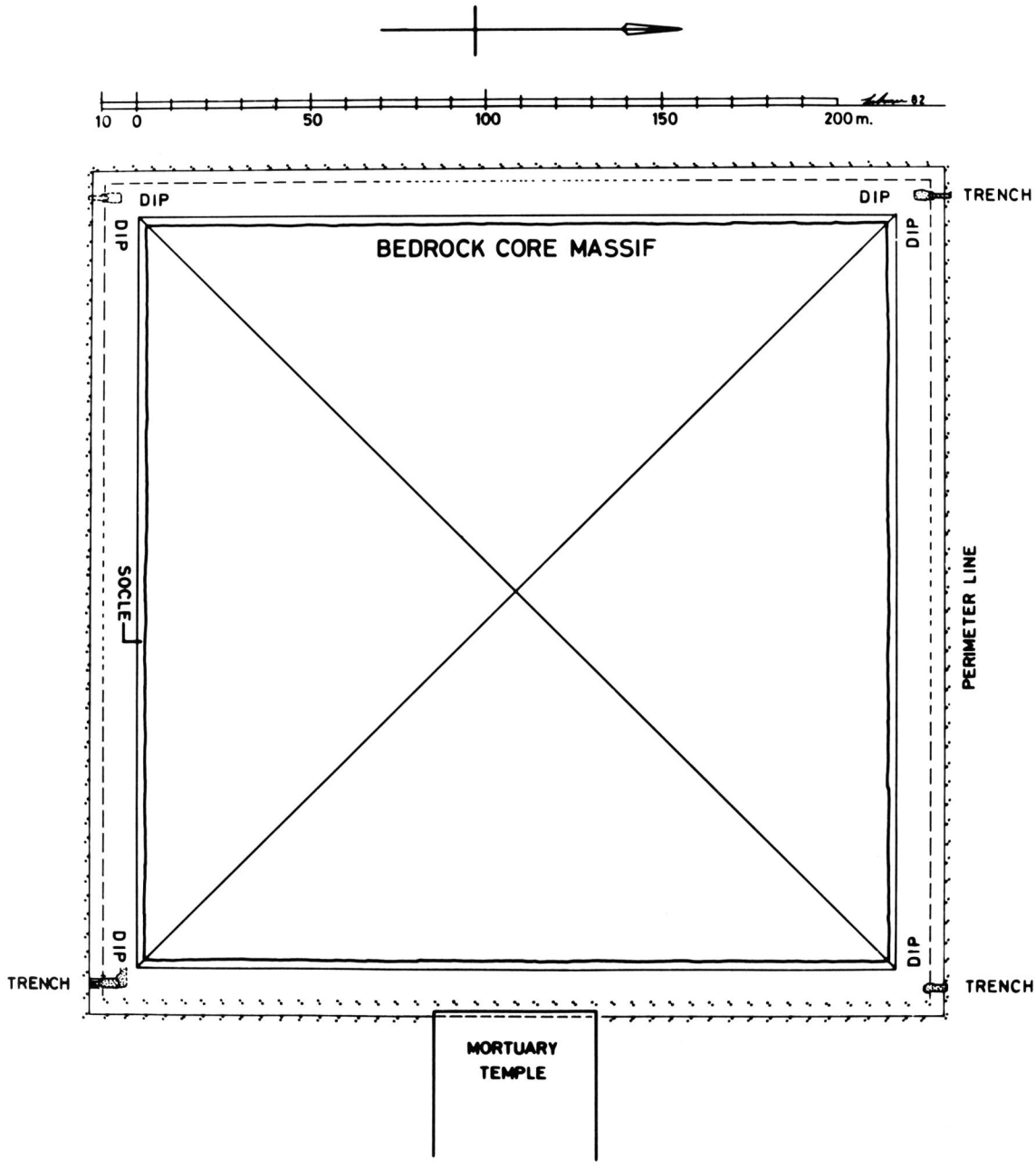


Fig. 1. Schematic plan of the Khafre pyramid court showing lines of holes, corner trenches and the dip or trough.

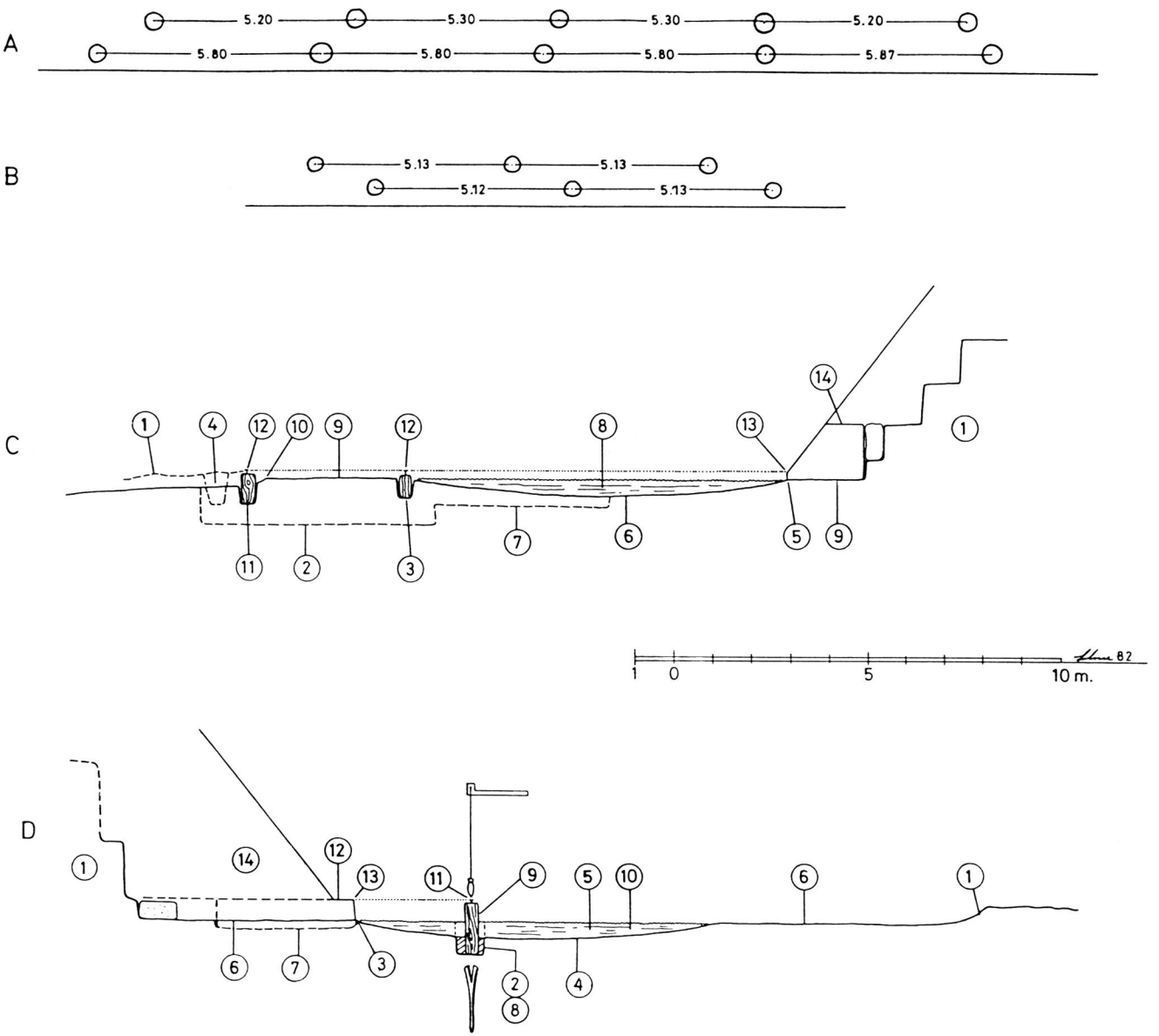


Fig 2. A and B: Spacings between holes along the outer line of the enclosure wall at the far north end of the west side of the Khafre pyramid court. C: Schematic section at the NW corner of the Khafre pyramid with layout and leveling steps. D: Schematic section at the NE corner of the Khufu pyramid with layout and leveling steps.

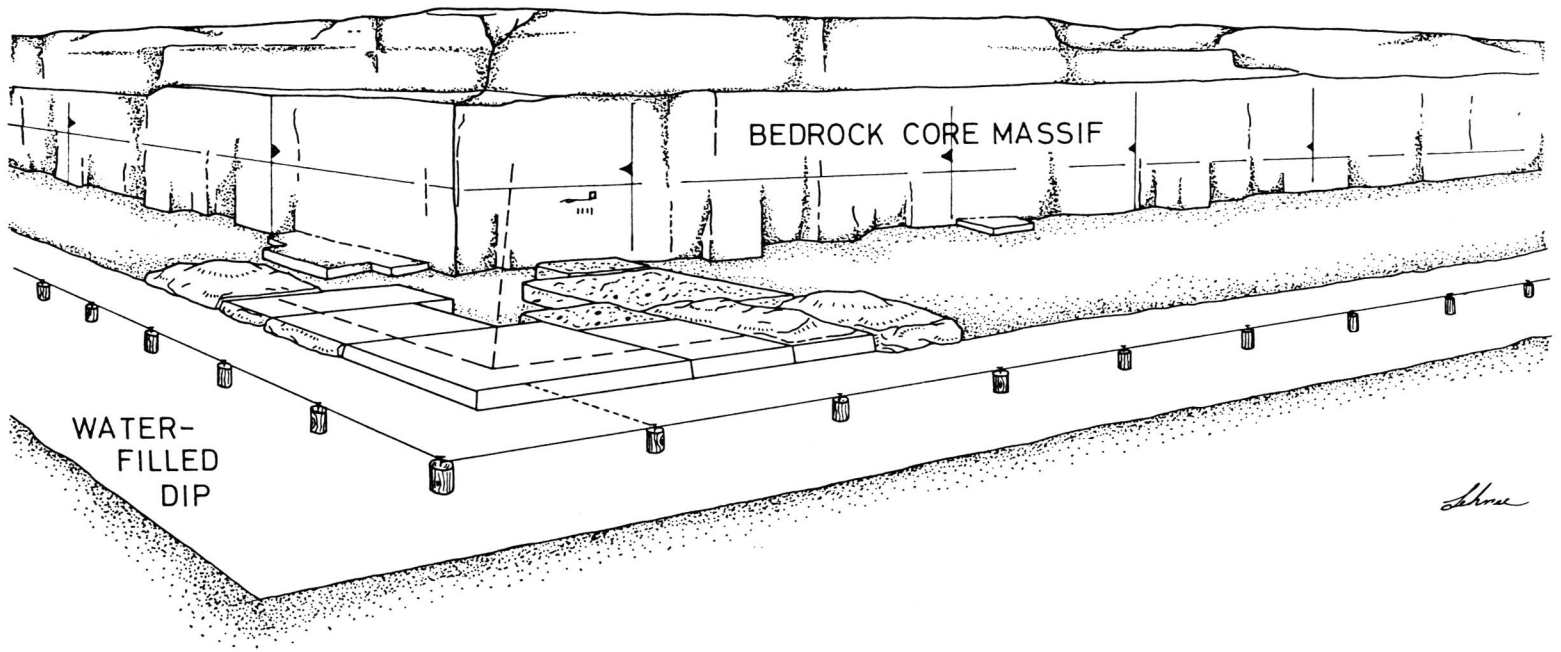
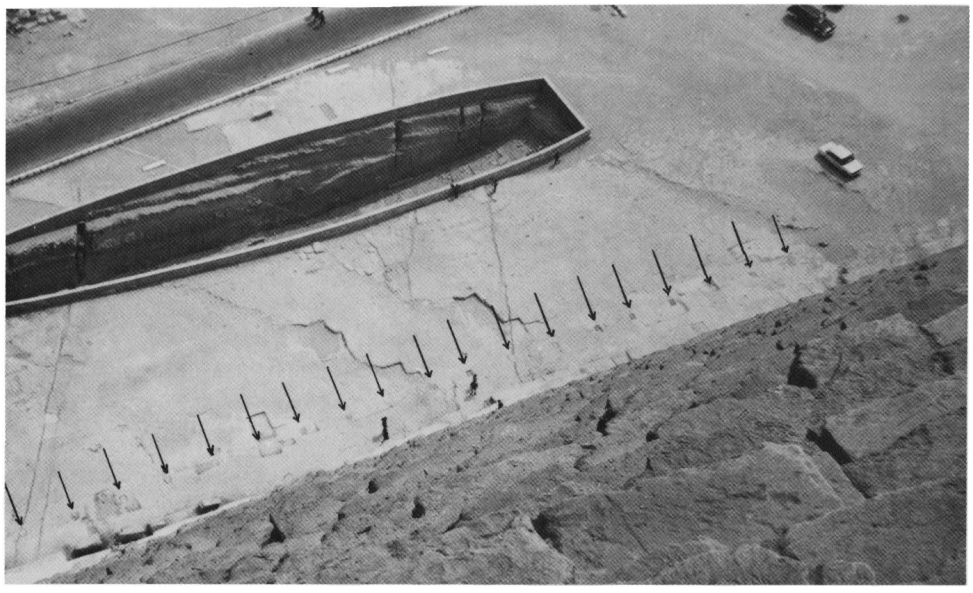


Fig. 3. Perspective reconstruction of the layout and leveling system at the Khufu pyramid.



a. Series of holes 3 m. from the foundation platform along the east side of the Great Pyramid, south end.

b. NE corner of the Khufu pyramid court with NE corner cutting and outer limit of the enclosure wall marked. Outside of the court series of smaller holes are emphasized.

General view of the Apis House looking northeast. In the center is the niched recess in Wall CD; Table 4 is behind it, and the west jamb of Entrance AB is on the left.