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Devoted to the Science of Religion, the Religion of Science, and the Extension of the Religious Parliament Idea

Founded by EDWARD C. HEGELER

NAPOLEON ON ST. HELENA.
A Japanese woodcut. (See page 742.)

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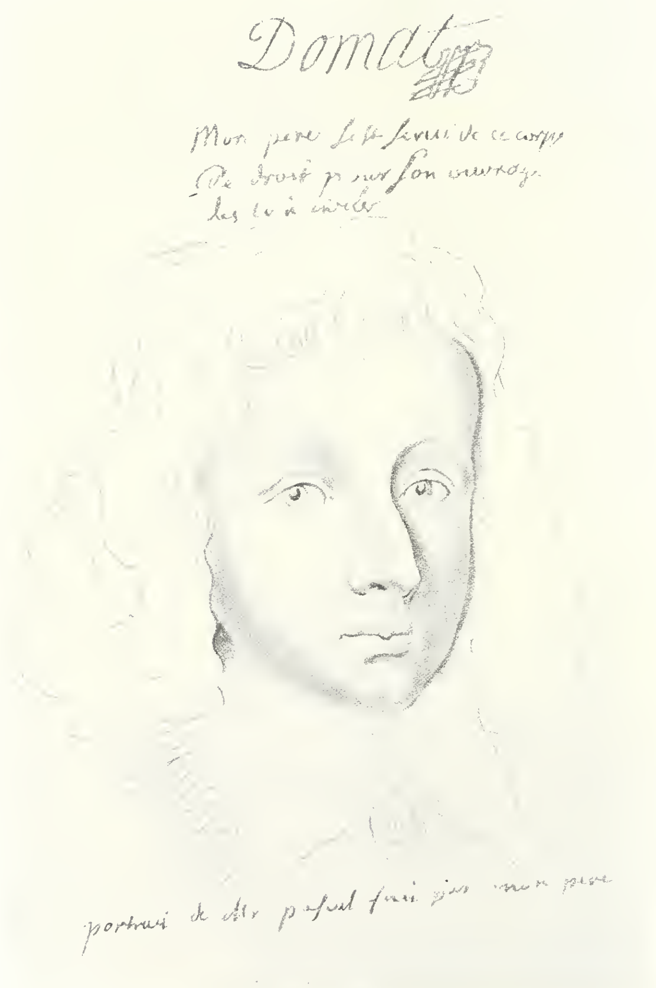

BLAISE PASCAL.

From a contemporary drawing by Domat (See page 766).

Frontispiece to the Open Court.

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AN ANCIENT EGYPTIAN MECHANICAL PROBLEM.

PAPYRUS ANASTASI I.

About 1300 B. C.

BY F. M. BARBER.

SO far as I am aware this is the only ancient Egyptian Papyrus that has ever been found which makes even a remote reference to the apparatus used or methods employed in the installation of their gigantic monuments, and even here the account is so fragmentary as to seem at first sight merely to excite curiosity rather than to offer a satisfactory solution.

The papyrus was first partly translated by M. Chabas about 1870 and his interpretation of the portion referring to mechanical processes, when put into English from the French of his book is as follows (pages 48 to 51):

"Par. 11 of the papyrus, page 13, line 4, to page 14, line 8.

"I announce to thee the order of thy Royal Lord: how thou his Royal Scribe shalt go with the grand monuments of the Horus, Lord of the two worlds; because thou art a skilful scribe who art at the head of a troop. There was made a passage of 230 cubits [402.5 feet, assuming that the royal cubit of 21 inches was used] by 55 cubits [96.2 feet] in 120 *rokata* full of timbers and fascines; 60 cubits [105 feet] high at its summit; its interior of 30 cubits [52.5 feet] by two times 15; its lodge (seat, balcony) is 5 cubits [8.7 feet]. The Military Intendant prepared the base. The scribes were installed everywhere....

"Answer me about your affair of the base: see that what you need is before you as well as thy .... of 30 cubits [52.5 feet] by 7 cubits [12.2 feet]....

"Let there be made a new obelisk, sculptured [or cut] in the name of the Lord Royal, of 110 cubits [192.5 feet] in height, including the base of 10 cubits [17.5 feet]. The periphery of its foot will be 7 cubits [12.2 feet] on each side: that it may go (*qu'il aille*) by two times of the side of the head of 2 cubits [3.5 feet]....

"Thou hast placed me as chief of those who haul it....

"Par. 13 of the papyrus, page 16, line 5, to page 17, line 2.

"Thou sayest I need the great box which is filled with sand with the colossus of the Lord Royal thy master which was brought from the red mountain. It is of 30 cubits [52.5 feet] extended on the ground, by 20 cubits [35 feet], divided into 10 compartments full of sand of the sand pits: the width or inside measure (*travers*) of the compartments forms 44 cubits [77 feet]. They are 50 cubits [87.5 feet] high in all. Thou wast ordered by him who was present, the king, to see that each man worked during six hours. That suited them, but they lost courage to exert themselves; the time had not arrived. Thou didst give food to the troops; they took their repast and the colossus was installed in its place. The heart of the king regarded it with satisfaction."

M. Chabas in his reflections on the subject concludes that both the "passage" and the "box" were inclined planes; but he frankly says that he cannot explain the combination of figures and makes no attempt to demonstrate them. He simply discusses the abnormal dimensions of the obelisk, the extraordinary flatness of the pyramidon and the circumference of it, and he concludes that the obelisk measures 4 cubits on each side of the head, since "a right line drawn along the center of one side from the middle of the base would arrive at 2 cubits from each angle of the summit. It appears to me that this is a forced construction of the expression *qu'il aille* and that the wording really means that the head measures 2 cubits less than the base or 5 cubits. This is the proportional taper of the Karnak obelisk and nearly that of most others. The height of 100 cubits [175 feet] M. Chabas thinks not unreasonable and quotes an inscription at the temple of El-Assassifat Thebes which mentions "two obelisks of 108 cubits [189 feet] high entirely covered with gold."

In 1871 M. de Saulcy in a letter to M. Prisse d'Aresnes published by the *Revue archéologique* in 1873 endeavors to demonstrate by mathematical calculations and drawings that the "passage" was an inclined plane as M. Chabas thought. The unknown word *rokata* he assumes to mean a caisson measuring 30×20×5 cubits filled with timbers, fascines, etc., and the entire inclined plane to be composed of 120 of these caissons. The plane has a roadway 30 cubits wide up the middle of it with a "rebord" or log or rail 5 cubits high and 15 cubits wide on each side of the road.

With regard to the "grand coffre," however, he thinks that it was really a huge box, habitually used in such work, as high as the highest point of the road-way up the inclined plane and composed of 10 compartments or caissons each 30×20×5 cubits and the *travers* of 44 cubits he construes to mean the inside measure round the compartment, and the outside measure being 30+20 = 50 gives 6 cubits for the 4 sides or 1½ cubits = 32 inches for the thickness of each side of the box. These caissons were placed one on top of the other, the lower one surrounding the pedestal and the whole filled with sand.

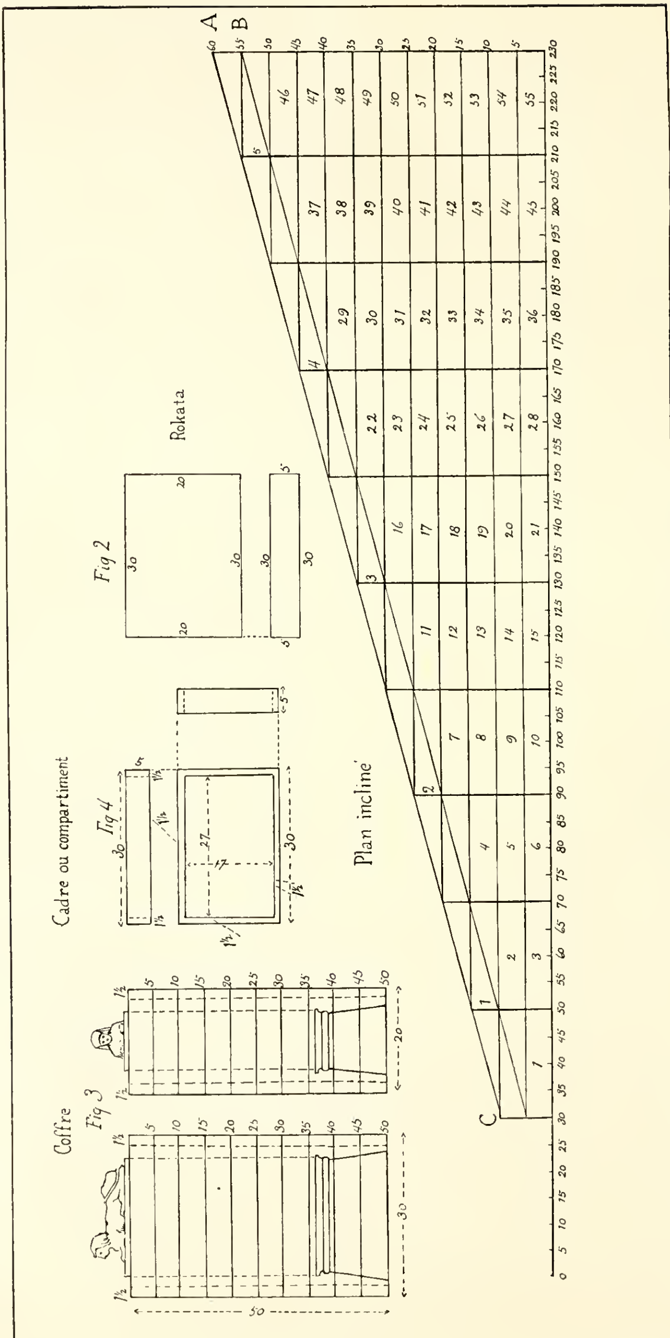
He supposed that the huge stone monument was dragged up the incline by means of capstans until it reached the middle of the surface of the upper caisson of the sand-box, the sand was then thrown out of the upper caisson by native baskets, allowing the monument to settle to the next caisson when the sides of the upper caisson were removed, and so on in succession until the monument rested on the pedestal as shown in the figure.

In the case of an obelisk he thinks it was to be hauled up the incline until the heel rested over the upper caisson, and then the sand was allowed to run out at the level of the pedestal until the obelisk tilted about the center of gravity and sank in a *vertical* position to the pedestal; but he does not attempt to demonstrate it, which would be extremely difficult.

The illustration from the *Revue archéologique* of 1873 shows M. de Saulcy's ideas regarding the placing of a sphynx. There are several objections to be made to it, the most obvious being that it would be unnecessary labor to drag a colossus up to a height of nearly 100 feet merely to lower it again by means of a box of sand to a pedestal whose height is less than 20 feet. This objection is so important that it is useless to discuss the others.

M. de Saulcy however is extremely modest in claiming any great degree of merit for his demonstration and says that it is merely an attempt to elucidate in a plausible manner one of the most curious documents that have come down to us and which had so much puzzled the original translator.

In 1902, having through the kindness of M. Capart of the Museum of Brussels become aware of the existence of the work of



M. DE SAULCY'S INTERPRETATION.

Reproduced from the *Revue archéologique*, 1873, Plate IX.

M. Chabas and M. de Saulcy, I studied them and concluded that a mistake had been made by M. de Saulcy in considering that the colossus and the obelisk were separate monuments; that in reality all the mechanical matter in the papyrus referred to the obelisk alone; but if this was true, the height of the box must be approximately equal to the combined height of the center of gravity of the obelisk and the height of the pedestal. This I found to be the case. The height of the center of gravity is 41 cubits, the height of the pedestal is 10 cubits and that of the box is 50 cubits.

In order however to learn if a more recent translation of the papyrus would throw additional light on the subject, I wrote to Professor Erman, director of the Egyptian Museum of Berlin, who in 1903 kindly sent me the following which is here translated from the German.

"The passages are no more intelligible to me than they were to M. Chabas and Professor Brugsch, or even less so. The technical terms employed therein are wanting, and besides Papyrus Anastasi I is very badly written and full of mistakes. In the first place the question is that the addressed person (the whole book is meant ironically) should have large monuments transported by his soldiers. A slope is made of 730 cubits, 55 cubits in width of 120 *Rgt* full of reeds and beams of a height of 50 cubits at the head, the middle of 30 cubits, the.... of 15 cubits, the seat of 5 cubits. They deliberate with the military officers about the want of bricks, while all the scribes are assembled without one among them understanding anything about it. They love you and say, 'You are a skilful scribe, my friend! answer me about the want of bricks. See the terraces are before you, each one with its *Rgt* of 30 cubits with the width of 7 cubits.'

"*Š't*? can also mean 'passage' as in the rock tomb; but the signification of 'ramp' is sure....

"*Rgt* is a chananean foreign word of unknown signification....

"Terrace is quite uncertain according as the word is differently determined. Here I should propose a word like dimension.

"The meaning of the paragraph seems to me to be that for transporting the monuments which are to be brought up somewhere the usual inclined plane is to be made of bricks. Then the scribes tell the officer the measures of the inclined plane and ask him (he understands nothing about it) to tell them how many bricks are necessary.

"In the second paragraph I understand still less.

"'Empty the box which is loaded with sand under the monument of your master that has been brought out of the red mountain.

It measures 20 cubits if it is stretched on the ground, width 20 cubits .... passover[?].... with 20 *Šmm* full of sand of the beach. The *Z:j* its? *Šmm* are 44 cubits in width, they are all 50 cubits high.'

"What follows concerns the people who will not work so long or something like it....

"*Šmm* is written as if it were a building.

"*Z:j* is unknown thus written.

"I think it is a question of sand cases such as Barsanti and Borchardt have shown recently."

Since 1903 I have been unable to give further attention to this interesting subject on account of official duties; but in the interval I believe that nothing has been discovered in Egypt or elsewhere which simplifies the problem.

Professor Erman's translation however confirms me in the opinion that the erection of an obelisk and not of a colossus is contemplated in the papyrus, because where M. Chabas and M. de Saulcy use the word *colosse* which M. de Saulcy interprets as a sphinx, Professor Erman uses the word *Denkmal,* a memorial monument, which would apply to an obelisk.

It will be noted that the dimensions given by the two translators differ somewhat. The length and height of the inclined plane M. Chabas gives as 230 cubits and 60 cubits while Professor Erman give 730 cubits and 50 cubits. This is important as it changes the slope from 1 in 4 to 1 in 14, which is very much more favorable and makes the plane the same height as the sand-box. The size of the box M. Chabas gives as 30×20×50 cubits while Professor Erman makes it 20×20×50 cubits. Neither box is long enough as I will show later. M. Chabas calls the *Šmm* "compartments" and says there are 10 of them. Professor Erman gives 20, which would be the most favorable for handling. The differences noted are simply indicative of the difficulty of accurate translation and do not alter the general meaning which is the same in both translations.

Most important of all: Professor Erman says that the last paragraph reads: "Empty the box which is loaded with sand under the monument of your master," which confirms M. de Saulcy's theory in a surprising manner.

Professor Erman's mention of Professor Borchardt and Signor Barsanti refers to the curious discovery of Sig. Barsanti in 1900 of the unoccupied rock tomb of the surgeon Psamtik at Saqqaara (about 500 B. C.) and described by M. Capart of the Museum of Brussels in the *Annales de la Société d'Archéologie de Bruxelles* in 1901 and by Professor Borchardt in the *Centralblatt der Bauverwaltung Ber-*

lin, Aug. 9, 1902. It is so important a proof of how sand was actually used in lowering heavy weights that I give the details.

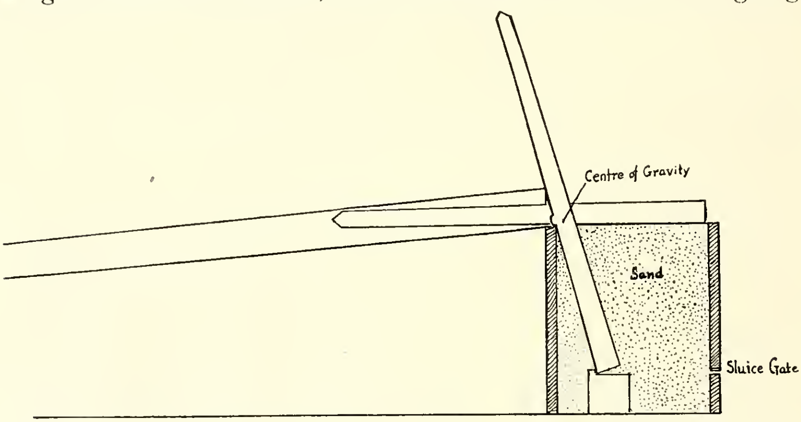
In this tomb was found an empty sarcophagus with its 17-ton cover resting on blocking sufficiently high above it to admit the mummy sidewise. This cover was furnished with four projections, two on each side, which fitted into vertical grooves in the sides of the tomb chamber. The vertical grooves connected at the bottom with horizontal grooves which in turn connected with a cavity in the floor under the sarcophagus. Immediately under the projections of the cover were cylindrical wooden plugs, the remainder of the grooves and the connecting cavity being filled with sand. After the mummy had been placed in the sarcophagus, the blocking was removed, leaving the cover resting on the wooden plugs. A workman then went under the sarcophagus and gradually removed the sand from the cavity, thus permitting the sand under the plugs to flow into the cavity until the cover descended to its final resting place on top of the sarcophagus. Occupied tombs were afterwards found with cover and plugs in place.

Professor Borchardt says that "this is the oldest instance of the use of sand-boxes which are now often utilized for gradually sinking and transferring heavy weights." This is quite true. In 1908 they were used at the launching of the cruiser Blücher at Kiel, the weight of the ship being transferred from the blocking to the launching ways by the use of cast iron boxes 22×16×16 inches in which oak plugs were loosely fitted. The boxes were half filled with burned molding sand which under pressure flowed out of holes in the middle of each side at the bottom, like heavy oil and flowed freely unless it caught and piled up on the bed timbers so as to rise to the level of the holes.

It is curious that Sig. Barsanti's discovery shows that the Egyptians were applying the sand-box method 500 years B. C. with weights of 17 tons while the Papyrus Anastasi I would indicate that it was being applied 800 years before that with weights of 1447 tons.

It has always interested mechanical minds to conjecture how the ancient Egyptians could have raised their obelisks considering the very primitive mechanical appliances to which they are supposed to have been limited, for no pictures or detailed descriptions have ever been found. The most plausible supposition is that it was done by dragging the heel to the top of the pedestal and lifting the head by means of ropes leading over an adjacent wall, the operation being assisted by levers and blocking under the head, and in 1905 Professor Borchardt in his *Baugeschichte des Ammonstempels von Karnak,* proves conclusively that the grooves now found in the pedestals of dismounted obelisks were used for wooden chocks to prevent the heel from slipping under these circumstances. It is true that M. Choisy in his *Ancient Egyptian Mechanics* shows by a series of line drawings, an obelisk at the top of an inclined plane pivoting itself automatically about its center of gravity with nothing whatever to support its larger end, and no explanation in the text; but it is needless to say that without the most modern appliances of heavy steel straps, trunnions, frames, movable girders, jacks, etc., etc., such as were used in mounting the obelisks in London and NewYork, such an operation would be impossible.

No obelisk that exists or whose remains have been found would weigh more than 400 tons; but in this case we have one weighing



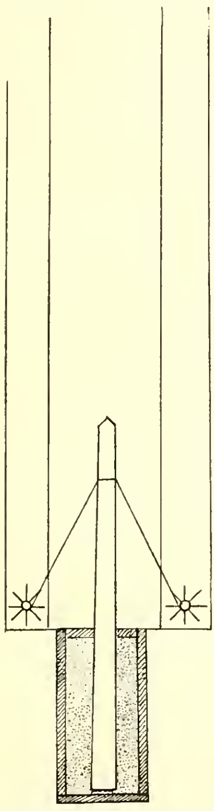
PIVOTING THE OBELISK ABOUT ITS CENTER OF GRAVITY—SIDE VIEW.

1447 tons and it seems idle to consider ropes leading over walls, or levers and blocking in mounting it.

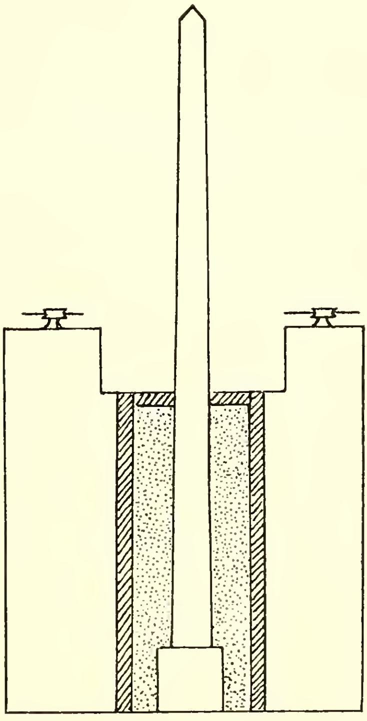
I once made a calculation[1] to ascertain how many men would be required to drag the Karnak obelisk which weighs 374 tons. It proved to be 5585 men harnessed in double rank to four drag ropes and covering a space of 1400 feet. The obelisk of the papyrus would therefore require 21,600 men, and they would cover a space on the road for over a mile. Nobody could drill such a body of men to pull together. Capstans must therefore have been employed. The *sakiya* or geared wheel and water buckets worked by cattle embodies the principle of the capstan, and Wilkinson and most other Egyptologists suppose it to have been introduced into Egypt at the time of the Persian invasion B. C. 527; but its principle must have been

[1] See Barber, *The Mechanical Triumphs of the Ancient Egyptians.* London, Kegan Paul, Trench, Trübner & Co., 1900.

used at least as early as the time of the Papyrus Anastasi I. By its use the obelisk was hauled up and projected on top of the sand-box as shown in the illustrations, where I have used Professor Erman's total height of 50 cubits which corresponds to the height of the road bed of M. de Saulcy. There must have been also a solid wide border or ledge on each side and higher than the road bed, not only for mounting the capstans, but in order to be able to wedge the obelisk



THE OBELISK ON THE CAISSON.
Vertical view.



THE OBELISK ON ITS PEDESTAL.
Front view.

back into position in case it got out of line in coming up the incline.

The height of the pedestal is 10 cubits and that of the center of gravity of the obelisk is 41 cubits from its base; together they are equal to 51 cubits which is one cubit more than the height of the box as given both by M. Chabas and Professor Erman.

The size of the box according to M. Chabas is 30×20×50 cubits; but according to my calculation and illustration it should be at least

40×20×50 in order that the obelisk may swing about its center of gravity. It is possible that the measure 44 of the "*Šmm* full of sand" has something to do with this dimension, and Professor Erman says it is written as if it were a building.

The box would be carefully caulked and would contain 11,000 tons of sand exclusive of the space occupied by the pedestal which weighs 461 tons. I have taken the weights of granite and sand from Haswell's *American Tables,* the former as 166 pounds per cubic foot and the latter as 120. Perhaps Egyptian sand and granite may be nearer alike. The nearer they are the less would be the tendency of the obelisk to slide as it approached the perpendicular, though any such small tendency could be overcome by leaving at the quarry a small projection on the obelisk nearly under the center of gravity, which would be cut off afterwards. The box would be strongly buttressed to prevent its bursting, and there would be lashings about the pivoting point of the obelisk; but the illustrations are only intended to show the principles involved and all superfluities are omitted.

The obelisk would at all times during its pivoting be steadied by rope guys from the head and heel, and I have placed the pedestal (with a projection to be cut off) at such a point that the obelisk when reaching it would rest on the edge of the heel and there would be a space of 5 or 6 inches at the opposite edge to clear the sand out before bringing it to the vertical by means of the guys. Very likely the edge would be splintered on account of the immense weight resting on it and it would necessarily pivot on this edge when coming to the vertical. Probably it would jump an inch or two just when it reached an upright position; but nearly all obelisks *are* splintered at the base, and Professor Borchardt's careful measurements show that they nearly all have jumped.

It is obvious that with so crude a method as this for mounting an obelisk without modern appliances to ensure accuracy—although it is very ingenious—the Egyptian engineers would be in great difficulties about landing the obelisk on the pedestal. They would be careful to pivot it at such a point that the heel would *not* come below the upper surface of the pedestal—such an error would be irreparable. They would more likely err in the other direction, i. e., the heel would perhaps arrive slightly above the pedestal. To meet this difficulty I have provided a small projection (afterward cut off) above the inner edge of the pedestal. If the error was still greater the upper edge of the inclined plane and the box would be cut away and the obelisk at great risk allowed to slide.

If my demonstration of this ancient problem is correct, the operation could be suspended at any time by simply closing the sluice gates. This is possibly what was done in order to rest and refresh the troops before the time arrived to run out the last of the sand and tilt the obelisk to the vertical when every man would be required.

* * *

Since sending this article to the publishers, I have seen Prof. A. H. Gardiner's learned and interesting *Papyrus Anastasi I.*[2] It is the most complete translation of this exceedingly difficult document that has ever been made, but it throws little additional light on the obscurities of the mechanical problem. The only material change in the data is that he makes 100 *Šmm* or compartments in the sand-box instead of the 20 of Professor Erman or the 10 of M. Chabas and this would make the sections of M. de Saulcy easier to handle. Professor Gardiner adheres to the idea of his predecessors that the colossus is a statue to be erected quite distinct from the obelisk to be transported, though his more complete translation shows that they both came from the same quarry which is an additional argument in favor of my idea that they are one and the same monument. He works out and illustrates both the inclined plane and the obelisk in the most satisfactory manner; but he does not attempt to demonstrate the working of the sand-box or to illustrate it either in connection with the colossus as does M. de Saulcy or with the obelisk as in my article.

Professor Gardiner's translation however brings out a side issue which is curious. He says that the transportation of the obelisk is in the form of a problem in which, the dimensions being known, the scribe is asked to estimate the number of men required to drag the obelisk. This being the case perhaps they did not use capstans; but if so they must have massed the men more solidly than in 4 double ranks or 8 abreast, which I took because it is the number shown in the famous picture of the transport of a colossus on a sledge on the wall of a tomb at El Berreh, B. C. 2466. Now if instead of 8 abreast, the men were placed 72 abreast occupying the entire width of the road of 55 cubits (allowing 16 inches to each man), the whole 21,600 would form a column 300 men long; and supposing each man to be 12 inches thick and the rows of men 24 inches apart, they would cover a space of 900 feet on the road. An ordinary man working 8 hours per day can pull or push with a force of 30 pounds, so that were these 21,600 men attached to 36 drag

[2] J. C. Hinrichs'sche Buchhandlung, Leipsic, 1911.

ropes or put into some kind of a strong wheeled frame measuring 96 feet wide by 900 feet long (slightly larger than the deck measurement of the Titanic) and furnished with cross spars, the force would be sufficient to drag the 1447 ton obelisk mounted on a sledge from the quarry to the foot of the inclined plane, and putting the frame behind the obelisk they could push it up the inclined plane and on top of the sand-box. Besides this number of men, if there were 58 spars lashed across the obelisk with 25 men on each side, 2500 men more could be added to the force. Were all these men drilled to push or pull together and by means of whips urged to exert themselves as was customary in those days, it would be possible to transport the obelisk without capstans. It seems more probable, however, that capstans were used on the inclined plane at least.

To drag an object on a sledge on a level or on any grade up to 1 in 10 a force of $\frac{1}{5}$ to $\frac{1}{6}$ its weight is required. I have allowed a little more than $\frac{1}{5}$ as the Egyptians are small men.